



Extended Filter For Real-time Multi-GNSS Orbit Determination

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Background

Real-time orbits&clocks

Broadcast	R(m)	T(m)	N(m)	3D(m)
GPS IIA	0.26	1.21	0.37	1.10
GPS IIR	0.14	1.04	0.42	0.52
GPS IIF	0.14	0.75	0.32	0.28
Galileo	0.63	2.65	2.29	1.62
BDS-I	0.50	2.42	1.31	0.87
BDS-M	0.50	2.42	1.31	0.87

Refer to igs.org and Montenbruck 2015



Background

Real-time orbits&clocks

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Ultra-Rapid (predicted half)	Accuracy		Latency	Updates
GPS	Orbits 5cm Clocks 1.5ns		Real time	UTC 03,09,15,21

Refer to igs.org and Montenbruck 2015



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Ultra-Rapid (predicted half)	Accuracy		Latency	Updates
GPS	Orbits 5cm		Real time	UTC
IGS-RTS	Accuracy		Latency	Updates
GPS	Orbits 5cm Clocks 8cm		Real time	-

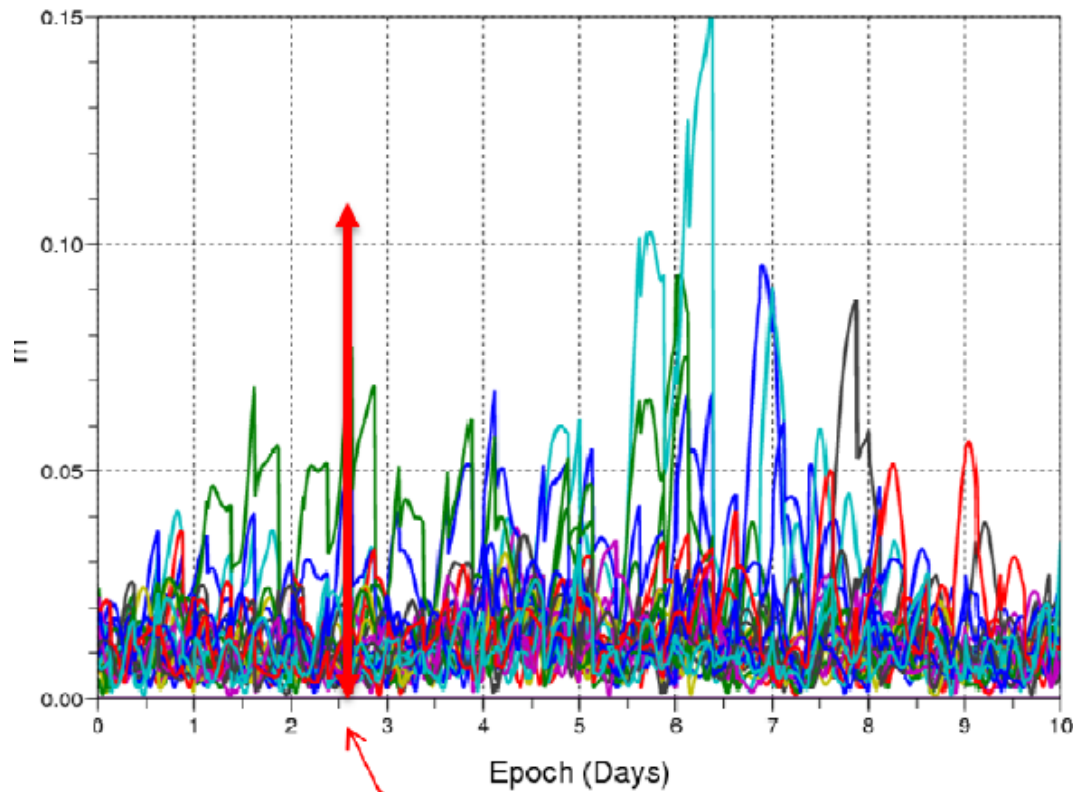
Refer to igs.org and Montenbruck 2015



Background

For eclipsing satellites, regional GNSS system, **orbits prediction accuracy suffers**

IGU [h+3,h+9] orbit error effect on measurements



Ambiguity wavelength

Refer to Laurichesse et al, 2013



Background

Requirement of Real-time orbit determination

- ◆ Attractive real-time applications, e.g., hazards monitoring, LEO orbit, troposphere & ionosphere
- ◆ Constellation performance monitoring
- ◆ **Improve Signal in space (SIS) accuracy.**

Advantage of Multi-GNSS

- ◆ More observations, better geometry, better precision, short convergence



Real-time processing

From post to real-time

◆ Data cleaning

Most post-processing algorithm cannot satisfy real-time data processing, single-difference combination are added.

◆ Ambiguity resolution

Future measurements are not available, ambiguities fixed at two consecutive epochs will be treated as known values.

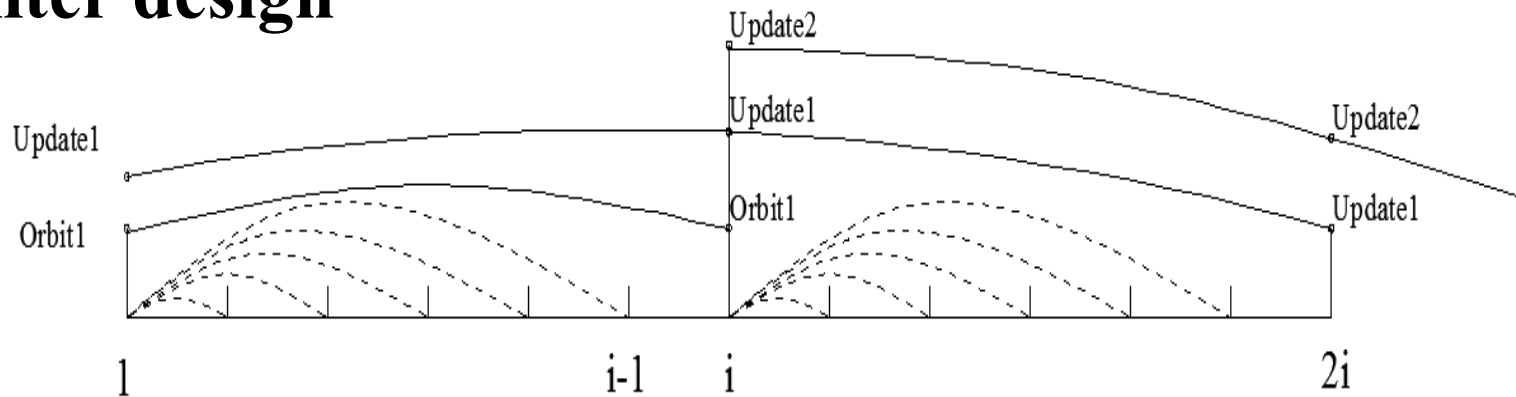
◆ Filter processing

LSQ method changed to a batch filter (**with capability to change update interval**)



Extend filter

Filter design



- **Filter update interval (arc length) is i epochs, all the linearizations are with respect to epoch 1;**
- **Update initial orbit at epoch 1 and extrapolate orbit and to epoch i ;**

i (arc length) can be chosen flexibly

◆ observation interval: the filter is a pure extended filter

◆ 3 days: filter results is the same as least square solution



Extend filter

Mathematics of the filter

- State vector

$$\begin{bmatrix} p \\ x \\ y \end{bmatrix}_{j+1} = \begin{bmatrix} M & 0 & 0 \\ V_p & V_x & V_y \\ 0 & 0 & I \end{bmatrix} \begin{bmatrix} p \\ x \\ y \end{bmatrix}_j + \begin{bmatrix} w_j \\ 0 \\ 0 \end{bmatrix}$$

Processing

Priori info

$$\hat{T}_{px} \begin{bmatrix} \tilde{R}_p & \tilde{R}_{px} & \tilde{R}_{py} & \tilde{z}_p \\ \tilde{R}_{xp} & \tilde{R}_x & \tilde{R}_{xy} & \tilde{z}_x \\ A_p & A_x & A_y & z \\ 0 & 0 & \tilde{R}_y & \tilde{z}_y \end{bmatrix} = \begin{bmatrix} \hat{R}_p & \hat{R}_{px} & \hat{R}_{py} & \hat{z}_p \\ 0 & \hat{R}_x & \hat{R}_{xy} & \hat{z}_x \\ 0 & 0 & \hat{A}_y & \hat{z} \\ 0 & 0 & \tilde{R}_y & \tilde{z}_y \end{bmatrix}$$

OBS Equ

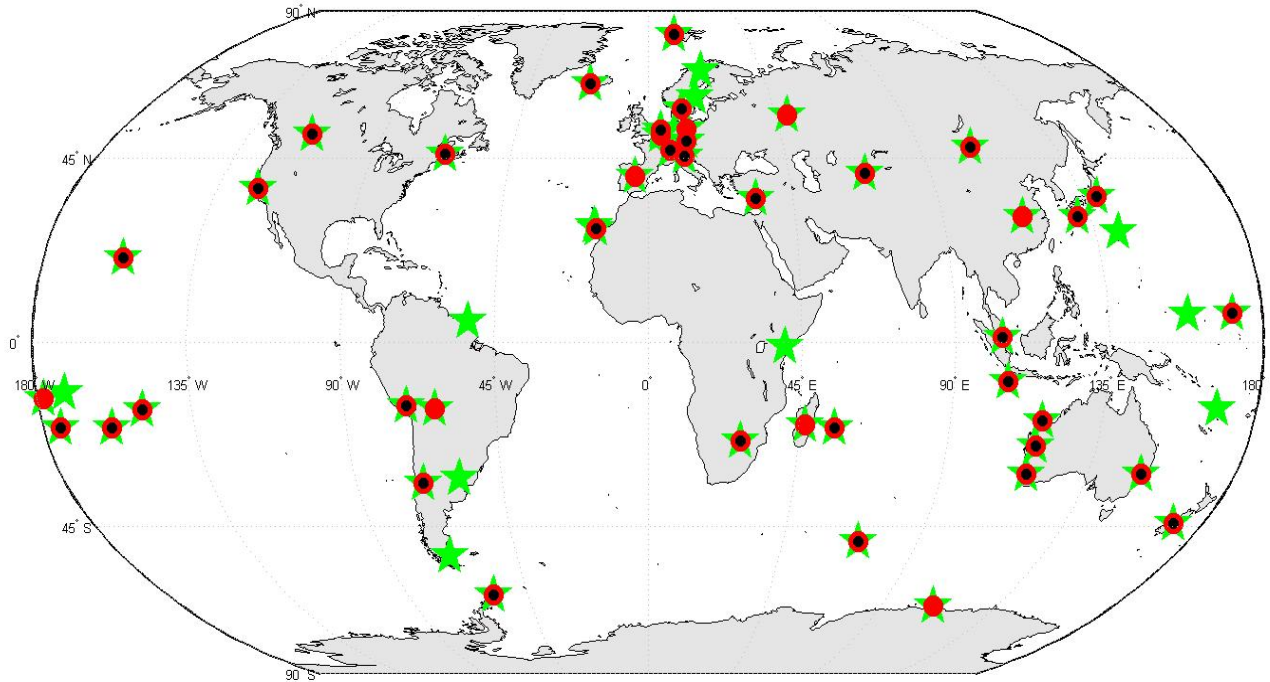
- Predict

$$T_p \begin{bmatrix} -R_w M & R_w & 0 & 0 \\ \hat{R}_p - (\hat{R}_{px} V_x^{-1}) V_p & 0 & (\hat{R}_{px} V_x^{-1}) & \hat{R}_{py} - (\hat{R}_{px} V_x^{-1}) V_y \\ \hat{R}_{xp} - (\hat{R}_x V_x^{-1}) V_p & 0 & (\hat{R}_x V_x^{-1}) & \hat{R}_{xy} - (\hat{R}_x V_x^{-1}) V_y \end{bmatrix} \begin{bmatrix} p_j \\ p_{j+1} \\ x_{j+1} \\ y \end{bmatrix} = \begin{bmatrix} z_w \\ \hat{z}_p \\ \hat{z}_x \end{bmatrix} - \begin{bmatrix} v_w \\ \hat{v}_p \\ \hat{v}_x \end{bmatrix} \rightarrow \begin{bmatrix} R_p^* & R_{pp}^* & R_{px}^* & R_{py}^* \\ 0 & \tilde{R}_p & \tilde{R}_{px} & \tilde{R}_{py} \\ 0 & \tilde{R}_{xp} & \tilde{R}_x & \tilde{R}_{xy} \end{bmatrix} \begin{bmatrix} p_j \\ p_{j+1} \\ x_{j+1} \\ y \end{bmatrix} = \begin{bmatrix} z_p^* \\ \hat{z}_p \\ \hat{z}_x \end{bmatrix} - \begin{bmatrix} v_p^* \\ \hat{v}_p \\ \hat{v}_x \end{bmatrix}$$



Real-time processing

Data information

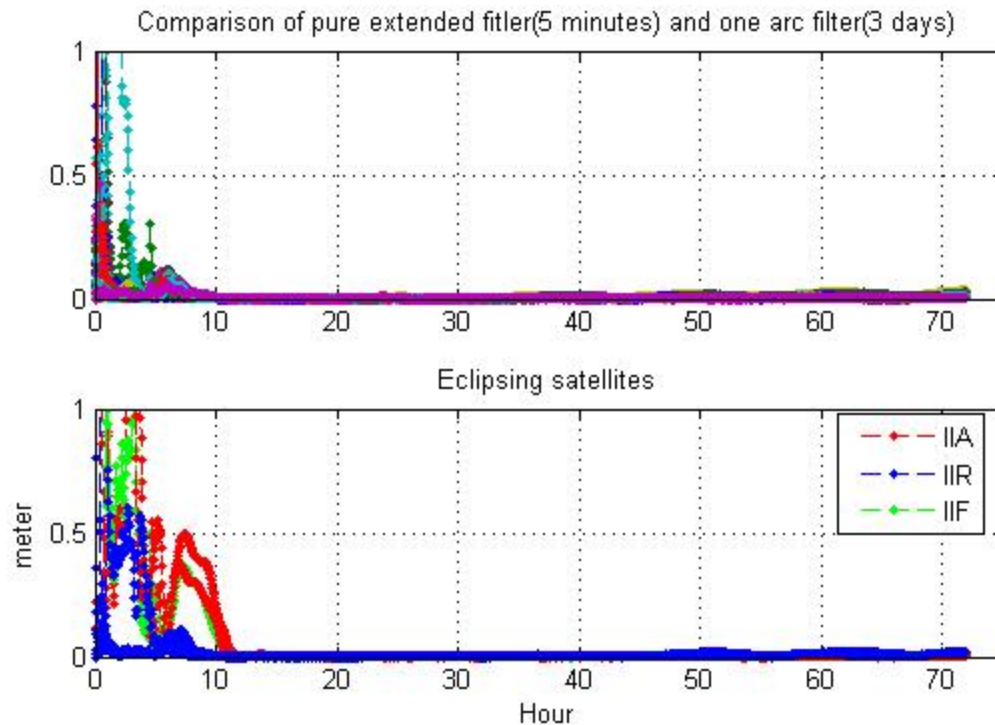


Data source : MGEX, 60 GPS sites, Green color stars
45 Galileo sites, Red color circles
36 Beidou sites, black color points



Real-time processing

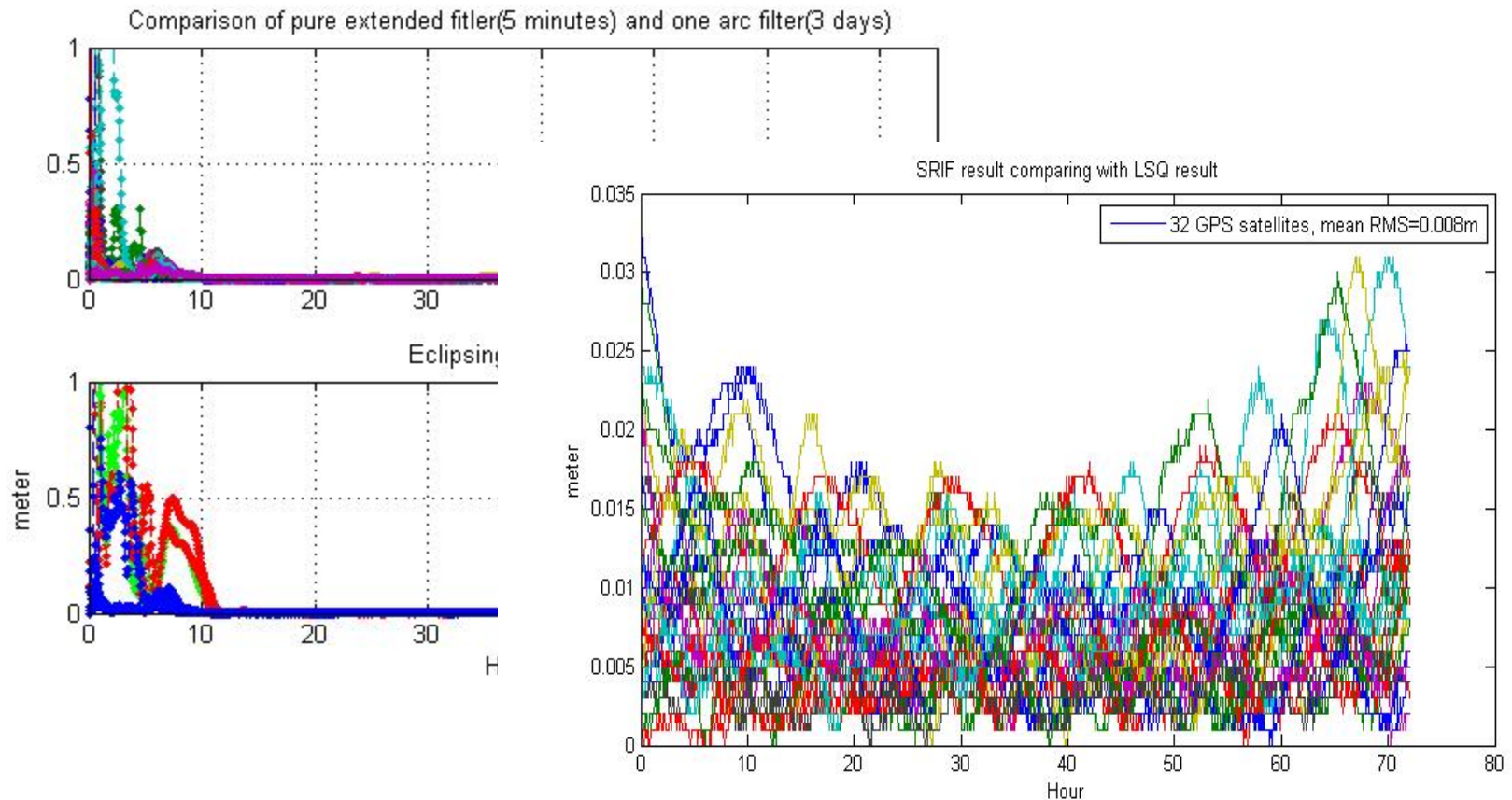
Comparison between Filter with different interval and LSQ result





Real-time processing

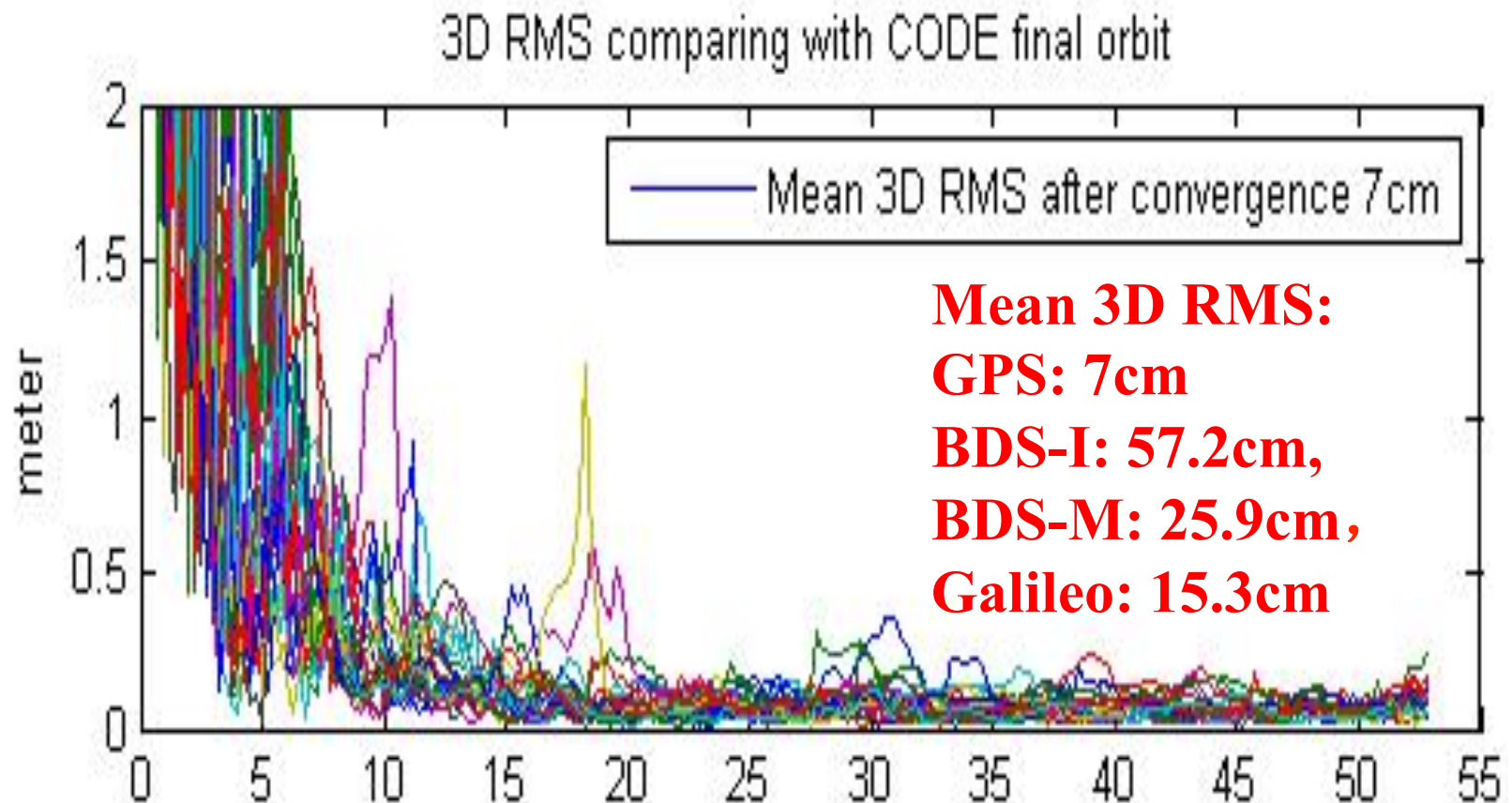
Comparison between Filter with different interval and LSQ result





Real-time processing

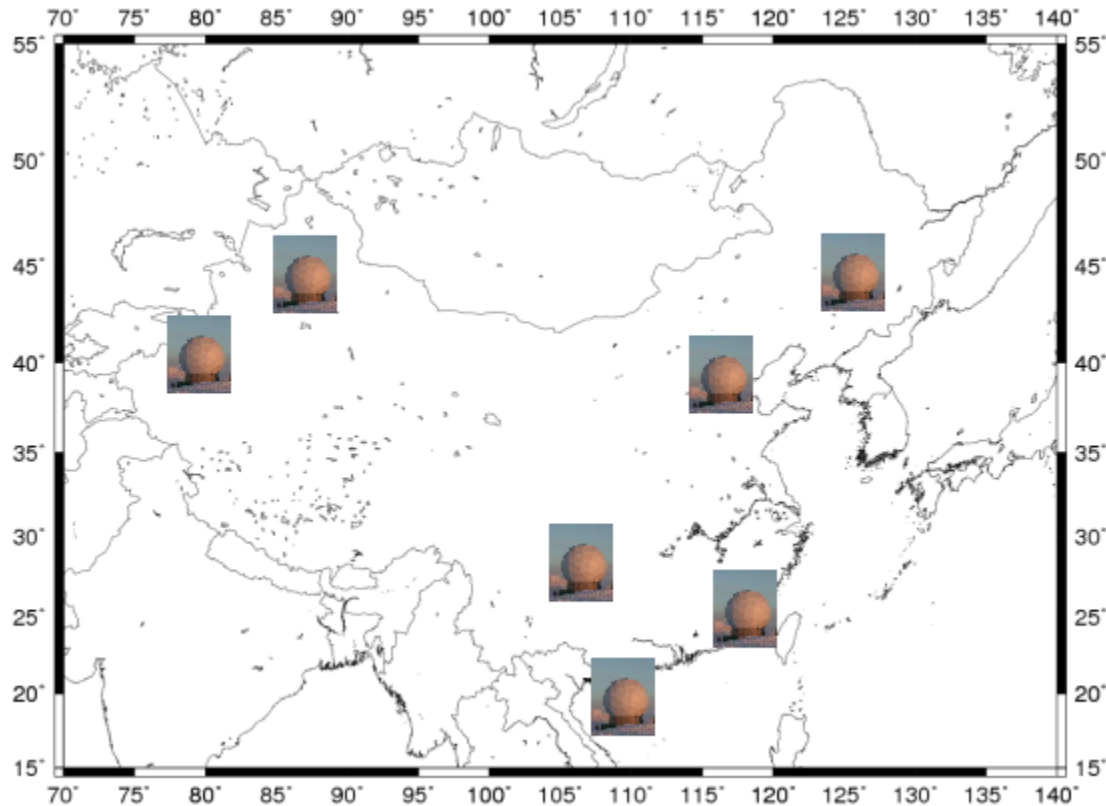
Compare with Reference post-processing orbits





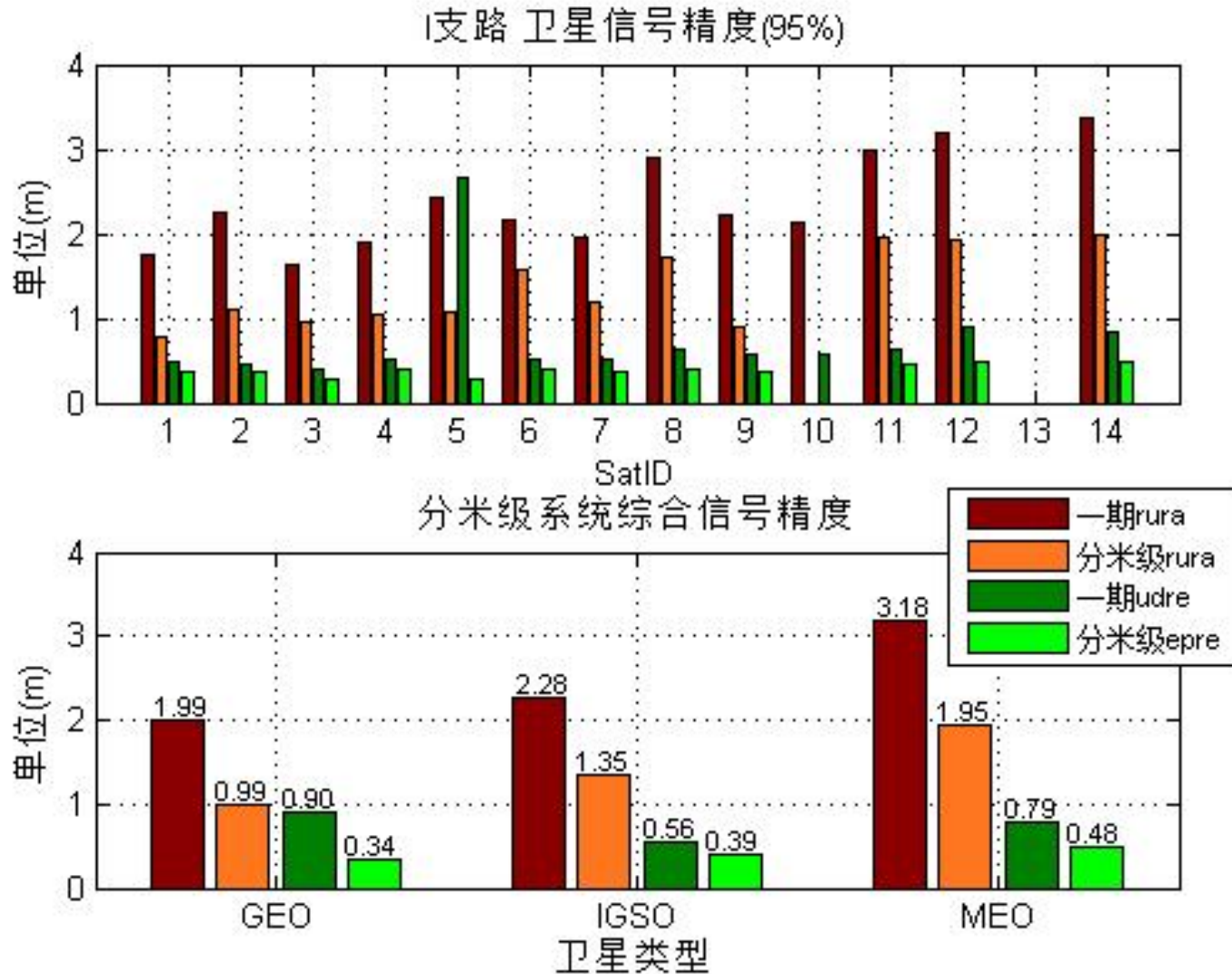
Application to BDS system

**Improving BDS system SIS accuracy.
Data length 2015.12.1-2015.12.28.**





Application to BDS system





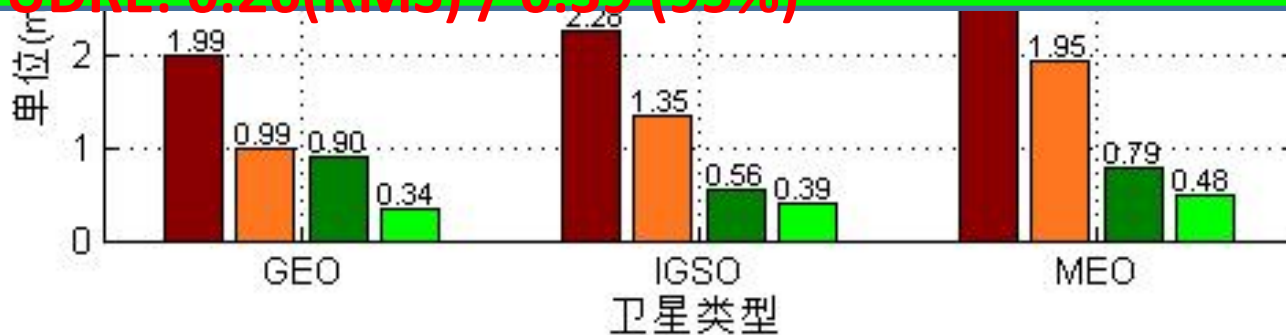
Application to BDS system



Civil signal SIS: URE, UDRE improved by 44%,
35%

URE: 0.76(RMS) / 1.35 (95%)

UDRE: 0.26(RMS) / 0.39 (95%)





Conclusion

➤ Conclusion

- Prototype system developed and validated
- With flexibility to change filter steps

➤ Next steps

- Solar radiation pressure parameter.
- Ambiguity resolution between different constellations.



SHA: GNSS Analysis Center at SHAO

http://www.shao.ac.cn/shao_gnss_ac

GNSS Analysis Center at Shanghai Astronomical Observatory (SHAO)

General Information About the Analysis Center (SHA)

About SHAO

Shanghai Astronomical Observatory (SHAO) has long history in research of Astronomy and Geodesy. The Center for Astro-geodynamics Research (SCAR) engages in measurement and analysis of the motion of the Earth and underlying dynamical mechanisms using the modern space techniques, including space Geodesy and astronomy. We operate a core site (Shanghai) with co-location of VLBI, SLR and GNSS equipments in the supporting the GGOS geodetic core network. We maintained the analysis centers for VLBI, SLR and GNSS.

SHAO hosts the Central Bureau of the Asia-Pacific Space Geodynamics (APSG) program, which unites all relevant activities in the Asia-Pacific region into a cooperative research project in plate tectonic, crustal motion and deformation, and sea level changes.

SHAO is the current one of collaborative coordinators in the establishment of the Crustal Movement Observation Network of China (CMONOC), which includes ~260 fiducial sites and ~2000 campaign sites and serves for GPS meteorology, network RTK, disaster early warning and monitoring, space weather research etc.

About the GGDAA

Supported by the "One hundred talents" program of the Chinese Academy of Sciences (CAS), Dr. Junping Chen joined SHAO and initiated the establishment of the Group of GNSS Data Analysis and Applications at SHAO (GGDAA) early 2011. Shortly after the setup of the GGDAA, we start the IGR-like GNSS data analysis using GNSS data from the global network together the CMONOC network. After a period of experimental operation, the system is in routine operation with good stability and precision. Our products have been utilized and acknowledged in many key space programs of China.

The ongoing tasks and activities of GGDAA are:

- Data analysis and products evaluation of the CMONOC network
- Data analysis and products provision of the IGS network

The GNSS data analysis at SHA is the **integrated GNSS solution** [Presentation at IGS Bias Workshop 2012] with products presented in



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