FUSING: a distributed software platform for real-time high precision multi-GNSS service

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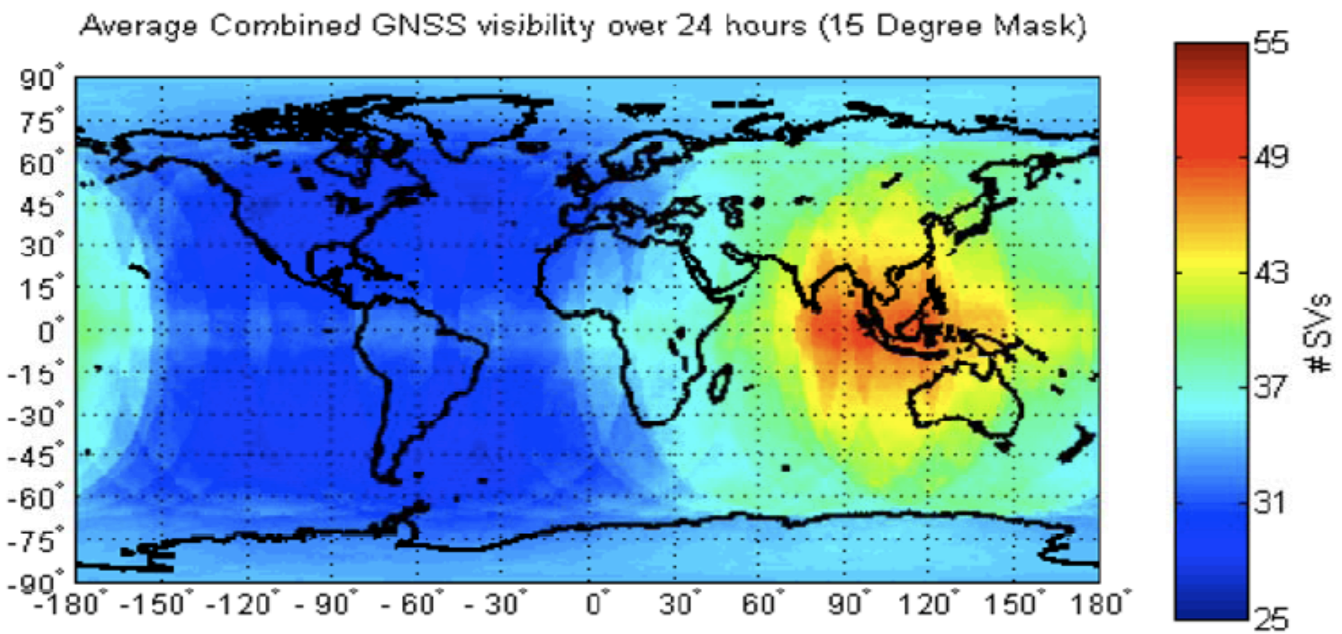
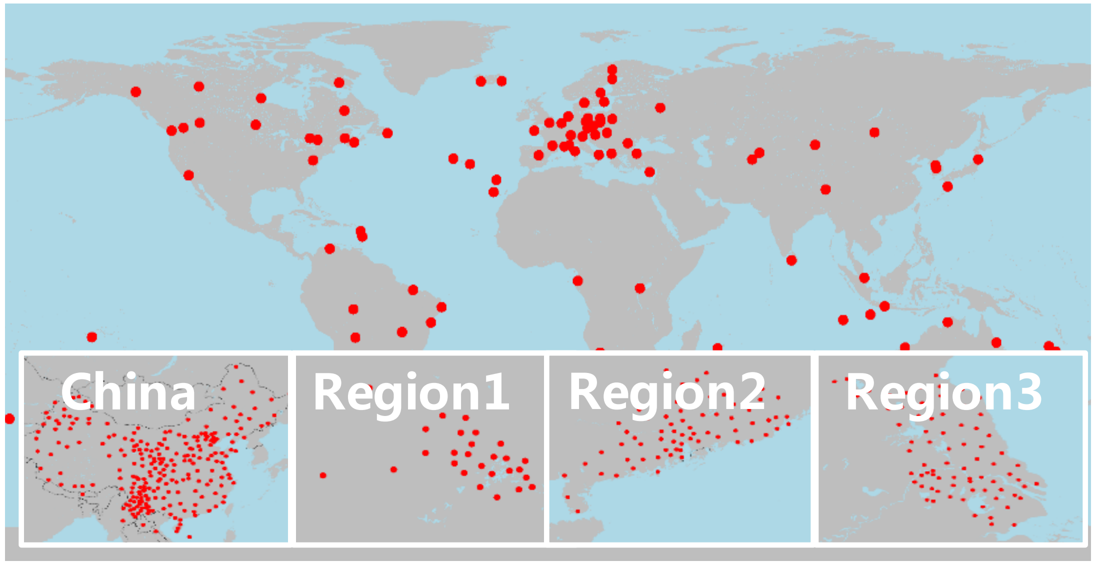
Outline

- Introduction of FUSING
- Features of FUSING
- Products by FUSING
- Conclusions

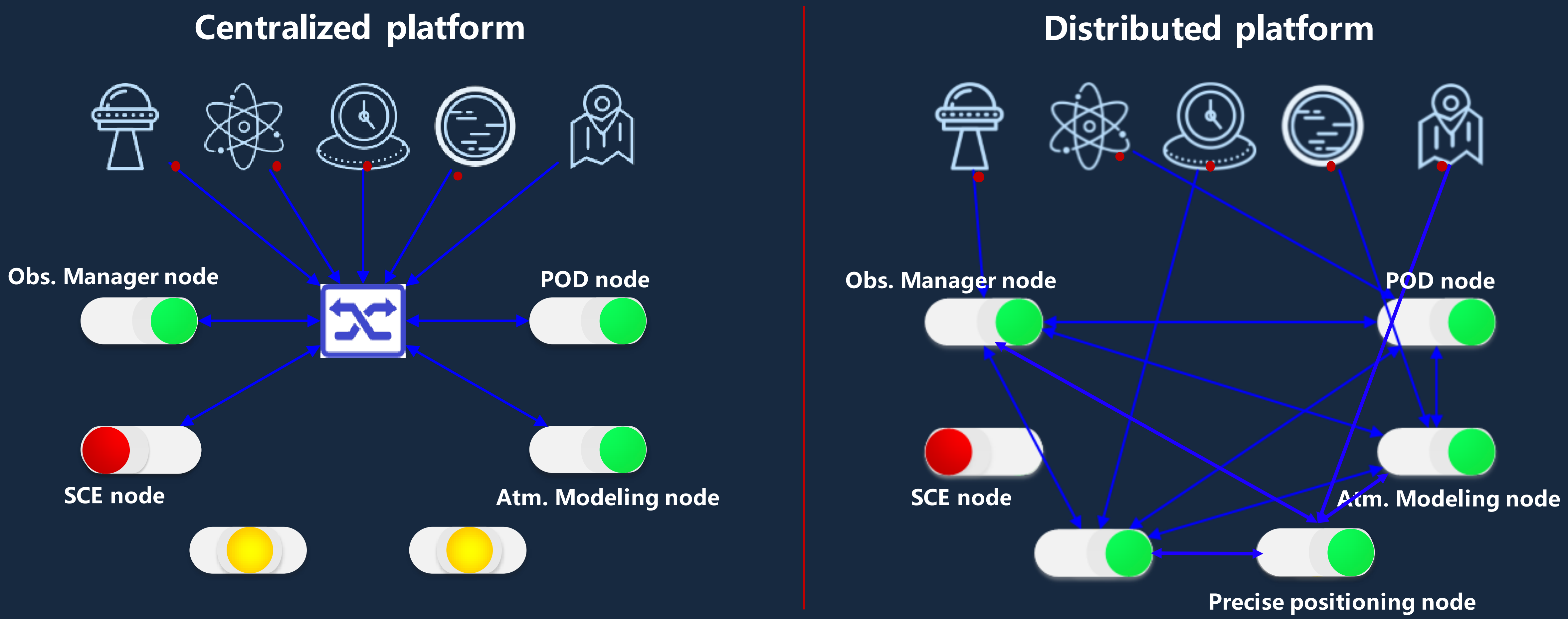
Challenge: RT GNSS solution with increasing Obs.

Key Points	
	High precision satellite orbit and clock products is a prerequisite of real-time PNT
	Product service reliability is the base of GNSS real-time applications
	Dara processing efficiency is the key of huge GNSS network solutions





FUSING: FUSing IN Gnss (复兴)



High reliability

Deploy unified processing mirror on different nodes to realize the task migration of fault node

High scalability

Use collaborative management of calculation, storage node and task to realize intelligent task scheduling

High concurrency

Design decentralization system architecture to realize the task balancing load

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Features of FUSING

- Undifferenced and uncombined observation model

- Satellites oscillator noise model for GPS, GLONASS, BDS and Galileo

  Shi C., et al. Multi-GNSS satellite clock estimation constrained with oscillator noise model in the existence of data discontinuity. Journal of Geodesy

- BDS related code bias and inter-frequency clock bias modeling

  Gong X., et al. Evaluation and calibration of BeiDou receiver-related pseudorange biases. GPS Solutions

  Lou Y., et al. Assessment of code bias variations of BDS triple-frequency signals and their impacts on ambiguity resolution for long baselines. *GPS Solutions*

  Poster 06-05
  Gong X., et al.

- Efficient GNSS network solution based on square root information filter

  Gong X., et al. An efficient solution of real-time data processing for multi-GNSS network. Journal of Geodesy

- Real-time filter solution for orbit, clock, atmosphere, etc.

UD UC Observation model based on DESIGN

Undifferenced and uncombined observation model

$$\begin{cases} P_f^s = \rho^s + t^s - t_r + T^s + 40.2/f^2 \cdot I^s + b_{r,f}^s + \varepsilon_P \\ \Phi_f^s = \rho^s + t^s - t_r + T^s + 40.2/f^2 \cdot I^s - \lambda_f \cdot N_{r,f}^s + \varepsilon_\Phi \end{cases}$$

DESIGN: **DE**terministic plus **S**tochastic **I**onosphere model for **GN**ss

$$I^s = a_0(t) + a_1(t)dL + a_2(t)dL^2 + a_3(t)dB + a_4(t)dB^2 + r(t)$$

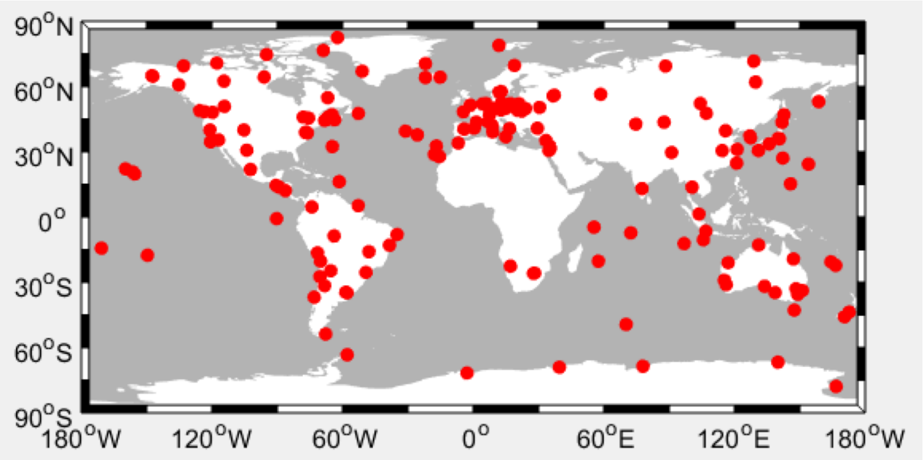
Deterministic part: non-stationary large scale component, the temporal behavior is studied with Fourier transform

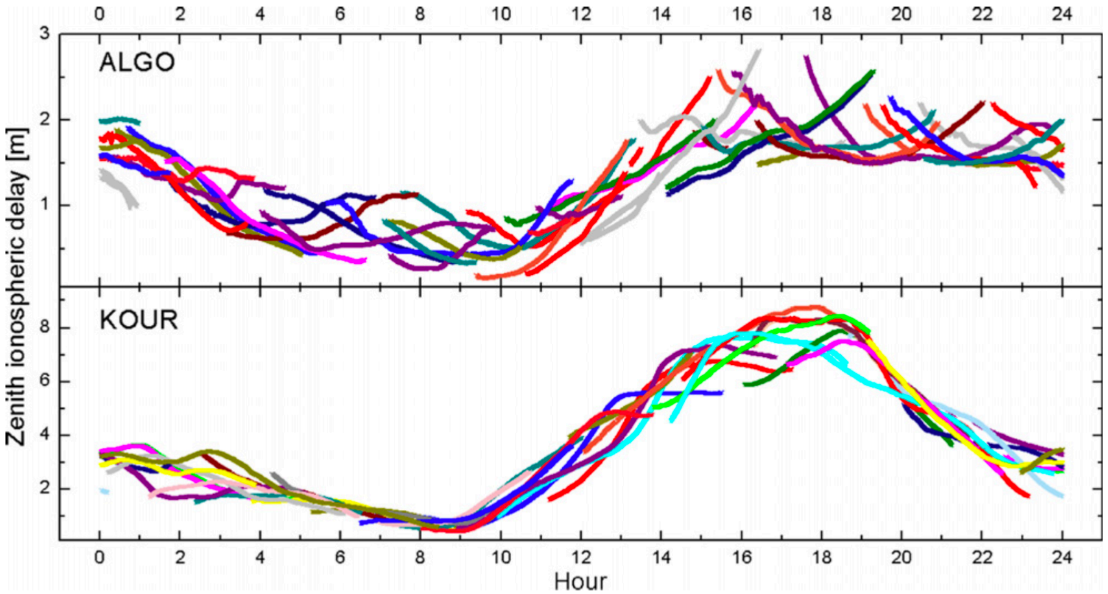
Stochastic part: stationary small-scale variation, the temporal behavior is studied with Variogram

This algorithm is served as the most basic model in Fusing, e.g, PPP, ionosphere / troposphere delay estimation, BIAS estimation. It is also expected to be applied in precise orbit determination (POD) as well as satellite clock estimation (SCE).

DESIGN-Statistic study of the ionosphere delay

Item	Value	
Stations	~150	
Period	Ionosphere quite	DOY 001-365, 2010
	Ionosphere active	DOY 001-365, 2014
Interval	30 second	

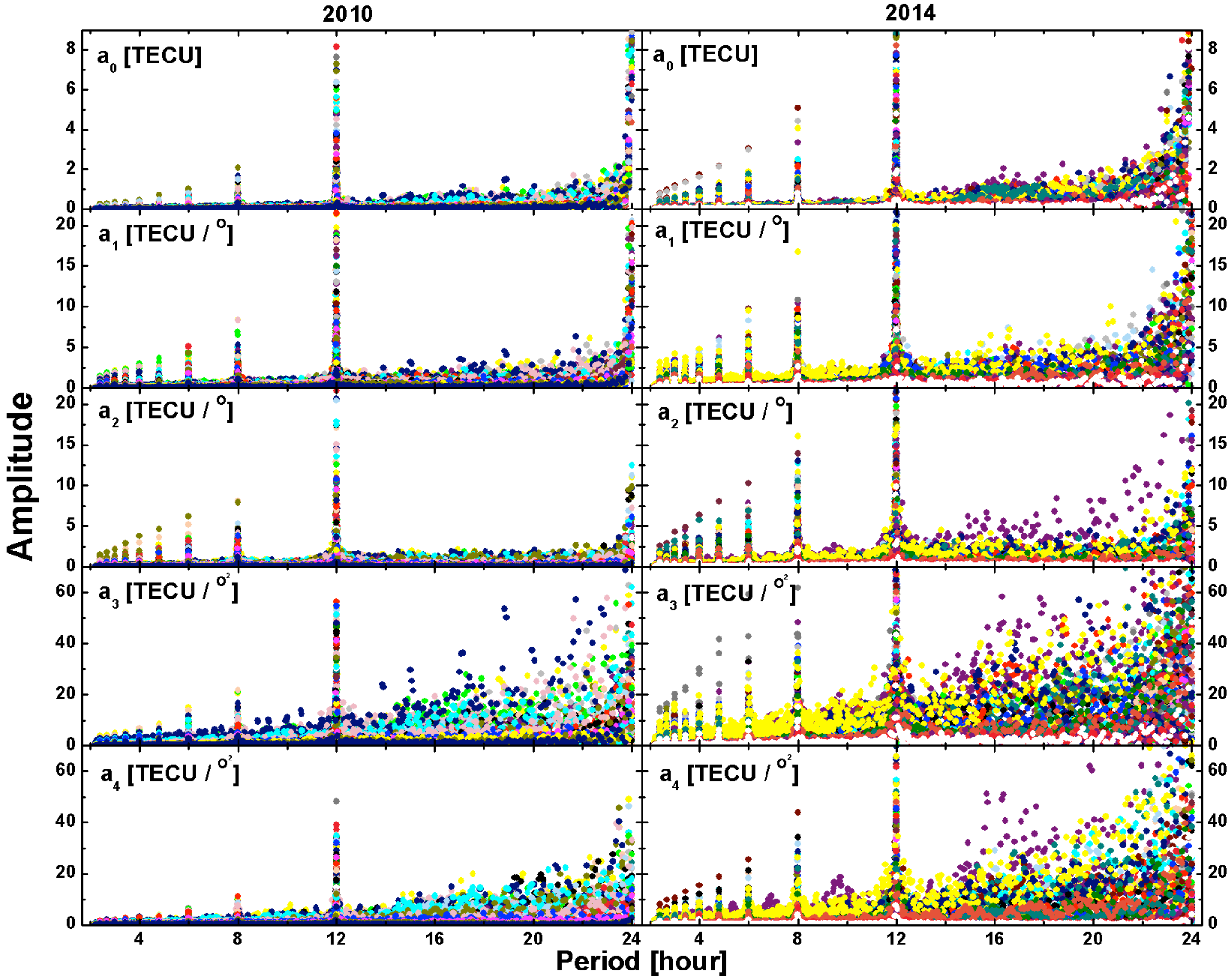




Zenith ionospheric delay which is used as samples for the statistic analysis in the following study. e.g., ALGO (top) and KOUR (bottom) on the DOY 091 2010

Deterministic Part of DESIGN: Fourier transform

$$I^s = a_0(t) + a_1(t)dL + a_2(t)dL^2 + a_3(t)dB + a_4(t)dB^2 + r(t)$$



Power spectrum of different frequency components for a_i based on the Fast Fourier Transform with over 150 stations denoted in different colors for 2010 (left) and 2014 (right)

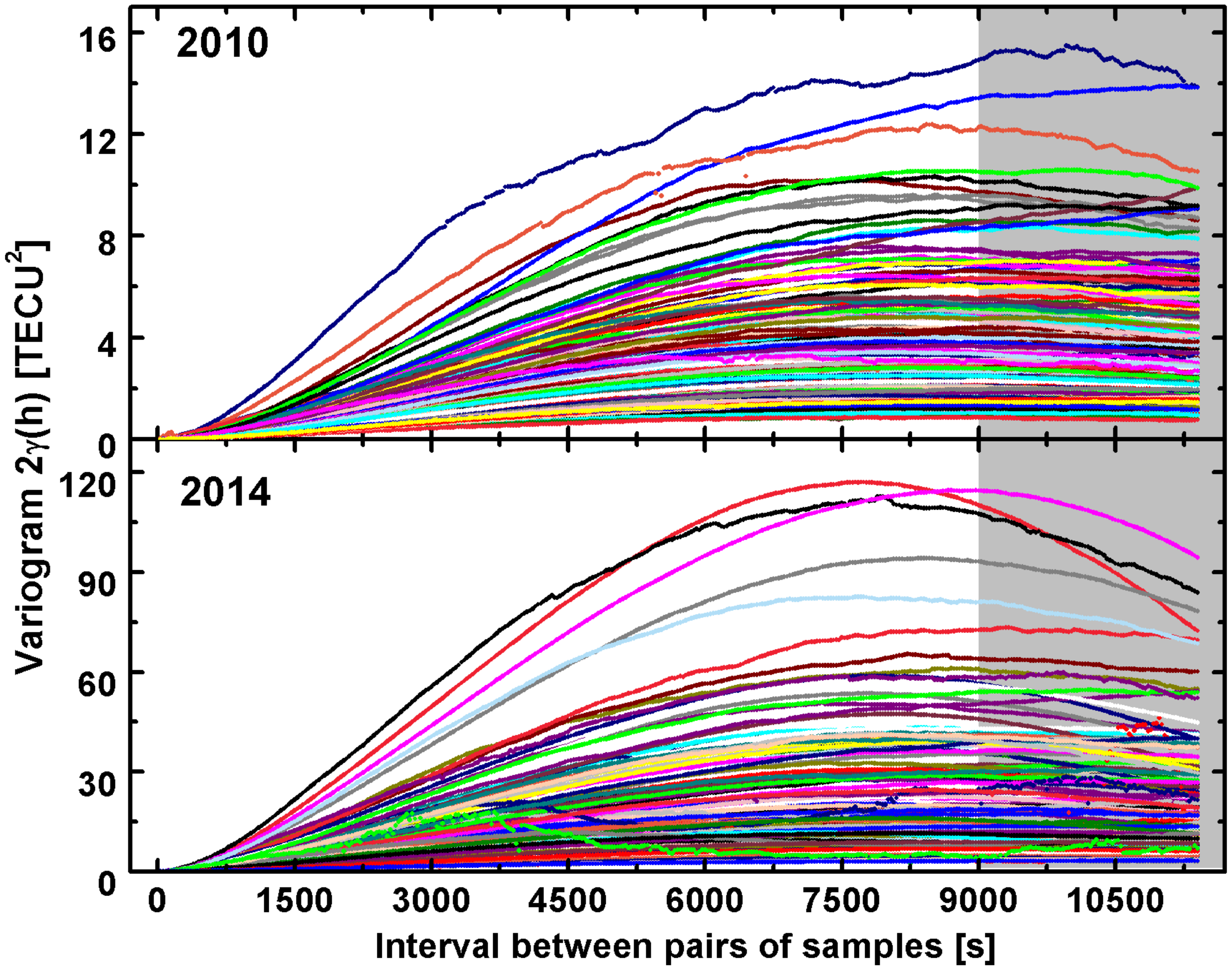
- ☐ Identical frequency (fixed)
- ☐ Different amplitude (estimated)

$$a_i(t) = \alpha_0 + \sum_{j=1}^{3}\left(\beta_j \cdot sin(2\pi t f_j) + \gamma_j \cdot cos(2\pi t f_j)\right)$$

Stochastic Part of DESIGN: Variogram

$2\gamma(\boldsymbol{r}_i, \boldsymbol{r}_j) = var(\boldsymbol{r}_i - \boldsymbol{r}_j)$

$$I^s = a_0(t) + a_1(t)dL + a_2(t)dL^2 + a_3(t)dB + a_4(t)dB^2 + r(t)$$



For each pair of the ionosphere delay residual (r_i, r_j) with different interval h, the variogram is derived

The spherical model is selected for the parametric semi-variogram $\gamma(r_i, r_j)$

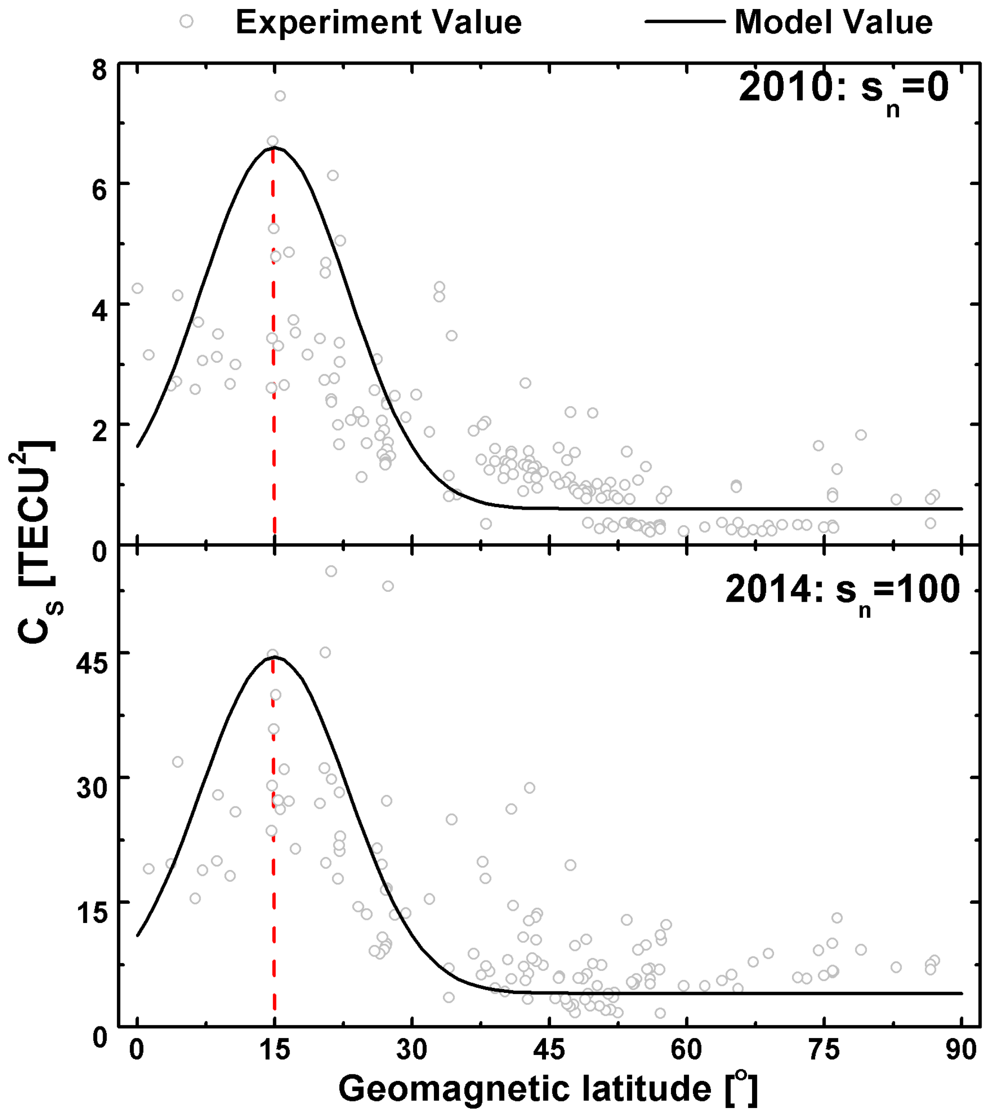
$$\gamma(h) = \begin{cases} c_s((3/2)(h/a_s) - (1/2)(h/a_s)^3) & , 0 \le h < a_s \\ c_s & , h \ge a_s \end{cases}$$

a_s: Maximum correlation distance, which is about 9000 s

c_s: Corresponding to the constant when the residuals r become uncorrelated

c_s: How to model the variance of c_s?

Variation of C_s



Varing of c_s against the geomagnetic latitude for 2010 (upper) and 2014 (bottom). The experiment value for different stations is denoted in gray cycle, while the model value is denoted in black line

c_s: Geomagnetic latitude and ionosphere activity status related

Model B variation with Gaussian function

$$c_s = c_{s,min} + c_{s,max} \cdot e^{-||B|-15|^2/128}$$

Model ionosphere activity with Epstein function

$$\begin{cases} c_{s,min} = 0.5 + (7.5 - 0.5) \cdot (1/(1 + e^{(s_n - 100)/20})) \\ c_{s,max} = 5.0 + (75.0 - 5.0) \cdot (1/(1 + e^{(s_n - 100)/20})) \end{cases}$$

s_n: Sun spot number

The above functions can describe the variance of c_s pretty well

Raw observable model with DESIGN

Poster 06-03
Wang Y., et al.

Undifferenced and uncombined observation model with ionosphere delay I^s constrained by DESIGN

$$\begin{cases} P_f^s = \rho^s + t^s - t_r + T^s + 40.2/f^2 \cdot I^s + \varepsilon_P \\ \Phi_f^s = \rho^s + t^s - t_r + T^s + 40.2/f^2 \cdot I^s - \lambda_f + \varepsilon_\Phi \end{cases}$$

$$I^s = a_0(t) + a_1(t)dL + a_2(t)dL^2 + a_3(t)dB + a_4(t)dB^2 + r(t)$$

a_i expressed as Fourier series with frequency component $f_i \in \left(\frac{1}{24} \quad \frac{1}{12} \quad \frac{1}{8}\right)$

$$a_i(t) = \alpha_0 + \sum_{j=1}^{3}\left(\beta_j \cdot \sin(2\pi t f_j) + \gamma_j \cdot \cos(2\pi t f_j)\right)$$

r estimated as random walk with constrains dependent on geomagnetic latitude B and sun spot number s_n

$$\gamma(h) = \begin{cases} c_s\left((3/2)(h/9000) - (1/2)(h/9000)^3\right), 0 \le h < 9000 \\ c_s \qquad , h \ge 9000 \end{cases}$$

$$c_s = c_{s,min} + c_{s,max} \cdot e^{-||B|-15|^2/128}$$

$$\begin{cases} c_{s,min} = 0.5 + (7.5 - 0.5) \cdot (1/(1 + e^{(s_n - 100)/20})) \\ c_{s,max} = 5.0 + (75.0 - 5.0) \cdot (1/(1 + e^{(s_n - 100)/20})) \end{cases}$$

Shi, C., Gu, S., Lou, Y., & Ge, M. (2012). An improved approach to model ionospheric delays for single-frequency Precise Point Positioning. Advances in Space Research
Lou, Y., Zheng, F., Gu, S., Wang, C., Guo, H., & Feng, Y. (2015). Multi-GNSS precise point positioning with raw single-frequency and dual-frequency measurement models. GPS Solutions
Zhao, Q., Wang, Y., Gu, S., Zheng, F., Shi, C., Ge, M., Schuh, H. (2018). Refining ionospheric delay modeling for undifferenced and uncombined GNSS data processing. Journal of Geodesy

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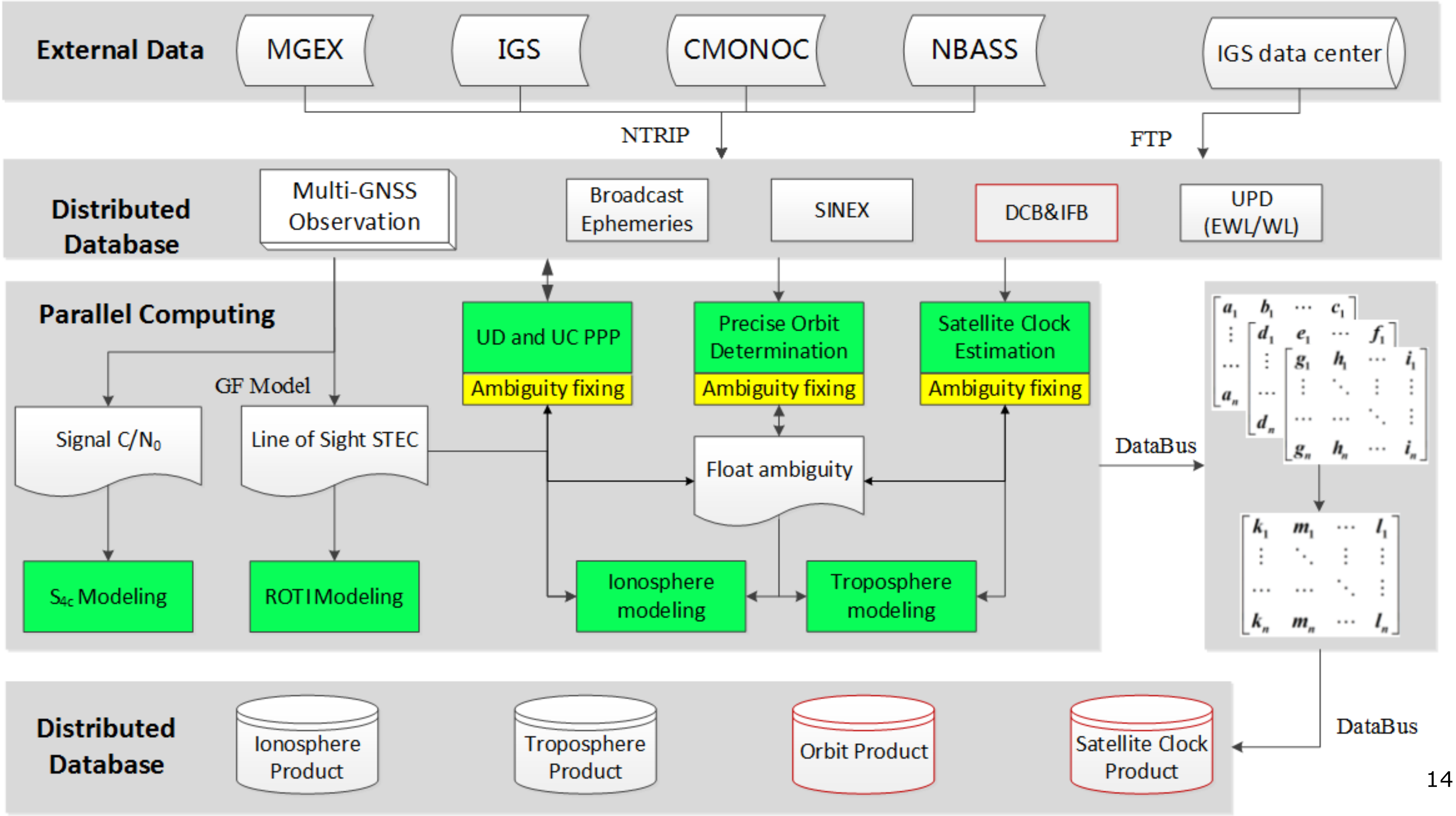
Architecture of FUSING



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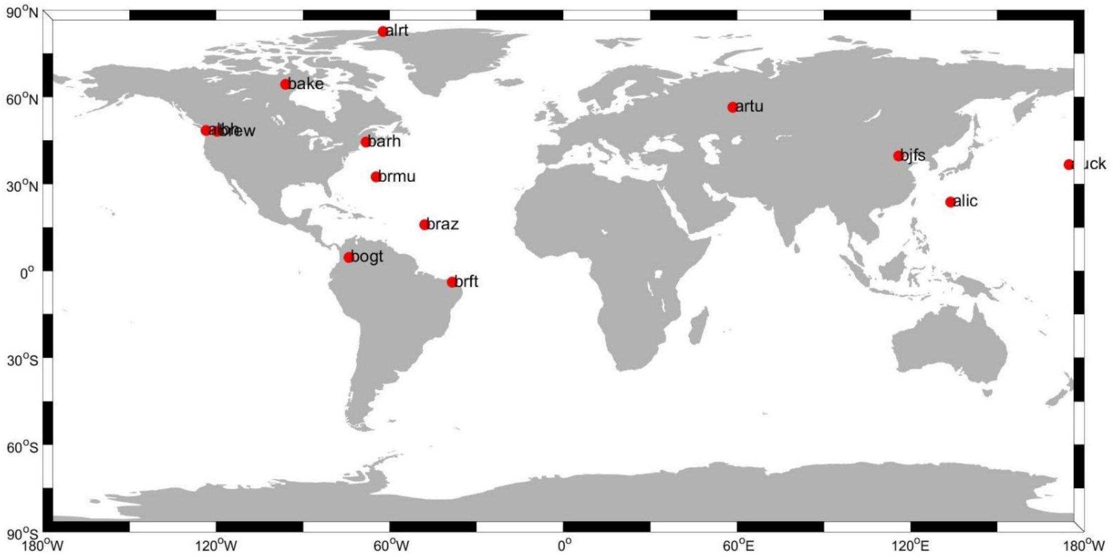
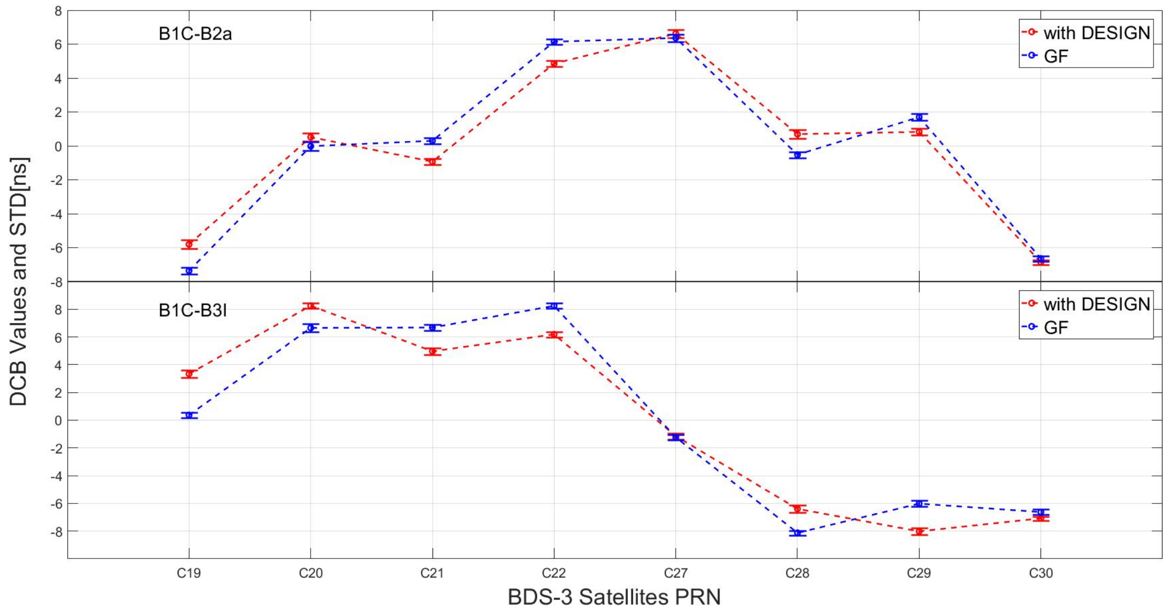
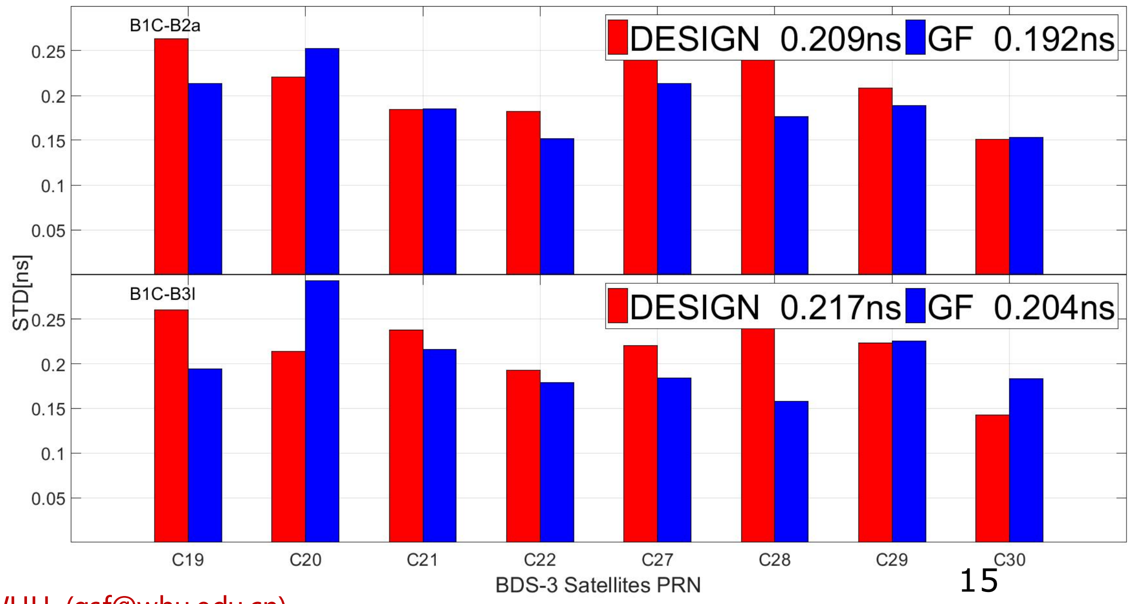
BDS-3 DCB estimation

Item	Detail
Date	DOY 133-148, 2018
Signals	B1C(1575.42MHz), B2a(1176.45MHz), B3I(1268.52MHz)
Orbit & Clock	Fixed with WHU final orbit products
Coordinates	Fixed
Statistic	Daily repeatability of estimated DCB values

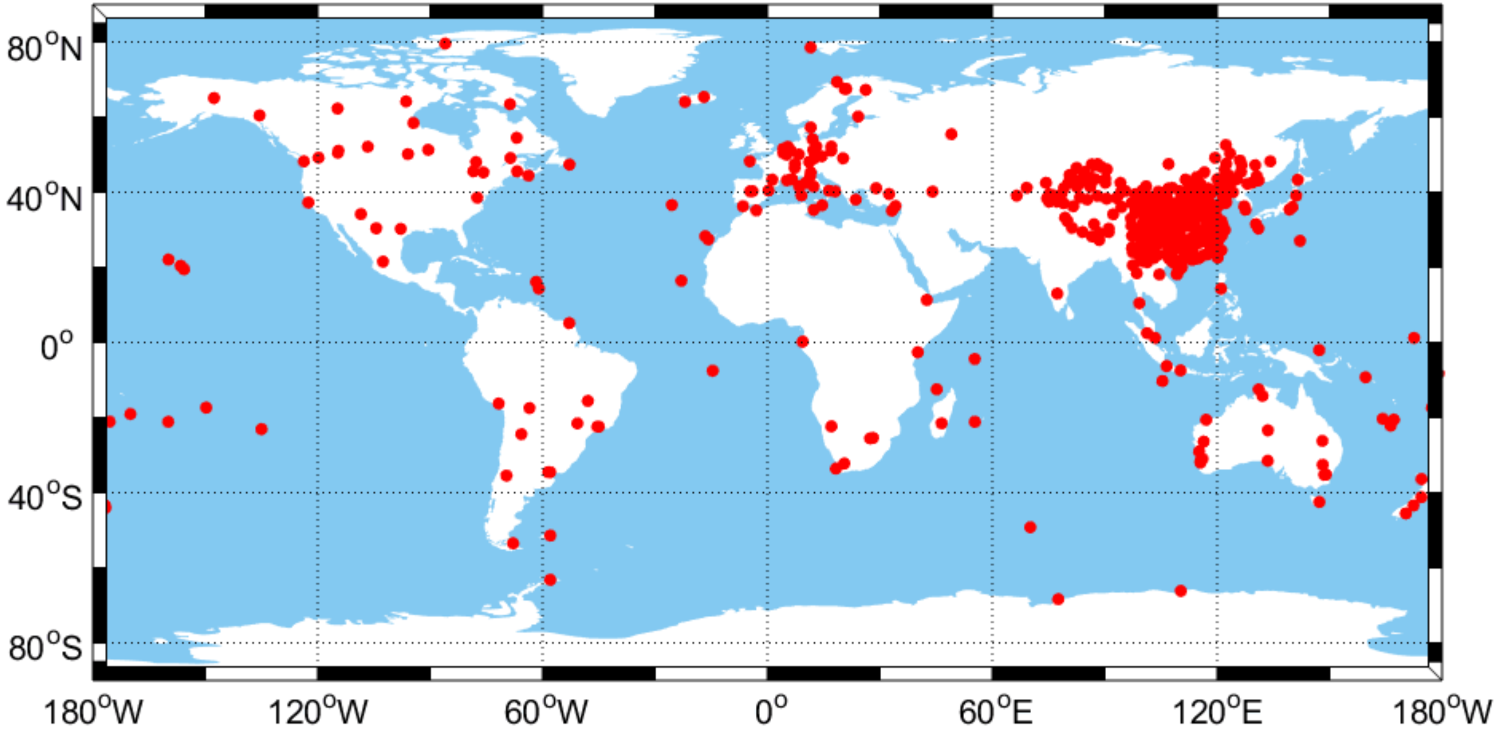




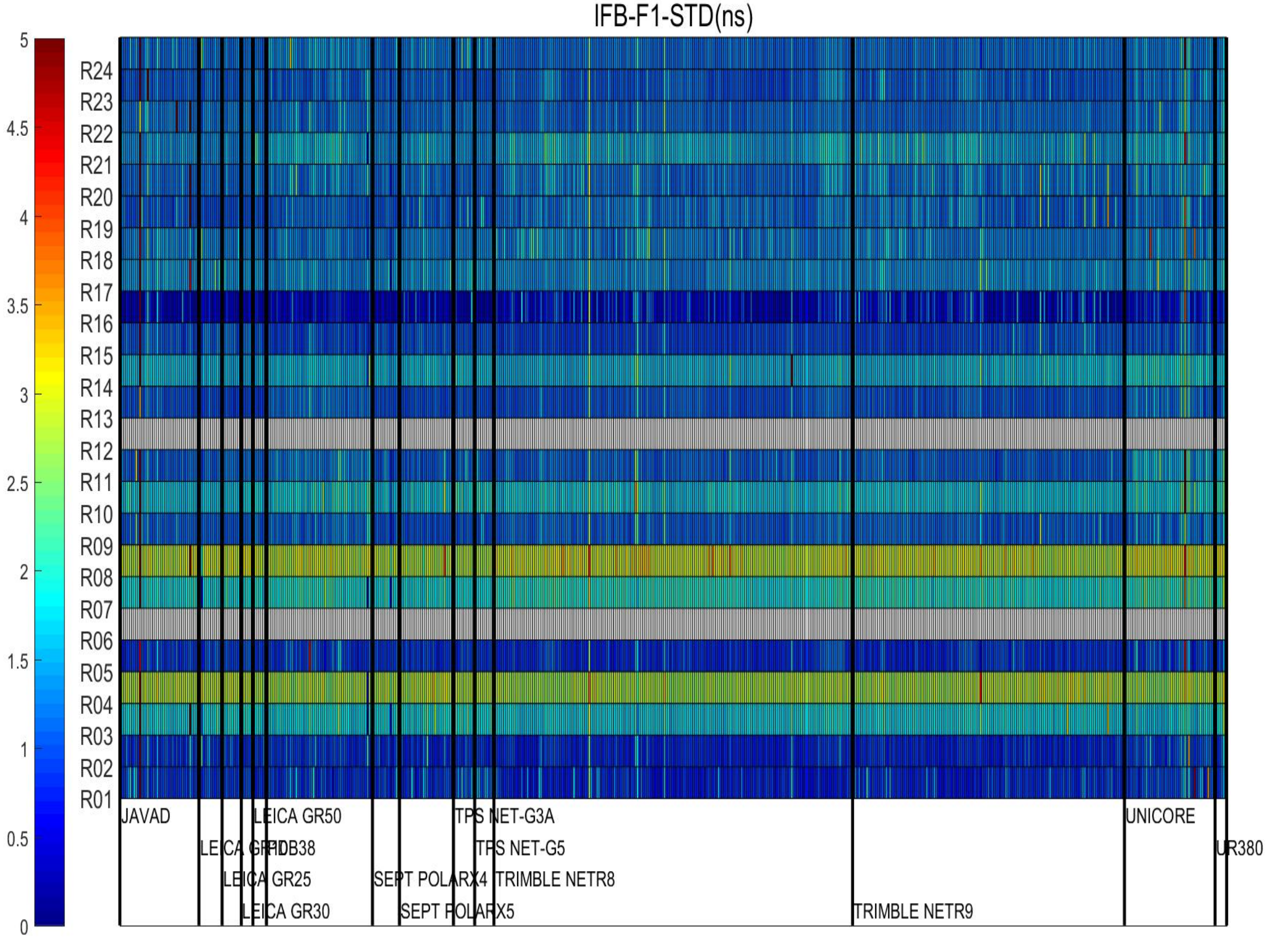


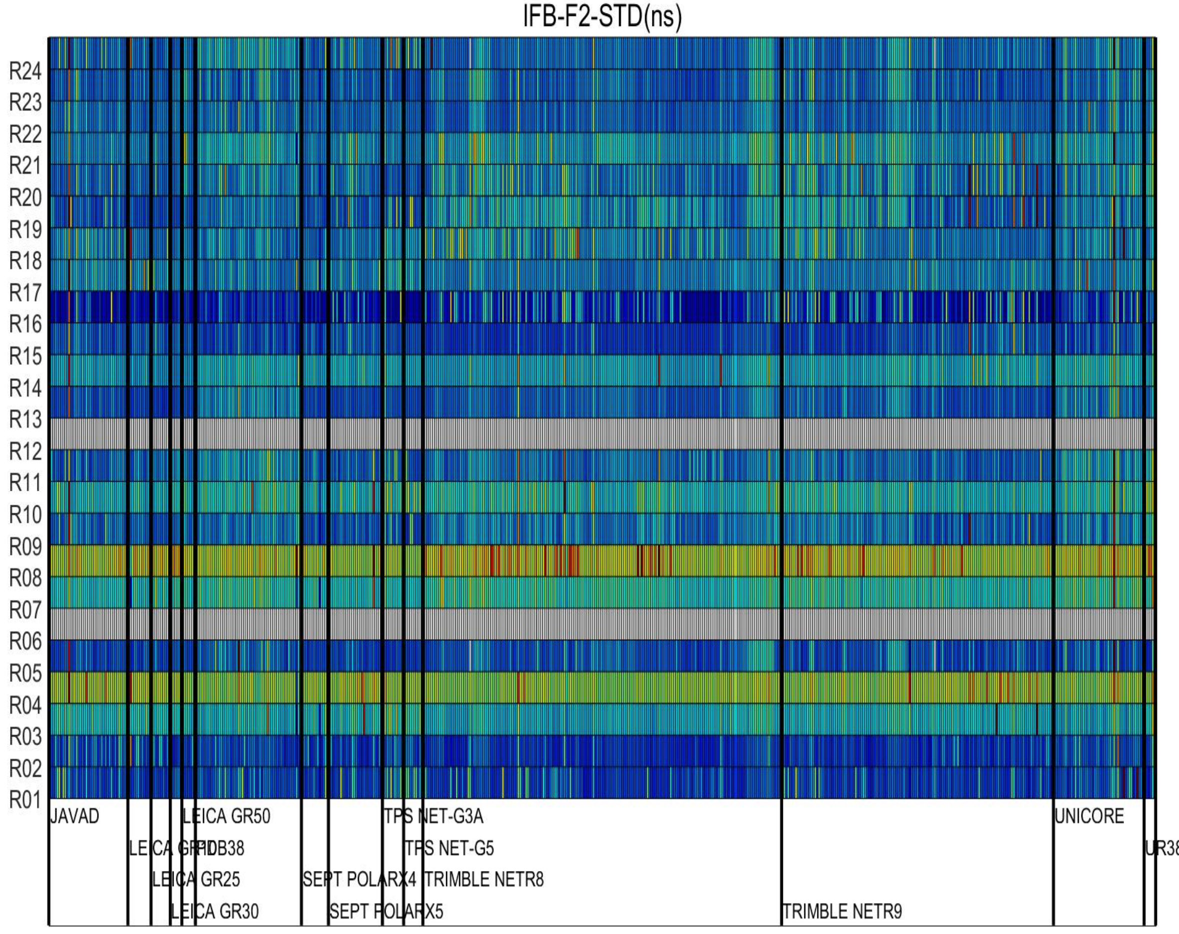
GLONASS IFB estimation: Data and strategy

Items	Details
Period	DOY 182~212, 2018
Interval	30 s
Station	MGEX: 230 CMONC: 249 NBASS: 114



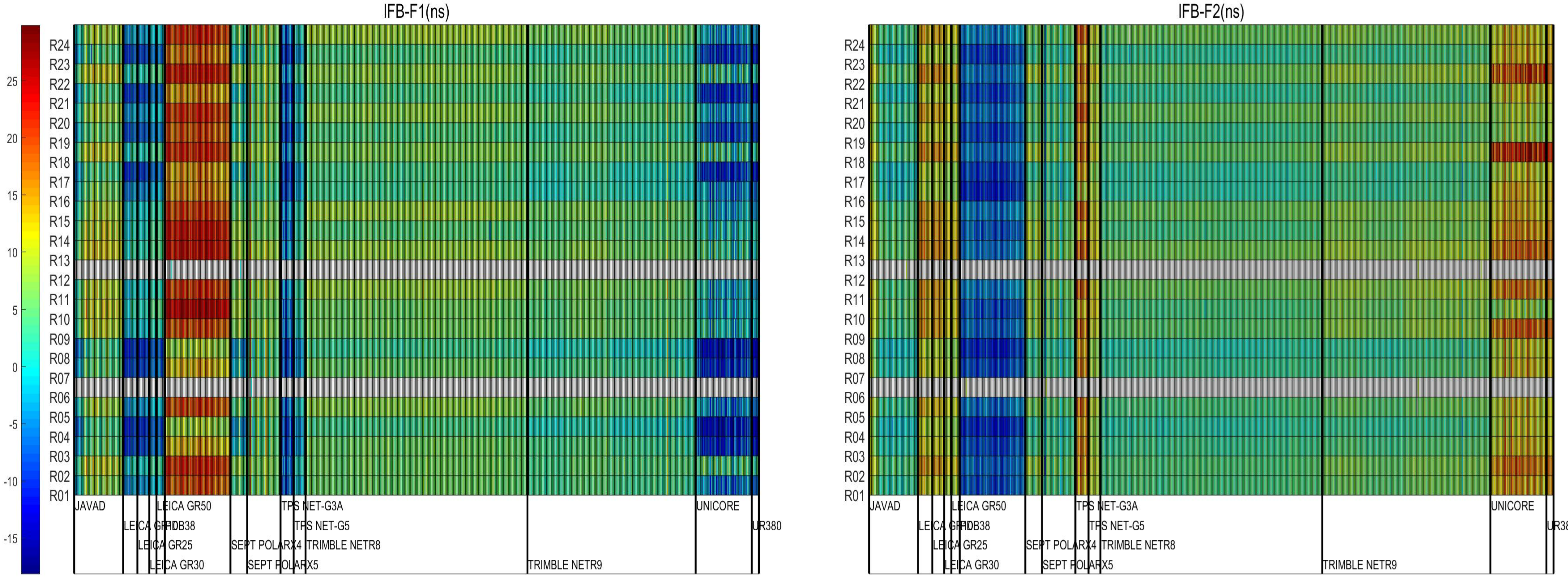
GLONASS IFB estimation: Efficiency and accuracy



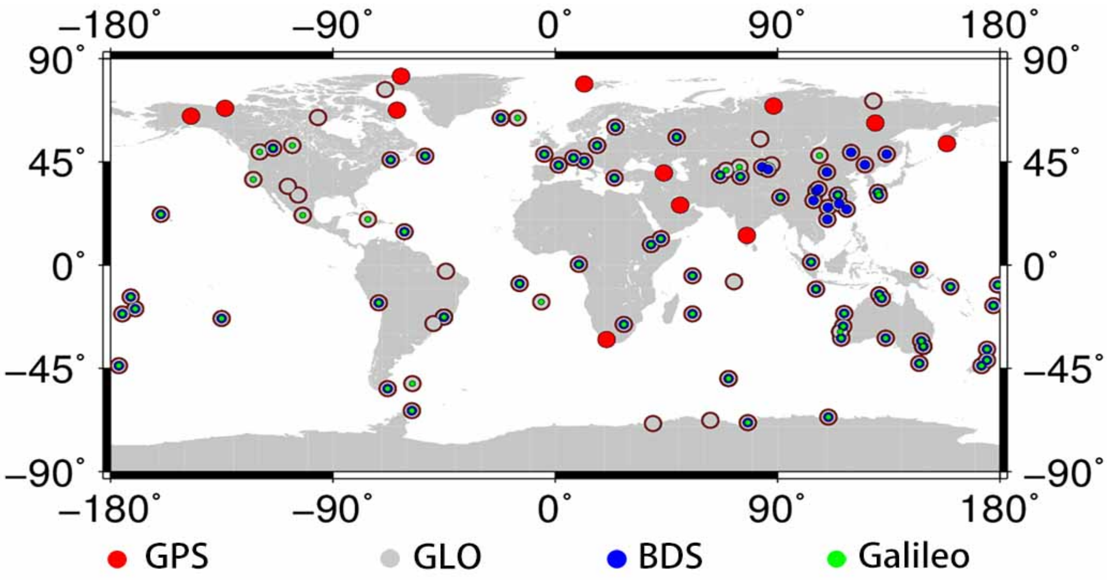


- STD-MEAN: 1.48ns
- STD-MEAN: 1.53ns

GLONASS IFB estimation: Efficiency and accuracy



Orbit and clock estimation: Data and strategy



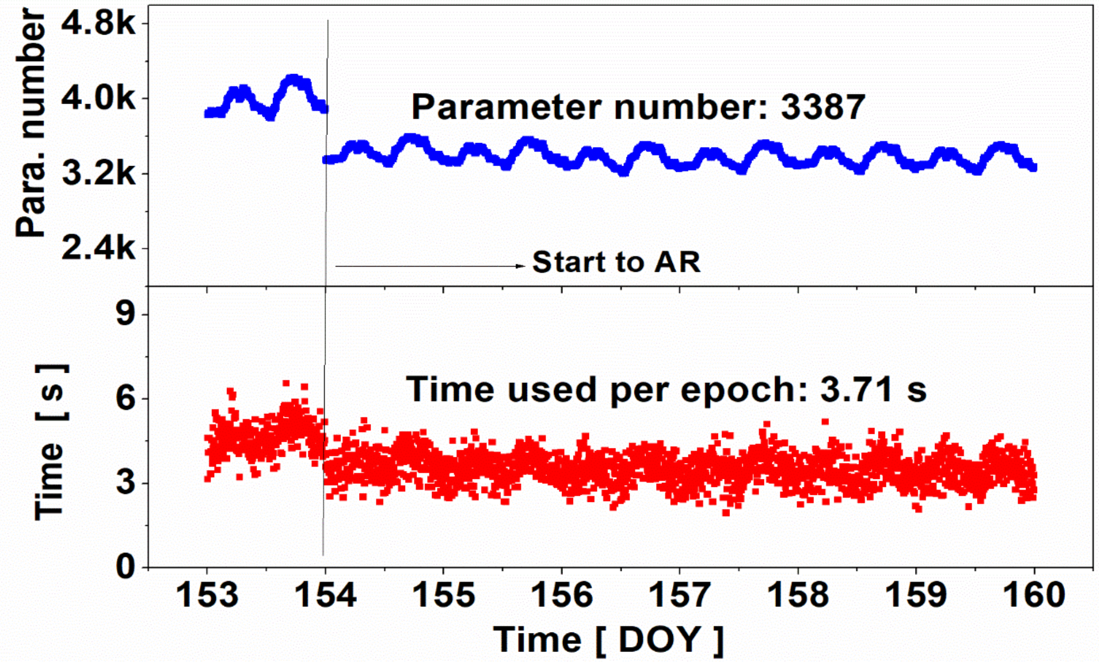
Items	Details	
Mode	SRIF	
Station number	GPS: 113 BDS: 74	GLONASS: 101 Galileo: 73
Satellite number	GPS: 32 BDS: 14	GLONASS: 24 Galileo: 13

Items	Details
Interval	30 s
Weighting	P = 1， elev >= 10° P = 5.75877×sin(elev)， elev<10°
Cut-off elevation	7°
PCO	igs14.atx
Attitude model	Kouba 2009
Troposphere	GPT2
Station Coor.	Fixed from igs2008.snx
Tide	Solid Earth Tide / Ocean Tide / Pole Tide
Relativity	IERS 2010
Earth Gravity	EGM96（12×12）
N body Gravity	JPL DE405
Earth radiation	GPS and GLONASS（Rodriguez-Solano 2012） BDS and Galileo ignored
Integration	Runge-Kutta / Adams
Observations	GPS： L1/L2 GLONASS：G1/G2 BDS：B1/B2 Galileo：E1/E5a

Orbit and clock estimation: Efficiency and accuracy

Item	Station	GNSS	Rcv. clock	Sat. Orbit	Sat. Clock	ERP	Troposphere	Ambiguity	Total
value	~113	G/R/C/E	~452	913	~83	6	~113	~2373	**~3940**

- Linux Server
- Intel core i5 CPU with 3.50 GHz and16 cores
- Memory size is 128 GB
- Level-1/2/3 caches are 32/256/15360 kb



- ~3.71s / epoch

System	Orbit (RMS, cm) Radial	Cross	Along	3D	Clock (ns) STD
GPS	2.2	2.8	4.0	5.5	0.030
BDS-GEO	31.5	275.0	310.8	416.2	0.042
BDS-IGSO	7.4	8.3	12.6	17.9	0.032
BDS-MEO	5.2	4.4	12.5	14.1	0.089
Galileo	5.7	6.8	12.0	14.9	0.082
GLONASS	3.8	7.1	10.7	13.4	0.122

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Conclusions

- FUSING (复兴): a new distributed GNSS huge network data processing platform is designed and developed with c++
- Undifferenced and uncombined observation model with ionosphere delay constrained by DESIGN is served as the most basic model in Fusing [Yintong Wang]
- BDS-3 satellite DCD estimation with a precision of ~0.2 ns based 14 IGMAS stations [Yintong Wang]
- GLONASS IFB estimation with a precision of 1.5 ns for each frequency with over 550 stations of IGS, MGEX, CMONOC and NBASS [Zheng Zhang]
- Efficient SRIF for combined satellite orbit and clock solution with about 113 stations for G/R/C/E: 3.71 s/epoch [Xinhao Yang/Xiaolei Dai/Yun Qin/Yaquan Peng]
- Ionosphere modeling with a precision of ~1 TECU over China in 2017 [Zheng Zhang/Xueyuan Jin/Xiaomin Luo]

Thank you for your attention

Acknowledgements: We thank YOYOSYS (http://www.yoyosys.com/) for their distribution environment, and also thank IGS, MGEX, CMONOC, iGMAS and NBASS for providing multi-frequency multi-GNSS observations.