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Impact of ambiguity resolution on multi-GNSS real-time precise orbit determination

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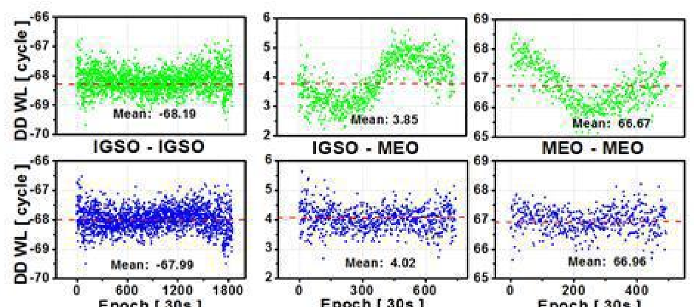
Abstract

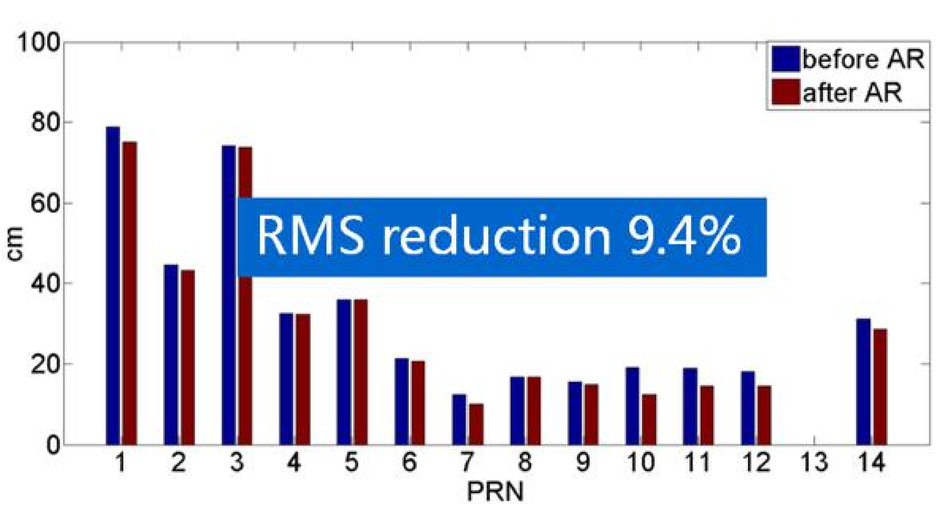
Multi-GNSS is expected to achieve a real-time precise positioning service with better accuracy and reliability than GPS-only service. In this study, we address the impact of ambiguity resolution on improving GPS+GLONASS+BeiDou+Galileo real-time precise orbit products. Firstly, the specific issue of improving GLONASS real-time orbit quality by resolving ionosphere-free ambiguity for long baselines in global network is discussed and investigated in detail. The ambiguity fixing rate and precision of real-time GLONASS orbit is analyzed. Secondly, BeiDou ambiguity resolution taking into account the satellite-induced code variations and its impact on BeiDou quality are discussed. A thorough analysis of the wide-lane and narrow-lane ambiguity fixing rate for baselines of various lengths is conducted. The results show that for BeiDou IGSO and MEO satellites, the correction of the elevation-dependent code biases can improve the fixing rate and orbit quality significantly in terms of both orbit overlap precision and satellite laser ranging residuals. For BeiDou GEO satellites, ambiguity resolution also helps to improve the real-time orbit quality. Finally, experimental validation is carried out based on the near real-time hourly data of the IGS/MGEX network. The ultra-rapid orbit products are assessed by a comparison with the IGS/MGEX final products. It is demonstrated that ambiguity resolution can contribute to improving the multi-GNSS ultra-rapid precise orbit products.

BeiDou ambiguity resolution method and performance

- Satellite-induced pseudorange variation, MW WL AR
- Wanninger et al (2015)
- Lou et al (2016)

Coefficients	GEO B1	GEO B2	GEO B3	IGSO B1	IGSO B2	IGSO B3	MEO B1	MEO B2	MEO B3
a_1	−0.436	−0.275	−0.048	−0.590	−0.257	−0.102	−0.946	−0.598	−0.177
a_2	1.158	1.087	0.566	1.624	0.995	0.748	2.158	1.635	0.652
a_3	−0.333	−0.452	−0.185	−0.645	−0.381	−0.307	−0.642	−0.556	−0.178





	Without AR (cm)			With AR (cm)		
	Mean	STD	RMS	Mean	STD	RMS
C01 (GEO)	-46.28	23.43	51.87	-45.65	24.12	51.63
C08 (IGSO)	0.45	8.05	8.06	0.78	5.43	5.48
C10 (IGSO)	5.01	6.21	7.98	2.41	4.78	5.35
C11 (MEO)	-4.52	4.22	6.18	-3.58	4.17	5.49

GLONASS ambiguity resolution method and performance

- GLONASS iono-free fixing method (Dai 2000; Rossbach 2000; Banville 2016; Liu et al 2016)

$$P_{a,n}^i = \rho_a^i - c(dt^i - dt_a) + I_{a,n}^i + T_a^i + \delta_{a,n}^i + \xi_{a,n}^i$$

$$L_{a,n}^i = \lambda_n^i \varphi_{a,n}^i = \rho_a^i - c(dt^i - dt_a) - I_{a,n}^i + T_a^i + \lambda_n^i B_{a,n}^i + \gamma_{a,n}^i + \varepsilon_{a,n}^i$$

$$P_{a,c}^i = \rho_a^i - c(dt^i - dt_a) + T_a^i + \delta_{a,c}^i + \xi_{a,c}^i$$
$$L_{a,c}^i = \rho_a^i - c(dt^i - dt_a) + T_a^i + \lambda_1^i B_{a,c}^i + \gamma_{a,c}^i + \varepsilon_{a,c}^i$$

$f_1^i : f_2^i = 9 : 7$

$$B_{a,e}^i \equiv \frac{32}{9} B_{a,c}^i = 7B_{a,w}^i + 2B_{a,1}^i \qquad \lambda_1^i B_{a,c}^i = \frac{9}{32}\lambda_1^i B_{a,e}^i$$

$B_{a,e}^i$ wavelength 5.3 cm

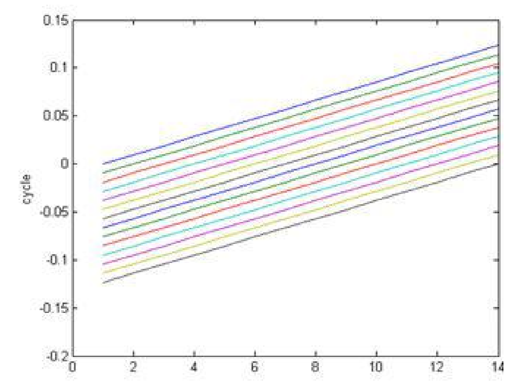
$$\Delta\nabla B_{ab,e}^{ij} = 7\Delta\nabla N_{ab,w}^{ij} + 2\Delta\nabla N_{ab,n}^{ij}$$

- **IFPB Calibration**
  - Priori IFPB not accurate enough (Wanninger 2012)
  - The same kind of receiver may have mm-level difference
  - Slight variation in time

$$\gamma_{ab}^i = K(i)\Delta\gamma_{ab}$$

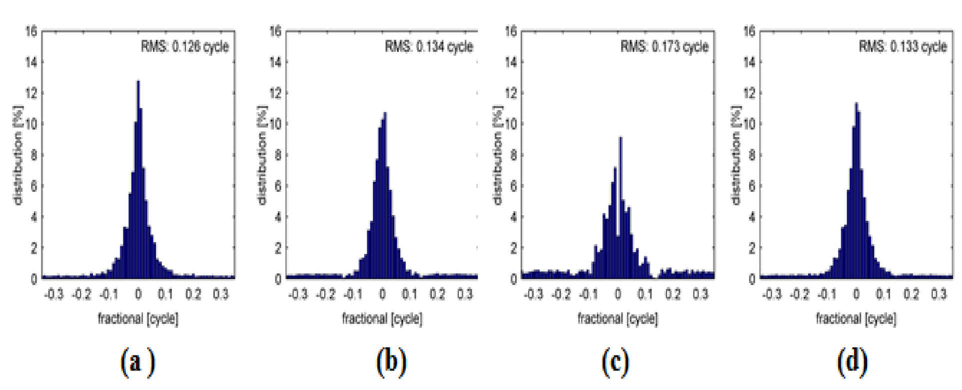
$$\mathrm{RATIO} = \frac{\breve{\sigma}'^2}{\breve{\sigma}^2} = \frac{\|\hat{b}-\breve{b}'\|^2_{Q_{\hat{b}}}}{\|\hat{b}-\breve{b}\|^2_{Q_{\hat{b}}}}$$

[-2,+2] cm/FN , step 0.5 mm



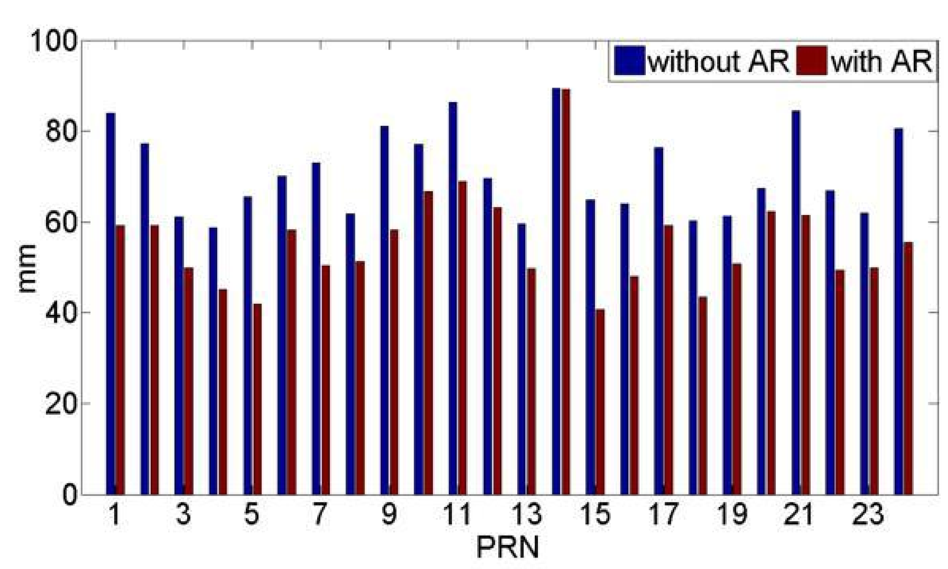
IFPB induced DD fractional bias

- **GLONASS Ambiguity resolution performance**

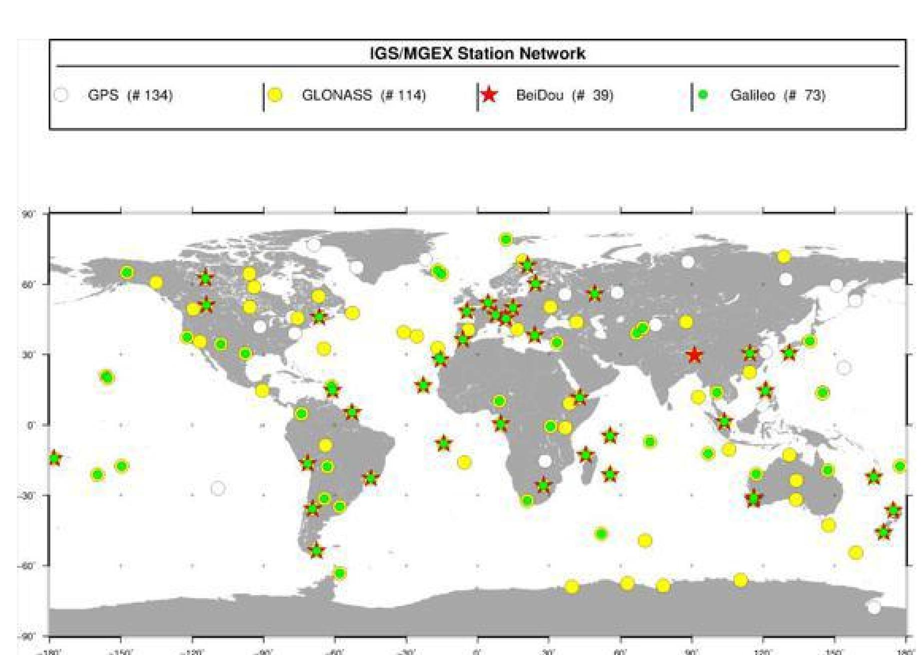


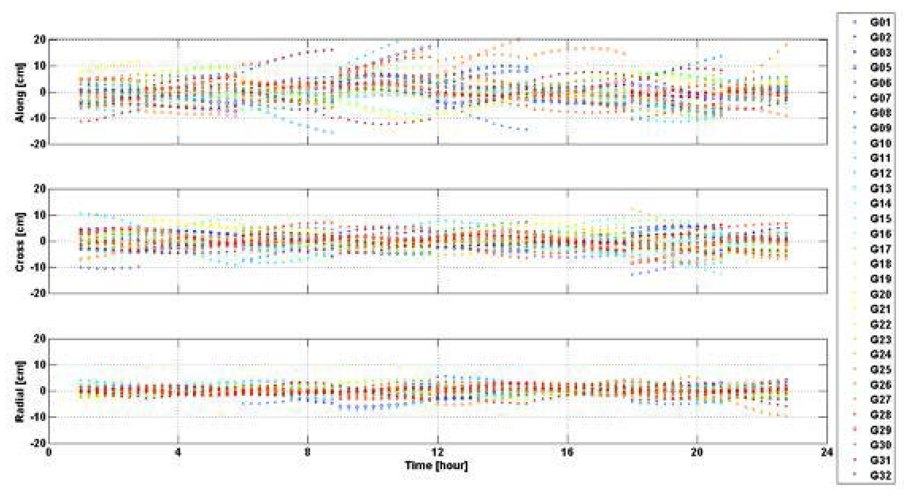
Distribution of the fractional part

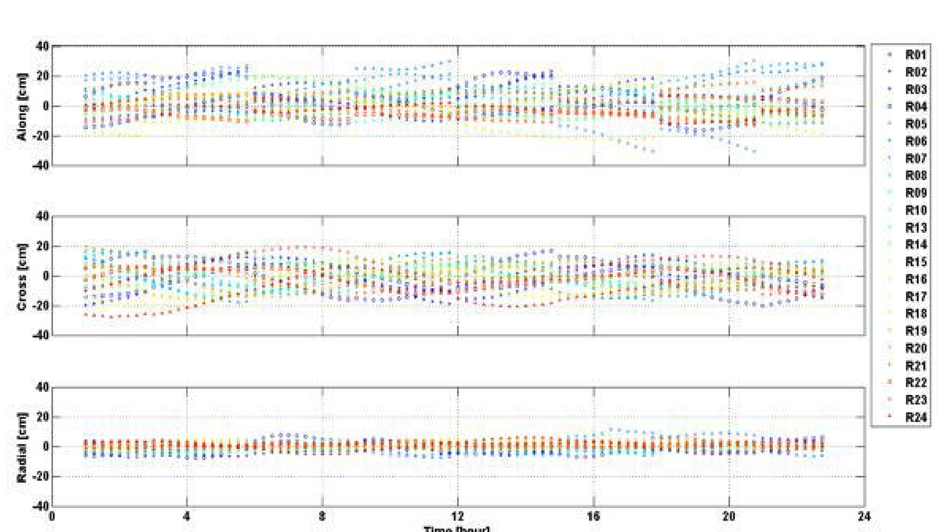
Baseline length	DD Amb No.	Fixing rate
<1000 km (a)	2802	92.9%
1000-2000 km (b)	2037	90.4%
>2000 km (c)	370	85.6%
All (d)	5209	91.4%



Experiment with IGS/MGEX Real-time GNSS network







The proposed data processing scheme for GLONASS ambiguity resolution is given in five steps.

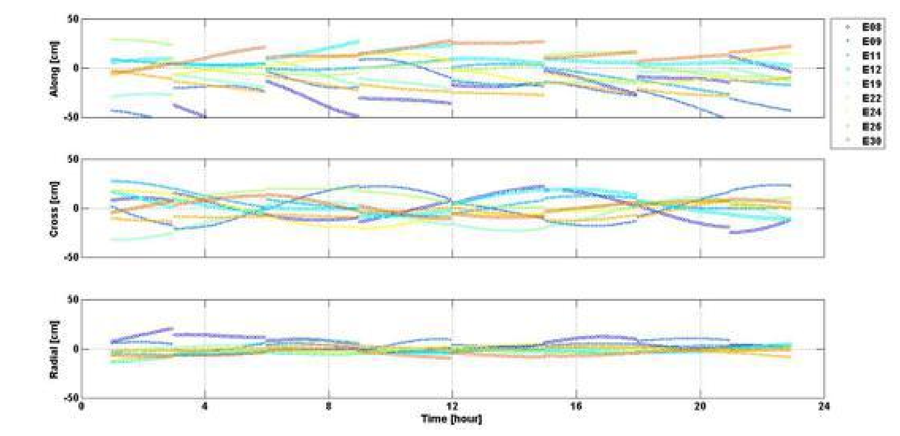
1)Process data using the ionosphere-free code and phase observations as usual with the float ambiguities and repeat the data cleaning until no more data is removed and no new cycle slip is detected.

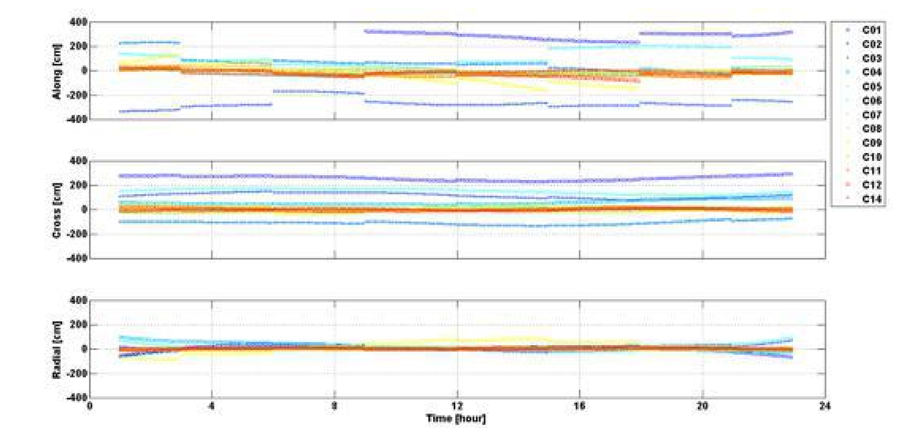
2)Transform the Normal Equation (NEQ) from the ionosphere-free ambiguities to the defined ionosphere-free linear combination ambiguities. In this step, before the transformation, the a priori phase IFB correction by Wanninger (2012) can be applied to the ionosphere-free ambiguities.

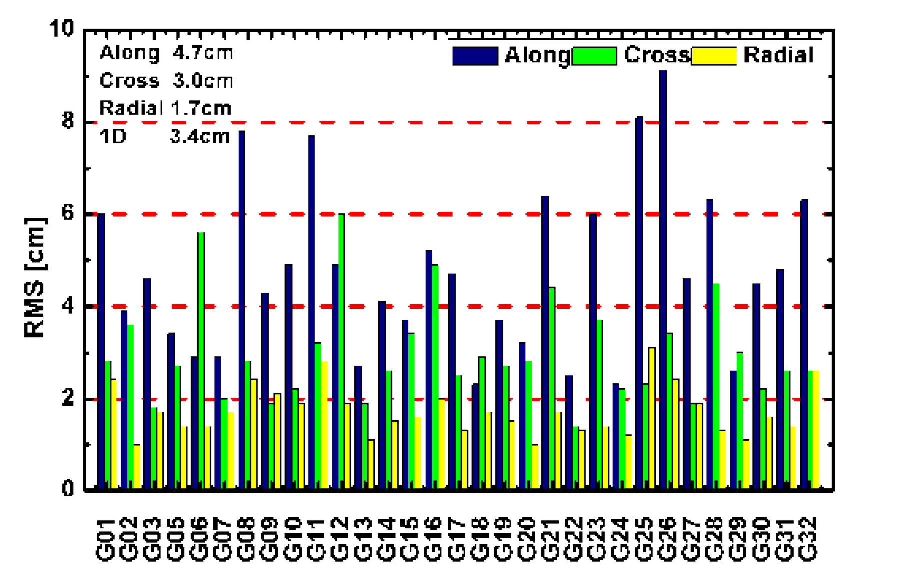
3)For each baseline, the related NEQ is retrieved from the network NEQ with the defined ionosphere-free linear combination ambiguities. Then, the IFB rate is estimated using the particle filter as described by Tian et al. (2015) for the baseline, and the converged estimate of the IFB rate of the last epoch is taken as known value for the IFB correction for the subsequent ambiguity resolution. The integer ambiguities corresponding to the estimated IFB rate are accepted as fixed DD-ambiguities of the baseline.

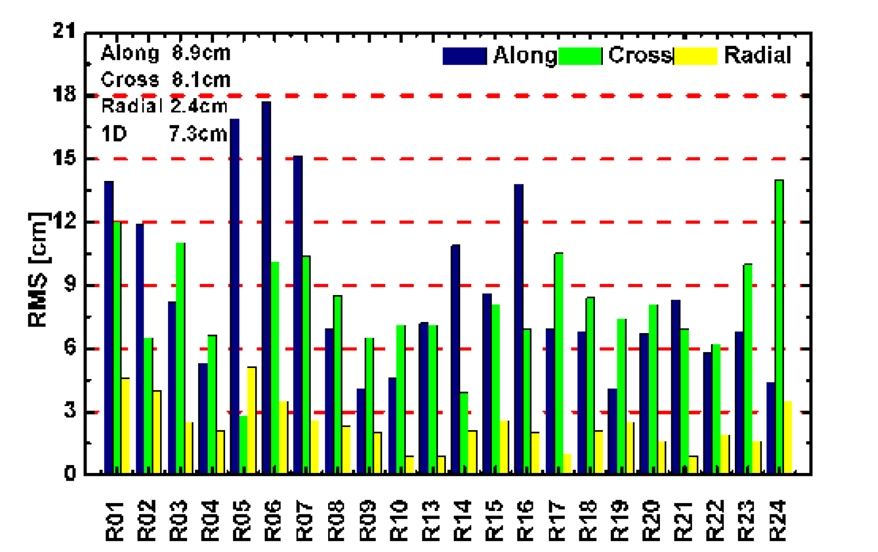
4)An independent set of the fixed DD-ambiguities is selected from the results in step 3. In step 3, the IFB rate estimation can be carried out for all possible baselines shorter than a certain length, for example 3000 km in this study, or just for a set of independent baselines. For the former one, an independent set of fixed ambiguities can be selected from all the fixed ambiguities, whereas for the latter one we can simply take all the fixed ambiguities. The former one will give more fixed constraints than the latter one but is rather time consuming.

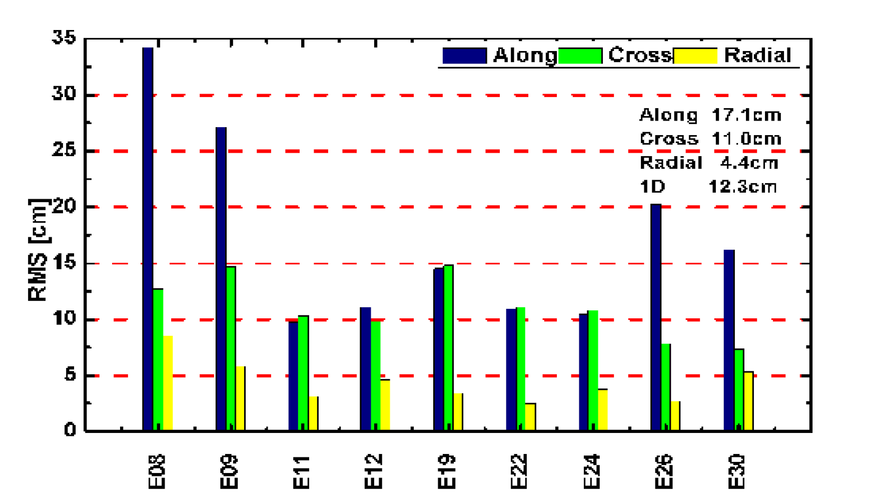
5)Implementing all the independent fixed ambiguities as constraints to the network NEQ to get the fixed solution

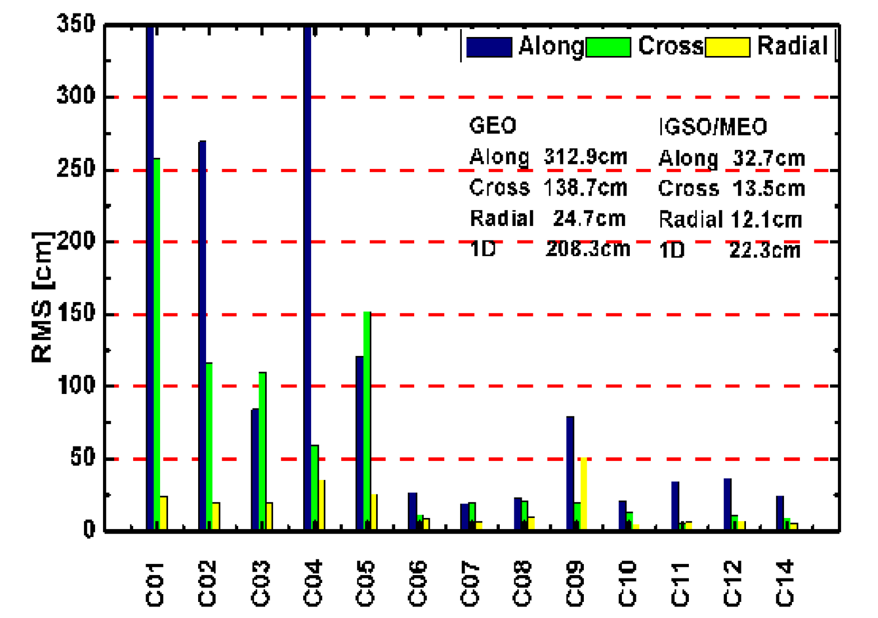












Conclusions

Ambiguity resolution for GLONASS global network of inhomogeneous receivers. After accurate calibration of IFPB, the ionosphere-free ambiguity resolution can be carried out, and the GLONASS satellite orbit precision can be improved.

BeiDou IGSO/MEO ambiguity resolution with the satellite pseudo-range bias correction. The BeiDou satellite orbit overlap precision can be improved and the SLR residual is significantly reduced.

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