Status and Progresses at IGG GNSS data Analysis Center

Yunbin Yuan (1), Bingfeng Tan (1), Wenwu Ding (1), Yongchang Chen (1), Ningbo Wang(1), Zishen Li(2), Min Li(1), Wei Li(1), Yafei Ning(1), Min Song(1), Teng Liu(1), Haitao Wang(1)

Analysis Centres-01

Y.Yuan: yybgps@whigg.ac.cn

(1) State Key Laboratory of Geodesy and Earth Dynamics, Institute of Geodesy and Geophysics, Chinese Academy of Sciences
(2) Academy of Opto-Electronics, Chinese Academy of Sciences

Y. Yuan: yybgps@whigg.ac.cn
B. Tan: bingfengtan@whigg.ac.cn
W. Ding: dingwenwu@.whigg.ac.cn

Introduction

With the advent of Chinese BeiDou navigation satellite system (BDS) and EU Galileo, as well as the ongoing modernization of US GPS and Russian GLONASS, China is now hosting the iGMAS (International GNSS Monitoring and Assessment) in support of a series of scientific activities. Quite similar to the IGS, the iGMAS manages a global network of permanent tracking stations, data centers, analysis centers as well as other auxiliary agencies.

The Institute of Geodesy and Geophysics (IGG), Chinese Academy of Sciences (CAS) has participated in the construction of the iGMAS since December 2012. As of March 2014, IGG accomplished the hardware deployment and software development. After underwent a long-term assessment of the integrity, accuracy, reliability and continuity of the GNSS products delivered, the IGG was accepted as one of the official iGMAS Analysis Centers (ACs) on December 2014.

Real-Time/Ultra-Rapid/Rapid/Final GNSS products, such as Satellite Ephemerides, Earth Rotation parameters, Multi-GNSS Satellite and Station Clocks, Tropospheric zenith path delay, Ionospheric TEC grid, Multi-GNSS DCB products, Coordinates of IGS and iGMAS Tracking Stations, integrity of Multi-GNSS system have been routinely delivered to the iGMAS analysis center coordinator since March 2014. Since mid of October 2015, we start to contribute our multi-GNSS DCB product based on IGGDCB method to the MGEX. IGG has also been accepted as an APREF (Asia-Pacific Reference Frame) LAC (Local Analysis Center) and provide precise coordinate products to GA (Geoscience Australia) since January 2015.
Many new methods and new models published by our research group, such as SHPTS, IGGDCB and IGGTrop, are employed when generating the routine products. Perhaps more interestingly, an analytical solar radiation pressure (SRP) for current Beidou satellites was developed and implemented, and preliminary results show that by augmenting the empirical CODE model with the new analytical model, significantly improved orbit solutions during BDS yaw-fixed attitude control period can be obtained.

Products available in IGGAC and it's accuracy

The software platform that is a backbone of IGGAC was developed independently by our GNSS research group (http://igggnss.whigg.ac.cn/). The software is capable of processing Multi-GNSS (BDS/GPS/GLONASS/GALILEO) data gathered from IGS/MGEX, iGMAS and also national/regional/local tracking networks.
At present, Real-Time/Ultra-Rapid/Rapid/Final Multi-GNSS satellite Orbit, Multi-GNSS Satellite and Station Clock; Earth Rotation parameters; Tropospheric zenith path delay; Ionospheric TEC grid; Multi-GNSS DCB products, Coordinates of IGS and iGMAS Tracking Stations, integrity of Multi-GNSS system have been routinely generated by IGGAC and delivered to the iGMAS analysis center coordinator since March 2014. After a long-term evaluation of the products, all the products generated by IGGAC can achieve the similar performance as the IGS counterparts. Performance of the products generated in IGGAC are shown in Table 1.

Table 1 Performance of the products generated by IGGAC during the period year 2015.

Types of products				Accuracy	Comment
Satellite Orbit	Ultra-Rapid (predicted half)	BDS	GEO	101.7cm	Compared with iGMAS final
			I/M	25cm	
		GPS		4.0cm	Compared with IGS Ultra-rapid
		GLONASS		5.0cm	
		GALILEO		25cm	Compared with TUM MGEX
	Ultra-Rapid (observed half)	BDS	GEO	80.5cm	Compared with iGMAS final
			I/M	20cm	
		GPS		2.5cm	Compared with IGS Ultra-rapid
		GLONASS		3.5cm	
		GALILEO		20.0cm	Compared with TUM MGEX
	Rapid	BDS	GEO	85.4cm	Compared with iGMAS final
			I/M	15cm	
		GPS		2.5cm	Compared with IGS Rapid
		GLONASS		3.3cm	
		GALILEO		10.0cm	Compared with iGMAS final
	Final	BDS	GEO	22.7cm	Compared with iGMAS final
			I/M	9.9cm	
		GPS		2.1cm	Compared with IGS Final
		GLONASS		3.0cm	
		GALILEO		7.0cm	Compared with TUM MGEX
Satellite and Station Clock	Ultra-Rapid (predicted half)	BDS		3.276ns	Compared with iGMAS final
		GPS		1.50ns	Compared with IGS Ultra-rapid
		GLONASS		2.50ns	
		GALILEO		2.630ns	Compared with iGMAS final
	Ultra-Rapid (observed half)	BDS		0.330ns	Compared with iGMAS final
		GPS		0.10ns	Compared with IGS Ultra-rapid
		GLONASS		0.40ns	
		GALILEO		0.668ns	Compared with

Types of products			Accuracy	Comment
ERP	Ultra-Rapid (predicted half)	PM	0.30mas	Compared with IGS Ultra-rapid
		PM rate	0.33mas/day	
		LOD	0.035ms	
	Ultra-Rapid (observed half)	PM	0.10mas	
		PM rate	0.22mas/day	
		LOD	0.03ms	
	Rapid	PM	0.07mas	Compared with IGS Rapid
		PM rate	0.19mas/day	
		LOD	0.03ms	
	Final	PM	0.05mas	Compared with IGS Final
		PM rate	0.18mas/day	
		LOD	0.015mas	
Ionospheric TEC grid	Rapid		1.50TECU	Compared with IGS Rapid
	Final		1.20TECU	Compared with IGS Final
Tropospheric zenith path delay	Ultra-Rapid		5.85mm	Compared with IGS Ultra-rapid
	Final		3.37mm	Compared with IGS Final
DCB	BDS		0.36ns	Compared with iGMAS Final
	GPS		0.15ns	Compared with IGS Final
	GLONASS		0.21ns	
Station Coordinates	Horizontal component		2.49mm	Weekly Repeatability
	Vertical component		3.14mm	

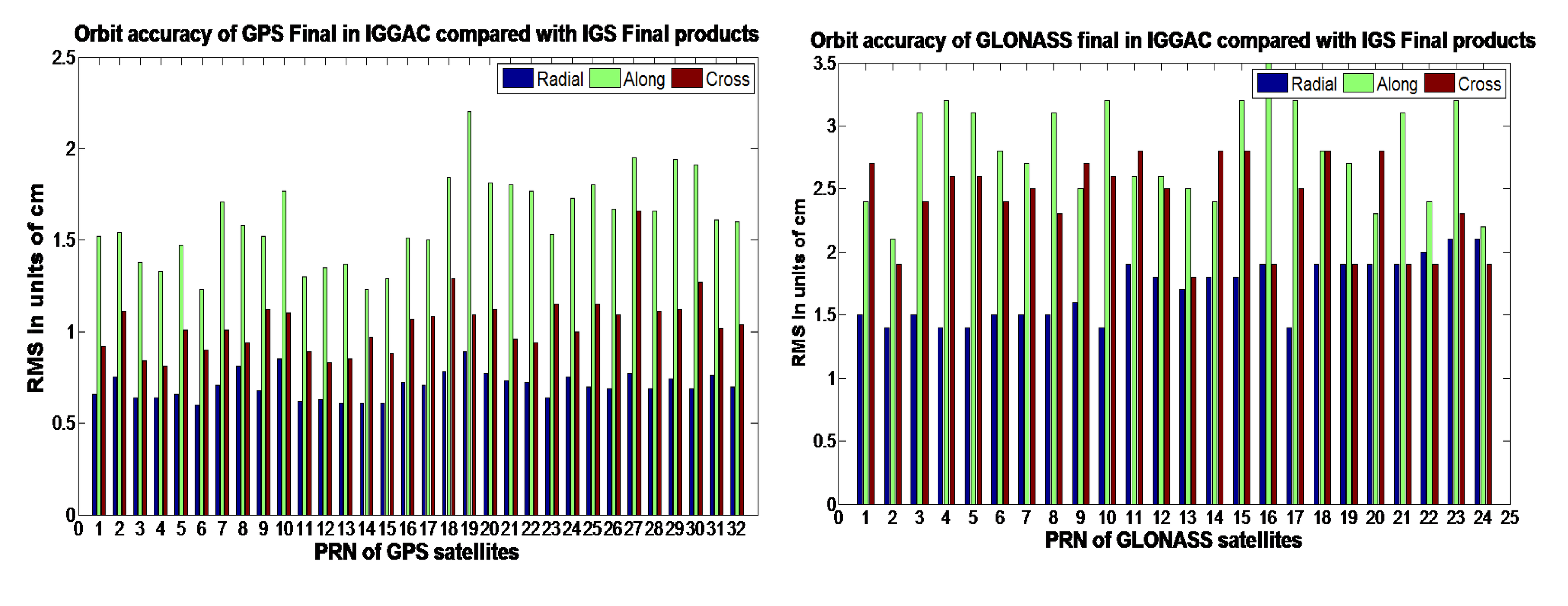

Fig. 1 Orbit difference of IGG Final products compared with IGS Final oproducts

SHPTS and IGGDCB Method

To take maximum advantage of the increasing GNSS data to improve the accuracy and resolution of global ionospheric TEC map (GIM), an approach, named Spherical Harmonic plus generalized Trigonometric Series functions (SHPTS), is proposed by integrating the spherical harmonic and the generalized trigonometric series functions on global and local scales, respectively. The SHPTS-based GIM over the area where no real data are available has the same accuracy level (approximately 2–6TECu) to that released by the current IAAC. However, the ionospheric TEC in the SHPTS-based GIM over the area covered by real data is more accurate (approximately 1.5TECu) than that of the GIM (approximately 3.0TECu) released by the current IAAC. The IGGAC's rapid and final GIM products based on GPS, GLONASS and BDS observations now routingly contribute to the iGMAS. In addition, we also work to be one of the IGS Ionospheric Analysis Centers (IIAC).

In order to better understand the GNSS differential code biases (DCBs) , the IGGDCB method is extended to estimate the intra- and interfrequency biases of the GPS, GLONASS, BDS, and Galileo based on observations collected by the IGS MGEX netwrk. In the approach of IGGDCB, the local ionospheric total electronic content is modeled with generalized triangular series (GTS) function rather than using a global ionosphere model or a priori ionospheric information. Since mid October 2015, we start to contribute this multi-GNSS DCB product to the MGEX, which is now made available at the IGS CDDIS (ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/ dcb) and IGN (ftp://igs.ign.fr/pub/igs/products/mgex/dcb) repositories.

BDS/GNSS zenith tropospheric delay models – IGGtrop and IGGtrop_ri (i=0, 1, 2)

Tropospheric delay is one of the main sources of measurement error in global navigation satellite systems. It is usually compensated by using an empirical correction model. The IGGtrop tropospheric model [Li et al., 2012] employed a 3D grid to accommodate the ZTD spatial distribution, which has a horizontal resolution of 2.5°×2.5° and vertical levels spaced at 1 km. At each grid point, coefficients that describe the annual mean value and seasonal variation of ZTD are stored. The root mean square (RMS) of IGGtrop is 4.0 cm for global mean and ranges between 2.1 and 8.0 cm around the world. However, the implementation of vertical levels leads to a large amount of data, which obviously requires much bigger storage space compared to 2D models. To enhance its application efficiency, Li et al. [2015] rebuilt a series of spatial grids with adaptive and irregular resolutions, compared to the old globally regular grid, and then correspondingly formed new model versions - IGGtrop_ri (i=1, 2, 3). Those three new models require only 3.1-21.2% data of the old model while the ZTD estimation accuracy has only been slightly degraded. Comparison between IGGtrop and IGGtrop_ri (i=1, 2, 3) models are shown in Table 2 and Comparison between IGGtrop, EGNOS and UNB3m models are shown in Table 3.

	IGGtrop	IGGtrop_r_1	IGGtrop_r_2	IGGtrop_r_3
Bias/cm	-0.8 [-5.8, 2.7]	-0.8 [-5.8, 2.7]	-0.9 [-5.8, 2.7]	-0.8 [-6.4, 4.3]
RMS/cm	4.0 [2.1, 7.9]	4.0 [2.1, 8.0]	4.0 [2.1, 8.0]	4.0 [2.1, 8.5]
Number of parameters	666000	141363	71307	20519
Storage space/KB	1302	276	139	40

Table 2 Comparison between IGGtrop and IGGtrop_ri (i=1, 2, 3) models

	IGGtrop	EGNOS	UNB3m
Bias/cm	-0.8	2.0	0.7
RMS/cm	4.0	5.4	5.0

Table 3 Comparison between IGGtrop, EGNOS and UNB3m models

An new analytical solar radiation model for all types of BDS satellites

An analytical solar radiation model has been developed for all types of BDS satellites including GEO, IGSO and MEO satellites based on a ray-tracing method. Numerical integration test has been done with the analytical model for BDS satellites. Results show that the integrated orbit differs from precise ephemerides generated by our own AC by circa 5m for GEO satellites and 2m for IGSO/MEO satellites. The analytical SRP model is also used as a priori model for BDS satellite precise orbit determination. Satellite Laser ranging (SLR) residuals show that for IGSO and MEO satellites, when using the analytical model as a priori model to enhance the ECOM model (ECOM+APR), SLR residual RMS improves by about 20-25 percent over the ECOM-only solution during Yaw-steering period, and about 40 percent improvement during yaw-fixed period. For BDS G01 satellite, 18 percent improvement can be achieved out of eclipse season, and 32 percent improvement during eclipse season. A remarkable reduction of the systematic SLR bias is also presented by using the analytical SRP model. The integration error for BDS satellites G01, I03, I05 and M03 are shown in Figs. 2-5. The case of non-eclipse for satellite G01 and the case of yaw steering for satellites I03, I05 and M03 are shown in Figs. 6-9.

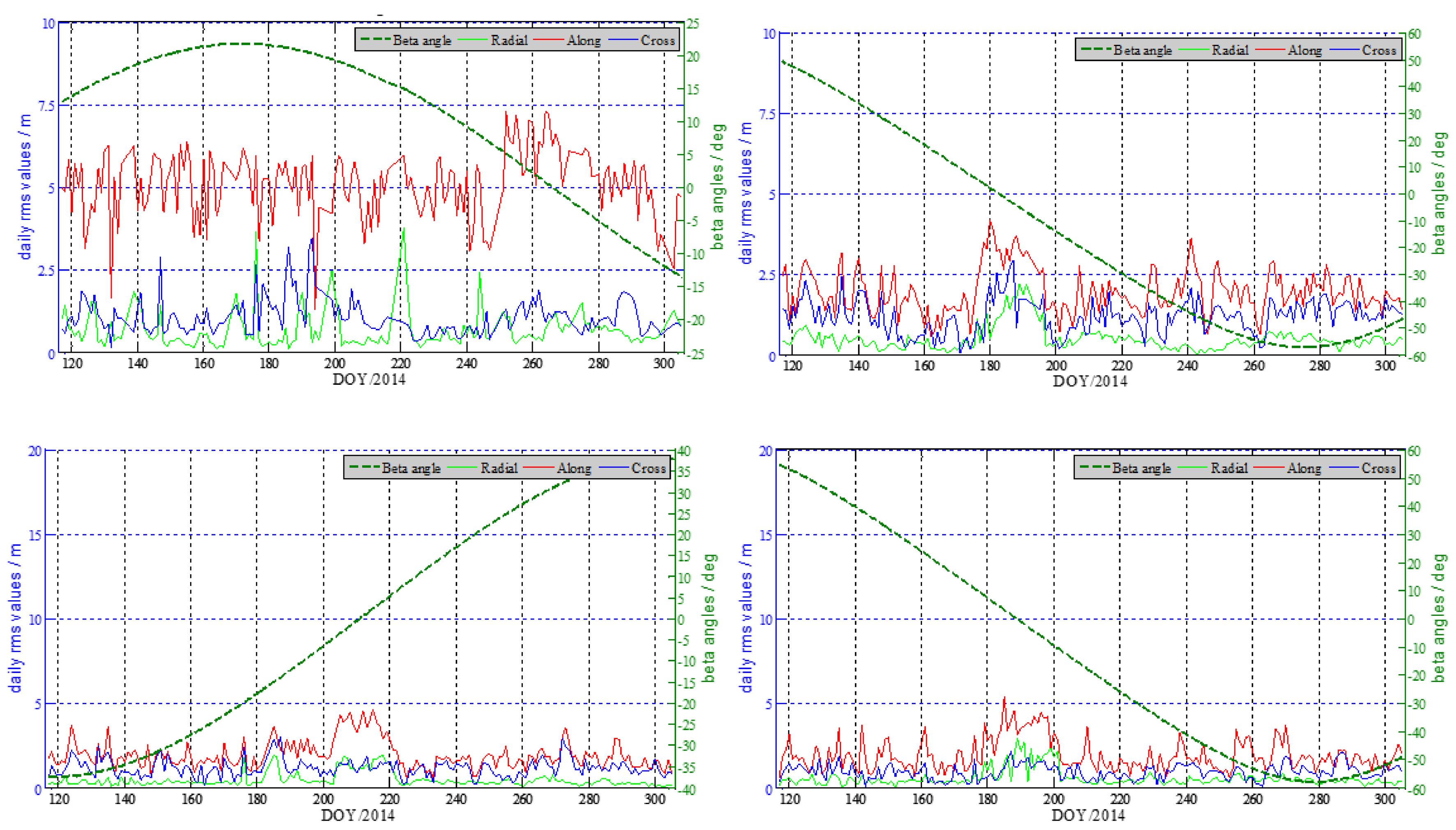

Fig. 2-5 BDS G01, I03, I05 and M03 satellite integration error in Radial, Along, Cross components

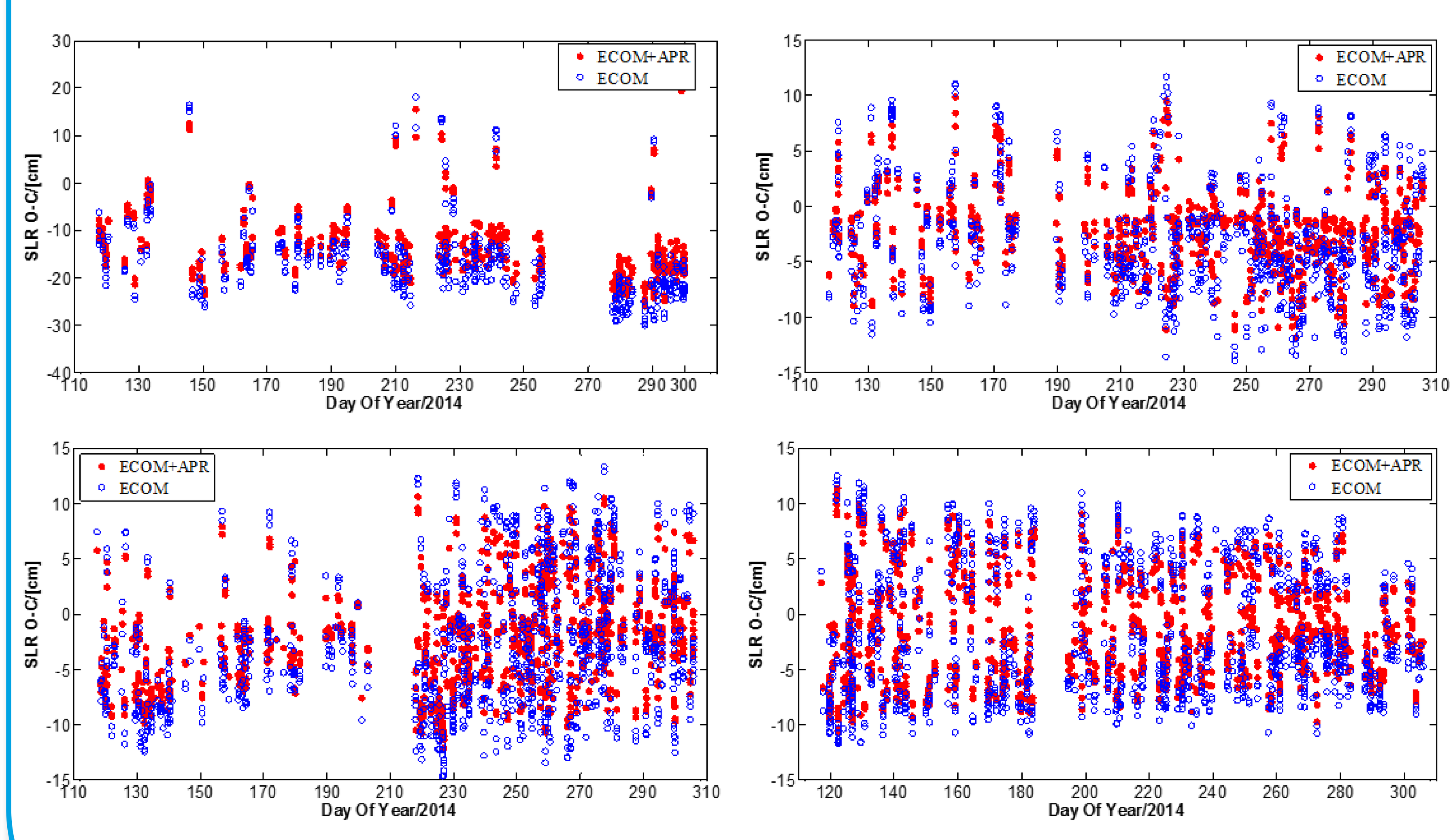

Fig. 6-9 SLR Validation for satellite G01, I03, I05 and M03 satellite during non-eclipse periodAlong, Cross components

Summary and outlook

a) IGGAC provides all types of GNSS related products to iGMAS analysis center coordinator since March 2014 routinely. After a long-term evaluation of the products, all the products generated by IGGAC can achieve the same performance as the IGS counterparts.

b) Since mid of October 2015, we start to contribute our multi-GNSS DCB product based on IGGDCB method to the MGEX. IGG has also been accepted as an APREF (Asia-Pacific Reference Frame) LAC (Local Analysis Center) and provide precise coordinate products to GA (Geoscience Australia) since January 2015.

c) Many new methods and new models published by our research group, such as SHPTS, IGGDCB and IGGTrop, an new analytical solar radiation pressure (SRP) for current Beidou satellites are employed when generating the routine products.