Zone-corrections: a new augmentation information for decimeter-level SBAS system

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- **Background**
- **Challenges in SBAS performance improvement**
- **Zone correction**
- **Design of demonstration system**
- **Summary**

Background

- Global Constellations
  - **GPS (24+)**
  - GLONASS (30)
  - Galileo (27+3)
  - Compass (27+3 IGSO + 5 GEO)

- Regional Constellations
  - QZSS (4+3)
  - IRNSS (7)
- Satellite-Based Augmentations
  - **WAAS (3)**
  - MSAS (2)
  - EGNOS (3)
  - GAGAN (2)
  - SDCM (3)

David Turner, 2014

SBAS systems

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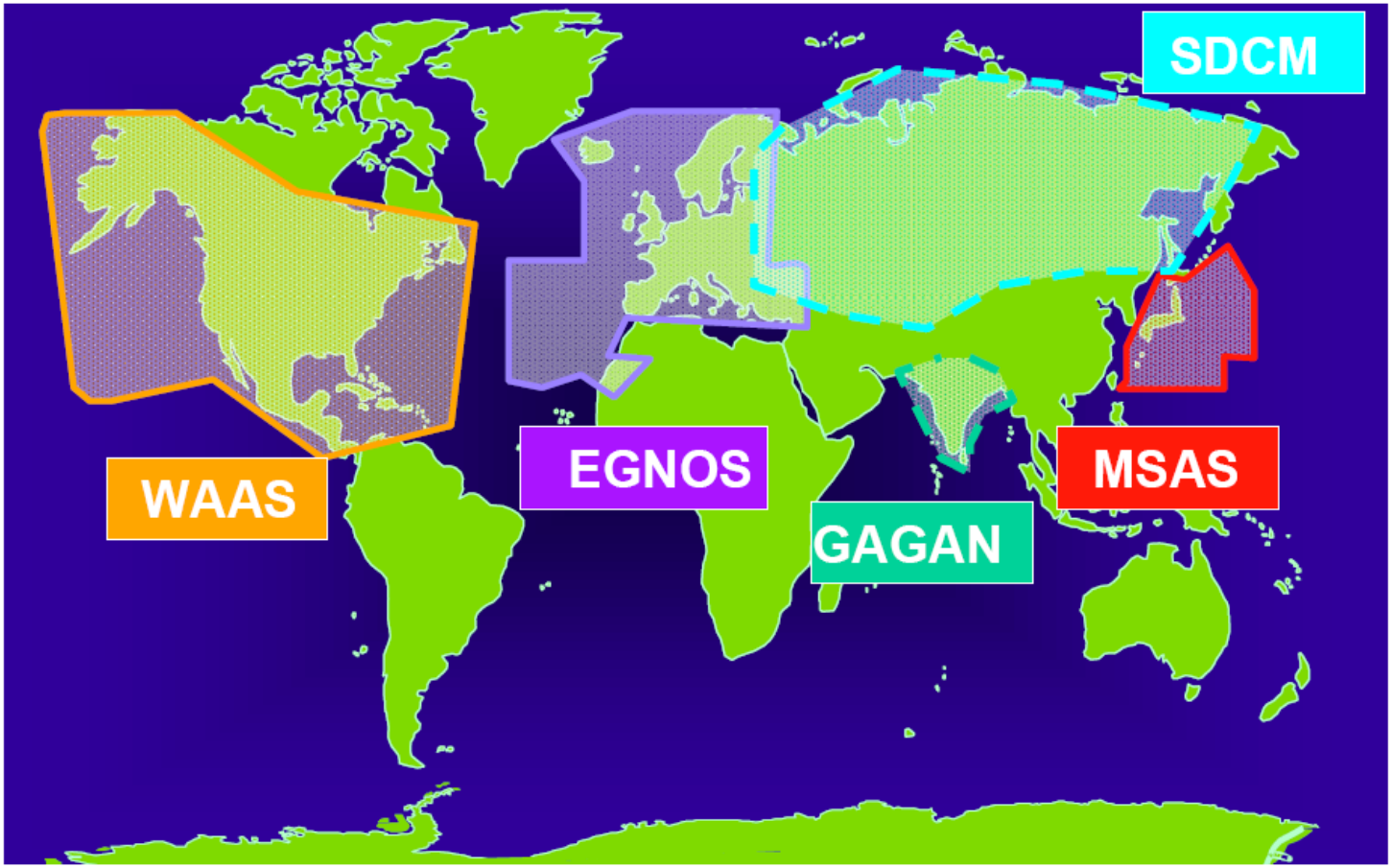
  - **GPS (24+)**
  - GLONASS (30)
- Regional Constellations
  - QZSS (4+3)



GPS SBAS performance

- Global Constellations
  - GPS (24+)
- Regional Constellations

Heßelbarth and Wanninger (2012); in cm

Region	Broadcast	SBAS		
		WAAS	EGNOS	MSAS
USA	55.9/122.7/134.6	13.6/25.7/30.7		
Europe	70.3/128.2/150.7		3.2/68.1/100.2	
Japan	55.2/123.6/174.1			36.6/74.3/112.0

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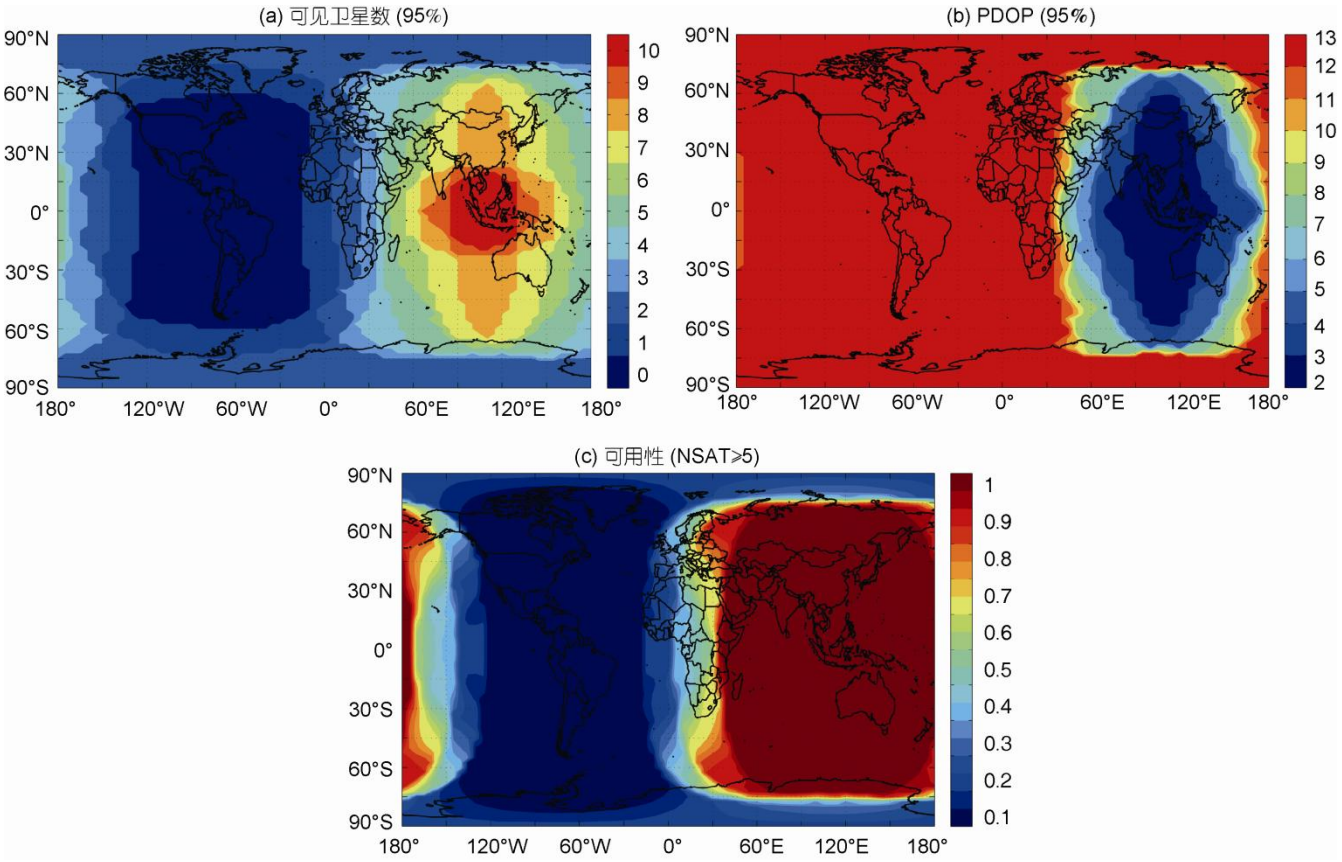
BDS: integrated PNT and SBAS service

➢BDS: constellation & positioning



Yang et al, 2014

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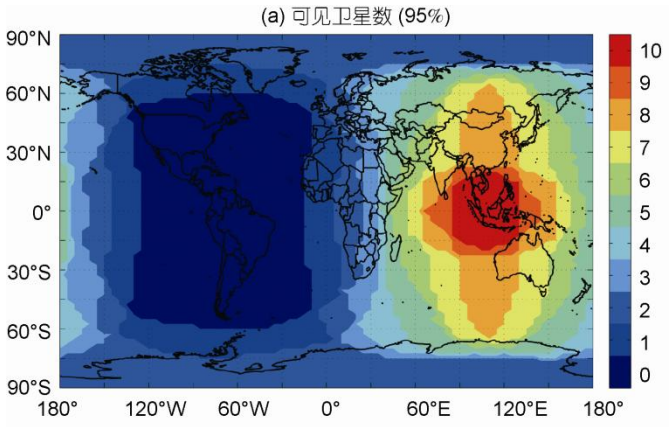
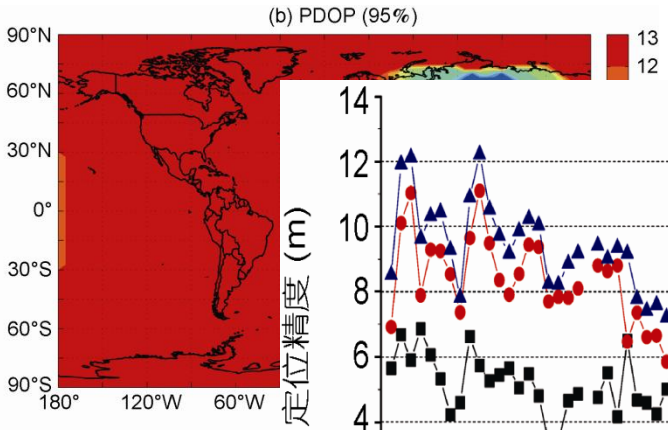
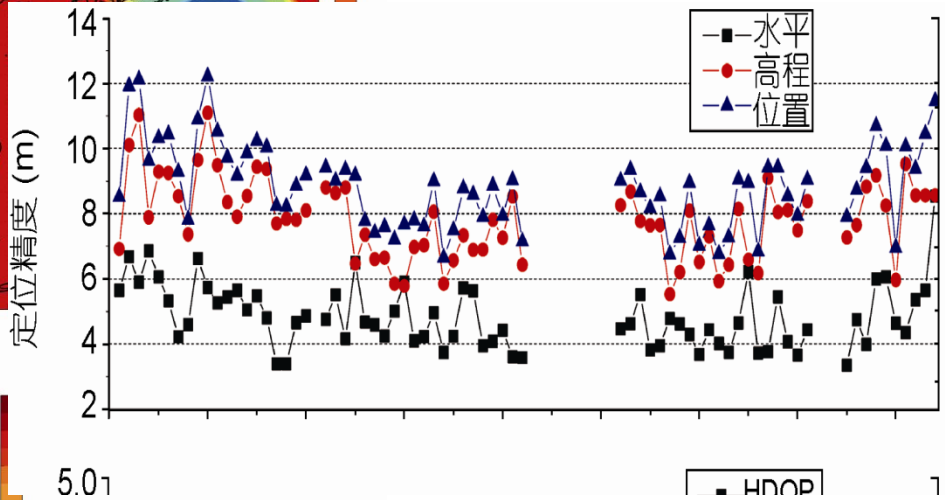
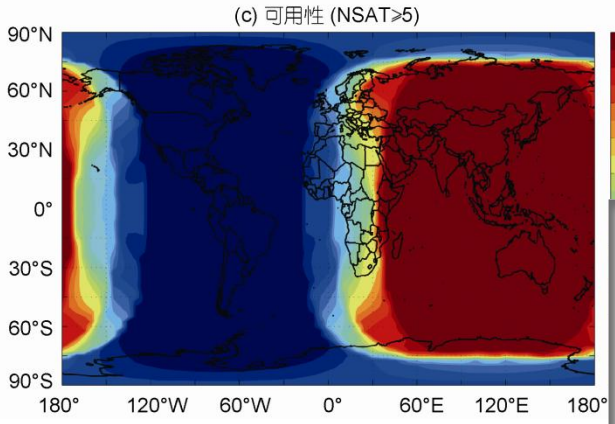
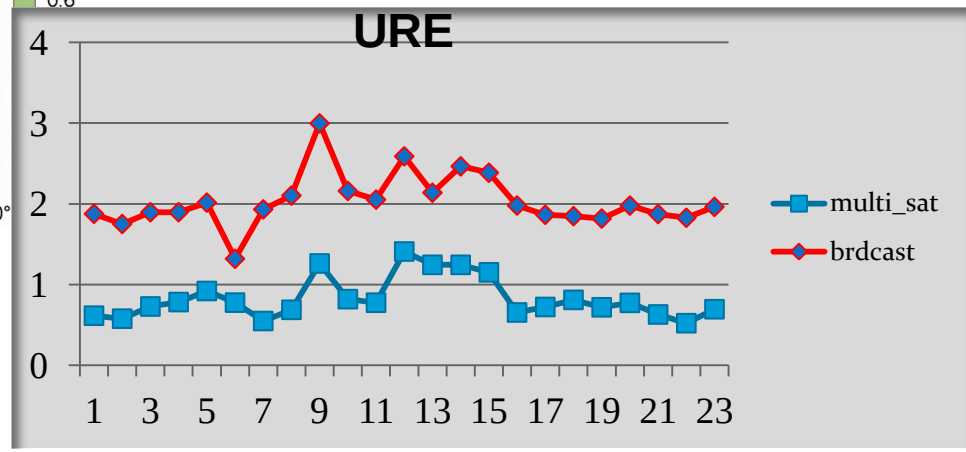










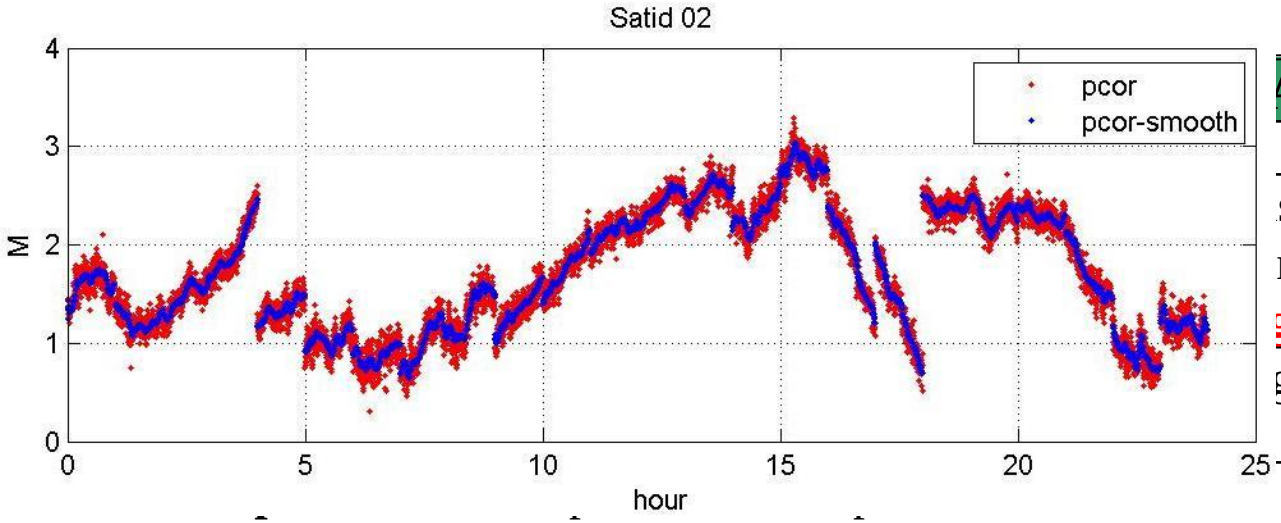
SBAS service of BDS

➢BDS: integrated augmentation service

	Open Service	Augmentated Service
	For public users	For authorized users
Stations	Master monitor station/Upload station/Orbit determination station	Master monitor station/Upload station/Orbit determination station; /**Augmentation monitor station**
Orbits and satellite clocks	Navigation message	Navigation + **Equivalent Satellite Clock Error**
Ionospheric correction	8 parameters/14 parameters Klobuchar model	**Ionospheric Grid**
Broadcasting	All satellites	**Geo satellites**
Information update cycle	One hour for orbits and satellite clocks; Two hours for Ionospheric model parameters	18 seconds for Equivalent Satellite Clock Error; 3 minutes for Ionospheric Grid

SBAS service of BDS

➢BDS: Equivalent Satellite Clock



		Augmentated Service
		Authorized users
		ster monitor station/Upload
		n/Orbit determination station;
		gmentation monitor station
		gation + **Equivalent Satellite Clock Error**
correction	Klobuchar model	**Ionospheric Grid**
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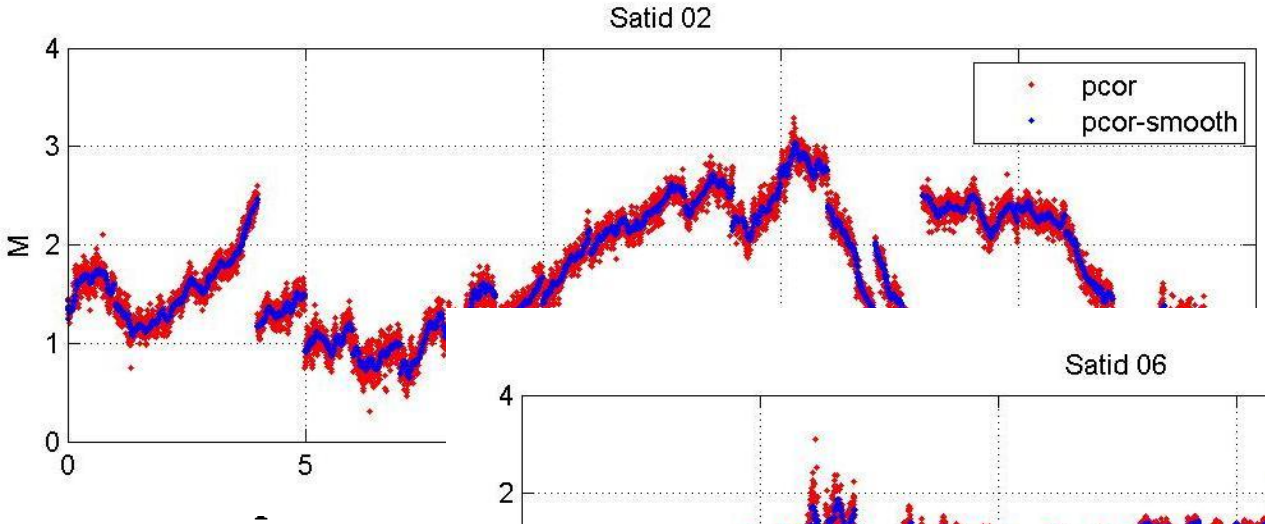

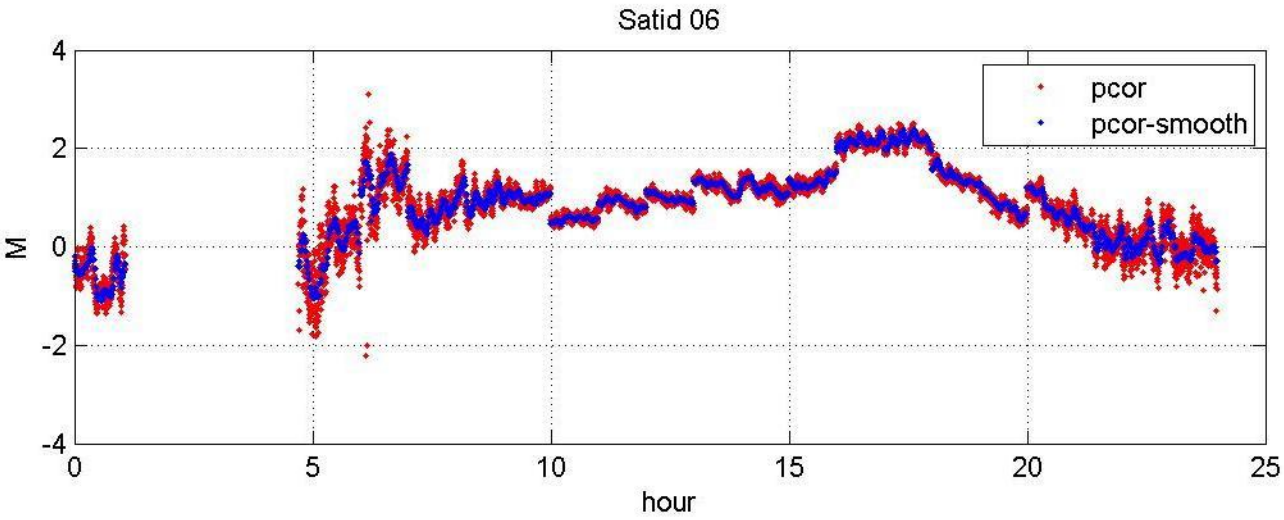

Augmentated Service
Authorized users
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Grid

correction
Broadcasting
Information update cycle

SBAS service of BDS

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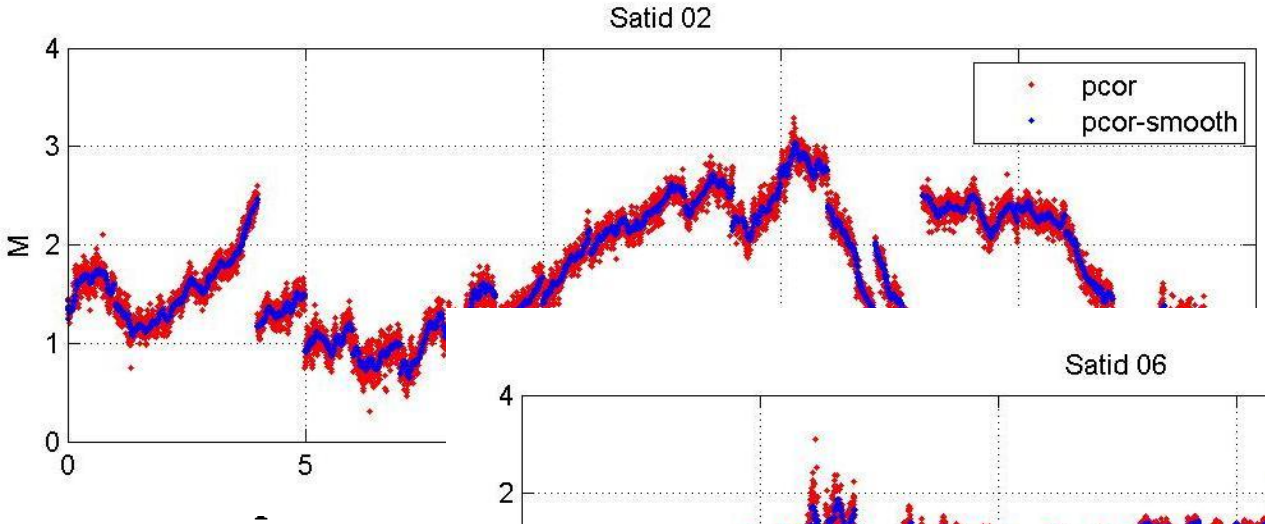

Augmentated Service

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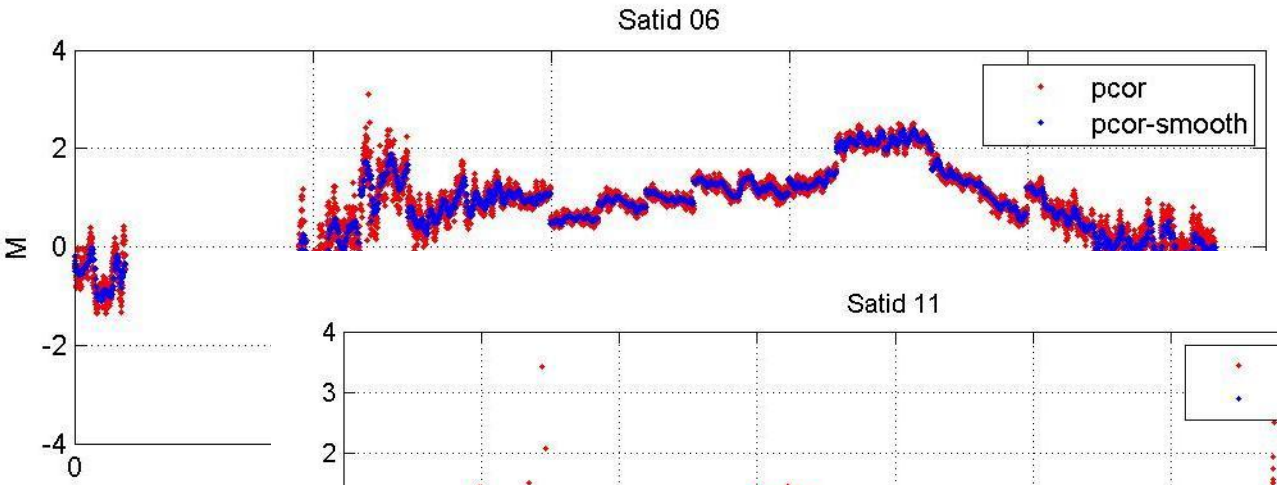
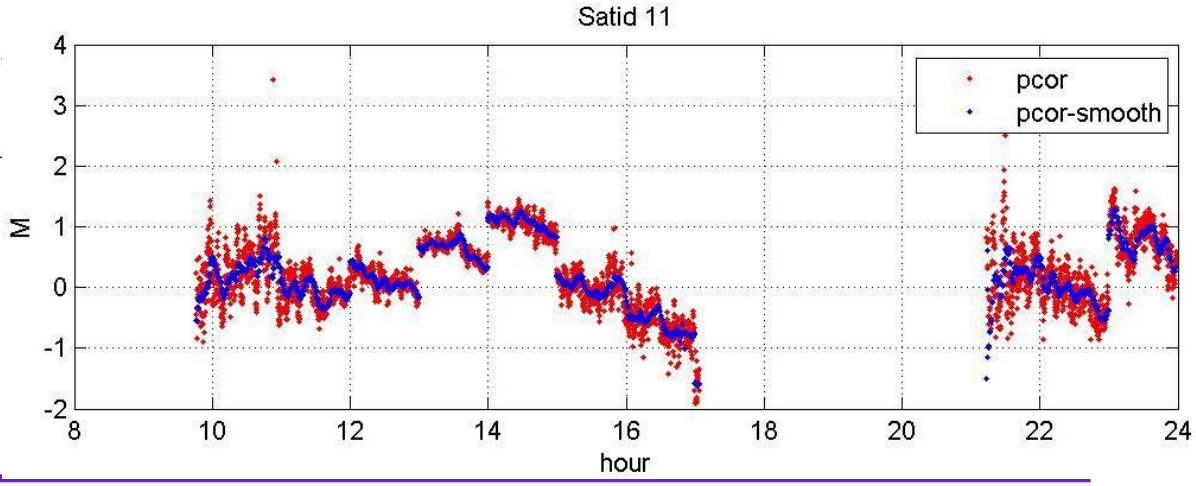
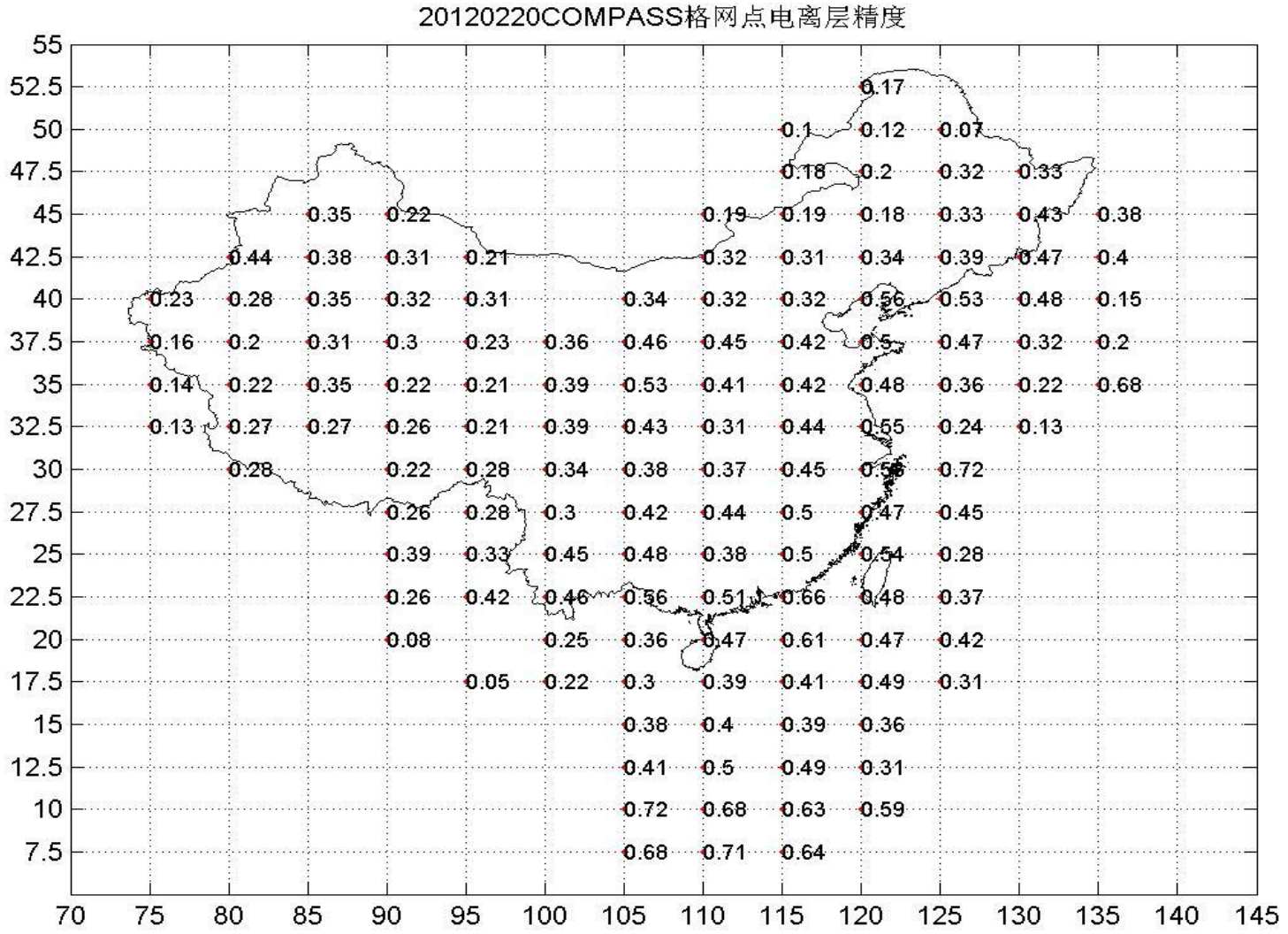




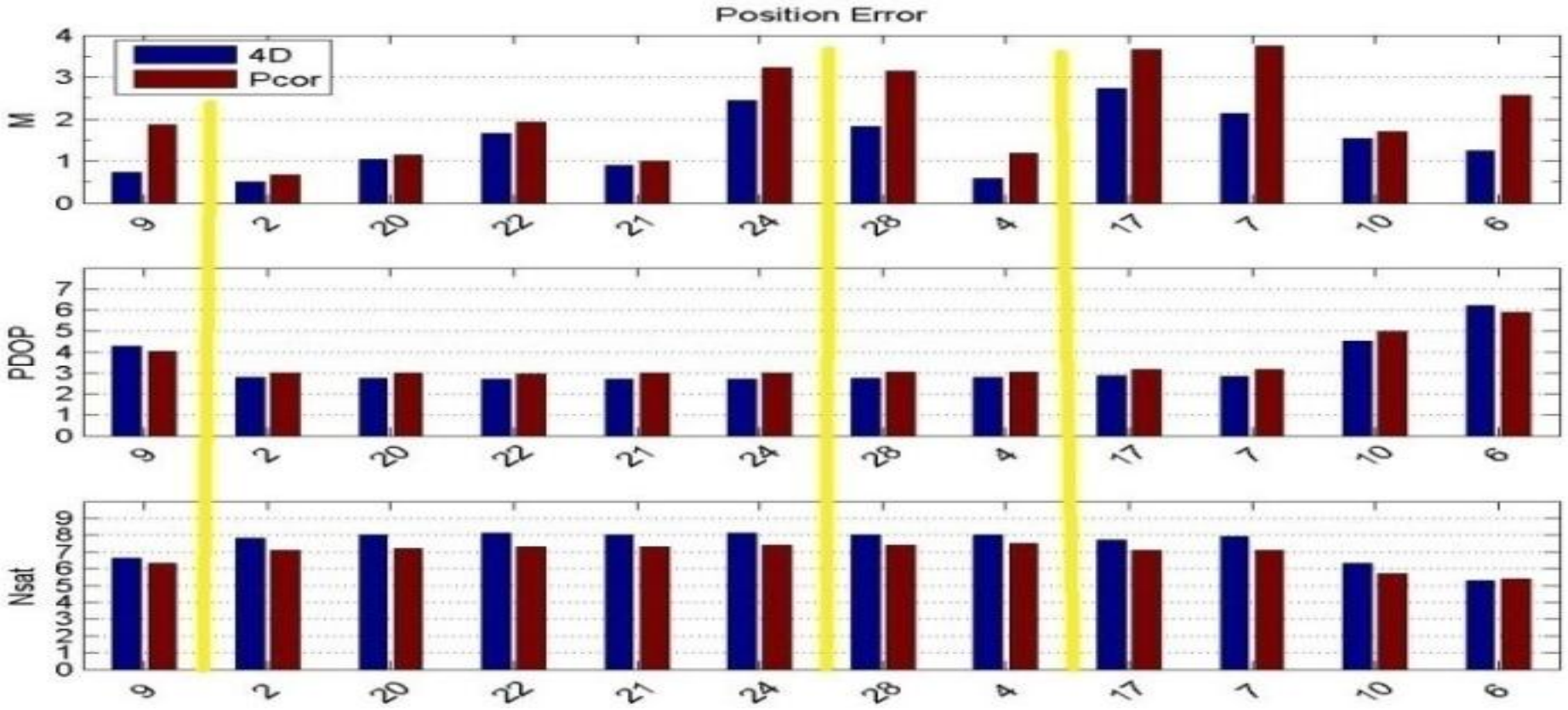
SBAS service of BDS

➢BDS: Ionospheric Grid



SBAS service of BDS

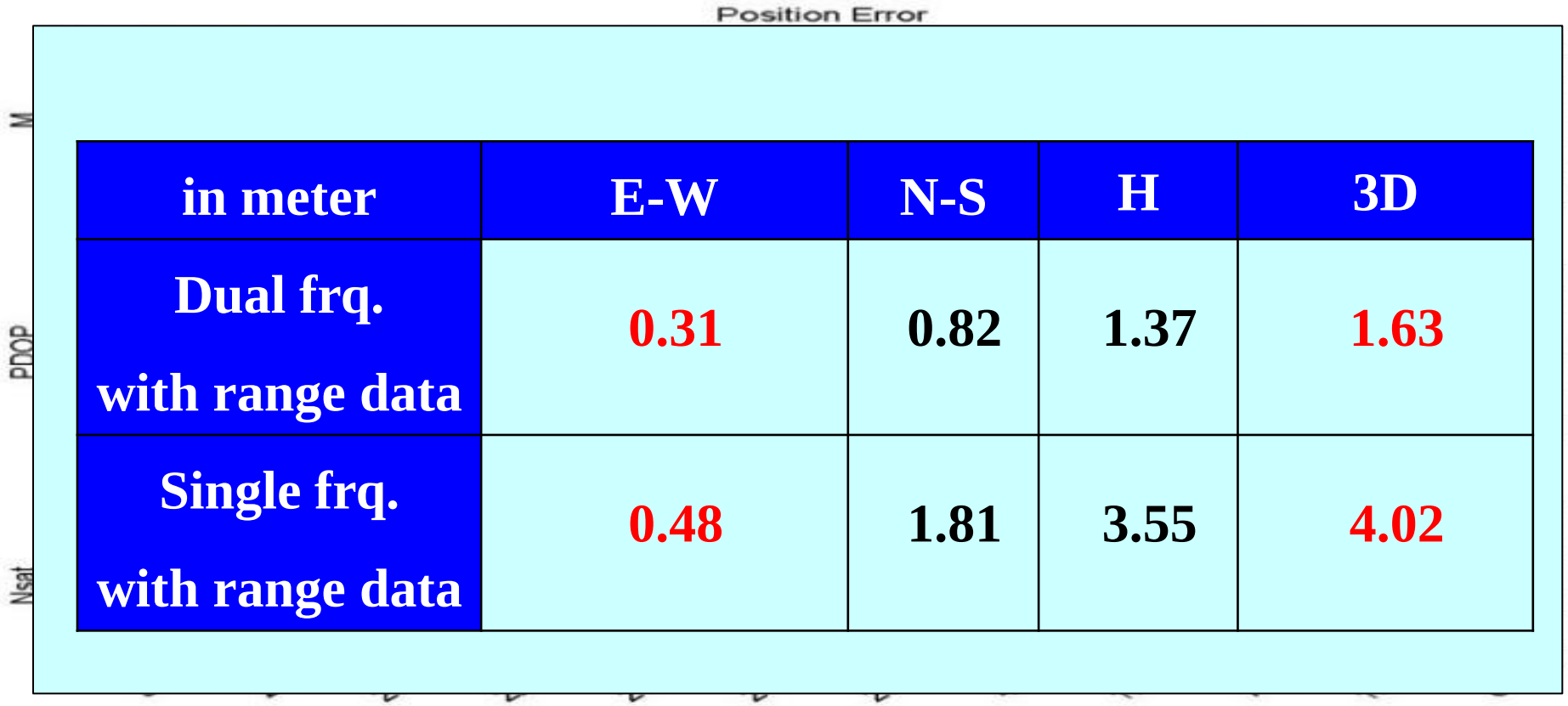
➢BDS: augmentation service precision



5° ×5°

SBAS service of BDS

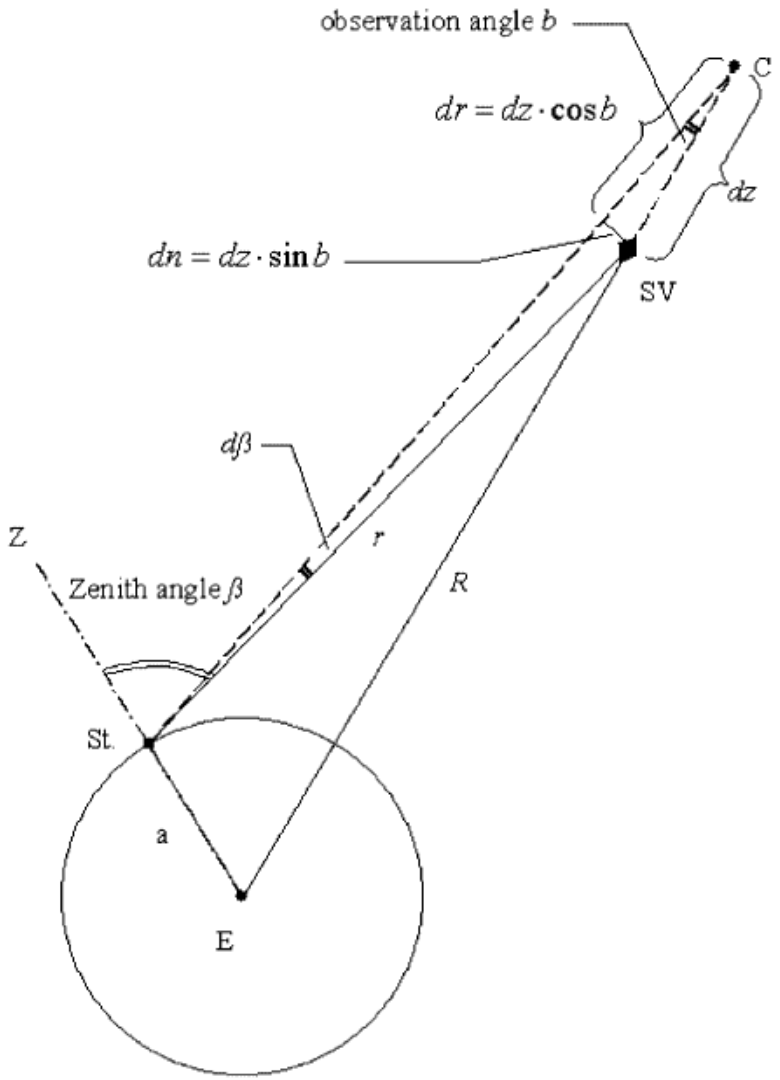
➢BDS: augmentation service precision



in meter	E-W	N-S	H	3D
Dual frq. with range data	0.31	0.82	1.37	1.63
Single frq. with range data	0.48	1.81	3.55	4.02

Challenges in SBAS performance improvement

➢Parameter de-correlation: orbits,clocks



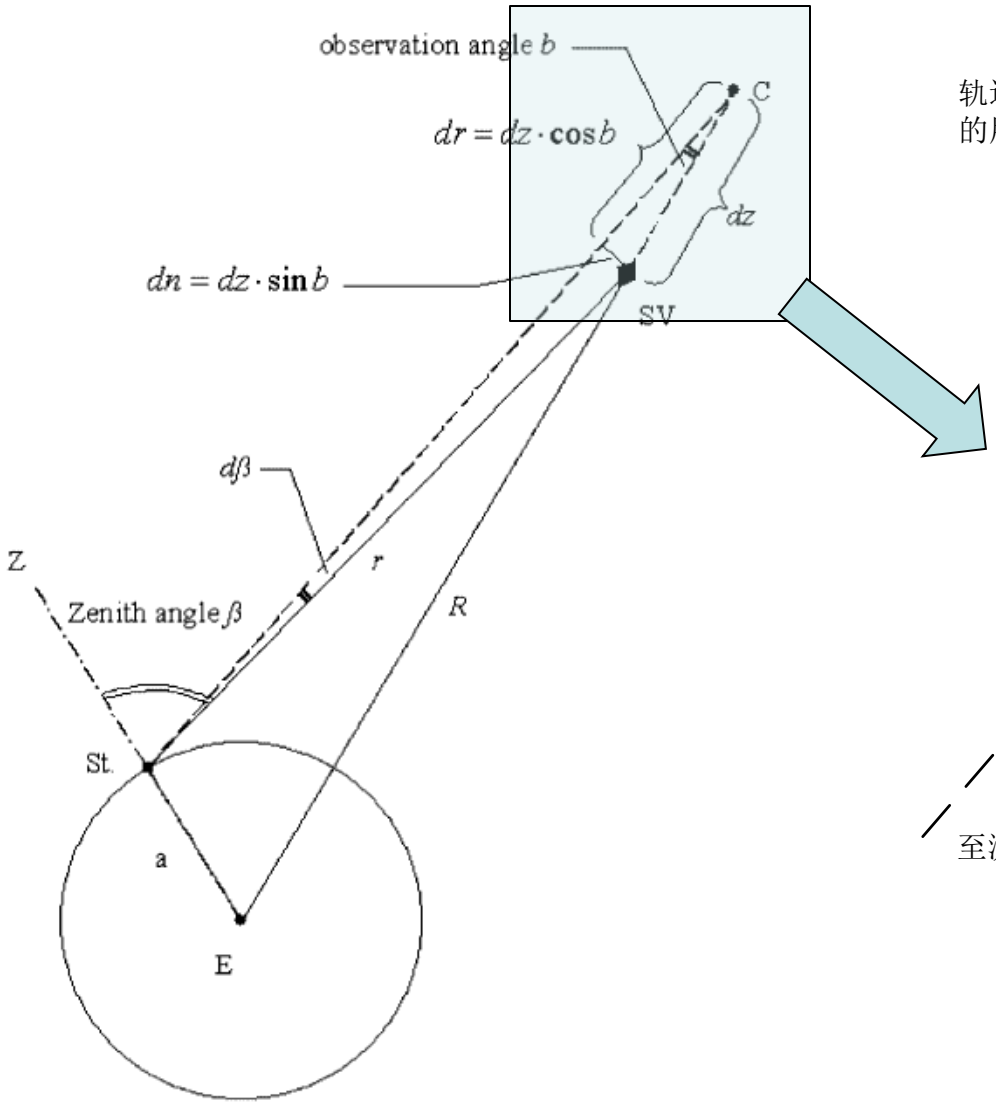
➢Augmentation information determined by regional tracking network

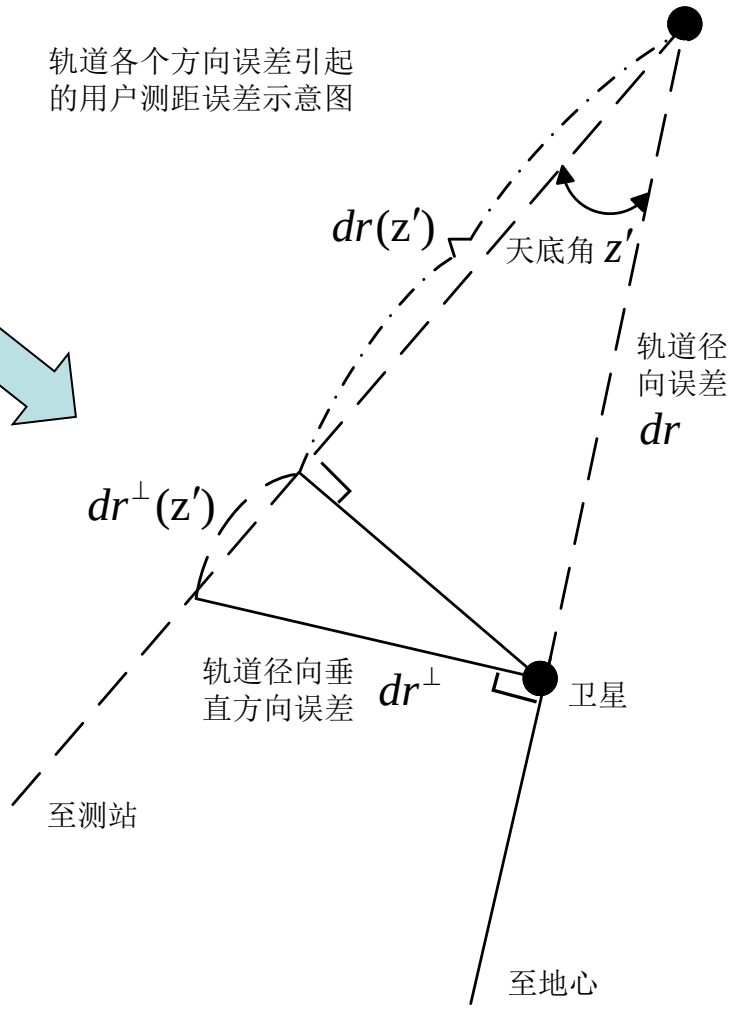
➢Geometry (kinematic) based strategy applied

➢Parameter de-correlation difficult

Challenges in SBAS performance improvement

➢Parameter de-correlation: orbits,clocks





Challenges in SBAS performance improvement

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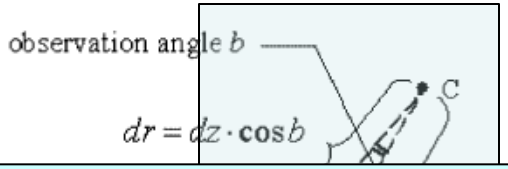
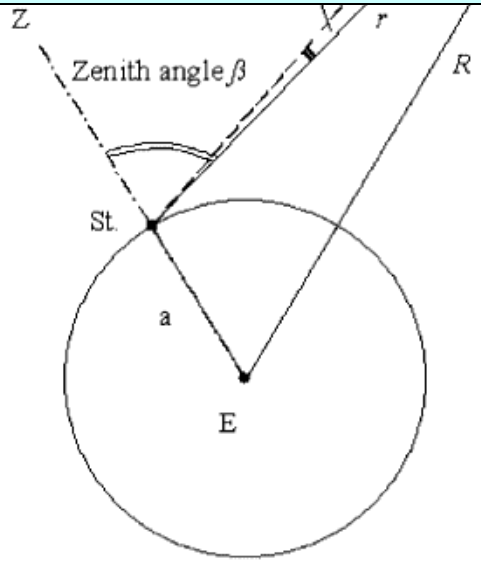
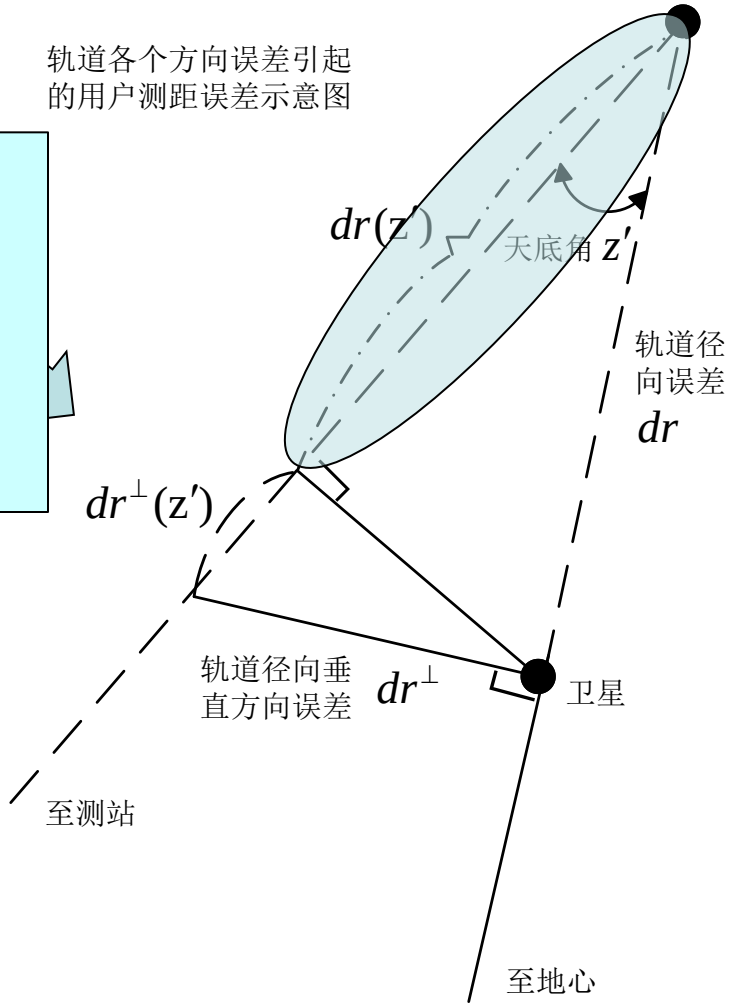


Radial orbit error on LOS

$$dr(z') = d\,r \cdot \cos z'$$



轨道各个方向误差引起的用户测距误差示意图



Challenges in SBAS performance improvement

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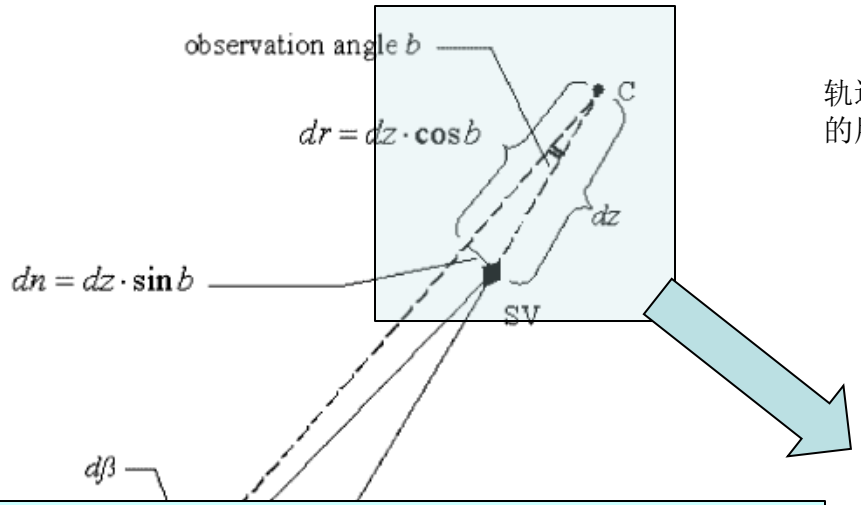
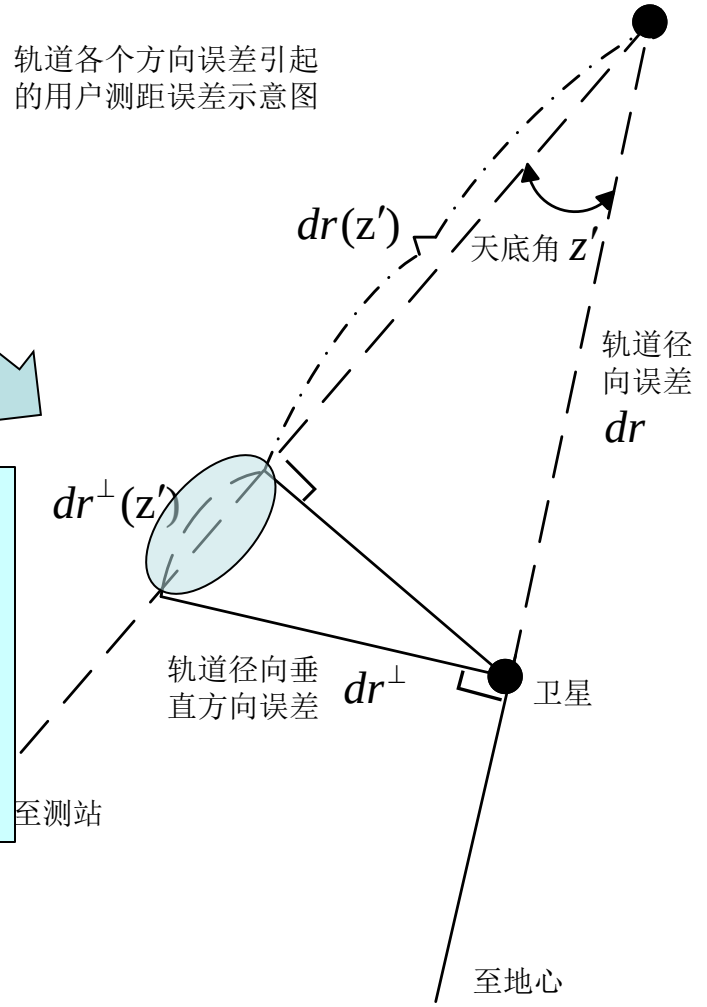


Non-radial orbit error on LOS

$$dr^{\perp}(z') = dr^{\perp} \cdot \sin(z')$$



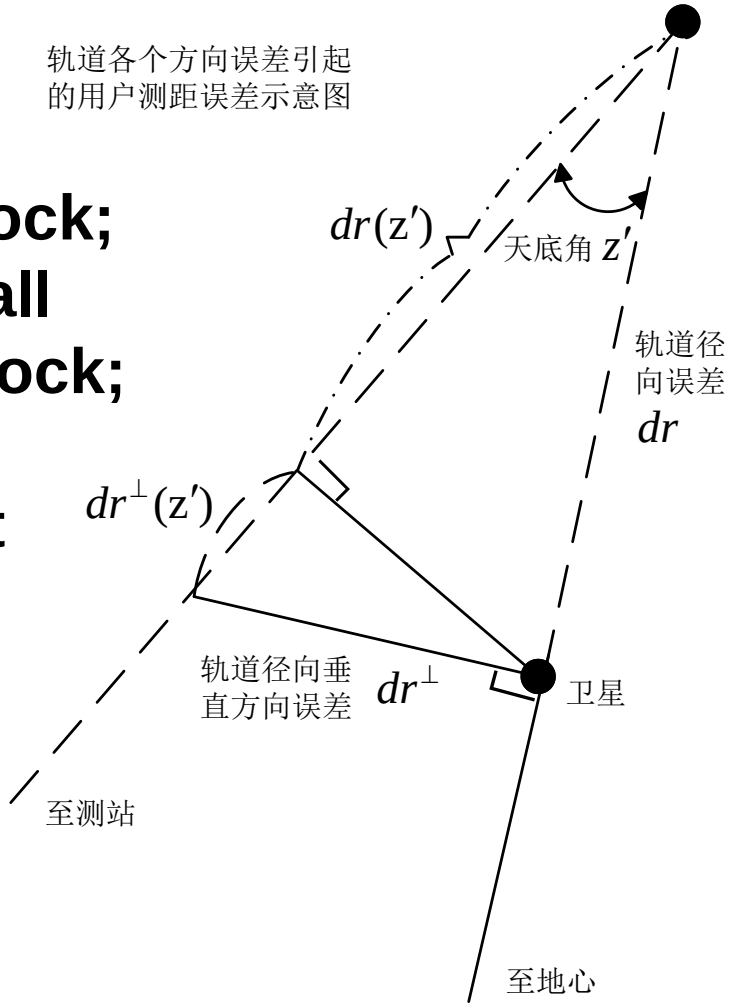
Challenges in SBAS performance improvement

➢Impacts of orbit/clock errors on line of sight observation

Satellite clock/radial orbit error highly correlated with station clock;
Mean clock/radial orbit error of all satellites absorbed by station clock;

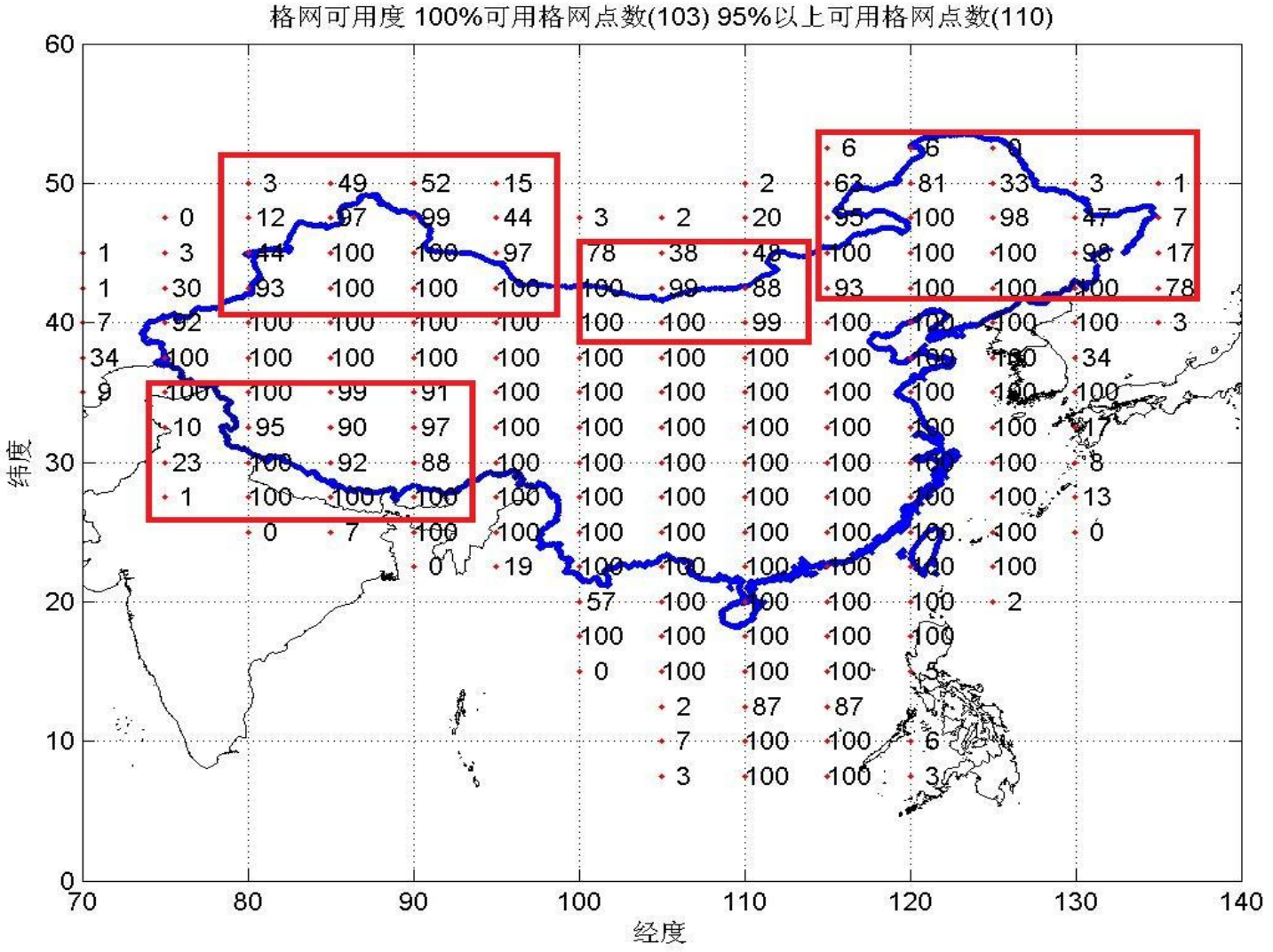
Final impact of clock/radial orbit error on LOS observation is:

$$\Delta dr(z') = d\,r \cdot (1 - \cos z')$$



Challenges in SBAS performance improvement

➢Ionosphere Grids



Challenges in SBAS performance improvement

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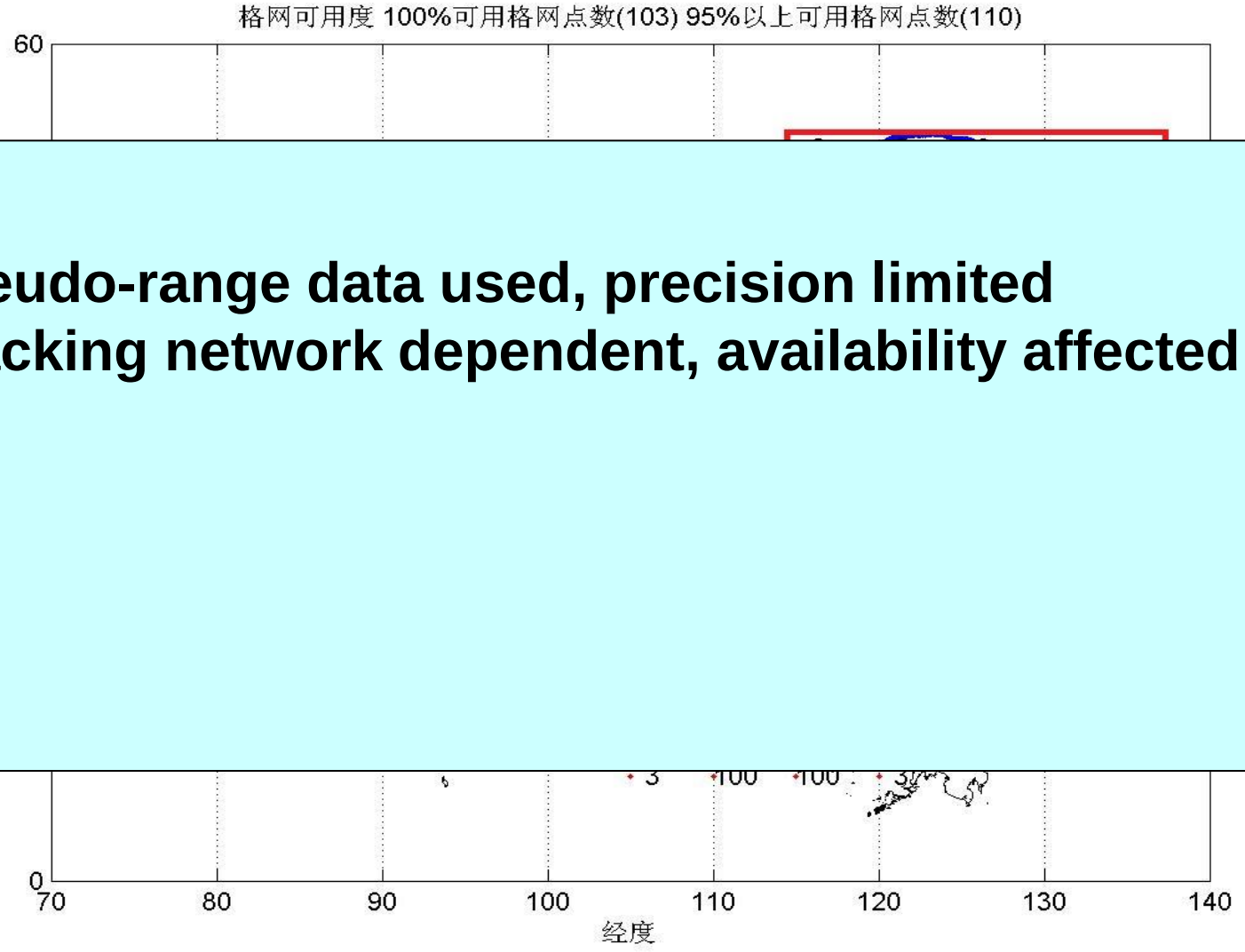


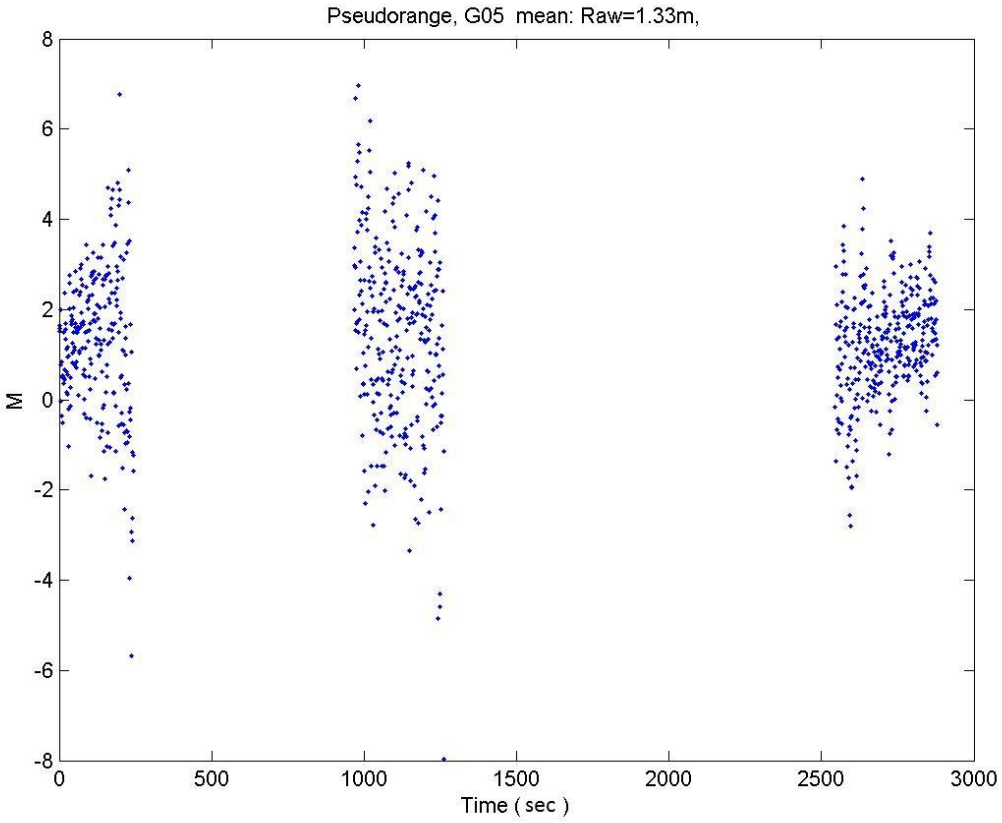
- **Pseudo-range data used, precision limited**
- **tracking network dependent, availability affected**

Zone correction: for decimeter level SBAS

➢Augmentation system corrections

Pseudo-range based corrections: large noise

Range-phase combined corrections: smooth and small noise



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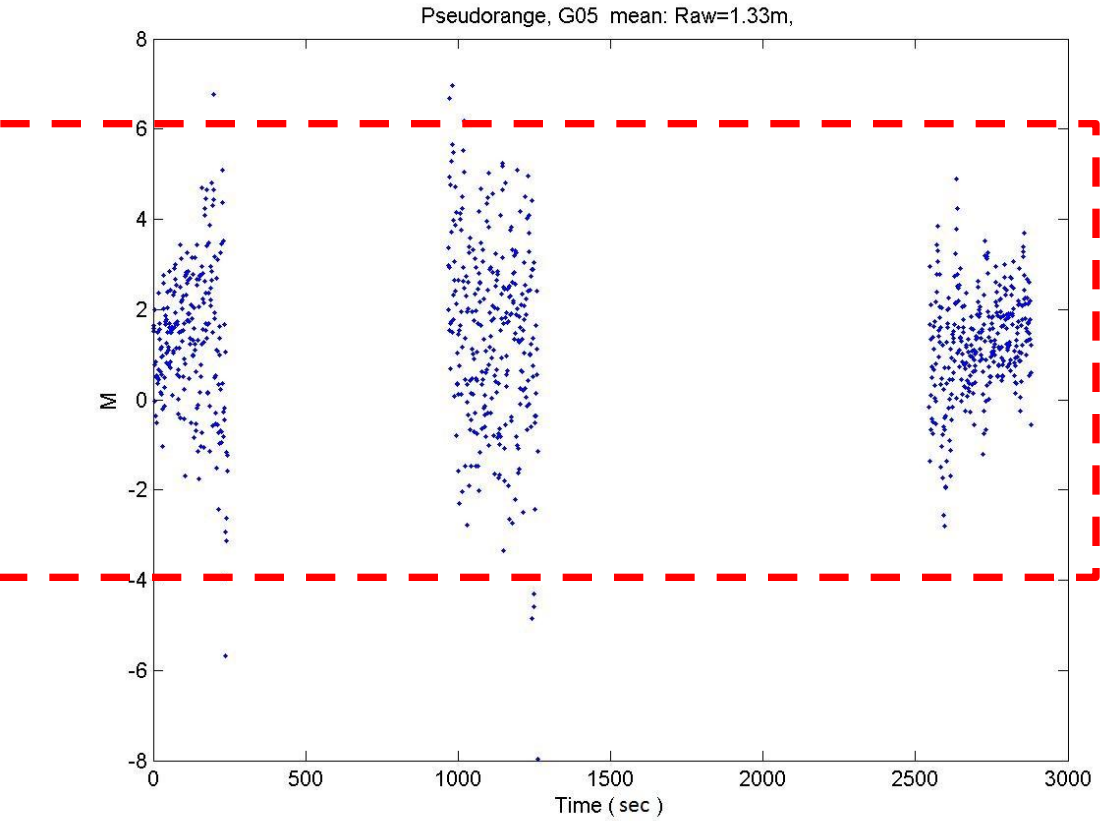

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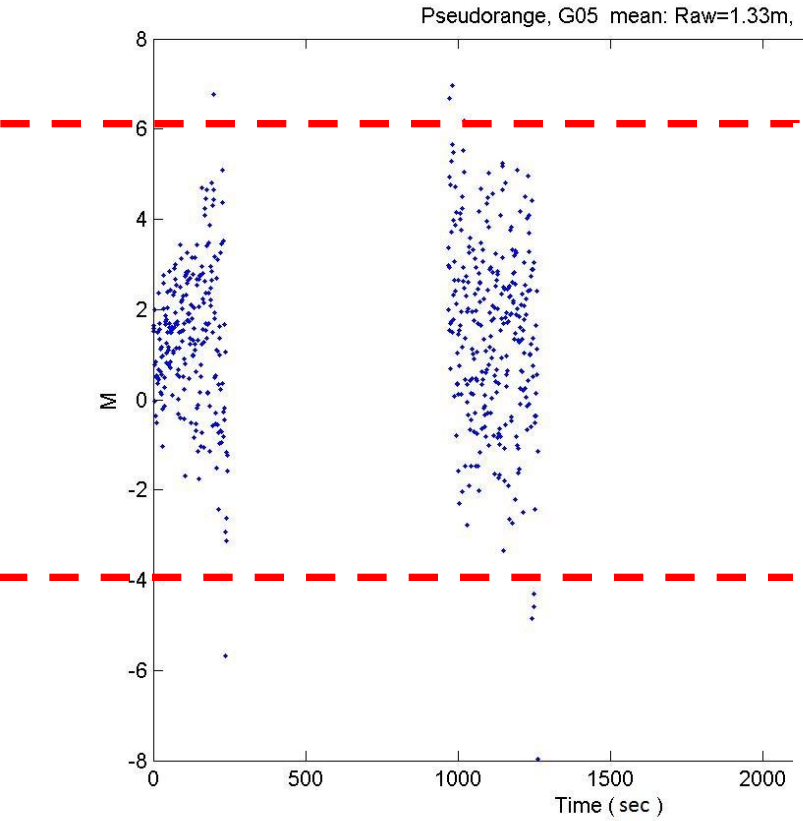
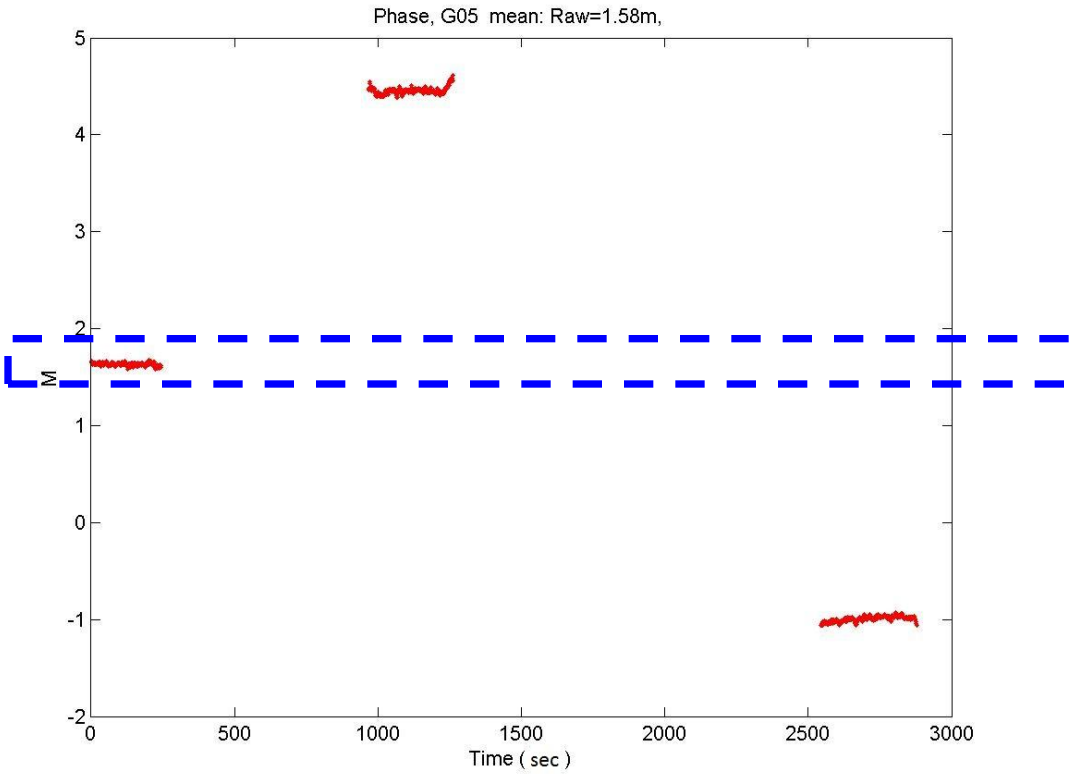




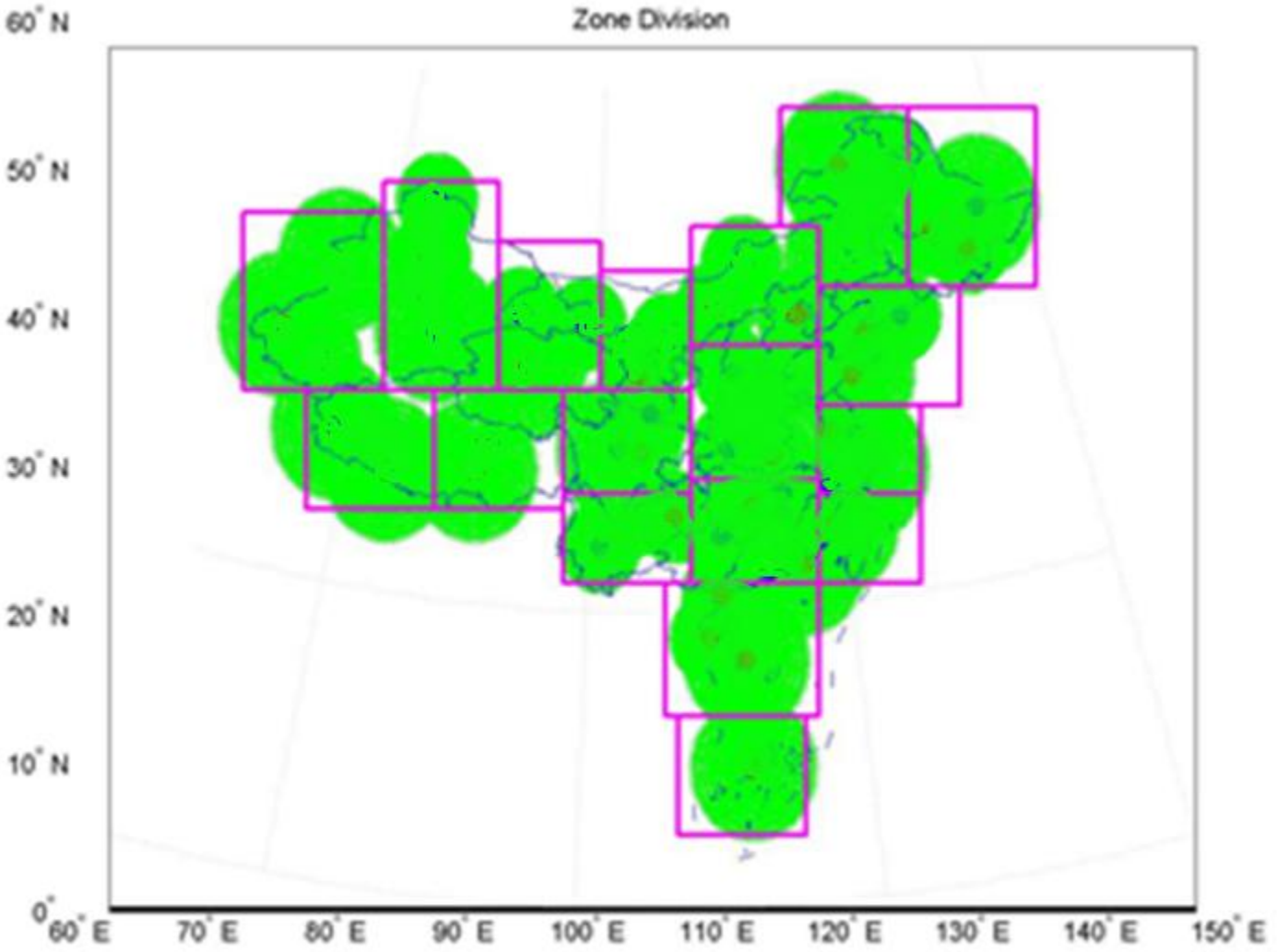
Zone correction: for decimeter level SBAS

➢Augmentation system corrections

Zone-correction (Chen et al. 2015) is defined as the augmentation information (including for pseudo-range and phase observations) for a zone covering up to 1000×1000 Km. It represents the errors introduced by mis-modeled orbits, clocks, troposphere and ionosphere etc.

Zone correction: for decimeter level SBAS

- **Augmentation system corrections**

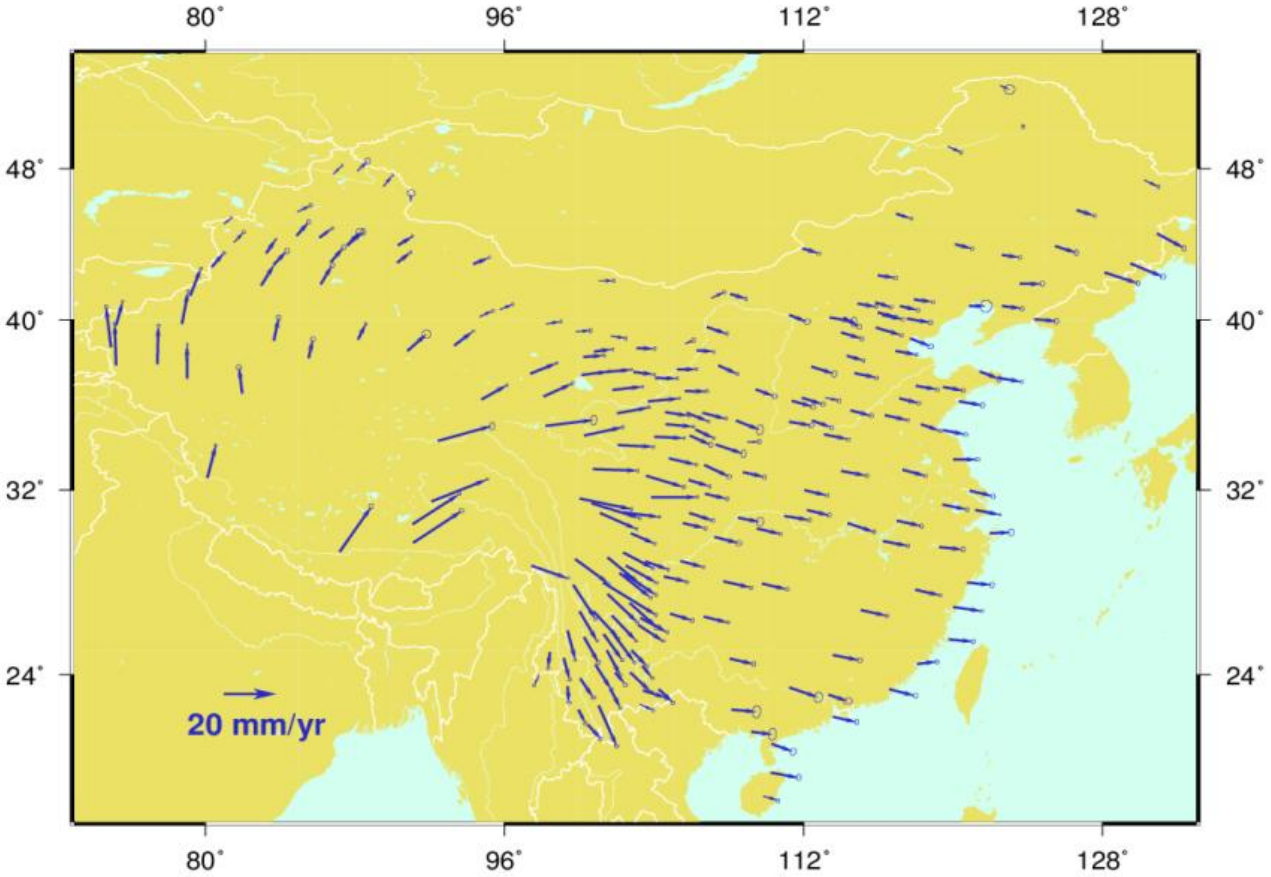


Design of demonstration system

- Real-time data of GNSS reference stations in China used to calculate augmentation information, namely the long-term correction, fast correction, and zone-correction.
- Augmentation information is broadcast to users through simulated streams.
- User stations apply the augmentation information and perform real-time kinematic PPP using pseudo-range and phase observations to derive their positions.

Data sets

- **Network**: Crustal Movement Observation Network of China (CMONOC)
- 20 well distributed stations as reference stations
- the other 240 stations are used for user positioning tests

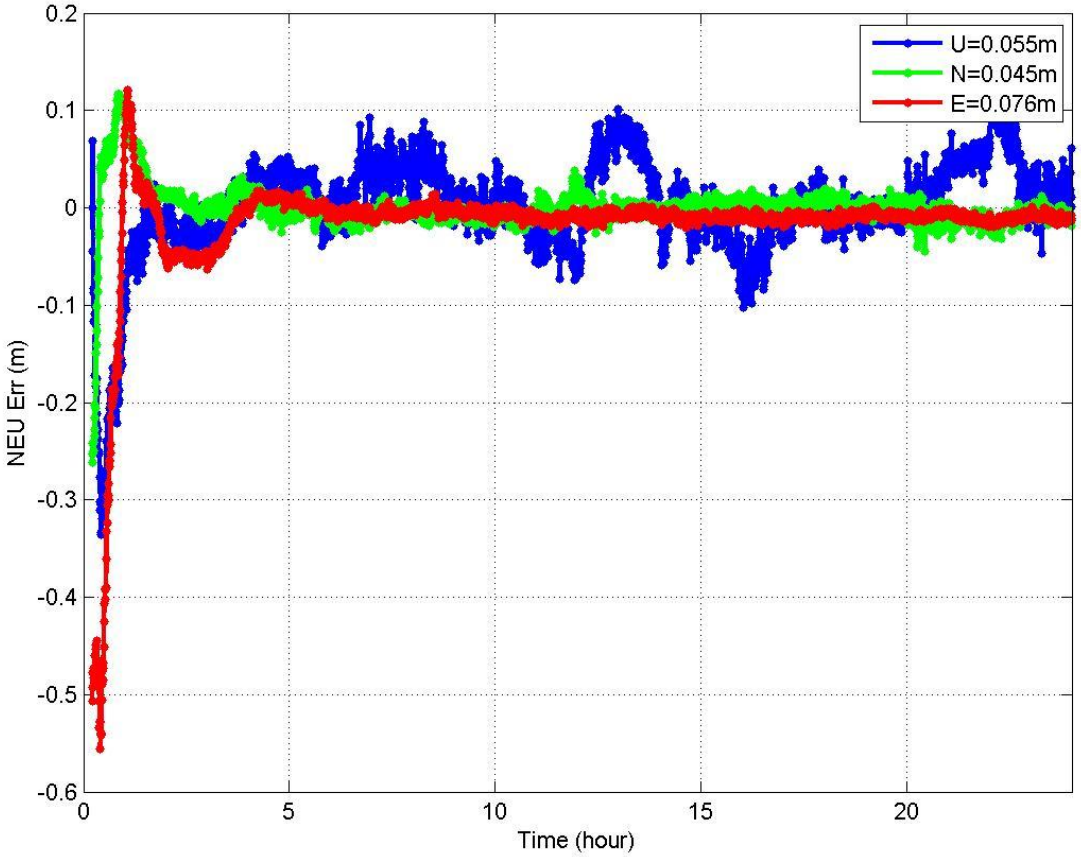


Evaluation of new augmentation information

➢User kinematic PPP: phase+range

Few epochs converged to precision better than 1m

Mean position precision better than 0.1 meter



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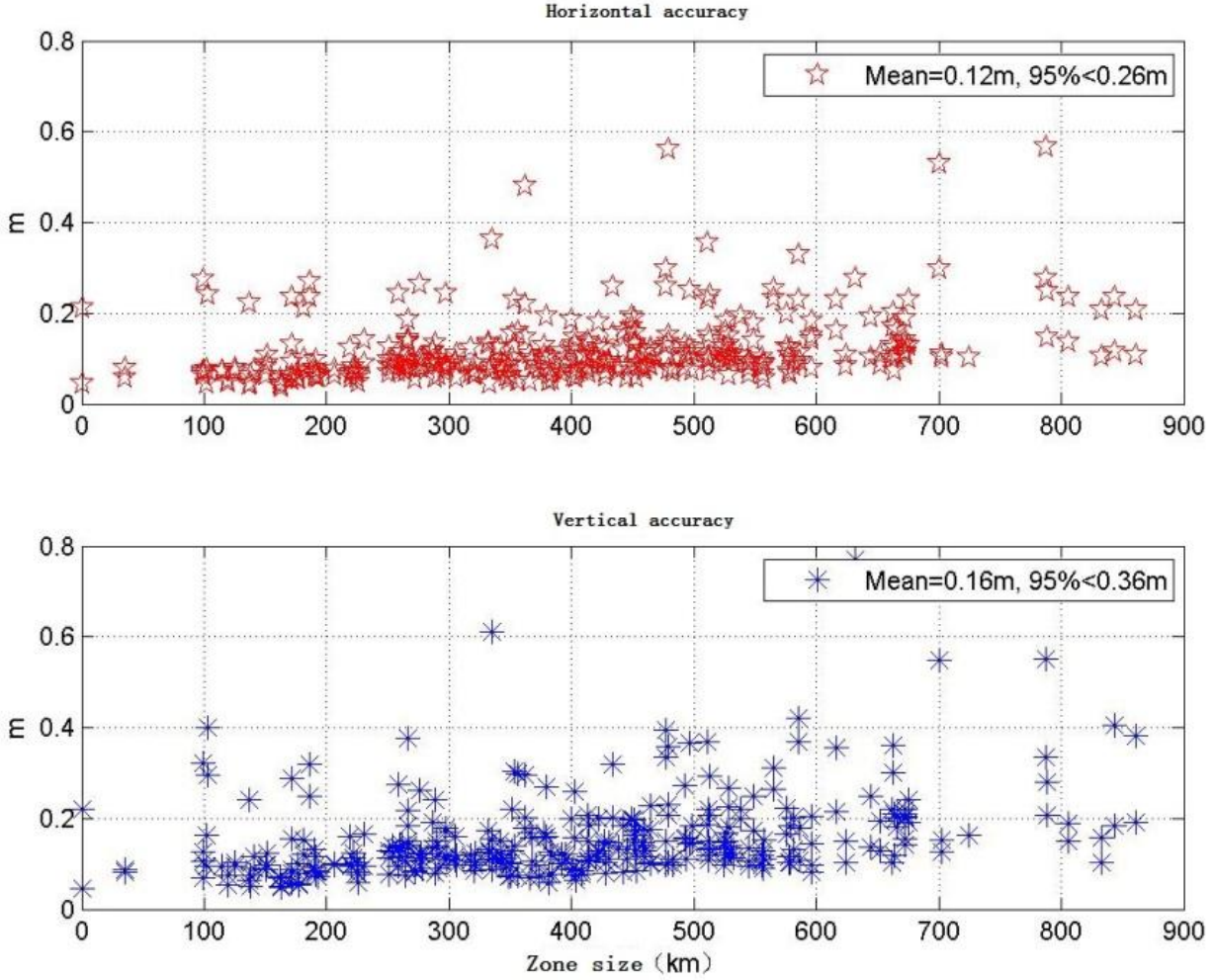
➢User kinematic PPP: phase+range

Positioning precision increased with distance from zone center



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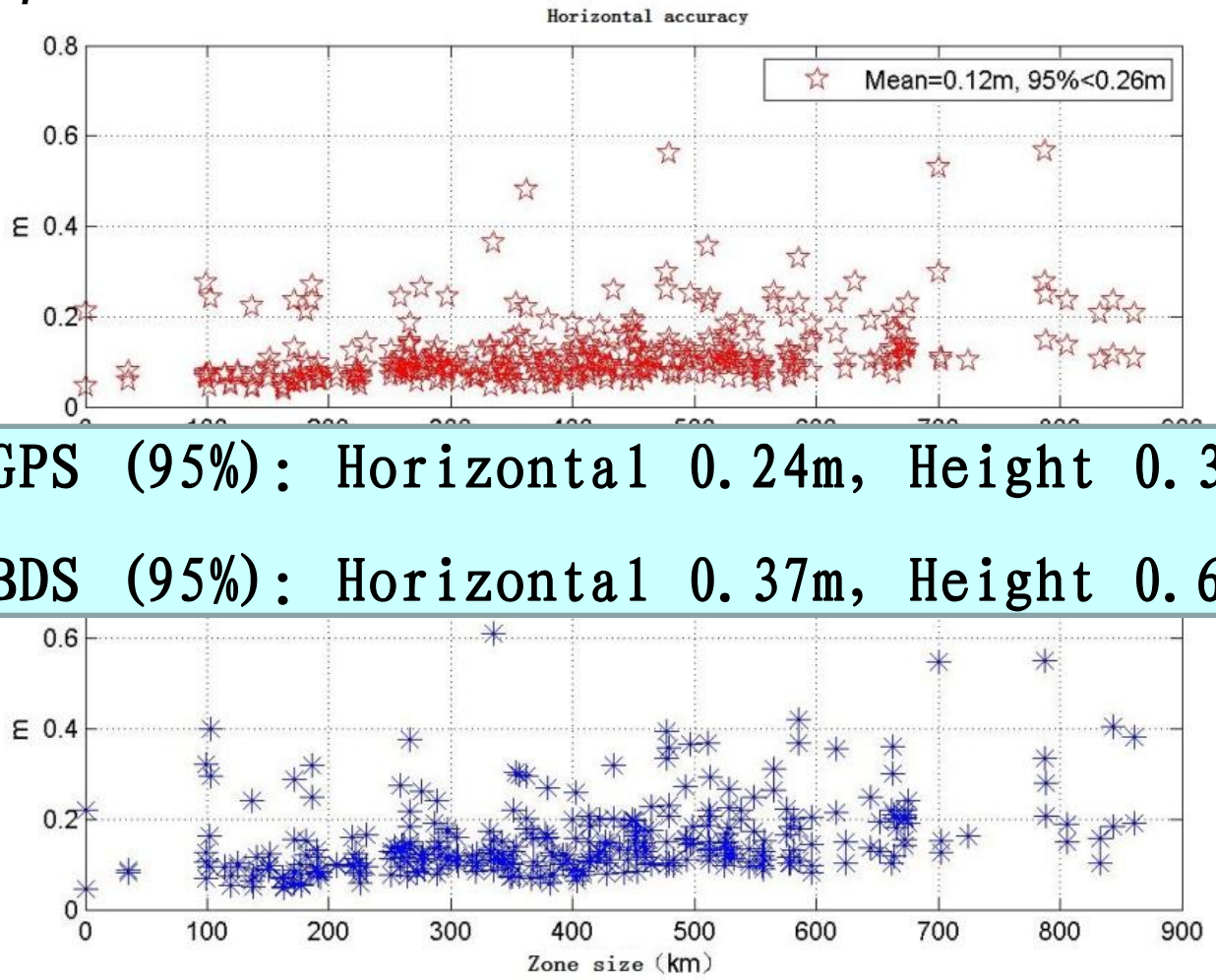
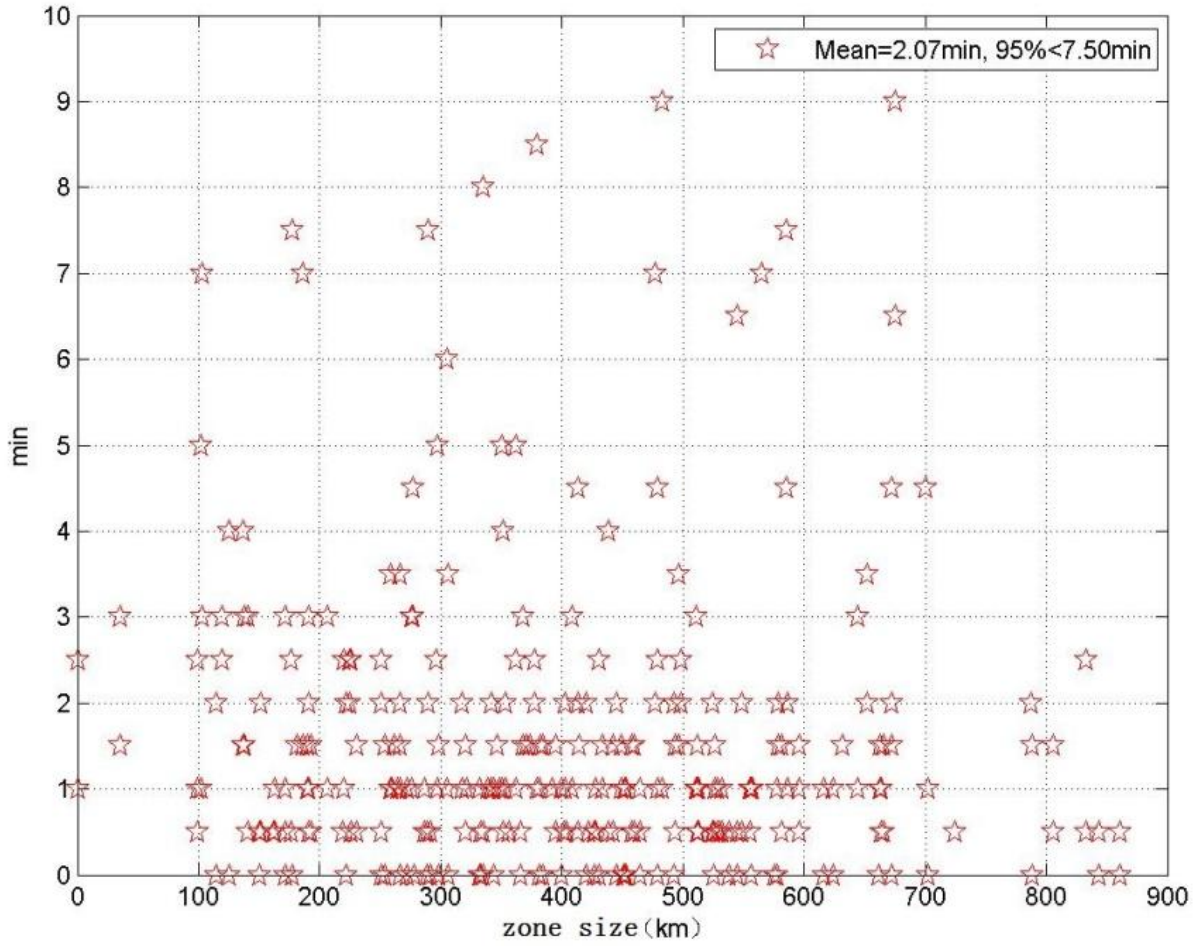


- GPS (95%): Horizontal 0.24m, Height 0.31m
- BDS (95%): Horizontal 0.37m, Height 0.62m

Evaluation of new augmentation information

➢User kinematic PPP: phase+range

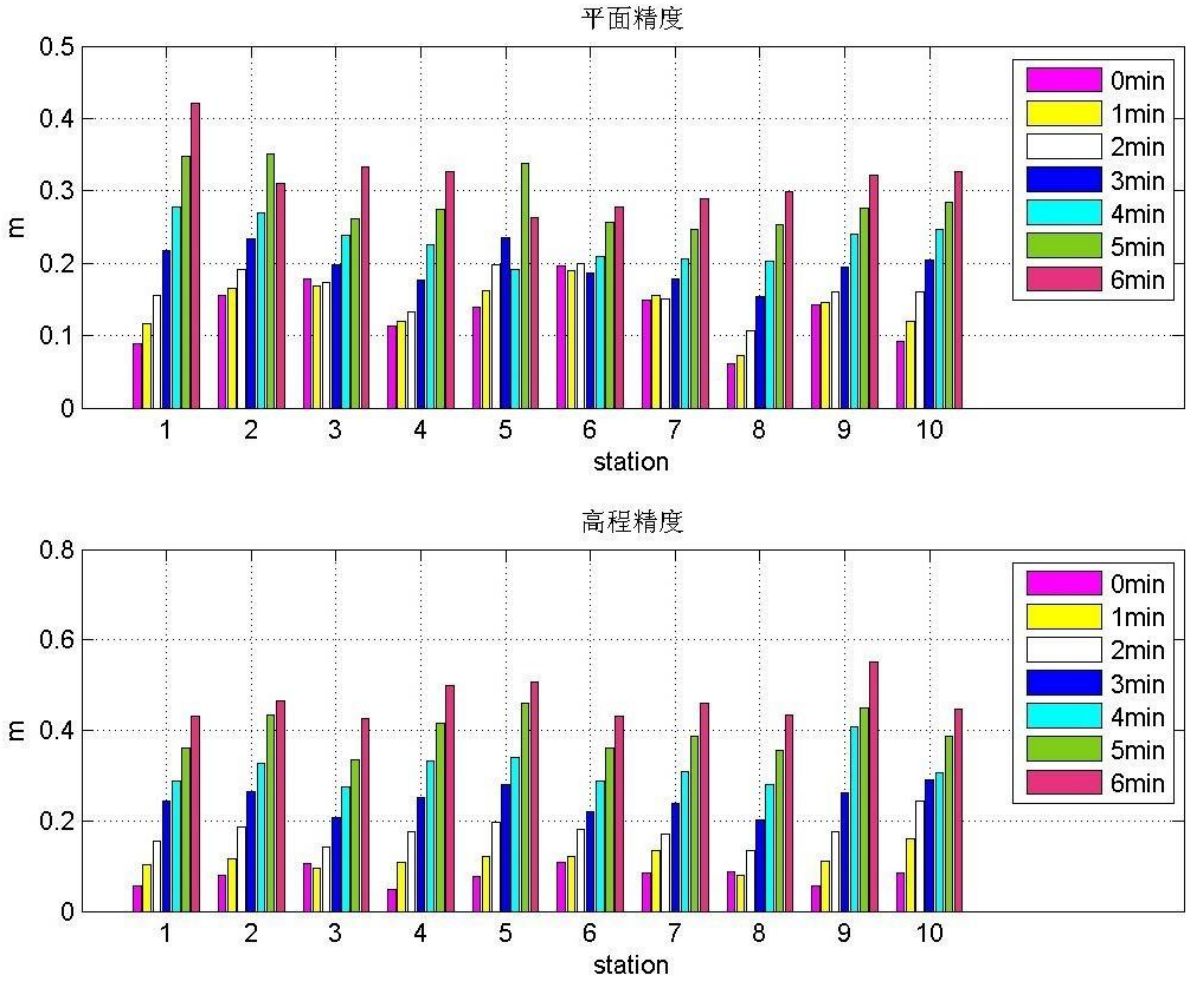
Convergence time: mean < 2min; 95%< 7.5min



Evaluation of new augmentation information

➢Broadcast Latency *vs* Positioning precision

Positioning precision decreased due to prediction error



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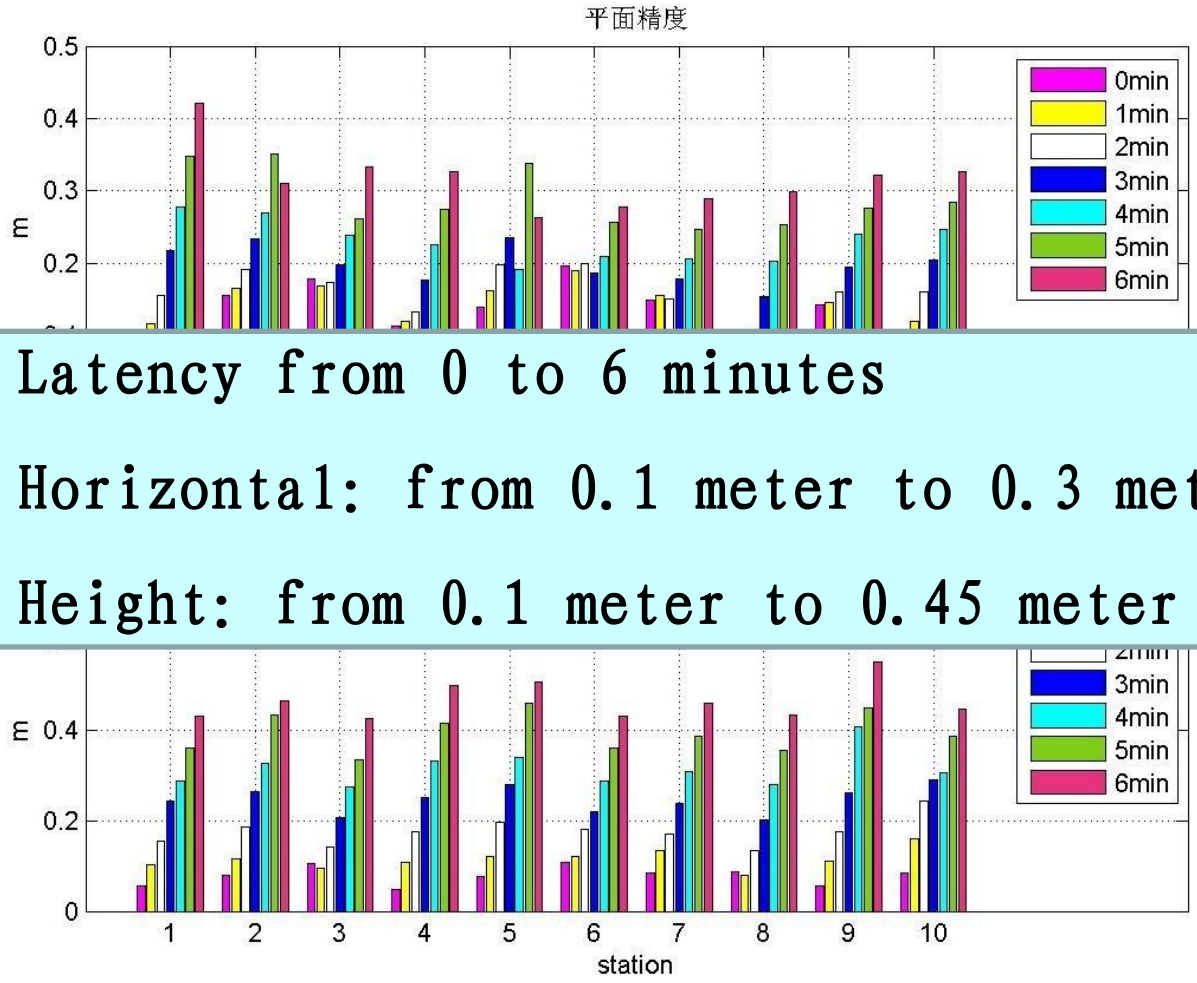
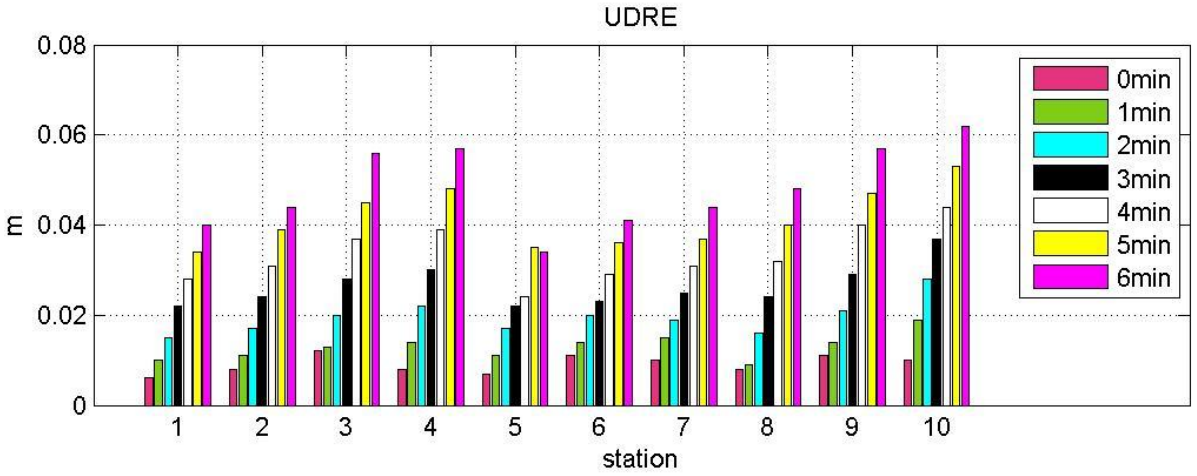


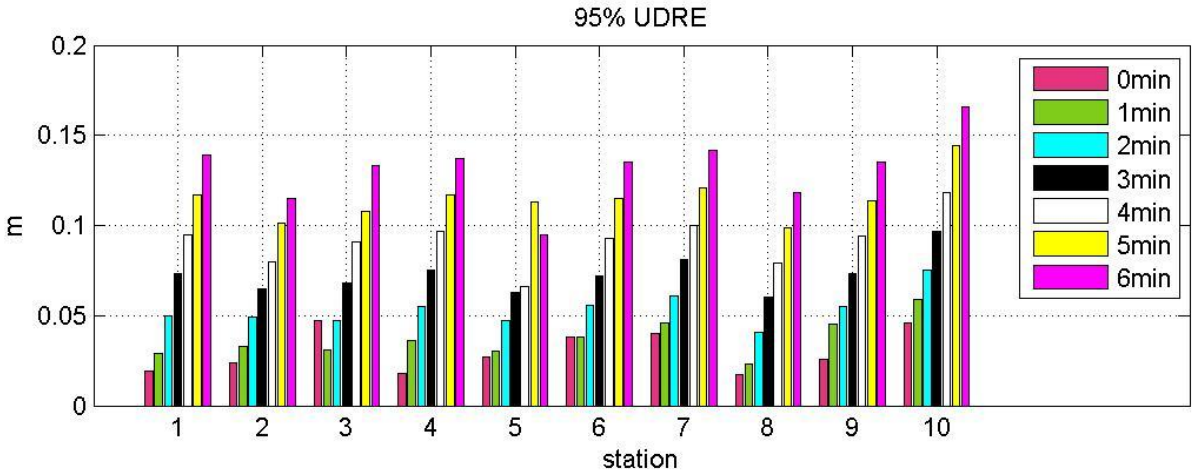
- Latency from 0 to 6 minutes
- Horizontal: from 0.1 meter to 0.3 meter
- Height: from 0.1 meter to 0.45 meter

Evaluation of new augmentation information

➢**Broadcast Latency** *vs* **Positioning precision**

Positioning precision decreased due to prediction error





Evaluation of new augmentation information

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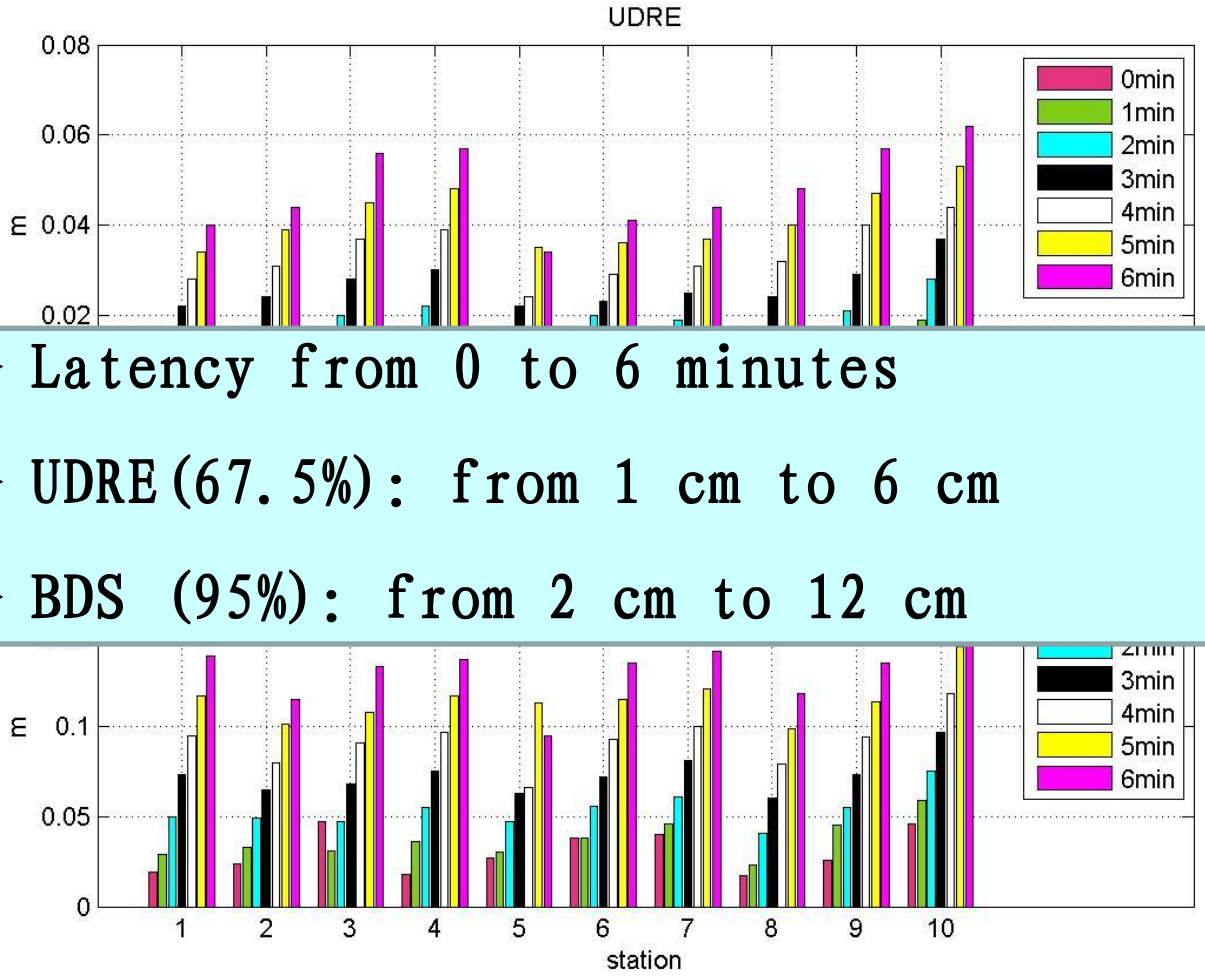

- Latency from 0 to 6 minutes
- UDRE(67.5%): from 1 cm to 6 cm
- BDS (95%): from 2 cm to 12 cm

Summary

- Review of current SBAS status and their challenges in performance improvement.

- Propose the zone correction as a new type of SBAS augmentation information for decimeter level accuracy.

We are aiming at improving SBAS service with the goal of better than 0.2 meter UDRE.

- Demonstration system introduced and results are presented.

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