Precise Point Positioning and Its Application in Geoscience

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25 July, 2018

Outlines

1. Review of PPP development

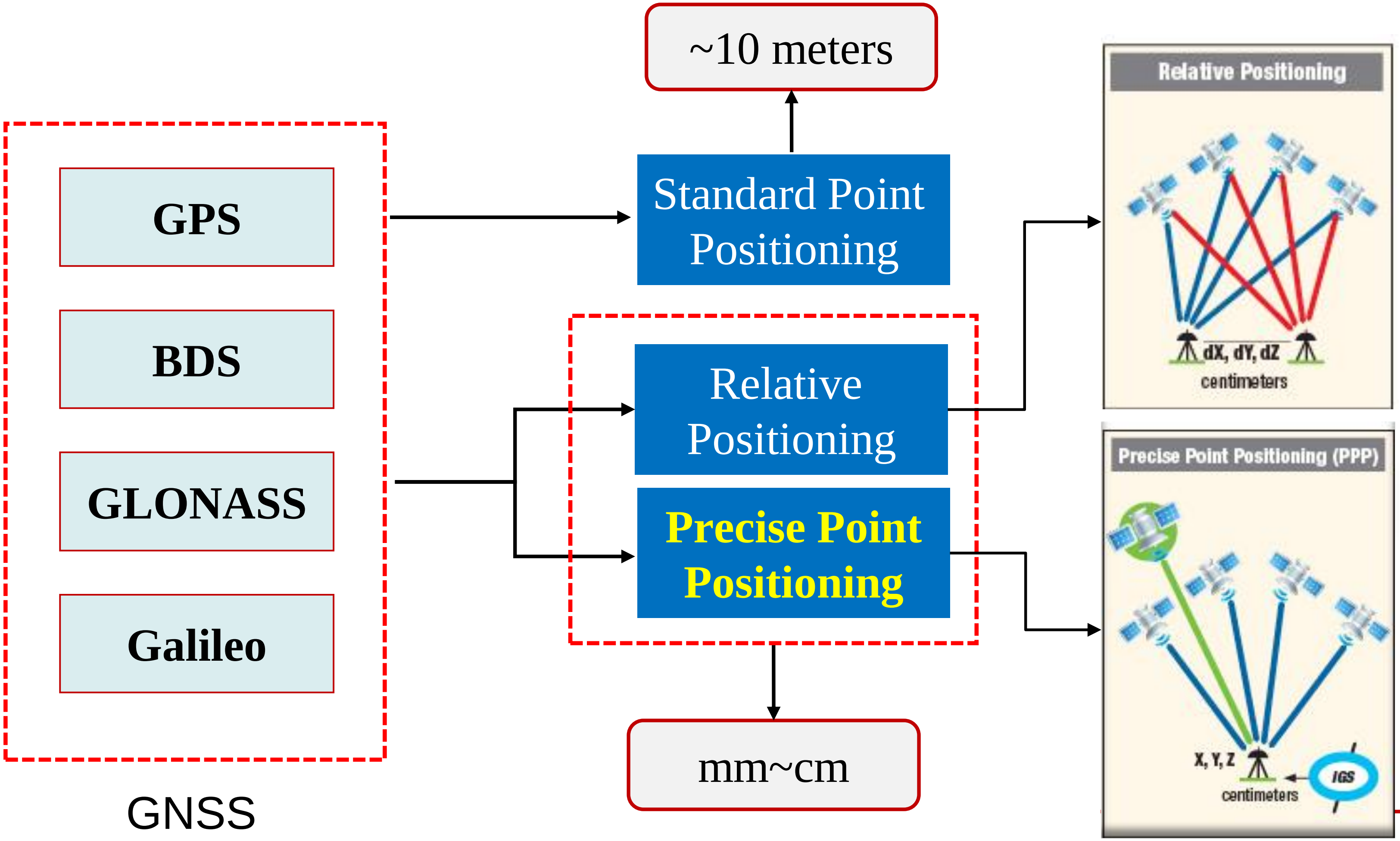
2. Benefits of Multi-GNSS for PPP

3. Challenges of Multi-GNSS for PPP

4. Applications in Geoscience

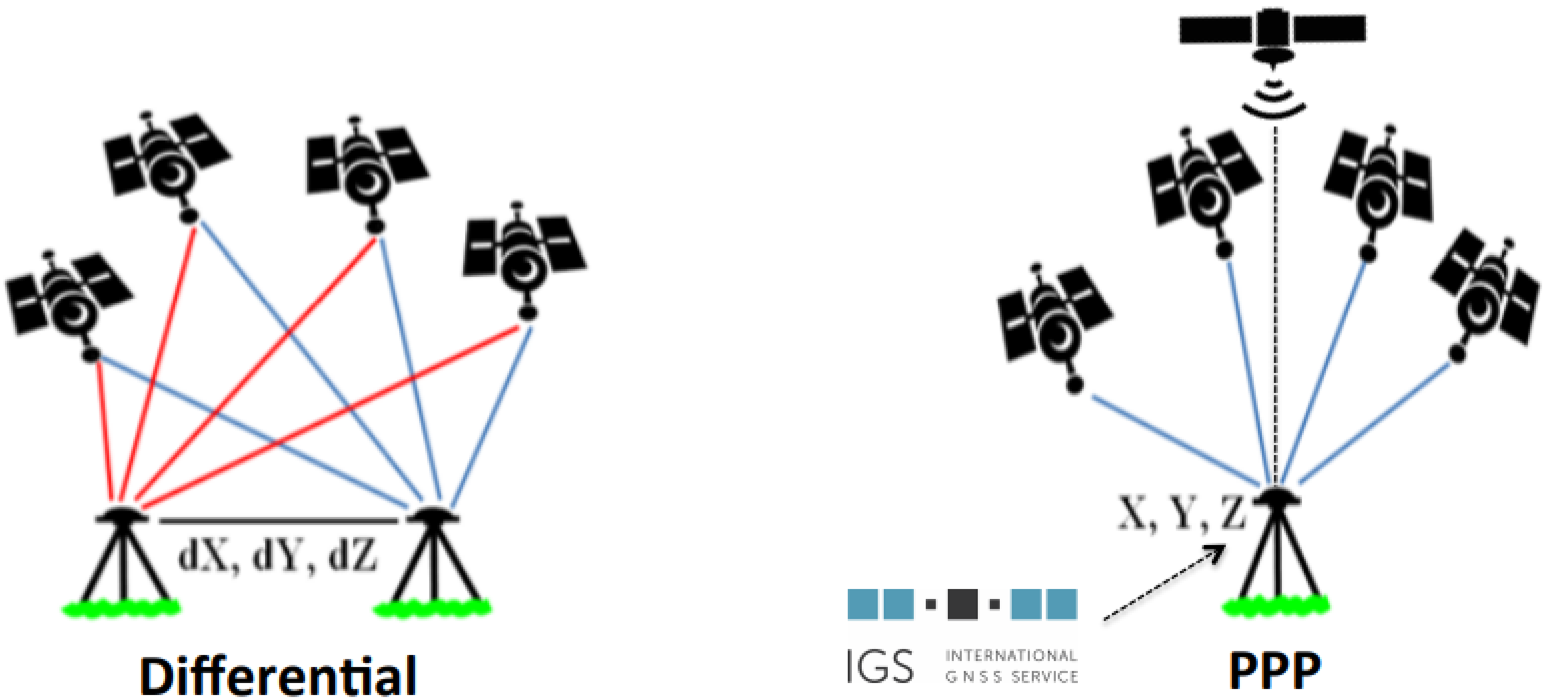
1. Review of PPP development

GNSS Positioning technologies



1. Review of PPP development

☐ How does PPP work ?



PPP uses state space representation (SSR) correction products such as **precise satellite orbits**, **clocks** and **signal biases** from either commercial or/and public (e.g., IGS) that are delivered to the user via satellite and/or internet.

1. Review of PPP development

Mathematematic model

$$L_i^k - \rho_i^k - c(\Delta t_i - \Delta t^k) - \alpha_i^k T_i + I_i^k - \lambda B_i^k - \varepsilon = 0$$

$$P_i^k - \rho_i^k - c(\Delta t_i - \Delta t^k) - \alpha_i^k T_i - I_i^k - c(b^k + b_i) - \varepsilon = 0$$

- L_i^k, P_i^k - undifferenced carrier phase and code observations (meters)
- ρ_i^k - geometric distance (satellite-receiver)
- B_i^k - carrier phase bias, where $\lambda B_i^k = \lambda(N_i^k + \delta N_i^k) + c(d^k + d_i)$
- $N_i^k, \delta N_i^k$ - integer carrier phase ambiguity and non-zero initial fractional phase
- $\Delta t_i, \Delta t^k$ - receiver and satellite clock offsets
- T_i - tropospheric total zenith delay
- α_i^k - troposphere mapping function
- I_i^k - slant ionospheric delay
- $b_i, b^k;\ d_i, d^k$ - receiver and satellite code and phase hardware delays
- λ - corresponding carrier wavelength
- c - speed of light
- ε - random error or residual

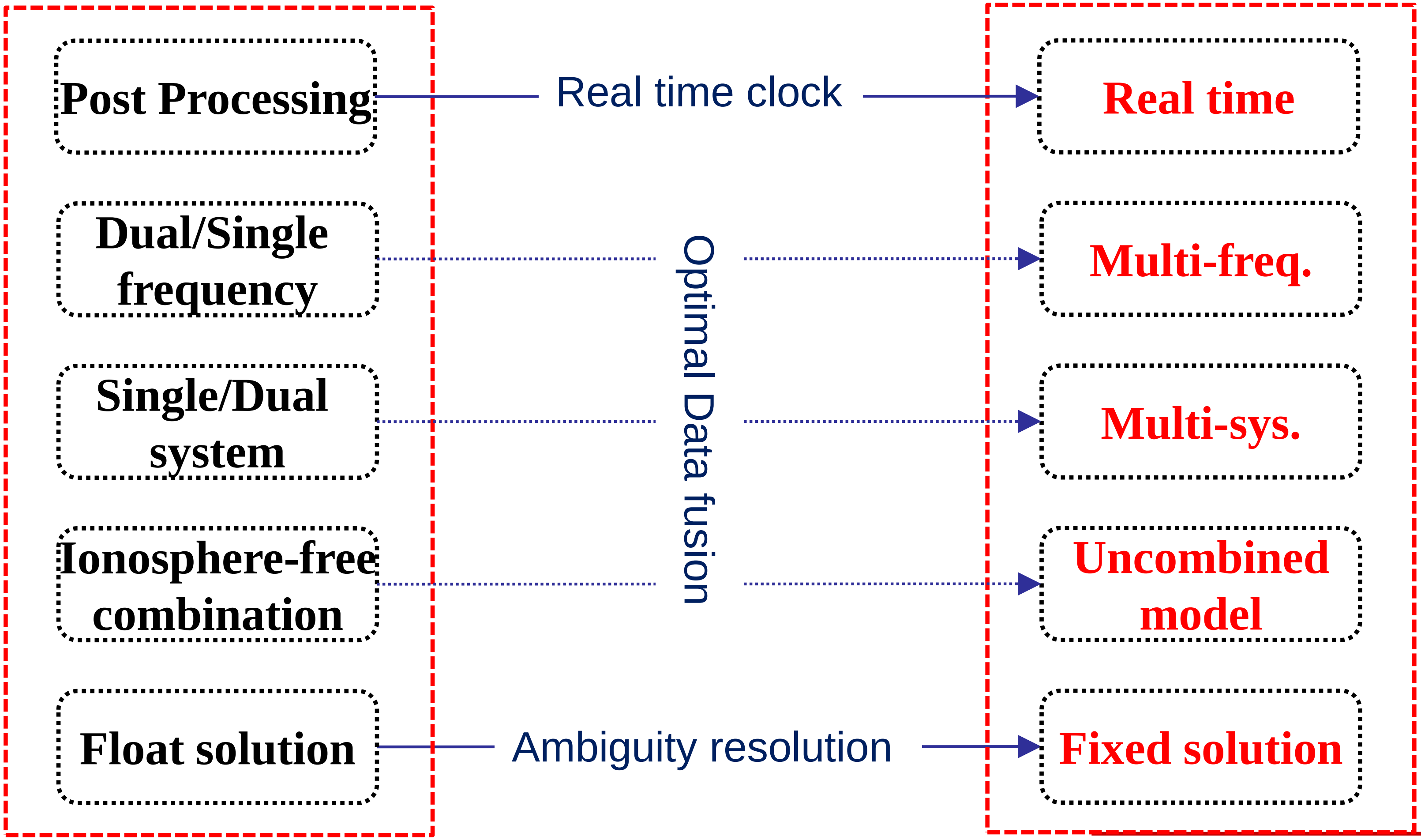
1. Review of PPP development

Benefits and limitations

- ✓ Advantages of PPP w.r.t Double Differencing (DD)
  - Flexibility, higher efficiency, without dedicated reference station
- ✓ Wide range of applications
  - Atmosphere, earthquake monitoring, POD of LEO, etc.
- ✓ Simple model but complicated processing
  - Simple functional model; complicated error elimination and ambiguity resolution
- ✓ PPP is not as mature as DD
  - **Accuracy, initialization time, reliability and stability**

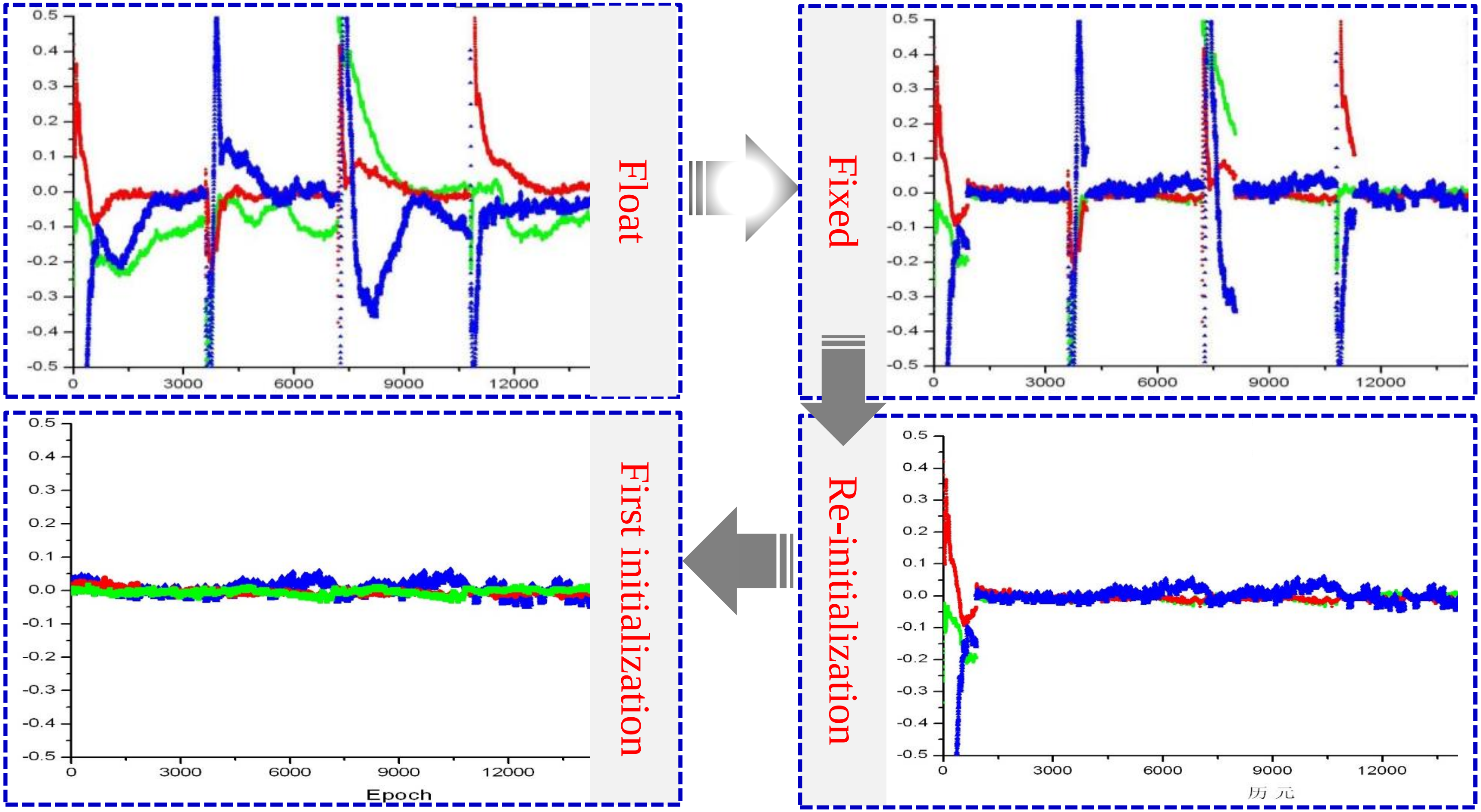
1. Review of PPP development

Development and evaluation of PPP



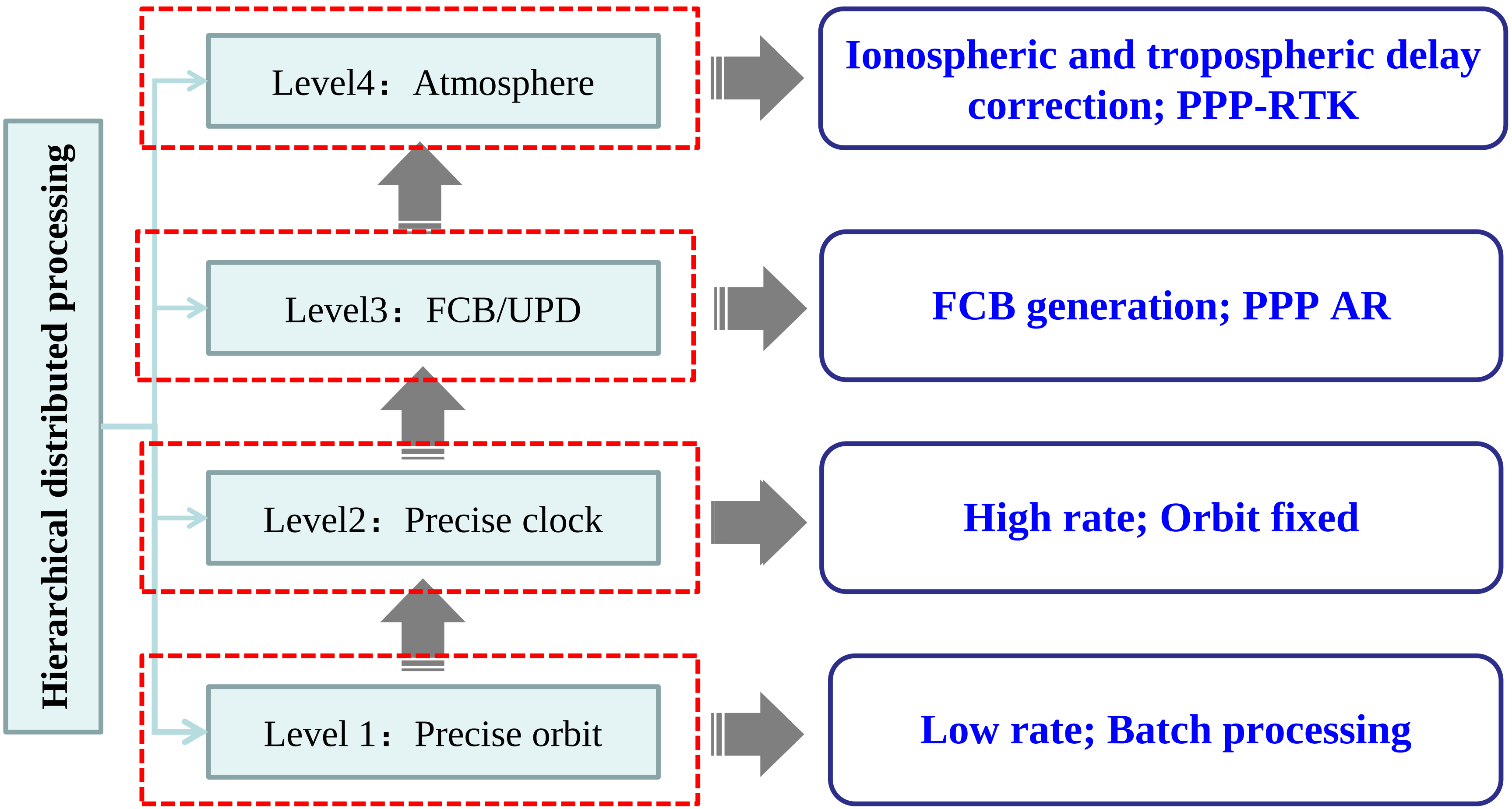
1. Review of PPP development

Development and evaluation of PPP



1. Review of PPP development

Towards PPP-RTK



1. Review of PPP development

Towards PPP-RTK

Method	What is transmitted?	Initialisation time	Accuracy (horiz)
RTK/NRTK	Corrections per satellite and per (virtual) reference station	< 20 s	~ 2 cm
PPP	▪ Orbits ▪ Clocks	> 40 min for float	a few cm
PPP-AR	▪ Orbits ▪ Clocks ▪ Phase biases	~ 30 min	a few cm
PPP-RTK	▪ Clocks ▪ Orbits ▪ Phase biases ▪ **Troposphere** ▪ **Ionosphere**	< 1 min	a few cm

Choy S (2018)

Outlines

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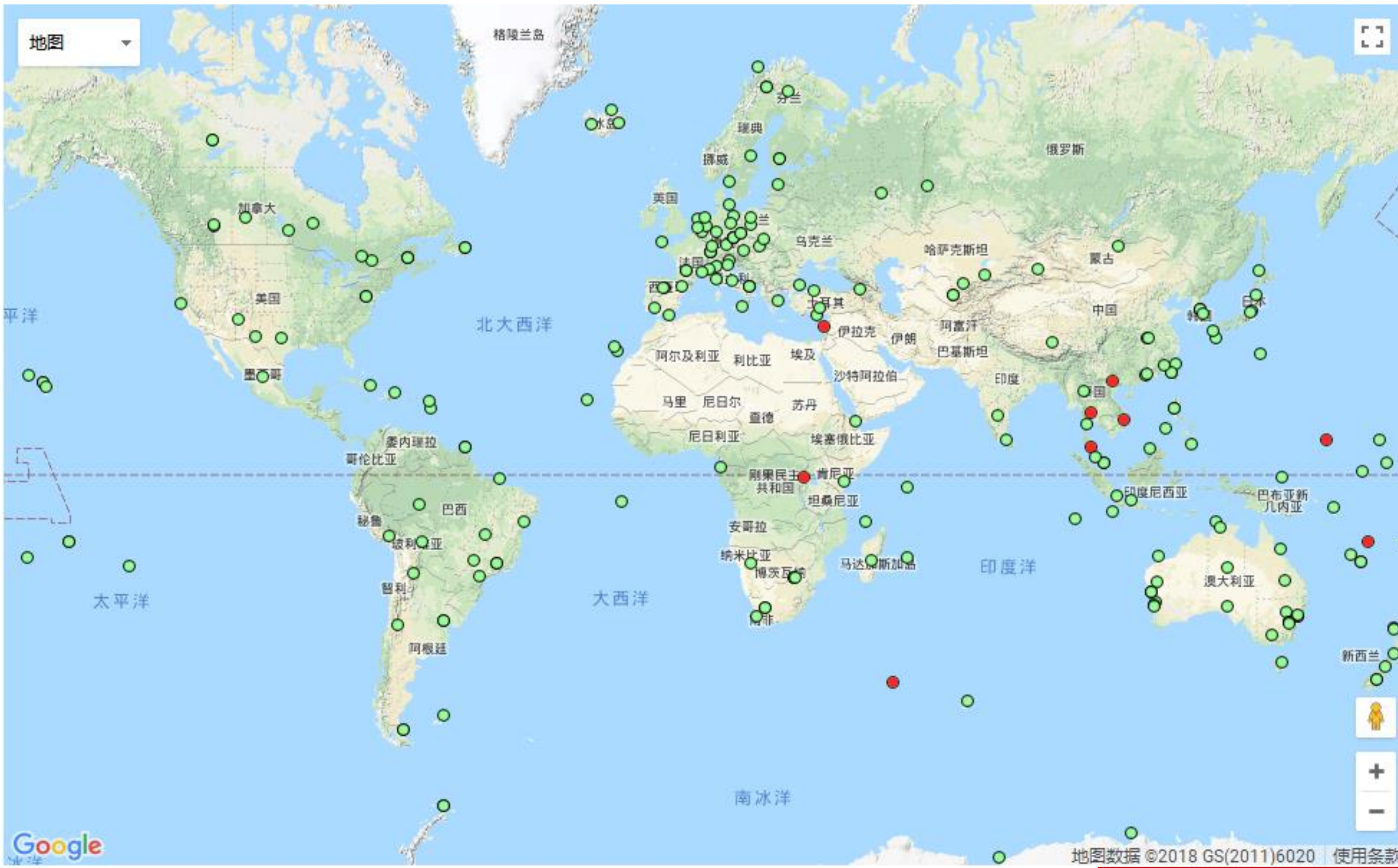
2. Benefits of Multi-GNSS

☐ Status of multi-GNSS

GNSS	Sat. type	Navigation signals	Num. Sat.
GPS	Block IIR-A Block IIR-B Block IIR-M Block IIF	L1 C/A, L1/L2 P(Y) L1 C/A, L1/L2 P(Y) +L2C +L5	8 4 8 12
GLONASS	GLONASS-M GLONASS-K1	L1/L2 C/A+P L1/L2 C/A+P, L3 (CDMA)	23 1 (+1)
BDS	GEO IGSO MEO BDS-3 Experimental BDS-3	B1, B2, B3 B1, B2, B3 B1, B2, B3 B1, B3,B1C, B2a, B2b etc. B1C,B2a,B1,B3	5 6 3 5 8
GALILEO	IOV FOC	E1, E5a/b/a+b E1, E5a/b/a+b	4 18
QZSS	IGSO	L1, L2, L5	4
IRNSS	IGSO GEO	L5, S L5, S	4 3

2. Benefits of Multi-GNSS

☐ IGS multi-GNSS (MGEX) tracking network

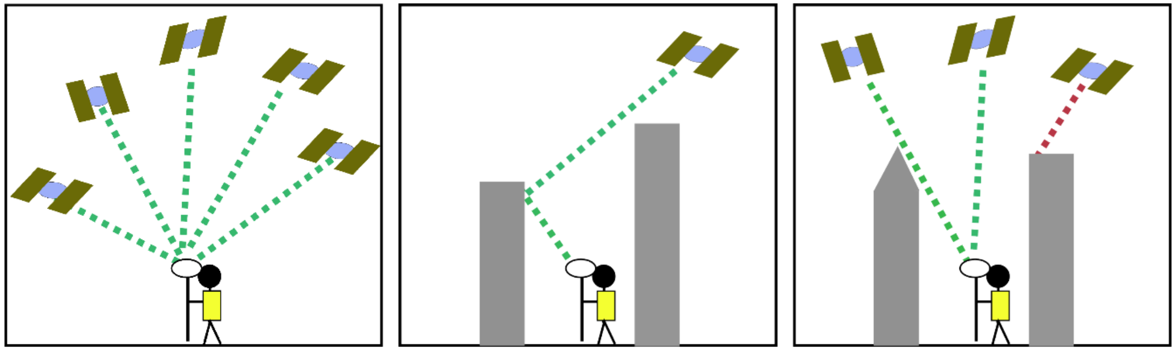


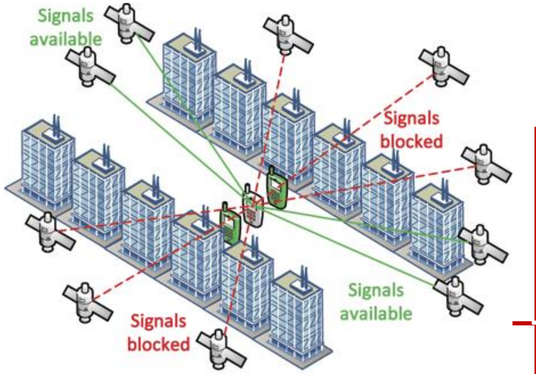
http://www.igs.org/network?network=multi-GNSS,mgex-experimental

2. Benefits of Multi-GNSS

☐ Improved usability/availability (multi-GNSS)

Station	GPS (%)				G/R/E/C (%)			
	10°	20°	30°	40°	10°	20°	30°	40°
CENT	100.0	99.6	89.2	41.5	100.0	100.0	100.0	100.0
CHDU	99.7	98.3	84.7	46.0	100.0	100.0	100.0	100.0
SIGP	94.8	93.7	72.1	39.2	100.0	100.0	99.9	99.5
CUT0	96.8	95.0	89.3	57.6	100.0	100.0	100.0	100.0
GMSD	98.1	97.6	79.5	30.2	100.0	100.0	100.0	99.8
NNOR	99.2	93.8	78.6	37.8	100.0	100.0	100.0	100.0
ONS1	96.1	93.3	62.5	30.6	100.0	100.0	99.9	99.6





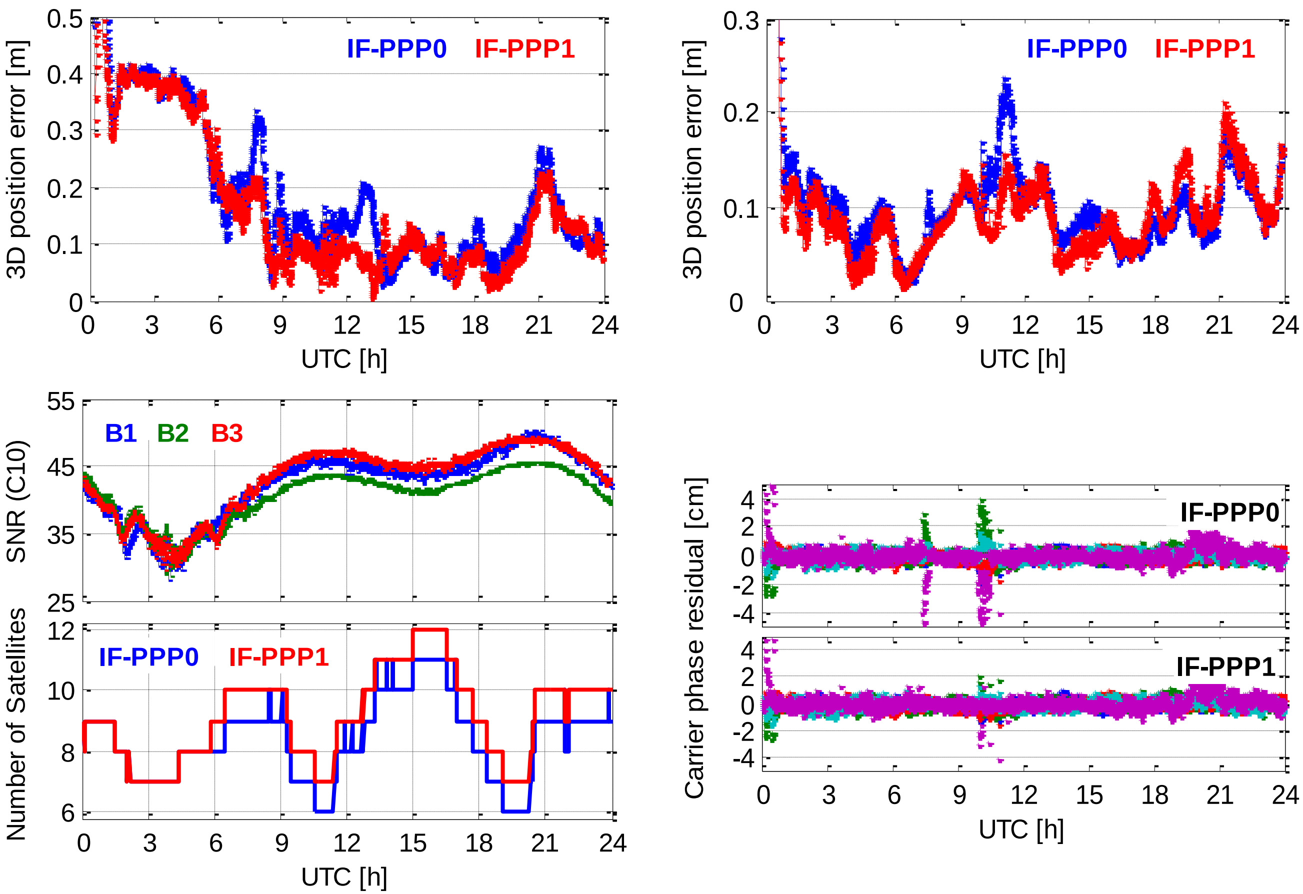
2. Benefits of Multi-GNSS

- More combinations available (multi-frequency)

Model	Obs.	e_1	e_2	e_3	Ion.	Noise
IF-PPP0	B1/B2	2.487	-1.487	0	0	2.90
IF-PPP1	B1/B2	2.487	-1.487	0	0	2.90
	B1/B3	2.944	0	-1.944	0	3.53
IF-PPP2	B1/B2/B3	2.566	-1.229	-0.337	0	2.86
UC-PPP	B1	1	0	0	1	1
	B2	0	1	0	1.672	1
	B3	0	0	1	1.514	1

2. Benefits of Multi-GNSS

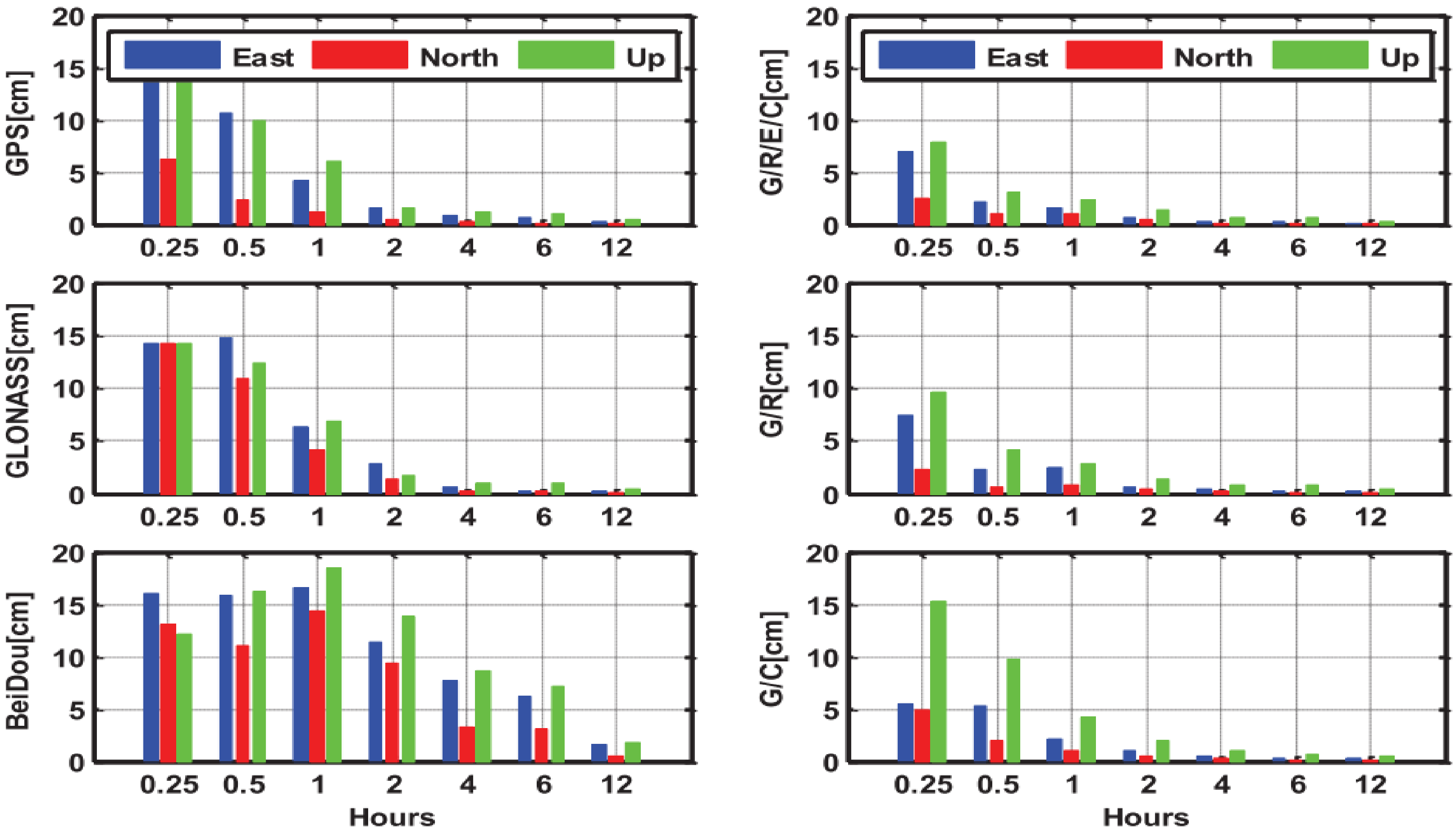
BDS dual- w.r.t. triple-frequency PPP



a more accurate and reliable solution can be achieved for triple-frequency PPP

2. Benefits of Multi-GNSS

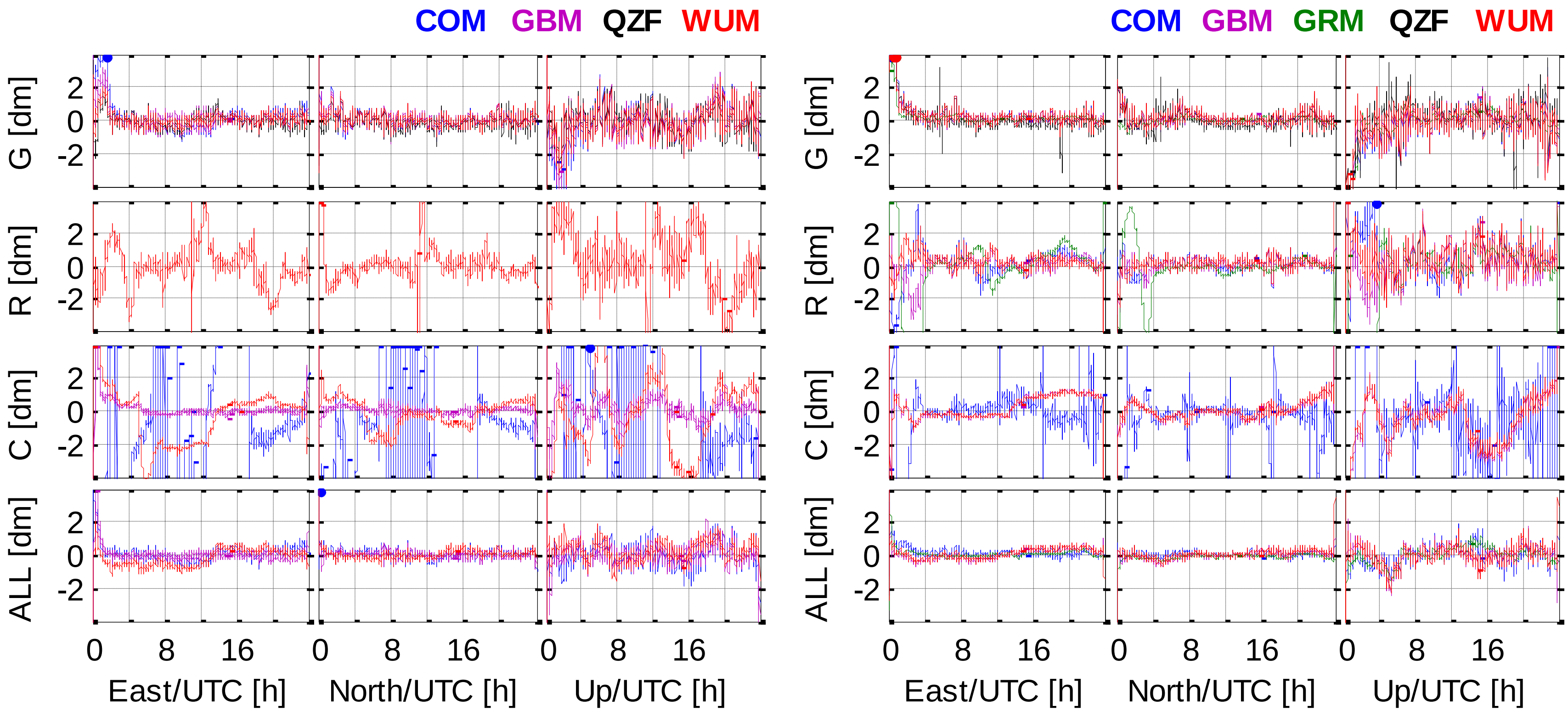
- Increasing positioning accuracy



Static PPP

2. Benefits of Multi-GNSS

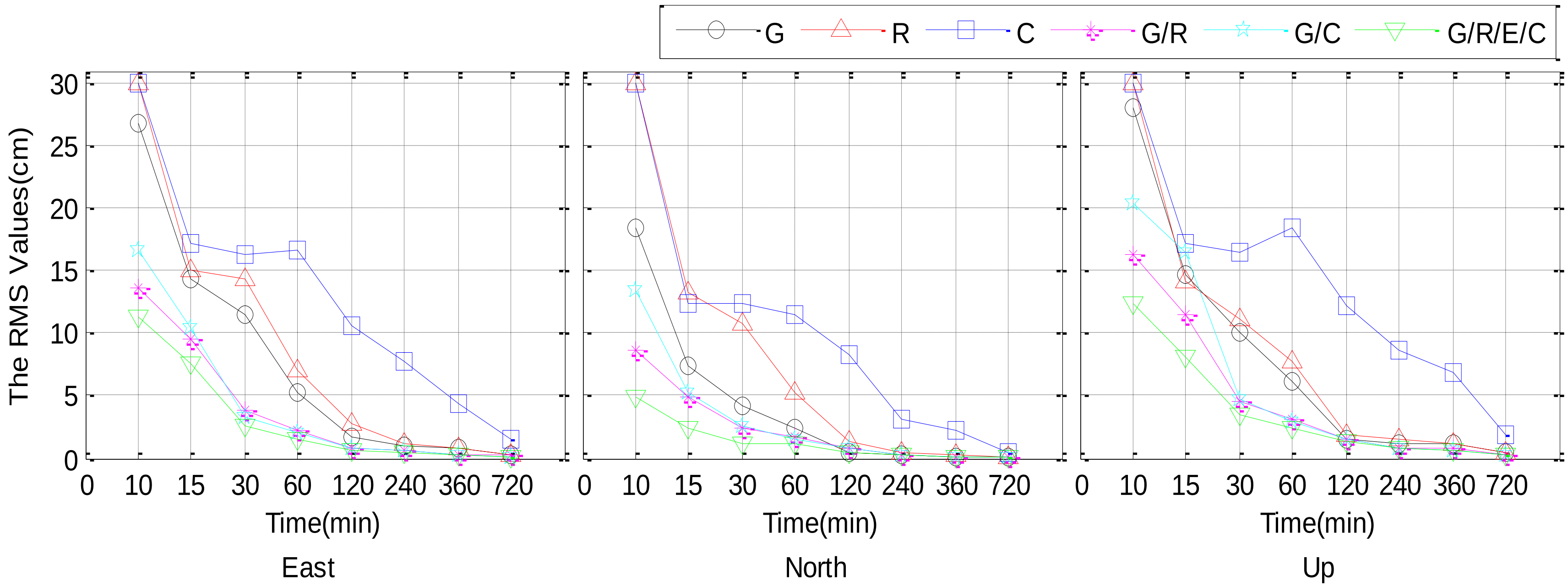
- Increasing positioning accuracy



Kinematic PPP

2. Benefits of Multi-GNSS

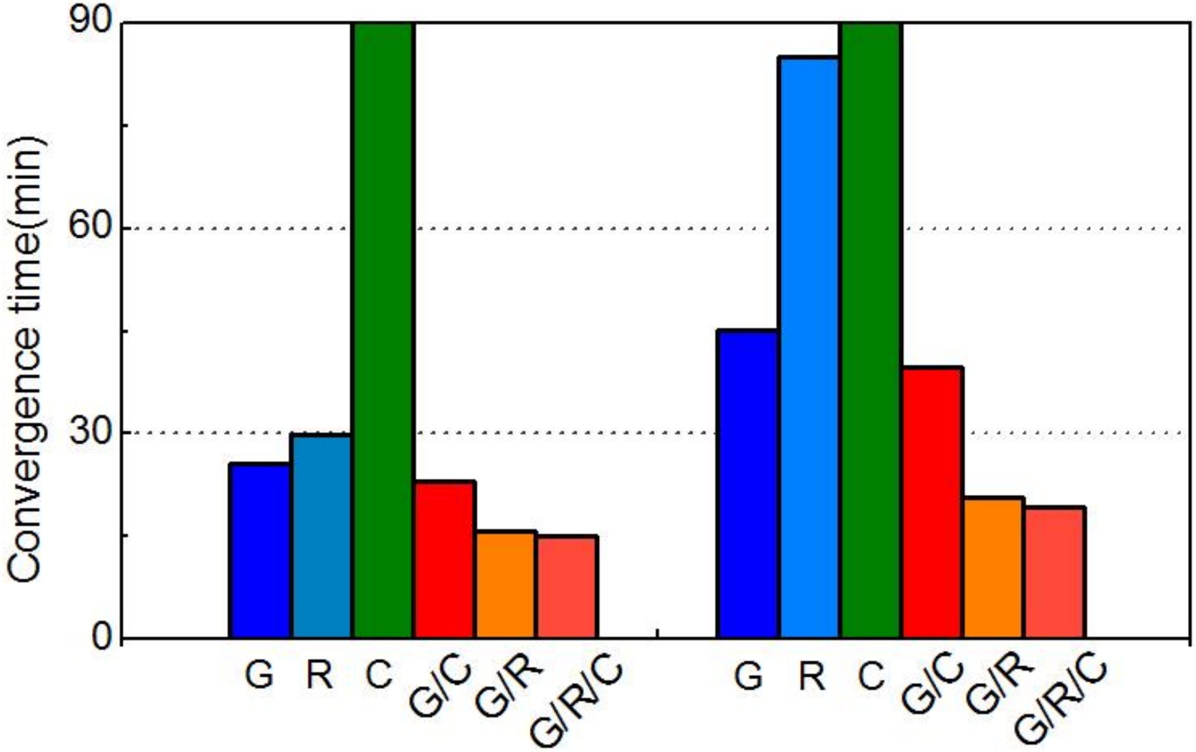
Speeding up the convergence



The convergence speed of multi-constellation is 30-50% higher than that of single GPS

2. Benefits of Multi-GNSS

- Speeding up the convergence



2. Benefits of Multi-GNSS

☐ Increasing fixing rate of PPP-AR

TTFF of PPP-AR(min)

	static	kinematic
BDS	**526.1**	**617.8**
GPS	**21.7**	**34.6**
GLONASS aided GPS	**17.5**	**26.9**
（GPS+BDS）	**16.7**	**24.5**
GLONASS aided （GPS+BDS）	**14.0**	**20.1**

Fixing rate of PPP-AR(%)

	static	kinematic
BDS	**16.8**	**12.1**
GPS	**98.7**	**95.3**
GLONASS aided GPS	**99.2**	**97.9**
（GPS+BDS）	**99.3**	**98.9**
GLONASS aided （GPS+BDS）	**99.6**	**99.1**

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3. Challenges of Multi-GNSS

- Different coordinate systems
- Different time systems
- Different constellation configurations
- Different signal structures
- Different data quality

3. Challenges of Multi-GNSS

- Increasing number of biases (ISB, IFB, IFCB, DCB, etc.)

Biases are not estimable in absolute sense

Relative
(fix a reference such as a ground receiver)

- **Inter-Frequency Bias (IFB)**
  - ✓ Satellite IFB
  - ✓ Receiver IFB
- **Differential Code Bias (DCB)**
  - ✓ Satellite DCB
  - ✓ Receiver DCB
- **Differential Phase Bias (DPB)**
  - ✓ Satellite DPB
  - ✓ Receiver DPB

Inter-System Biases
(multi-constellations)

- **Inter-system Time System Offset**
  - ✓ GPS/GLONASS
  - ✓ GPS/GALILEO
  - ✓ GPS/COMPASS
- **Inter-system Coordinate System Offset**
  - ✓ GPS/GLONASS
  - ✓ GPS/GALILEO
  - ✓ GPS/COMPASS

Steadily increasing number of types of biases to be dealt with

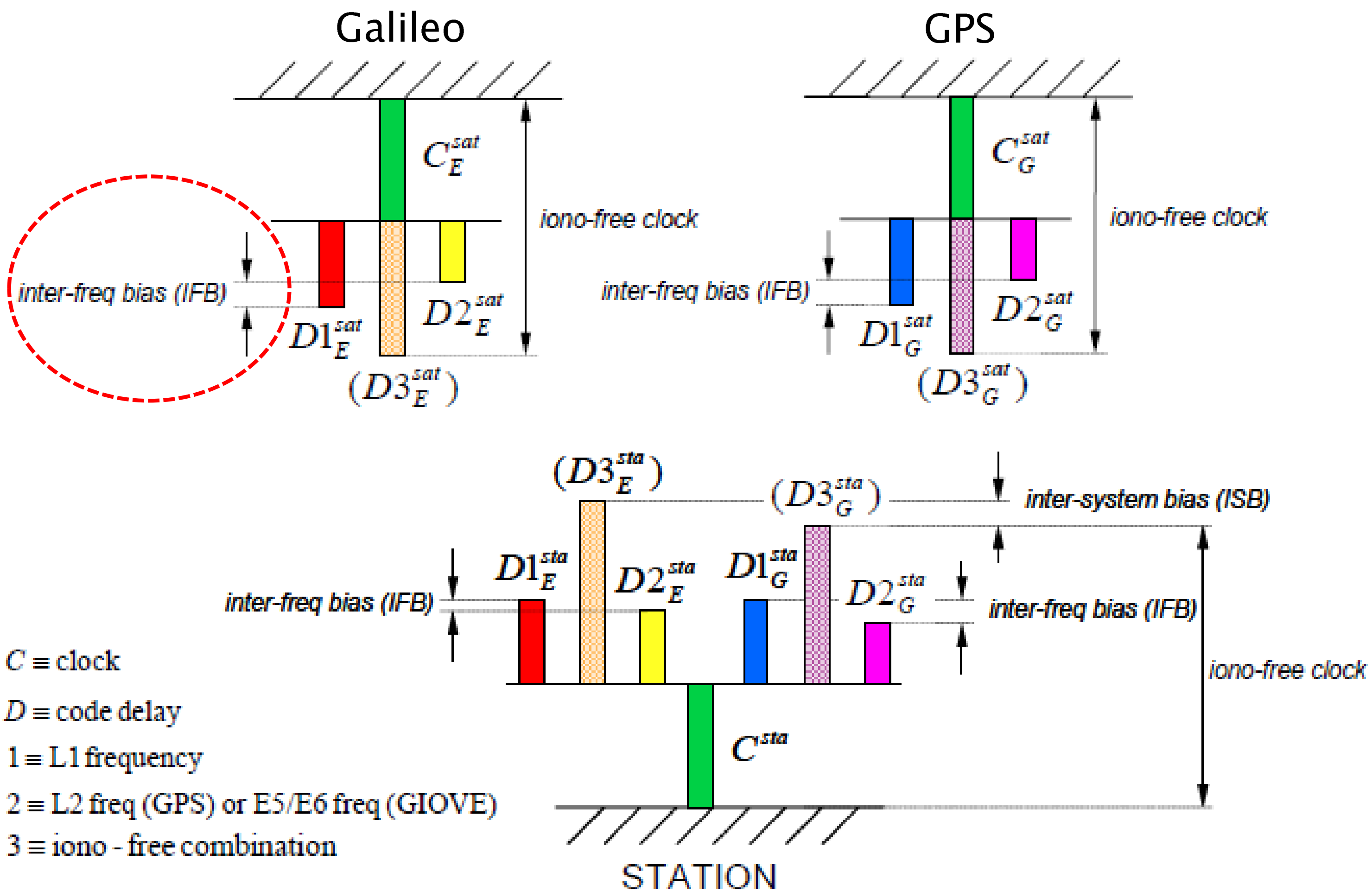
3. Challenges of Multi-GNSS

➢ Differential Code Bias (DCB)

GNSS	Types of DCB	Num.
GPS	Intra-freq.： C1C-C1W C2W-C2S C2W-C2L C2W-C2X Inter-freq.： C1C-C2W C1C-C2W C1C-C5Q C1C-C5X	8
GLONASS	Intra-freq.： C1C-C1P C2C-C2P Inter-freq.： C1C-C2C C1C-C2P C1P-C2P	5
Galileo	Inter-freq.： C1C-C5Q C1C-C7Q C1C-C8Q C1X-C5X C1X-C7X C1X-C8X	6
BDS	Inter-freq.： C2I-C7I C2I-C6I C7I-C6I	3

3. Challenges of Multi-GNSS

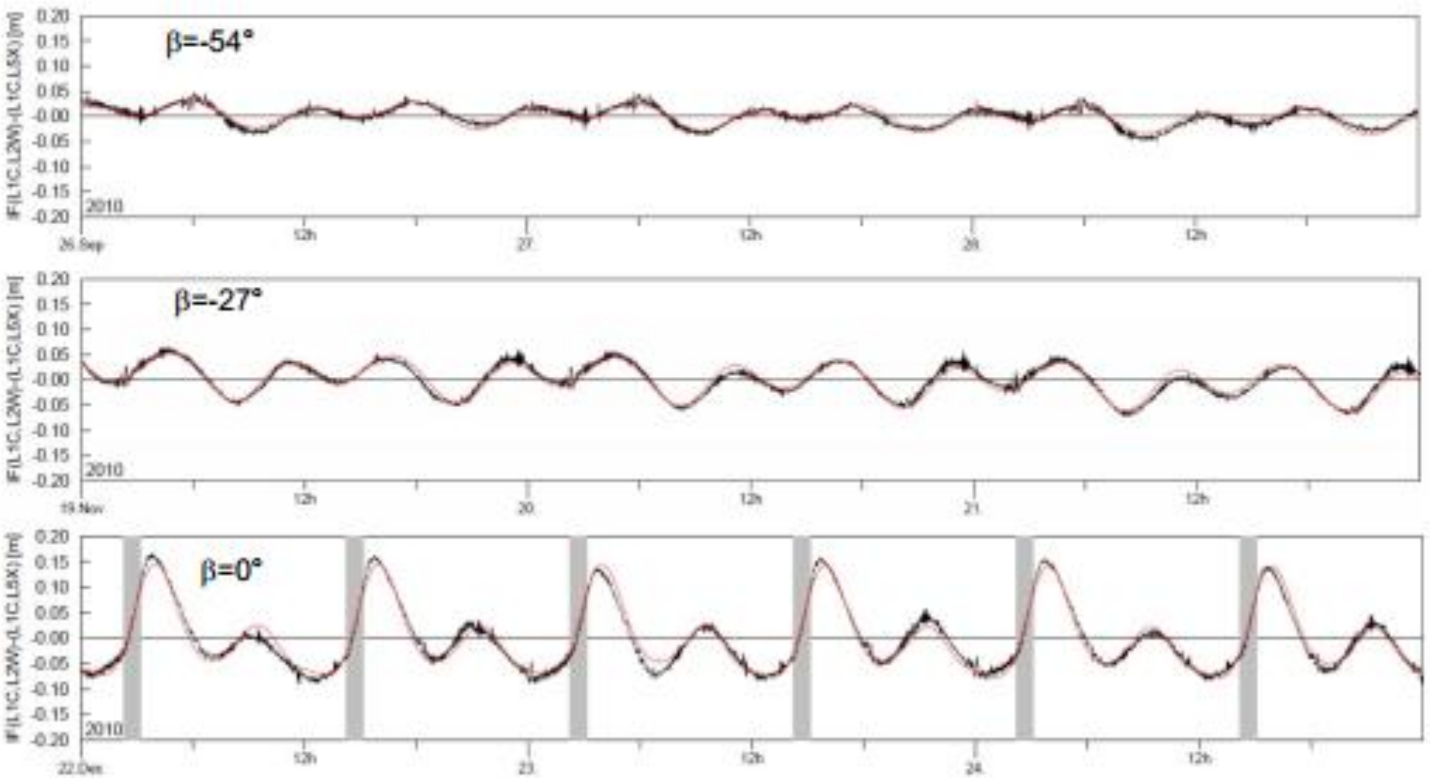
➢ Inter-Frequency Bias (IFB and IFCB)



3. Challenges of Multi-GNSS

➢ Inter-Frequency Bias (IFB and IFCB)

Seasonal Variation of L1/L5-L1/L2 Clock Difference

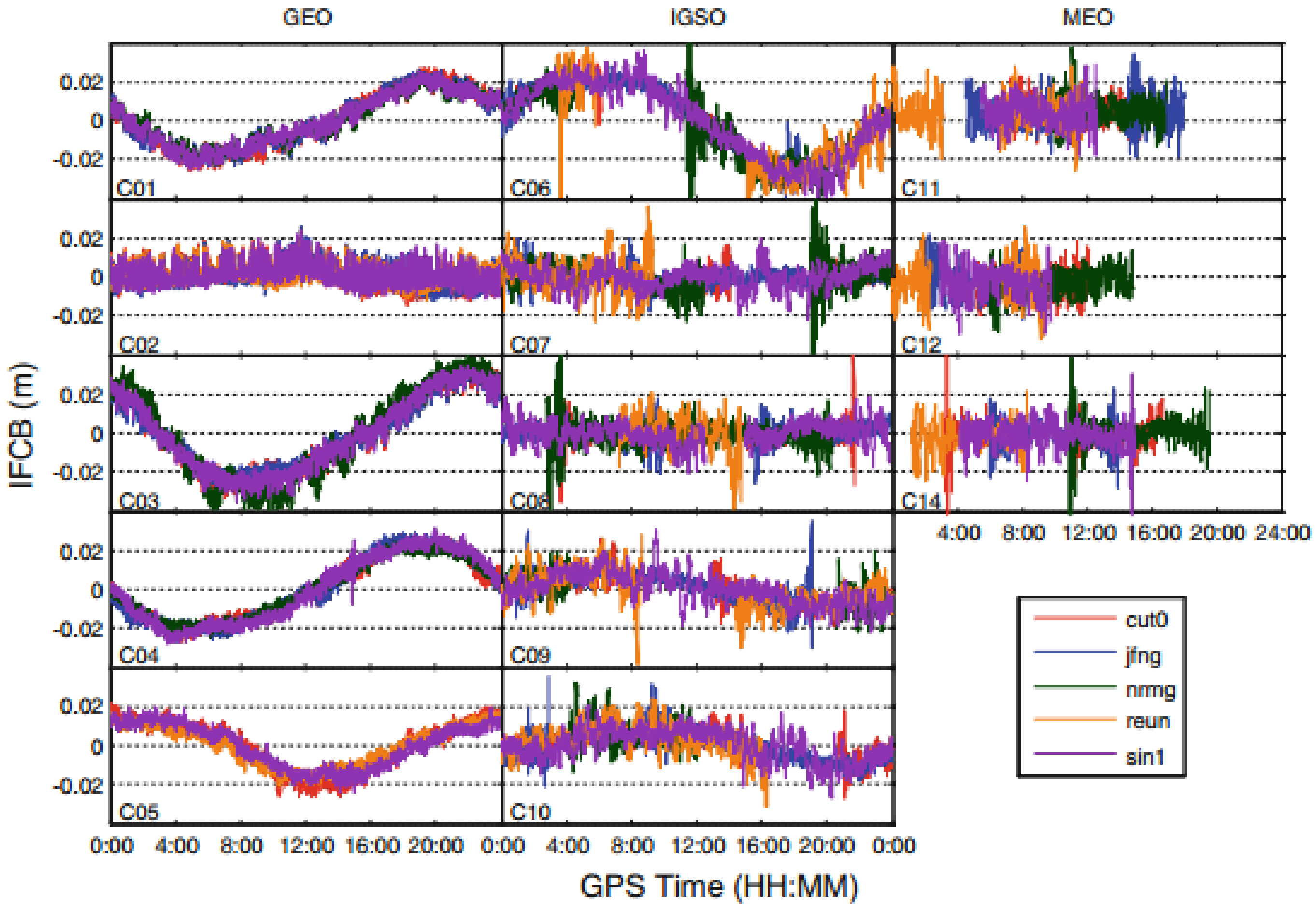


Variations for GPS satellites reach up to ±0.2 m

Oliver Montenbruck (2011)

3. Challenges of Multi-GNSS

➢ Inter-Frequency Bias (IFB and IFCB)

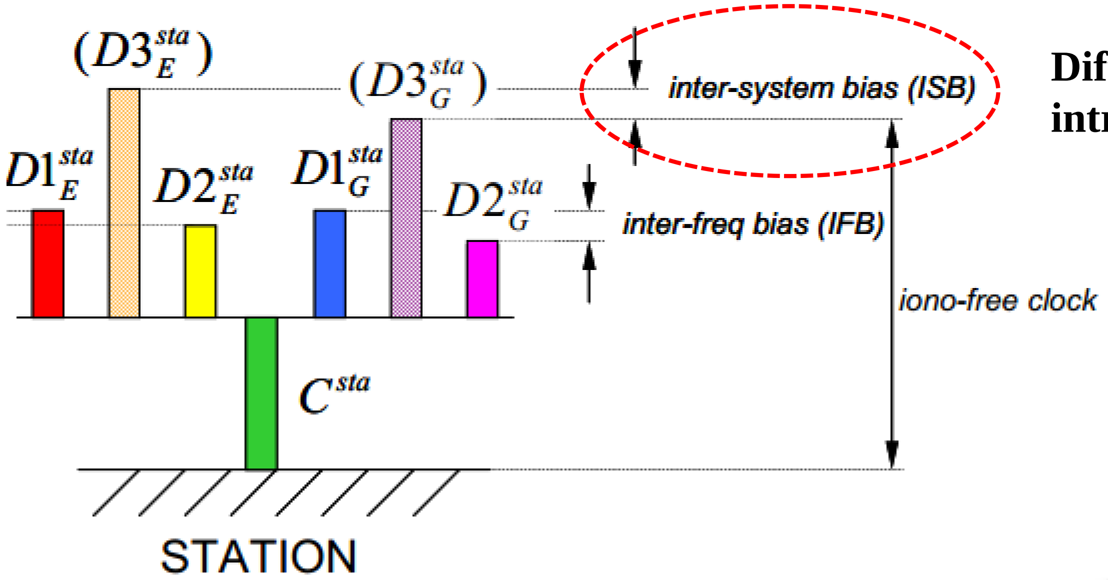


Variations for BDS satellites reach up to ±0.03 m

Pan et al (2016)

3. Challenges of Multi-GNSS

➢ Inter-System Bias (ISB)

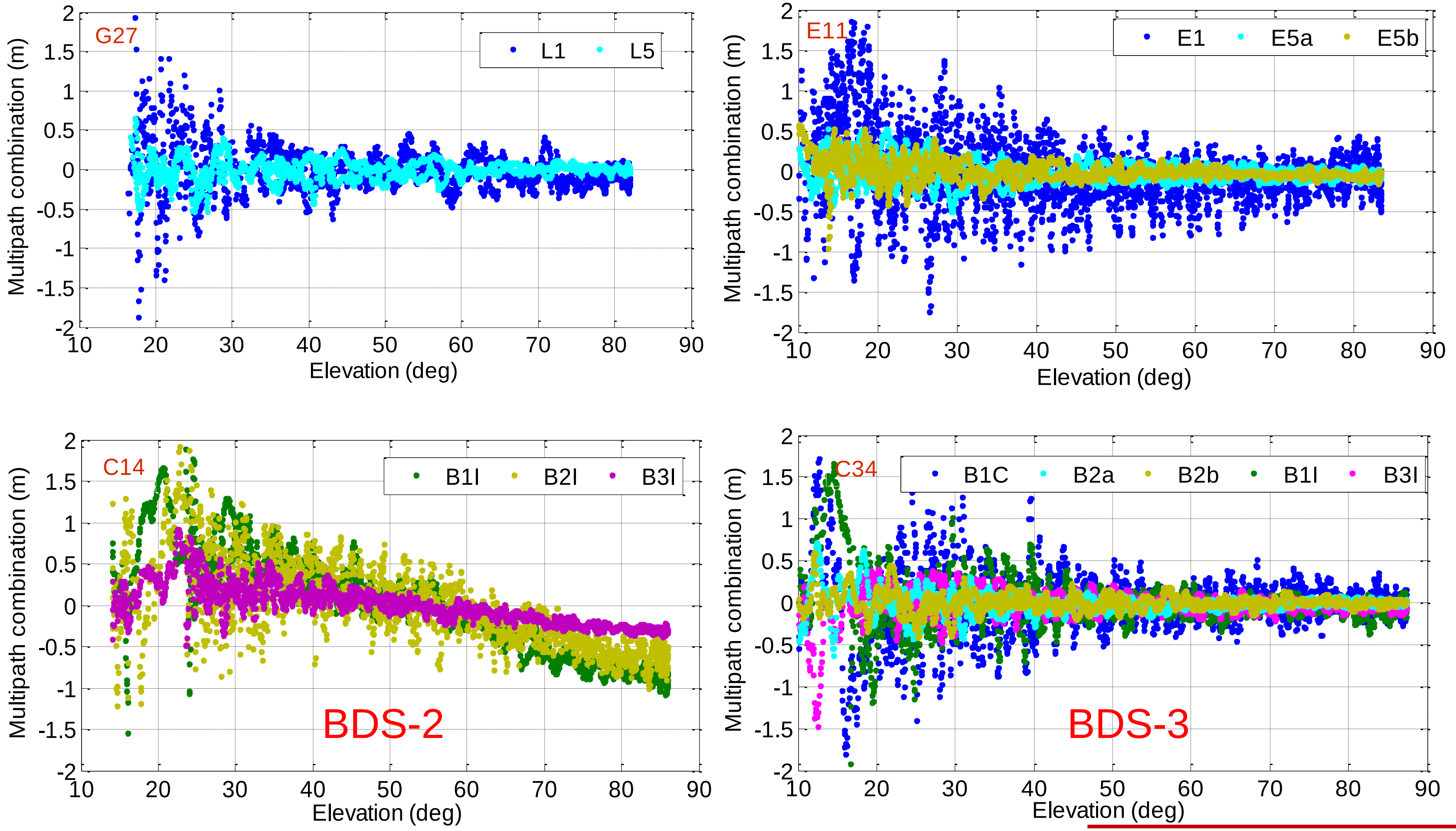


Different system delays introduced by receiver

- receiver type and firmware dependent

3. Challenges of Multi-GNSS

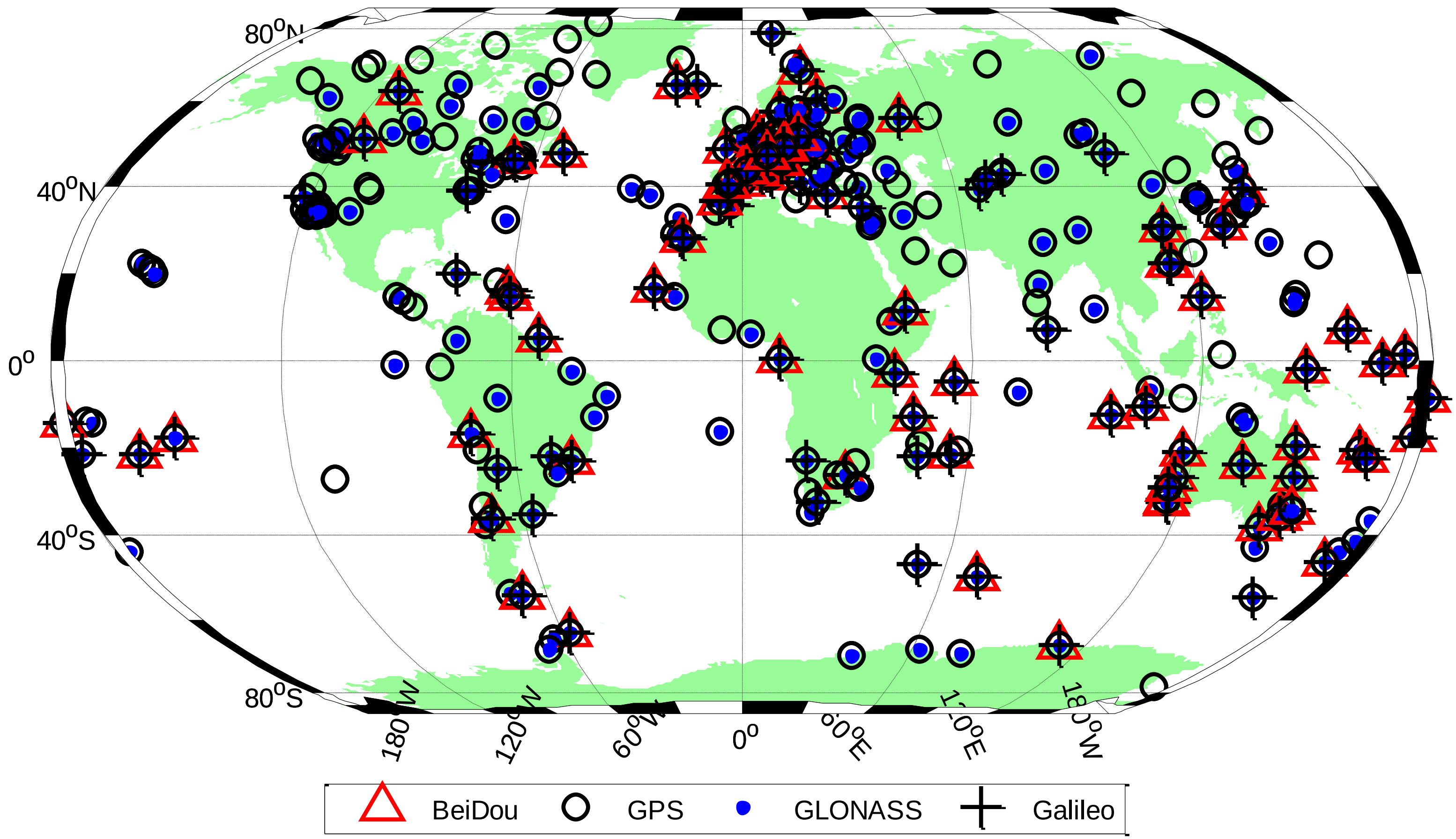
➢ BDS satellite-induced code biases



Zhang et al (2017)

3. Challenges of Multi-GNSS

- The efficiency of real-time processing of massive data



3. Challenges of Multi-GNSS

- Products are not mature yet
  - post/real time orbit
  - post/real time clock
  - PCO/PCV model for the new emergeing satellites
  - FCB products for PPP-AR
  - Quality of IGS released precise products
  - Standard conventions for IFCB and DCB products
  - Real time precise ionospheric delay products

3. Challenges of Multi-GNSS

☐ Models should be refined

- ✓ Consistency between various products, such as clock, ionospheric delay, FCB, DCB etc.
- ✓ Fast ambiguity resolution for the undifferenced ambiguities (with multi-frequency and multi-GNSS)
- ✓ Optimization of PPP function model and stochastic model
- ✓ Quality control issues for PPP-RTK
- ✓ Parameterization of the ionospheric delay for the undifferenced and uncombined PPP model
- ✓ Initialization time should be further shortened (with sparse CORS)

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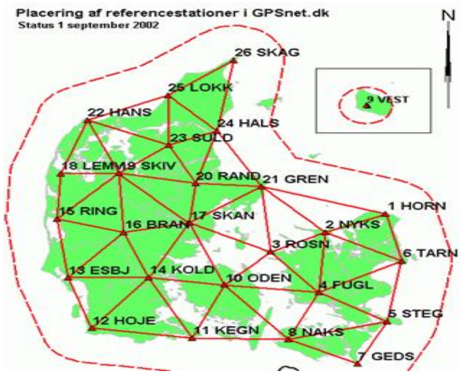
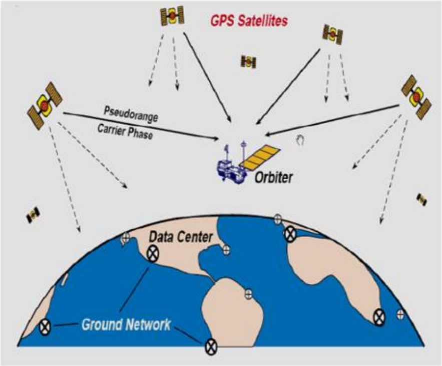
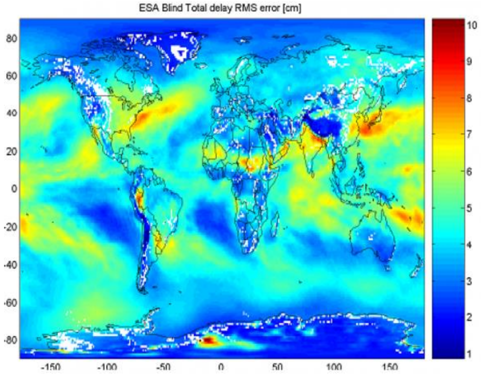
4. Applications in Geoscience

- Geodetic survey
- Trajectory monitoring
- GNSS seismology
- GNSS meteorology
- LEO POD
- ……

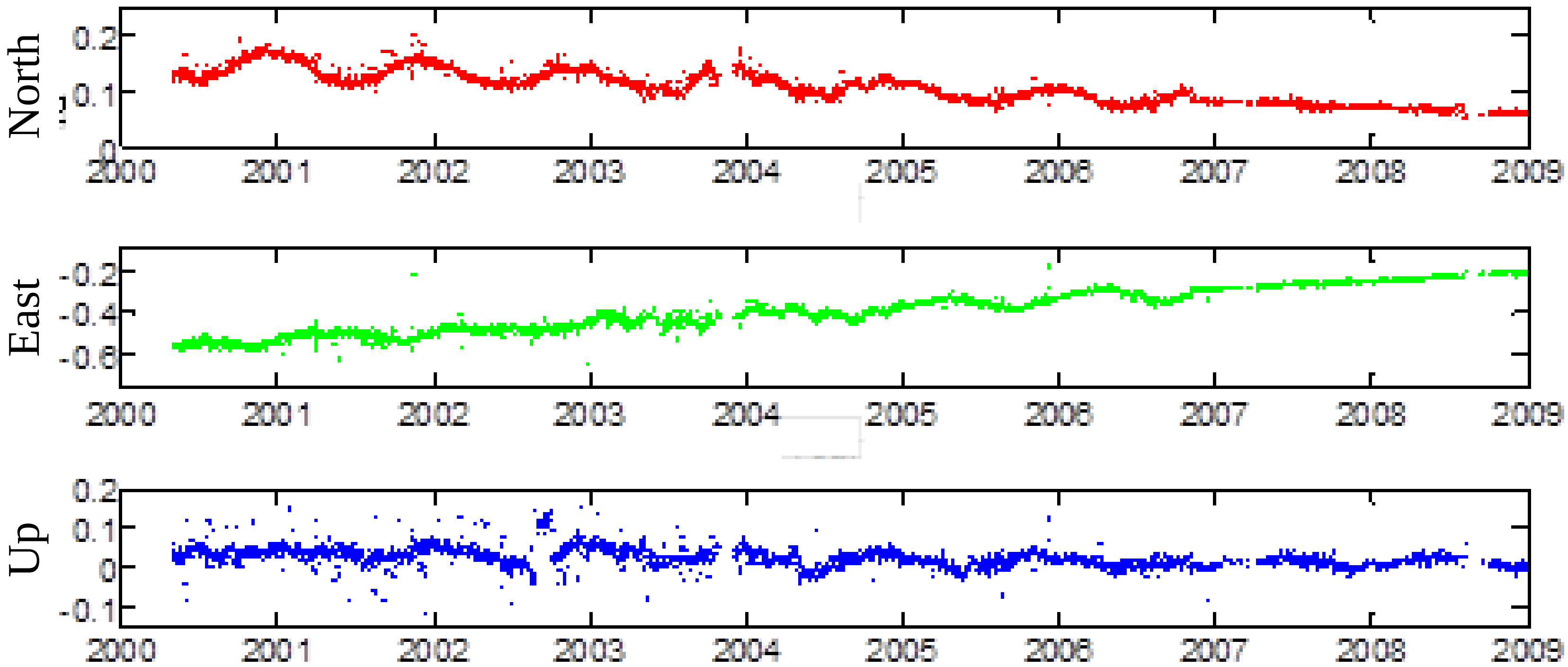






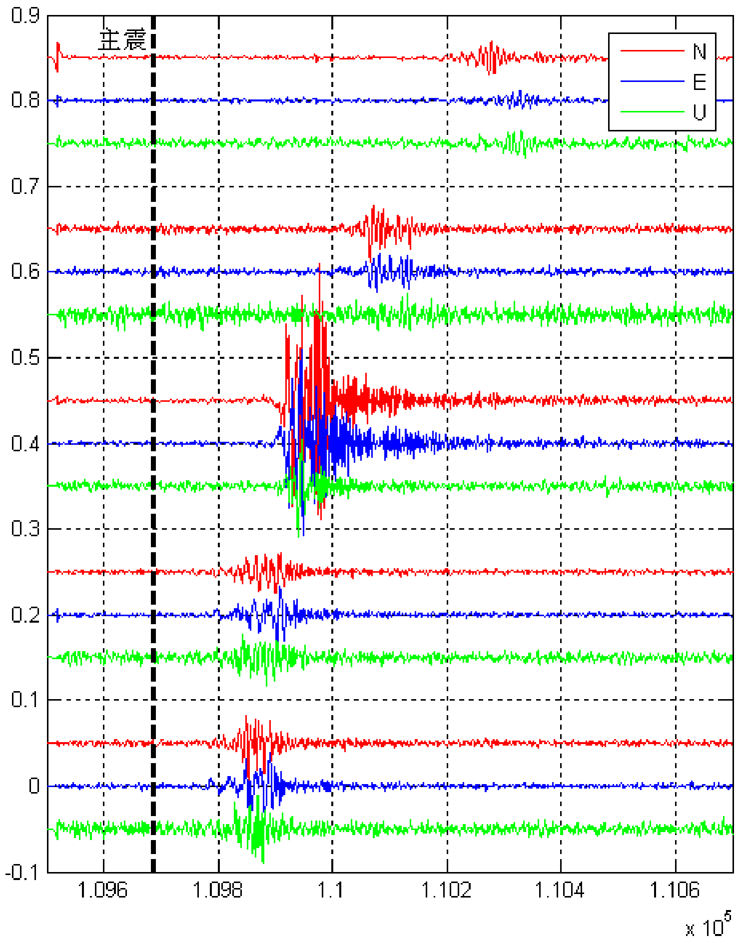
4. Applications in Geoscience

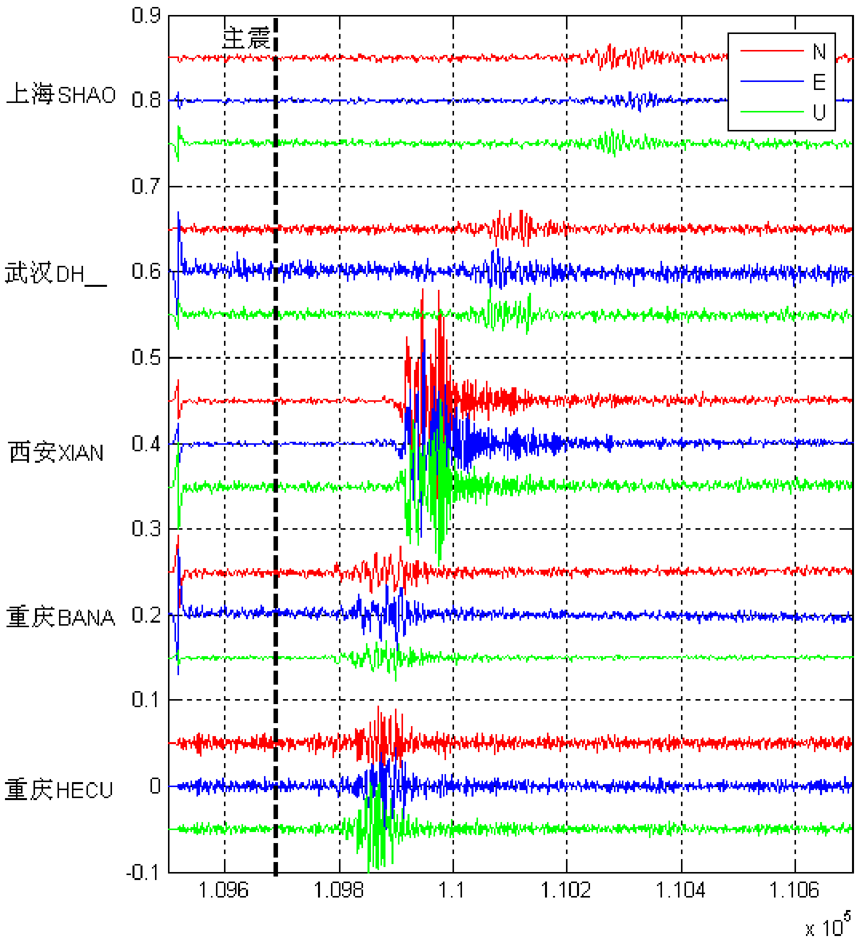
Geodetic survey



4. Applications in Geoscience

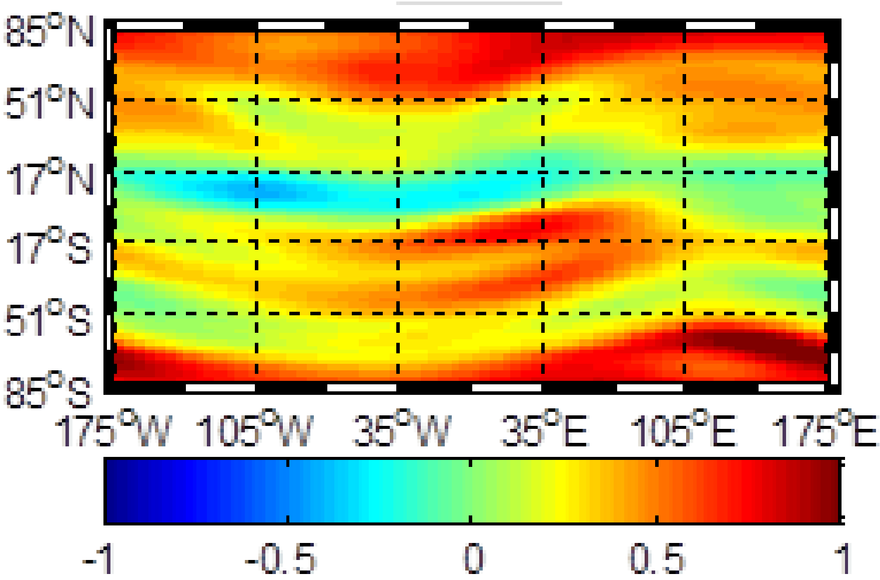
Coseismic displacement



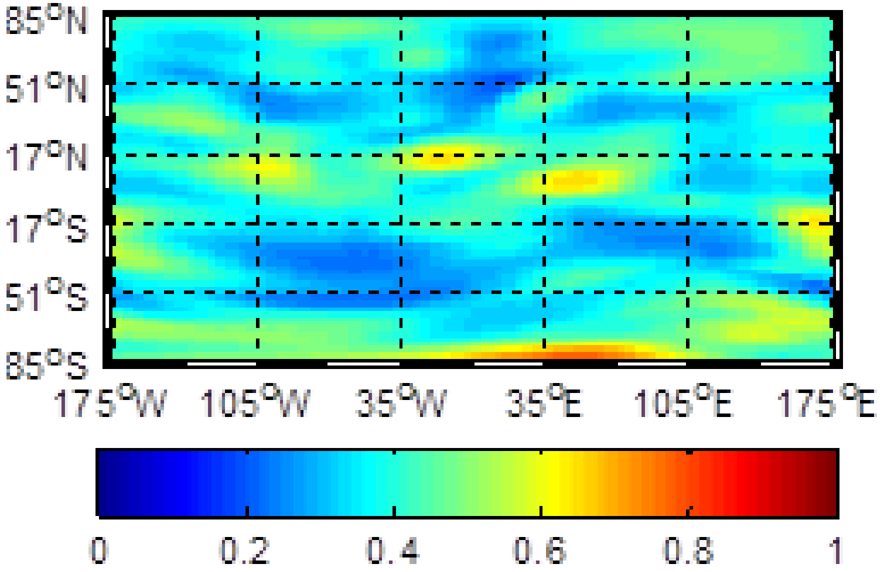


4. Applications in Geoscience

Ionospheric delay retrieval (TEC)



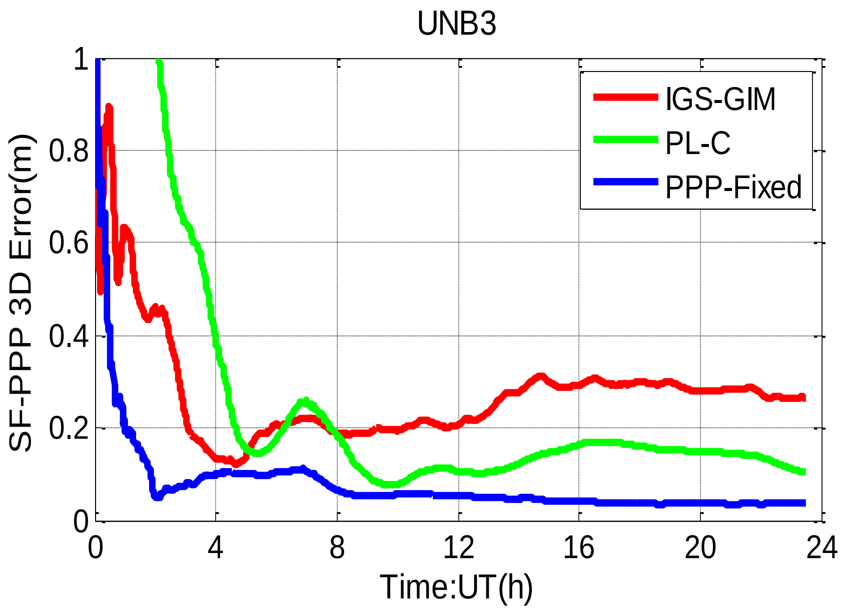
Mean bias

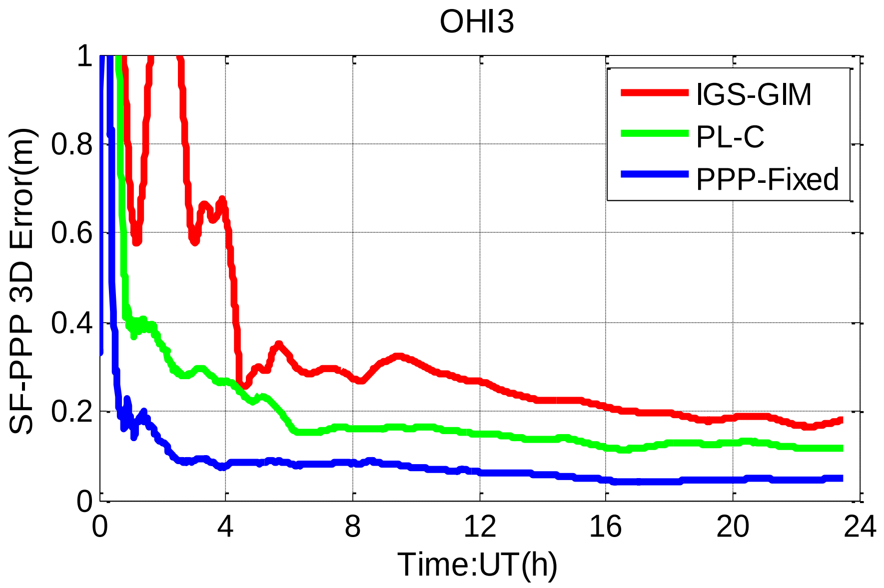


Standard deviation

4. Applications in Geoscience

◻ Ionospheric delay retrieval (TEC)

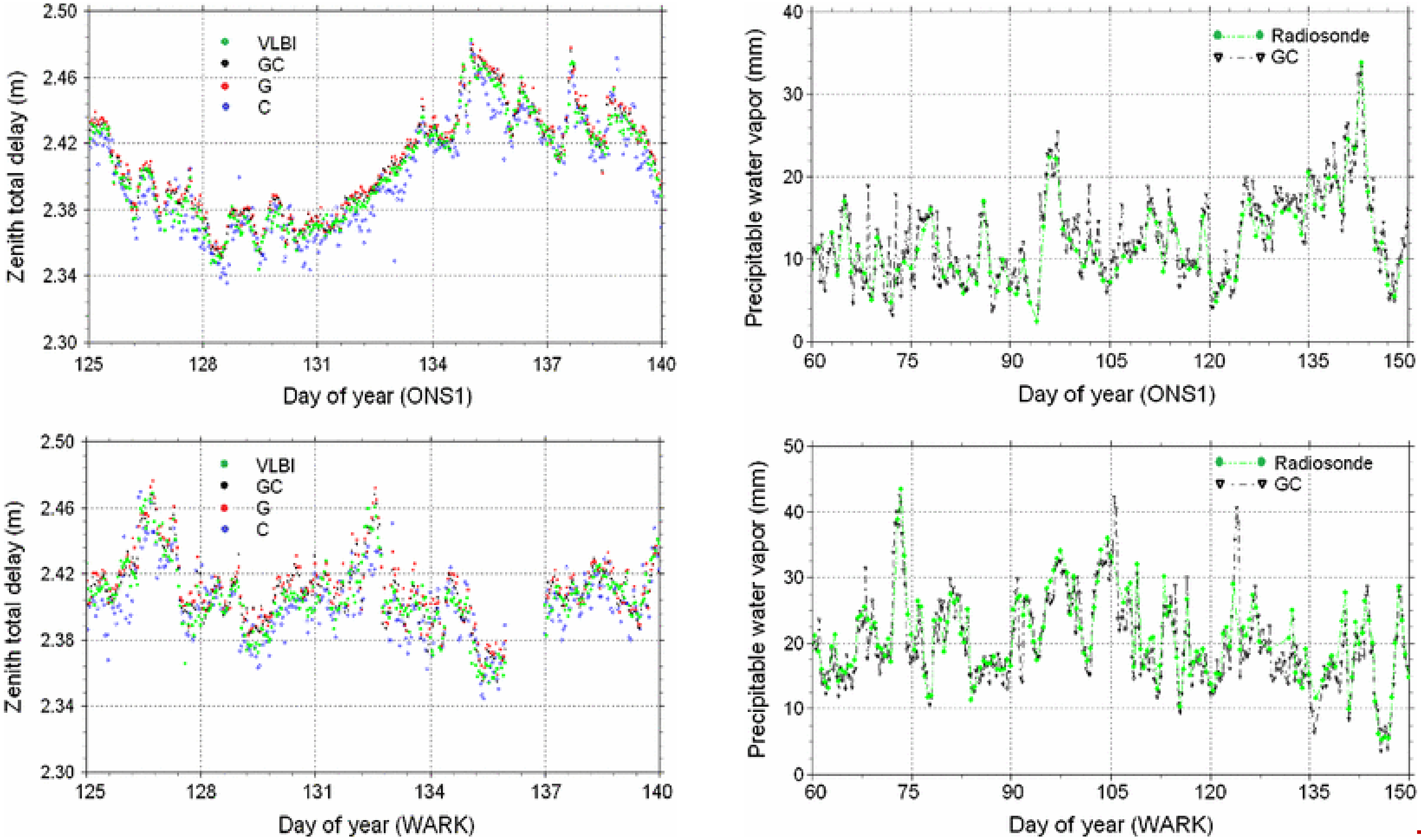




Single-frequency PPP results

4. Applications in Geoscience

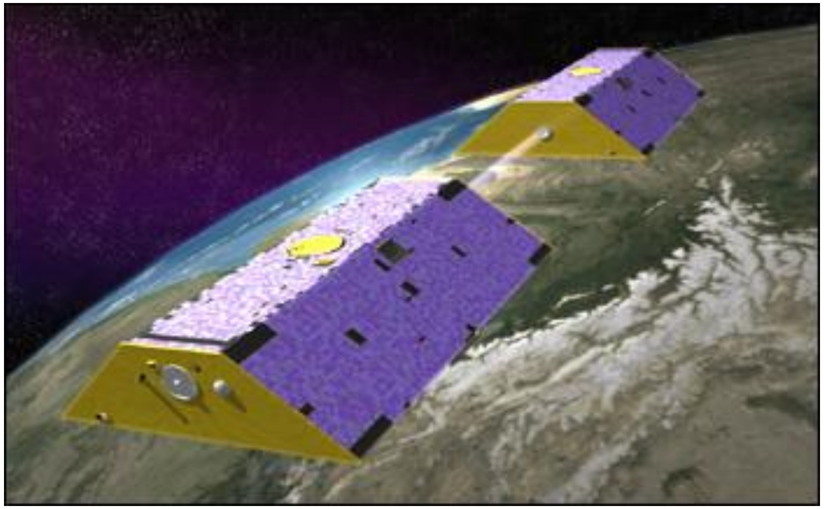
☐ Tropspheric delay retrieval (ZTD and PWV)

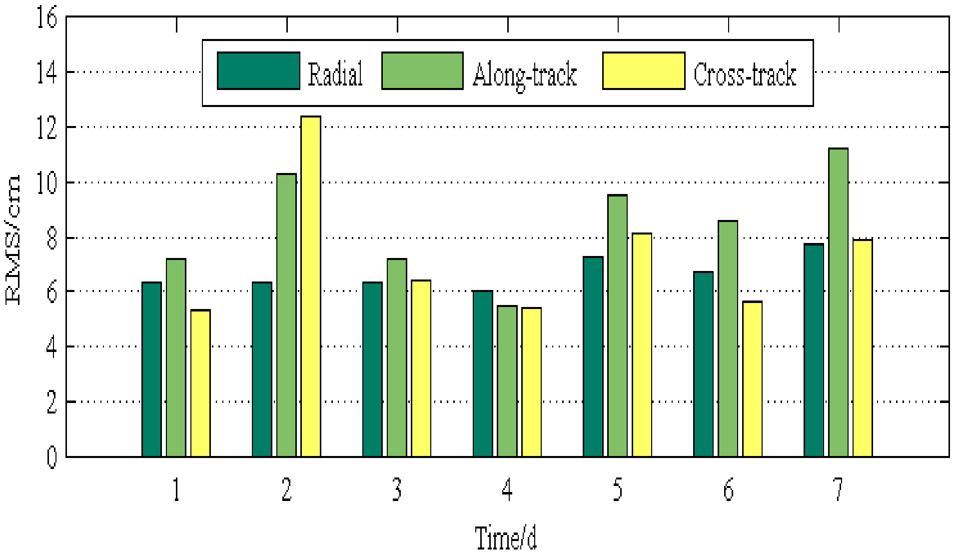


Lu et al (2015)

4. Applications in Geoscience

☐ Precise orbit determination for LEO





GRACE satellite orbit determination: ~5 cm

Future works

- GNSS+LEO enhanced PPP
- Quality control issues
- More applications
- ……

Thank you for your attention