Optimized Strategies for Precise Orbit Determination of Low Earth Orbiters Based on BDS

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Introduction for LEO POD Using BDS

Research Points

- **Enhance** BDS Orbit and Clock (Qile Zhao,2017; Xingxing Li,2017; Tian Zeng,2017; Chao Xiong,2017)
- FY-3C **P**recise **O**rbit **D**etermination (Chao Xiong,2017; Min Li, 2017)
- BDS **GEO** Code Multipath Modeling (Kecai Jiang,2017; Rengui Ruan,2017)
- Estimation for BDS **DCB** and Ionosphere (Wenwen Li,2017)

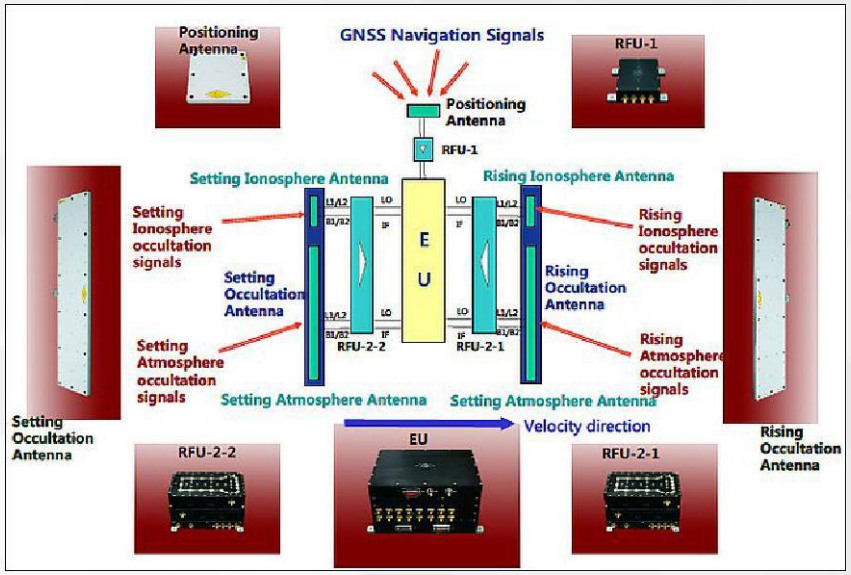
Questions

- LEO POD Using only BDS Data
- The Contribution of BDS GEO in LEO POD
- The Impact of BDS Orbit Daily Jumps

Introduction for FY-3C Satellite

Artistic Illustration of FY-3C

Item	Description
Launched Date	Sep 23, 2013
Orbit Type	Sun-synchronous near-circular orbit
Average Altitude	836 km
Inclination	98.75 degrees
Period	101.49 minutes



Architecture of GNOS receiver

Item	Description
Developer	Center for Space Science and Applied Research
System	GPS+BDS
Frequency	GPS: L1 L2 BDS: B1 B2

Basic FY-3C POD Configuration Using BDS

Dynamic Models

Item	Description
Earth gravity	EIGEN_06C, 100 degrees
Solid Earth Tides	IERS 2010
Ocean tides	FES2012, 30 degrees
Relativistic effects	IERS 2010
Atmospheric drag	Box-Wing model, DTM94 model
Solar radiation	Box-Wing model
Third body gravity	Solar system celestial bodies, DE421
Estimated parameters	Initial position and velocity; Atmospheric drag coefficients, **6 hours**; Empirical accelerations acting on along-track and cross-track, **6 hours**

Observation Models

Item	Description
POD arc length	**24 or 36 hours**
Observation selection	Ionosphere-free combination
BDS orbit and clock	GBM or WUM
BDS PCO&PCV	**IGS14.atx**
Phase wind-up	Corrected
Observation interval	30 s
Cut-off elevation	Accept all available observations
Observation weighting	Equal, weight 40000:1
Satellite attitude	Nominal attitude mode
Estimated parameters	Antenna PCO in Z; Receiver clock bias; Phase ambiguity bias

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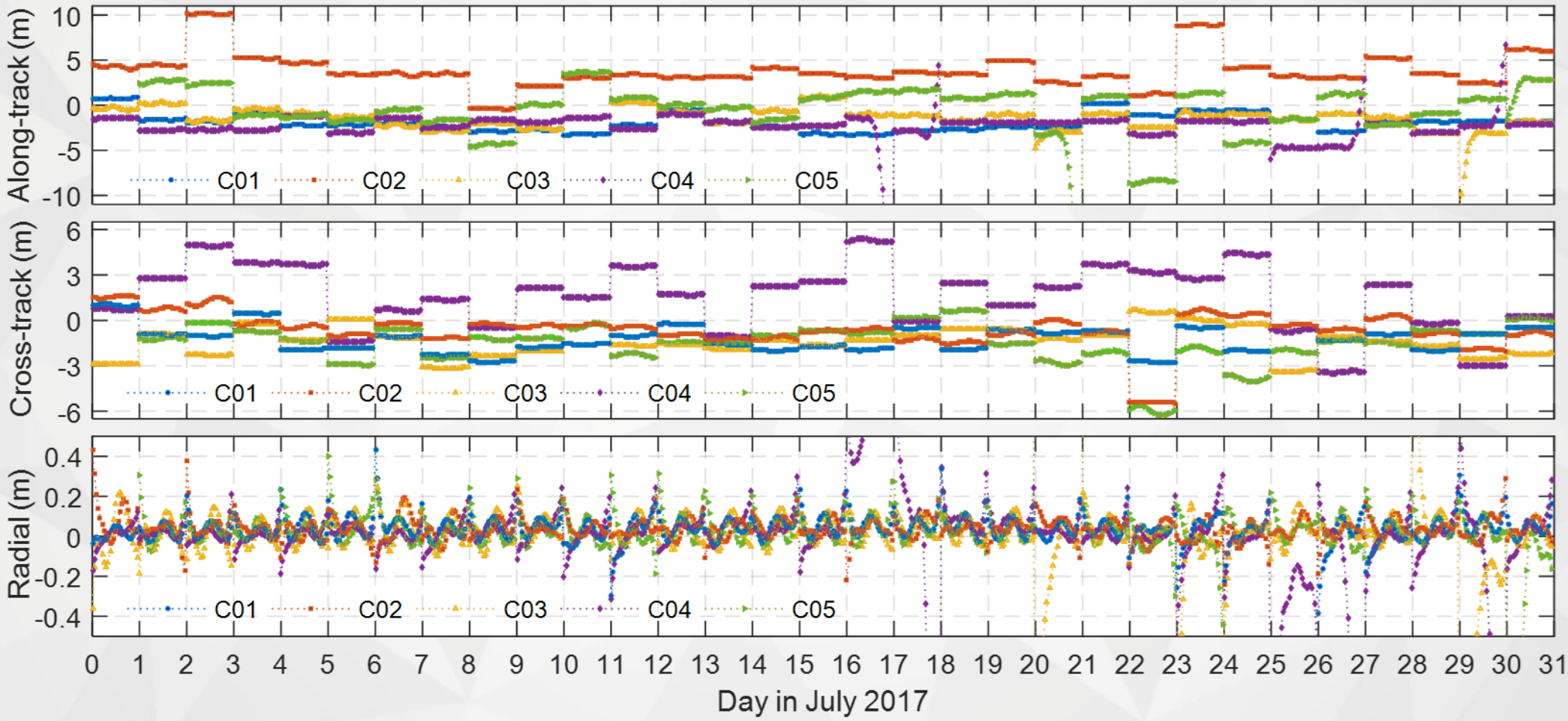
Mitigation of BDS GEO Orbit Errors

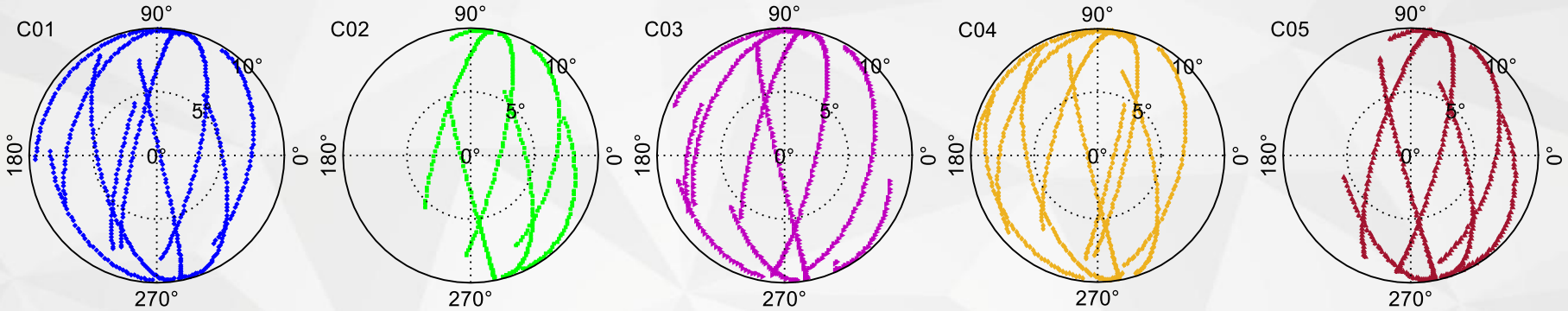
Characteristics of BDS GEO Orbit Oroducts



Orbit differences for BDS GEO between the GBM and WUM orbit products

Mitigation of BDS GEO Orbit Errors

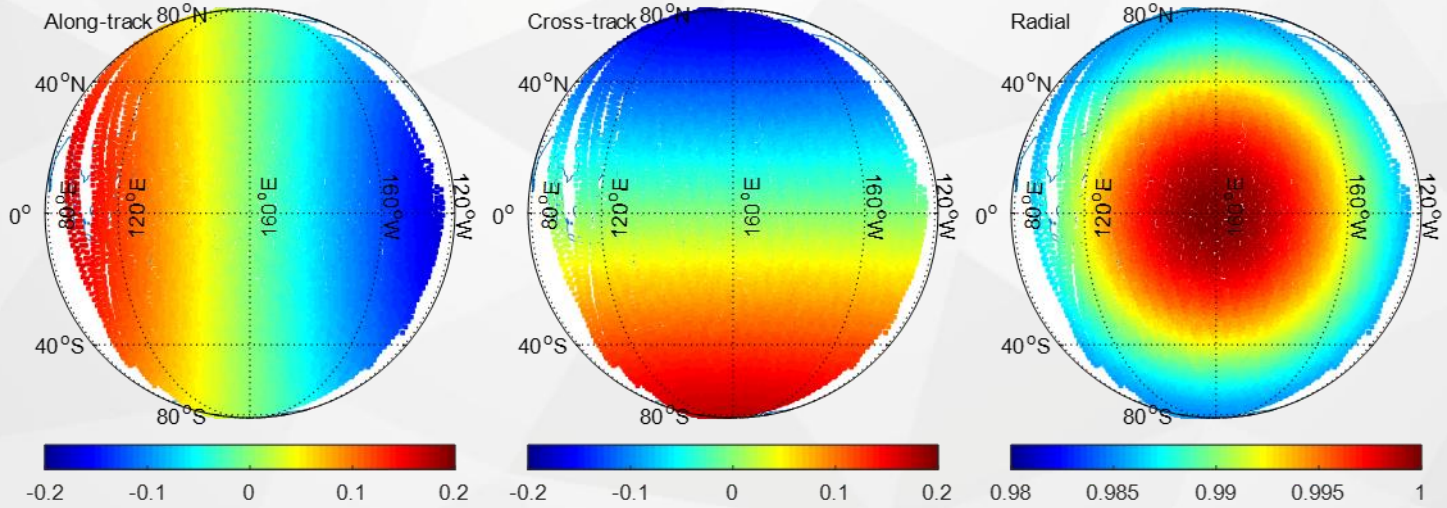
GEO Tracked by FY-3C



Zenith and azimuth variation of GEO in orbital reference frame during 14 July 2017

BDS GEO Phase Observation Equation

$$\rho(t_r, t^s) = \rho(\boldsymbol{r_0}, \boldsymbol{v_0}, \boldsymbol{p}, \boldsymbol{PCO}, \delta t(t_r), AMB, \boldsymbol{dA}, \boldsymbol{dC}, \boldsymbol{dR})$$



Distance errors caused by unit orbit biases in the observable region for C04

Mitigation of BDS GEO Orbit Errors

FY-3C POD Strategies

- **Solution A**

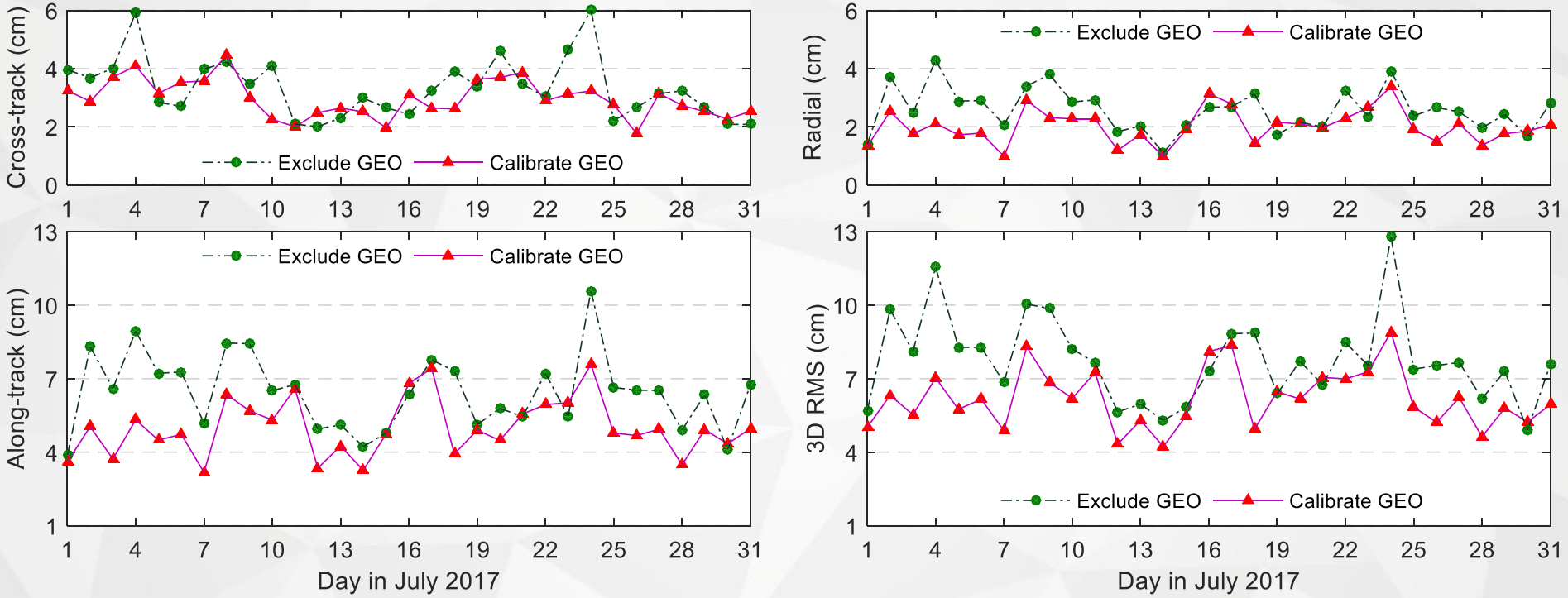
  Exclude BDS GEO roughly.

- **Solution B**

  Include BDS GEO and apply GEO orbit along-track and cross-track biases calibration.

Mitigation of BDS GEO Orbit Errors

Assessment of BDS-derived FY-3C Orbit



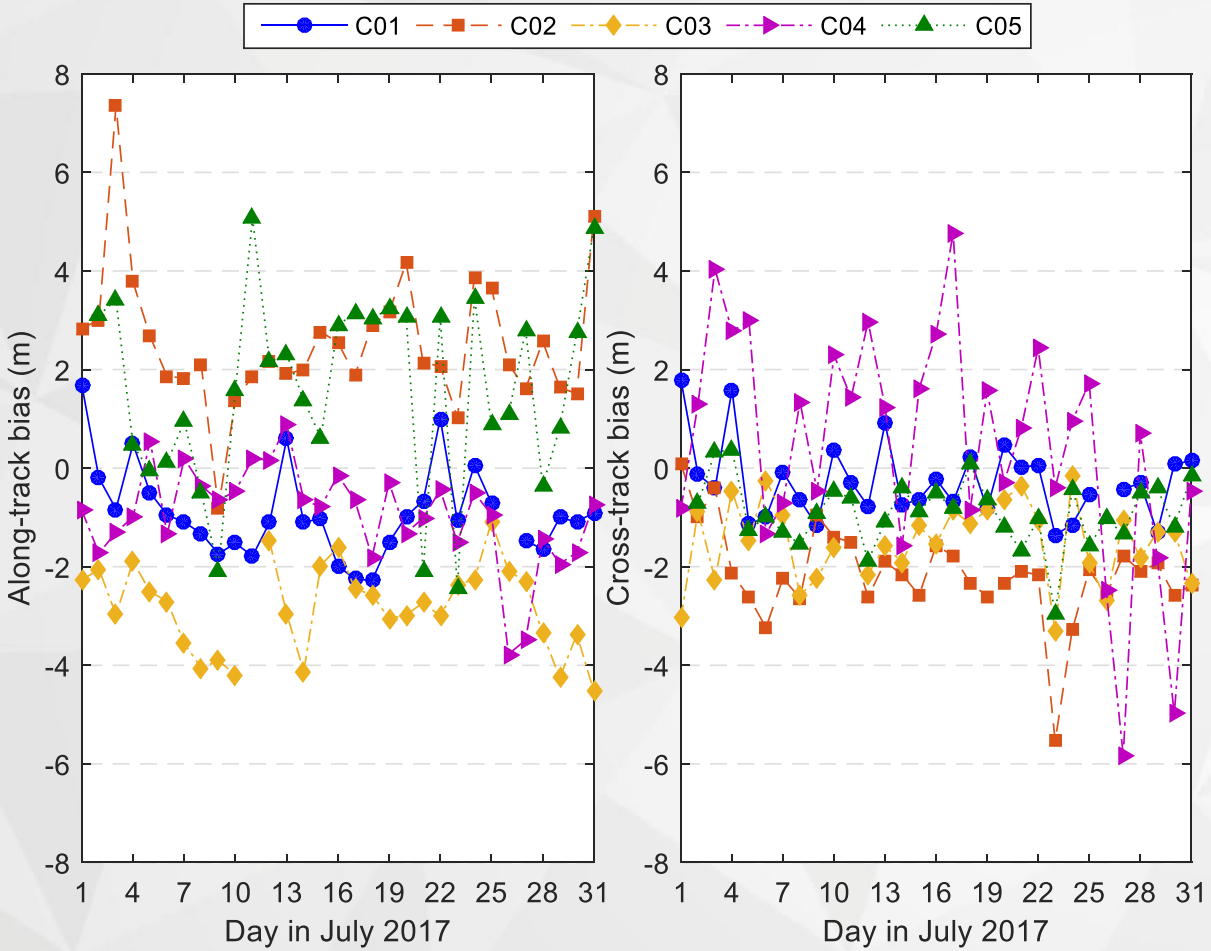
Daily RMS series of orbit differences between BDS-derived and GPS-derived FY-3C orbit

Average daily RMS of orbit differences for FY-3C POD using only BDS (unit: cm)

Category	Along-Track	Cross-Track	Radial	3D
Solution A	6.4	3.3	2.6	**7.8**
Solution B	5.0	3.0	2.0	**6.2**

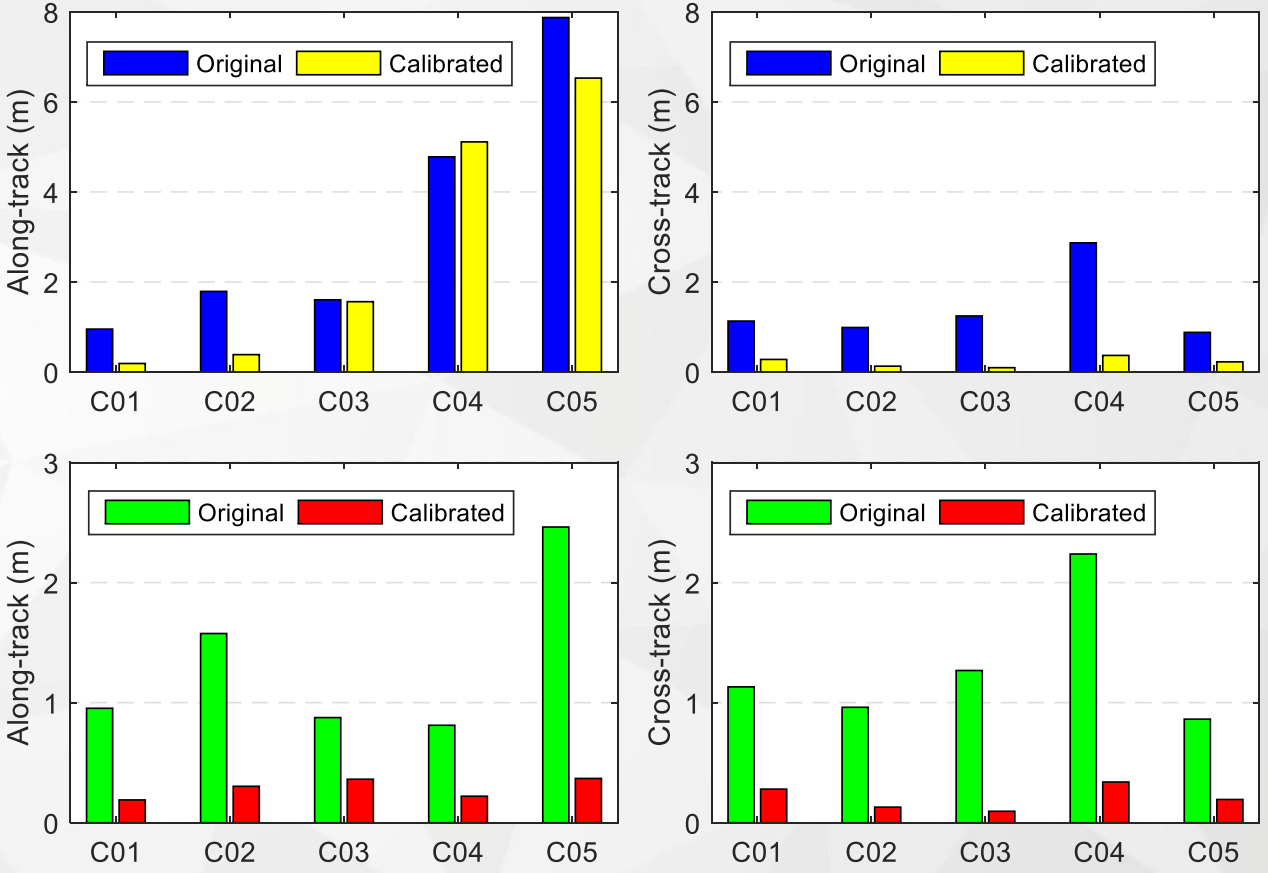
Mitigation of BDS GEO Orbit Errors

Estimated BDS GEO Orbit Biases



Estimated daily systematic orbit biases in along-track and cross-track of GBM GEO orbit products

DBDs of Calibrated GEO Orbit Products



RMS of Daily boundary discontinuities (DBDs) for GEO original and calibrated orbit products

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LEO BDS Antenna PCV Calibration

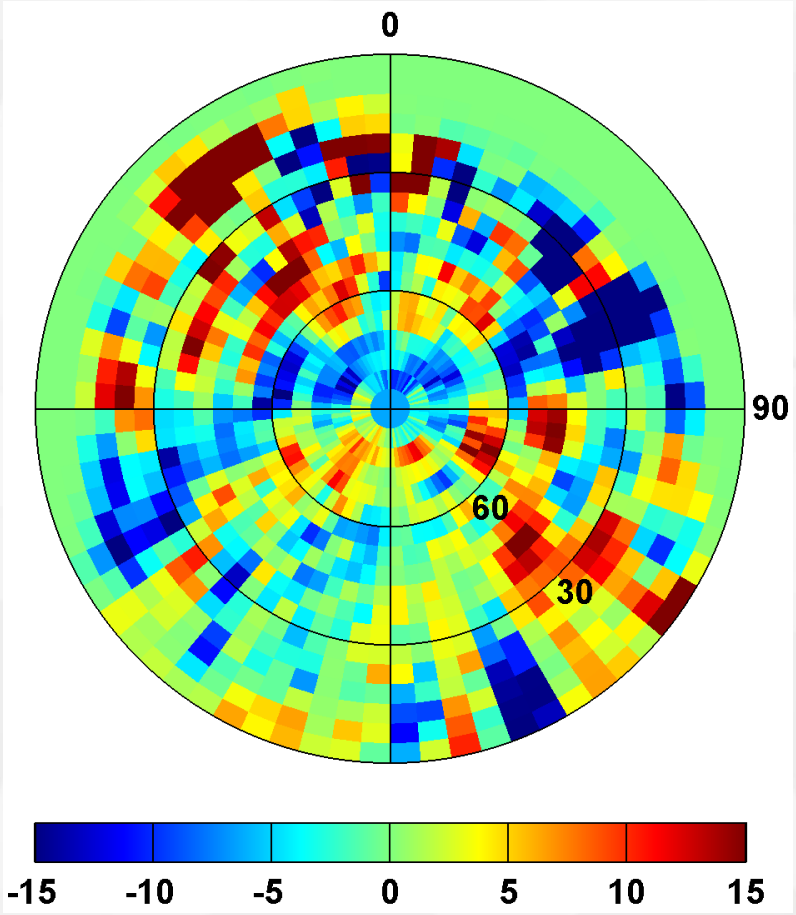
PCV Estimation Using Residuals Method Comparison Between Two PCV Maps

Estimation of PCV

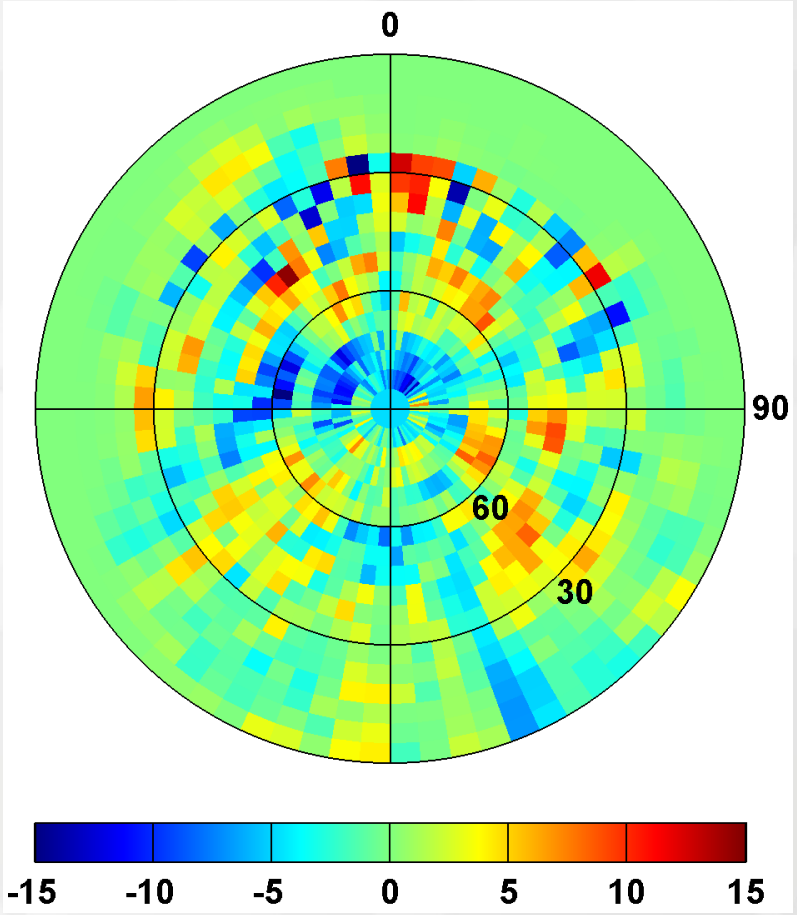
- GPS PCV, grid space is 5°
- BDS PCV, grid space is 5°

Impact of PCV on POD

- BDS data + GPS-derived PCV
- BDS data + BDS-derived PCV



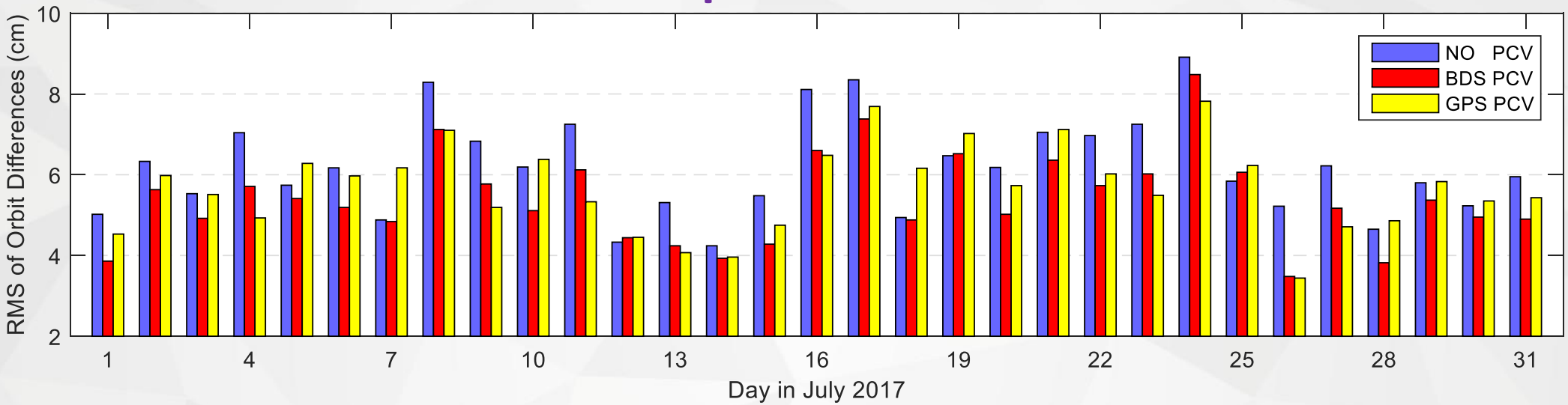
PCV recovered from GPS (mm)



PCV recovered from BDS (mm)

LEO BDS Antenna PCV Calibration

FY-3C Orbit with Different PCV Maps



Daily RMS of FY-3C orbit precision using PCV from BDS and GPS observations, respectively

FY-3C orbit precision with three different PCV using only BDS data

Strategy	**Average RMS of daily orbit differences (cm)**			
	Along-track	Cross-track	Radial	**3D**
No PCV	5.0	3.0	2.0	**6.2**
BDS PCV	4.3	2.6	1.7	**5.4**
GPS PCV	4.6	2.7	1.8	**5.7**

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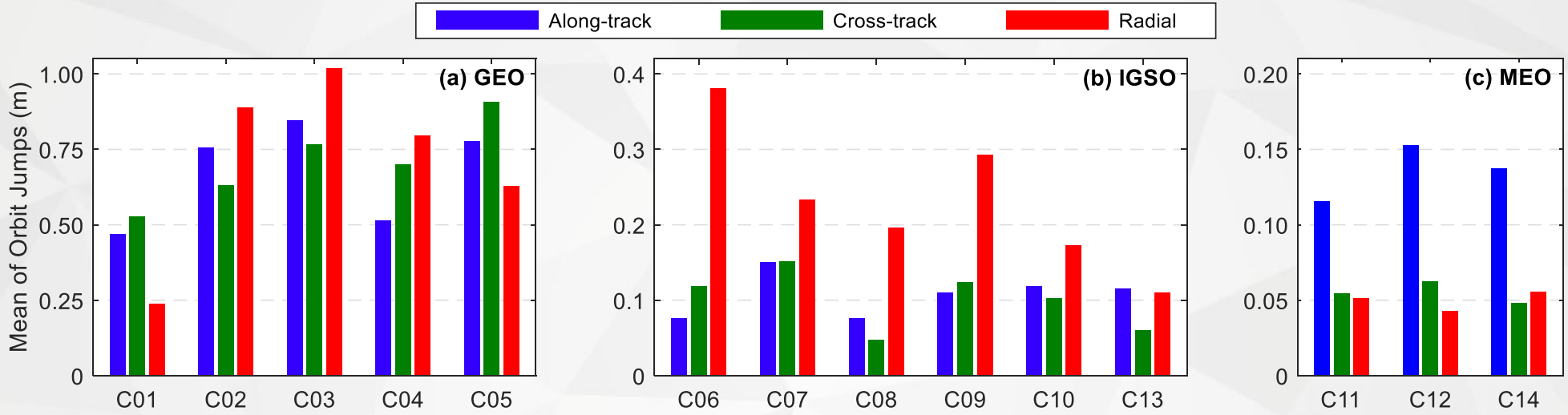
Consideration of BDS Orbit Daily Jumps

Statistics of BDS Orbit Daily Jumps



Average of the orbit daily jumps for the WUM BDS orbit products

Maximum, minimum and average of the orbit daily jumps for the WUM BDS orbit products

Satellite Type	Statistics of Orbit Daily jumps (m)			
	Along-track Max / Min / Mean	Cross-track Max / Min / Mean	Radial Max / Min / Mean	3D Max / Min / Mean
GEO	5.49 / 0.03 / 0.67	3.92 / 0.03 / 0.71	1.83 / 0.14 / 0.72	6.85 / 0.20 / 1.37
IGSO	0.42 / 0.00 / 0.11	0.78 / 0.00 / 0.10	0.91 / 0.01 / 0.23	1.22 / 0.03 / 0.30
MEO	0.42 / 0.00 / 0.14	0.21 / 0.00 / 0.05	0.15 / 0.00 / 0.05	0.44 / 0.02 / 0.17

Consideration of BDS Orbit Daily Jumps

FY-3C POD Strategies

- **Solution 1**

  24 hours using original BDS orbit products

- **Solution 2**

  36 hours using original BDS orbit products

- **Solution 3**

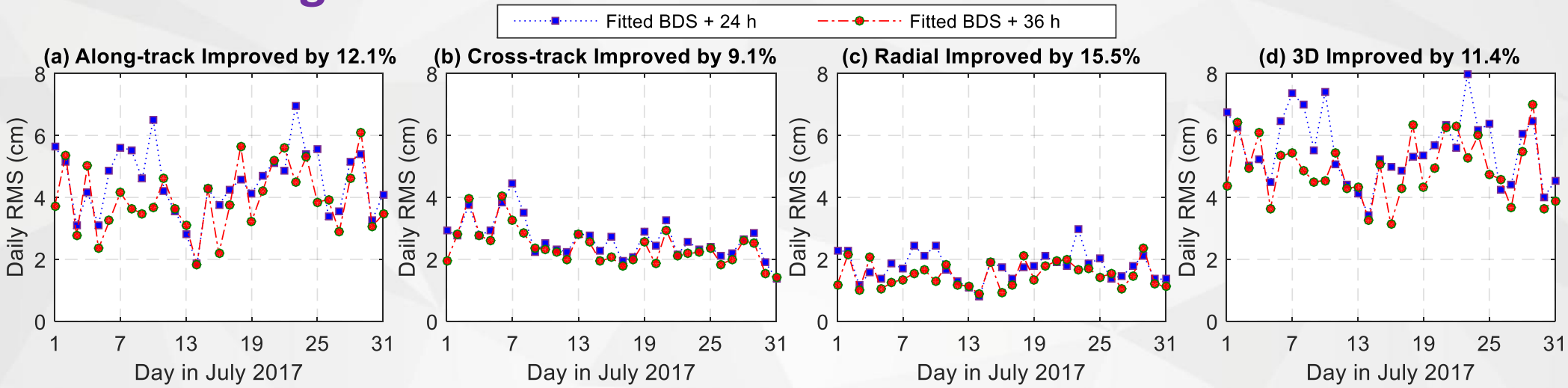
  24 hours using fitted BDS orbit products

- **Solution 4**

  36 hours using fitted BDS orbit products

Consideration of BDS Orbit Daily Jumps

Impact of Arc Length on FY-3C POD



Daily RMS of FY-3C orbit precision using two different strategies based on WUM products

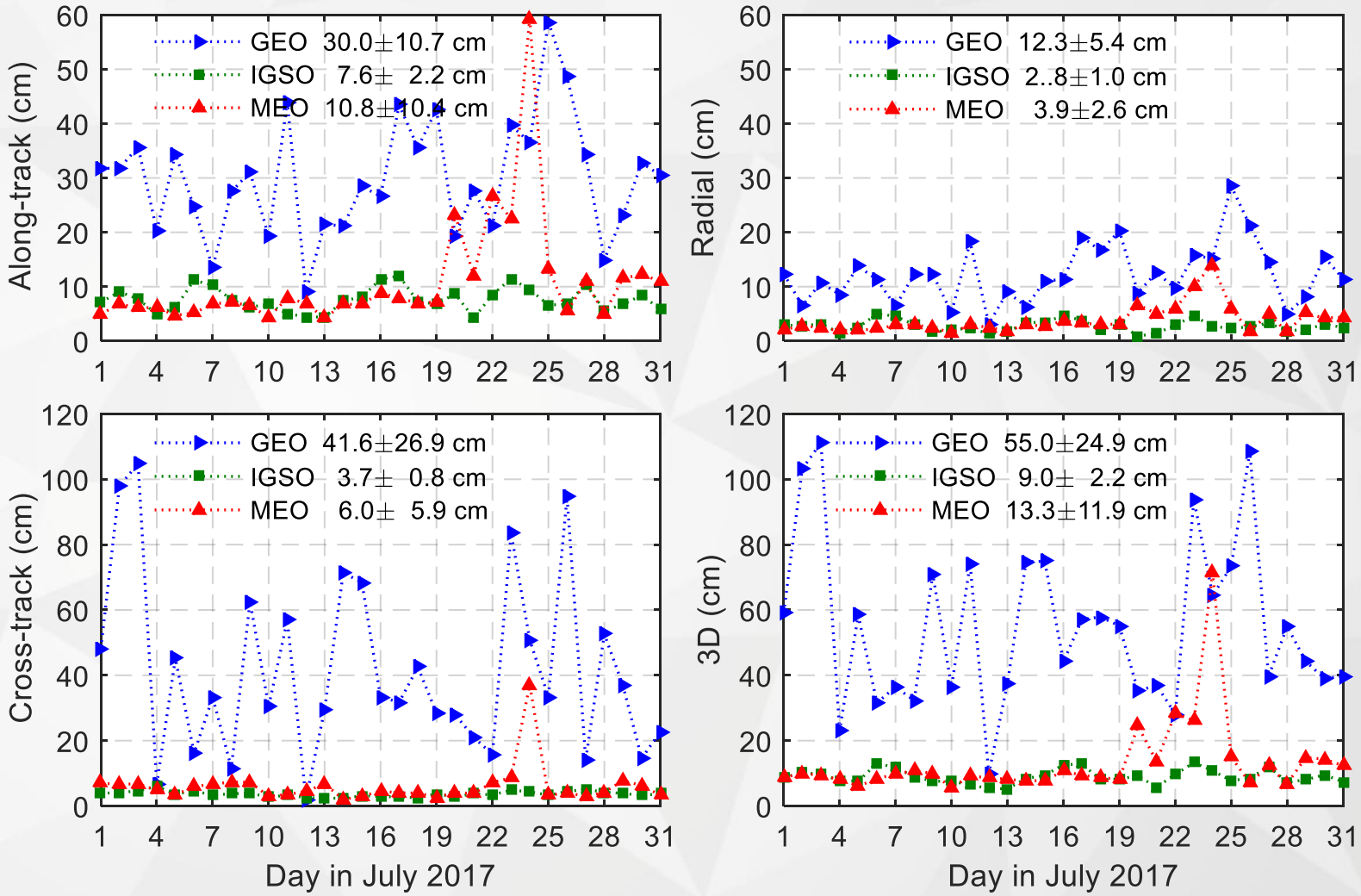
FY-3C orbit precision using four different strategies based on BDS only

Strategy	Exclude GEO (cm)				Include GEO (cm)			
	A	C	R	3D	A	C	R	3D
24 h ORG	8.3	4.5	3.2	10.1	7.9	6.4	3.2	10.9
36 h ORG	6.2	3.5	2.5	7.7	5.8	4.7	2.2	8.0
24 h FIT	4.9	2.6	1.9	5.9	4.5	2.6	1.8	5.6
36 h FIT	4.4	2.3	1.7	5.3	3.9	2.4	1.5	4.9

Consideration of BDS Orbit Daily Jumps

FY-3C POD Using Each BDS Satellite Type

- GEO get larger POD errors
- IGSO, MEO work better
- IGSO obtain the best results



Daily RMS of FY-3C orbit precision using BDS GEO, IGSO and MEO, respectively

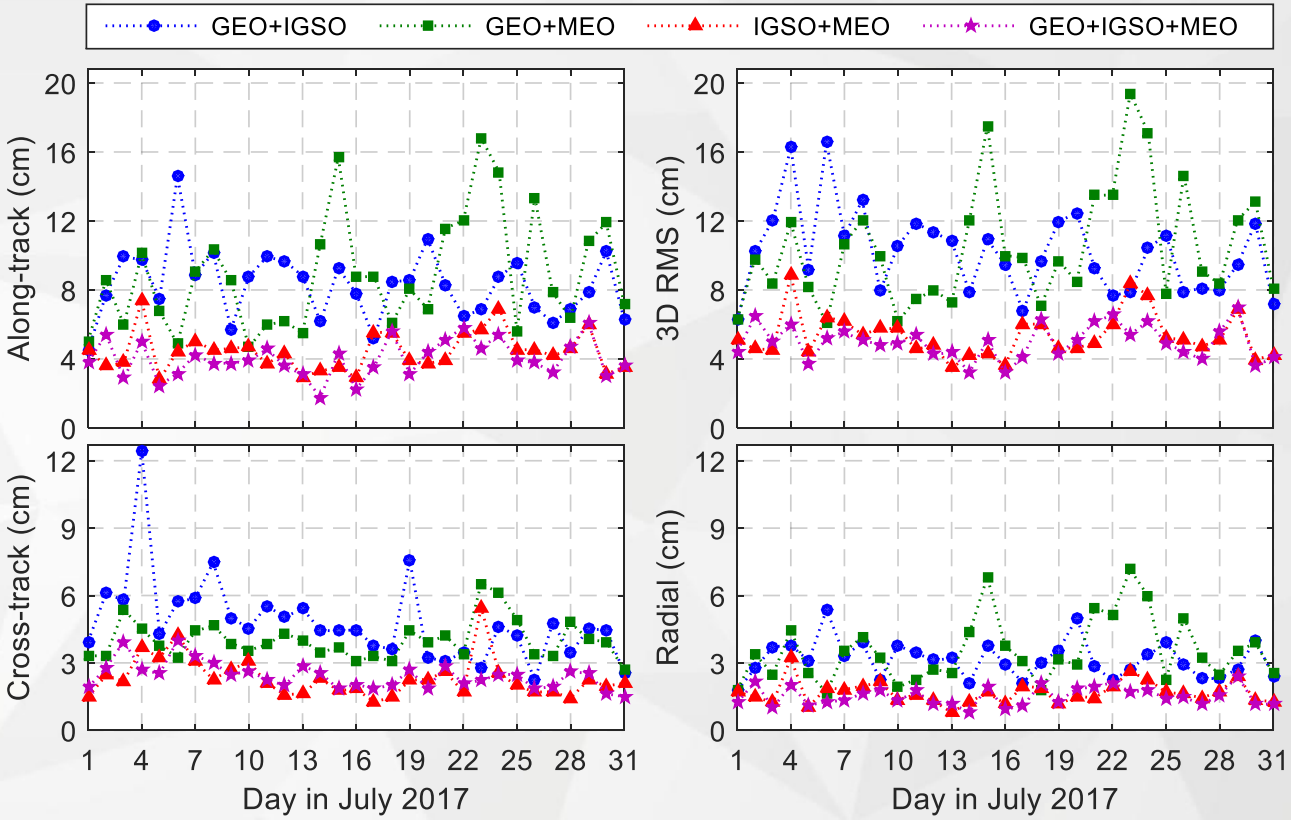
Consideration of BDS Orbit Daily Jumps

FY-3C POD Using Combination of BDS Satellite Type

Average and STD of daily RMS for FY-3C orbit precision using BDS satellite type combination

Combination of BDS	Mean and STD of Daily RMS (cm)			
	A	C	R	3D
GEO+IGSO	8.3±2.0	4.8±1.9	3.2±0.8	10.2±2.4
GEO+MEO	8.9±3.2	4.0±0.9	3.5±1.4	10.4±3.4
IGSO+MEO	4.4±1.1	2.3±0.9	1.7±0.5	5.3±1.3
ALL	4.0±1.1	2.4±0.6	1.5±0.4	5.0±1.0

- GEO+IGSO, GEO+MEO show nearly same
- Contribution of GEO is very small
- IGSO+MEO maybe the best choice



Daily RMS of FY-3C orbit precision using combination of BDS GEO, IGSO and MEO

Contents

Conclusion, Discussion and Forecast

➢ Conclusion

- Calibrate BDS GEO orbit biases is practicable
- Achieve cm level FY-3C orbit using only BDS
- PCV is consistent between GPS and BDS
- Reduce the influence of daily jumps in BDS orbit products

➢ Discussion

- More BDS observations
- More precise BDS orbit and clock products
- POD for other missions

➢ Future work

- GPS+BDS integration
- Variance component estimation
- Integer ambiguity resolution

Thanks for your attention!