Extended Filter For Real-time Multi-GNSS Orbit Determination

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- Background
- Extended filter
- Real-time data analysis
- Application to BDS system
- Conclusion

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

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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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Real-time orbits&clocks

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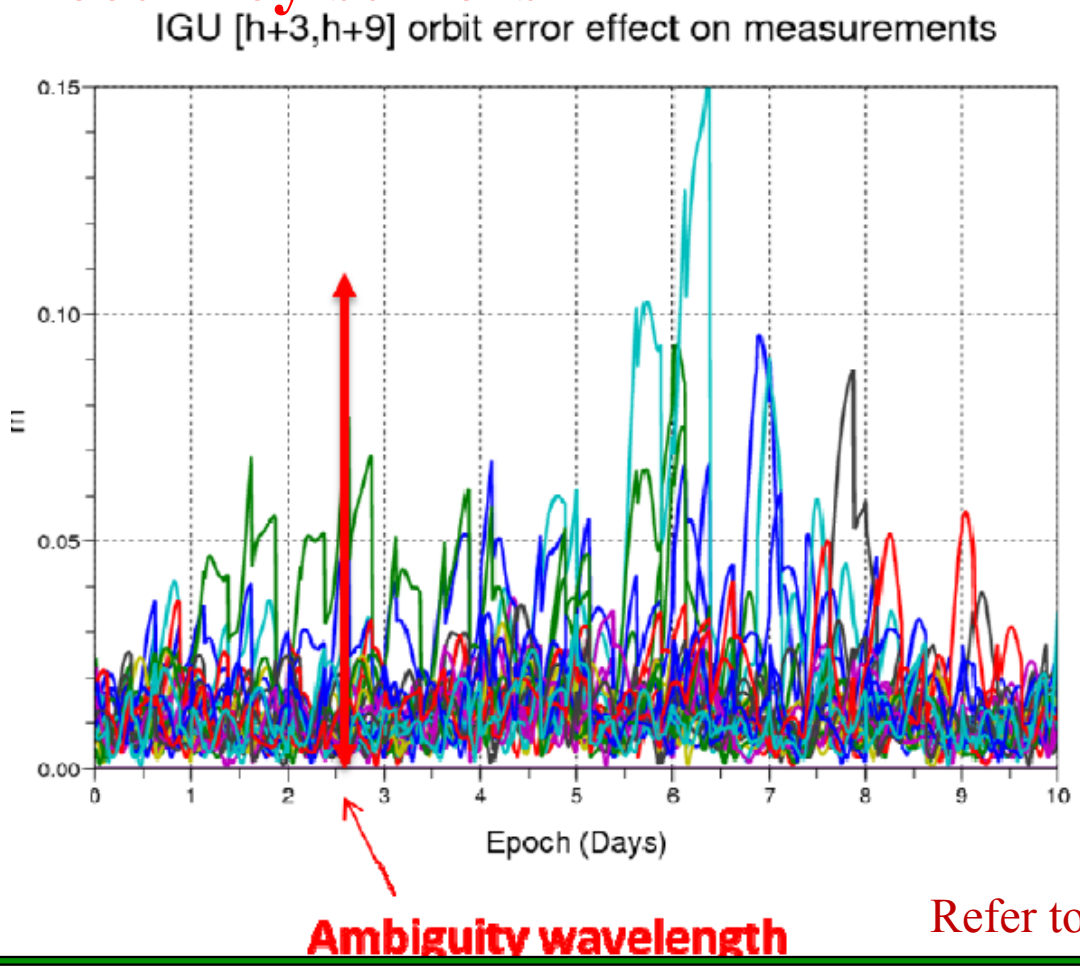
Ultra-Rapid (predicted half)	Accuracy	Latency	Updates
GPS	**Orbits 5cm**	Real time	UTC
IGS-RTS	**Accuracy**	**Latency**	**Updates**
GPS	**Orbits 5cm** **Clocks 8cm**	Real time	-

Refer to igs.org and Montenbruck 2015

Background

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



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**

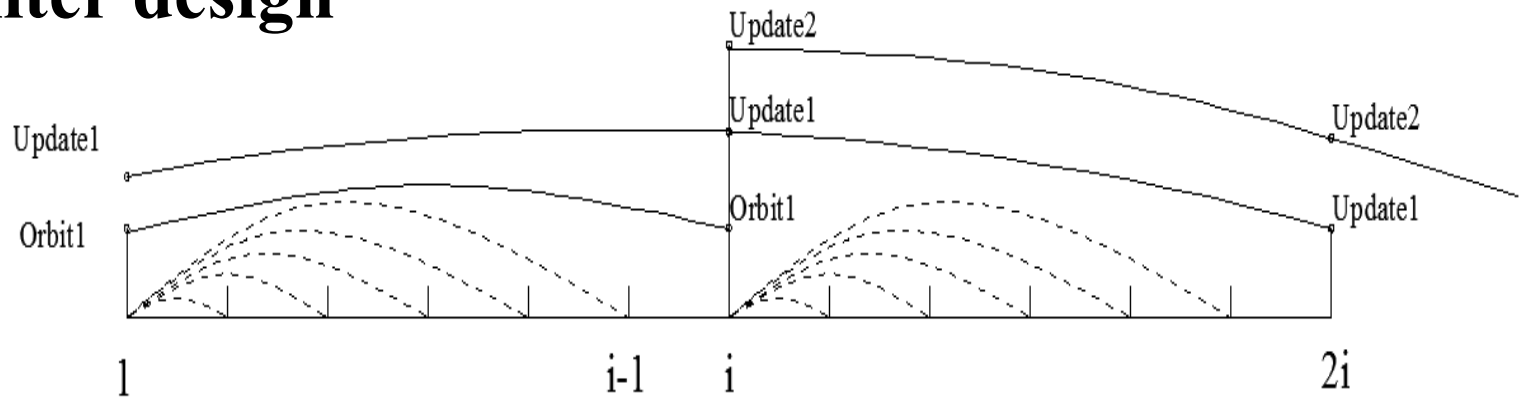
Future measurements are not available, ambiguities fixed at two consecutive epochs will be treated as known values.

◆ **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

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

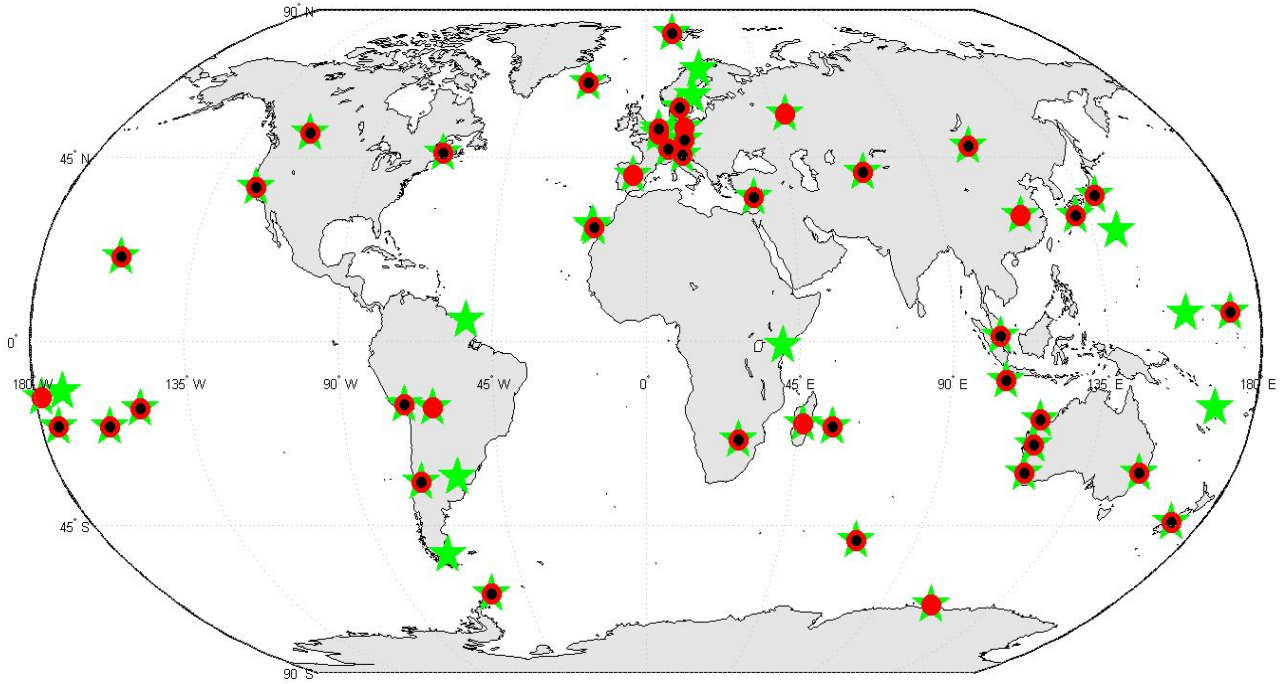
OBS Equ

- 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

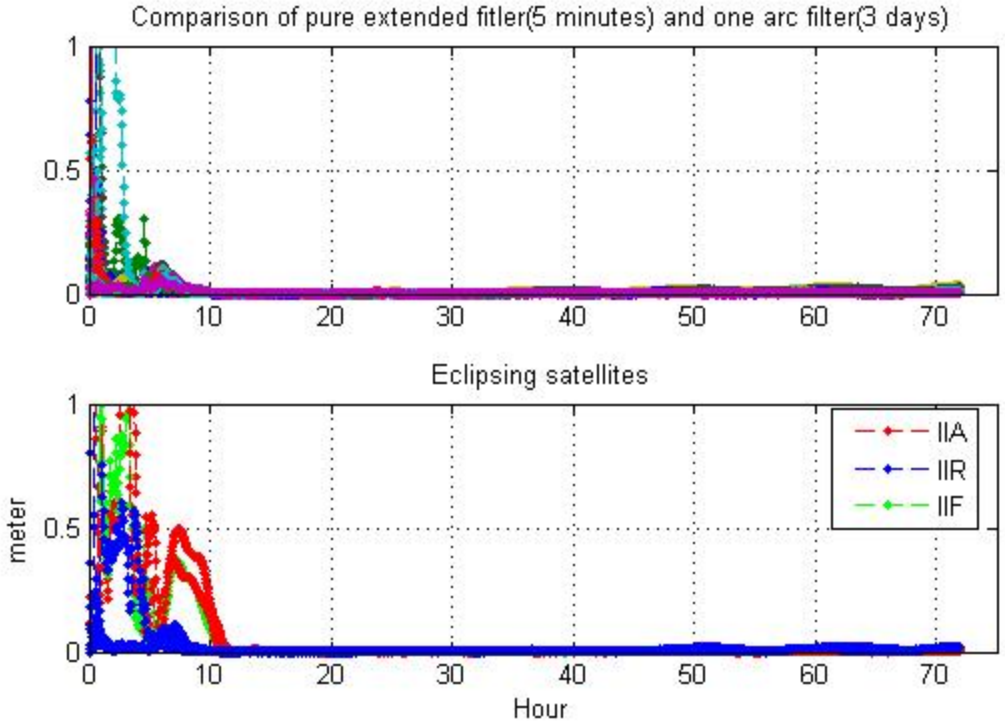
Data information



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

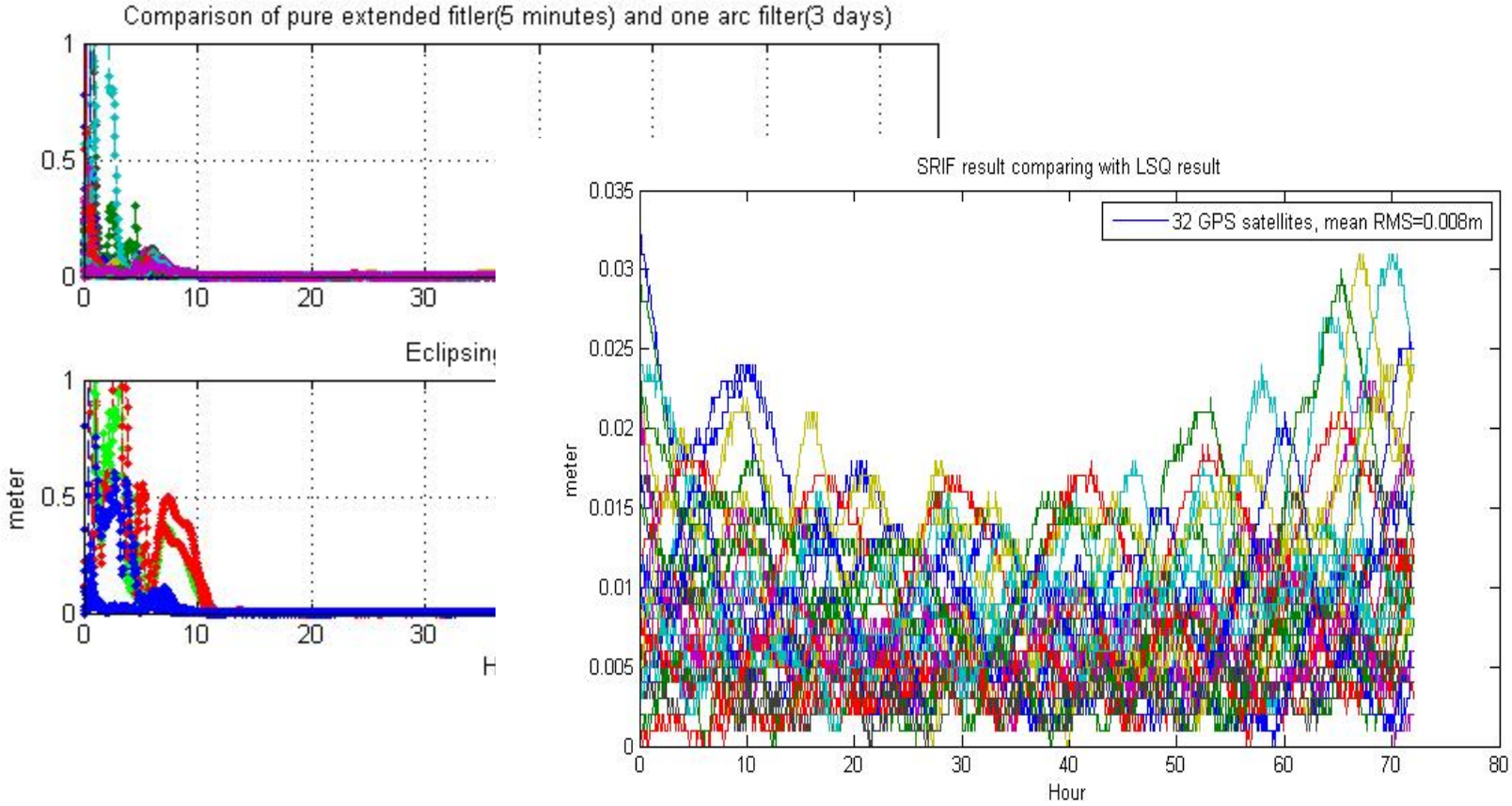
Real-time processing

Comparison between Filter with different interval and LSQ result



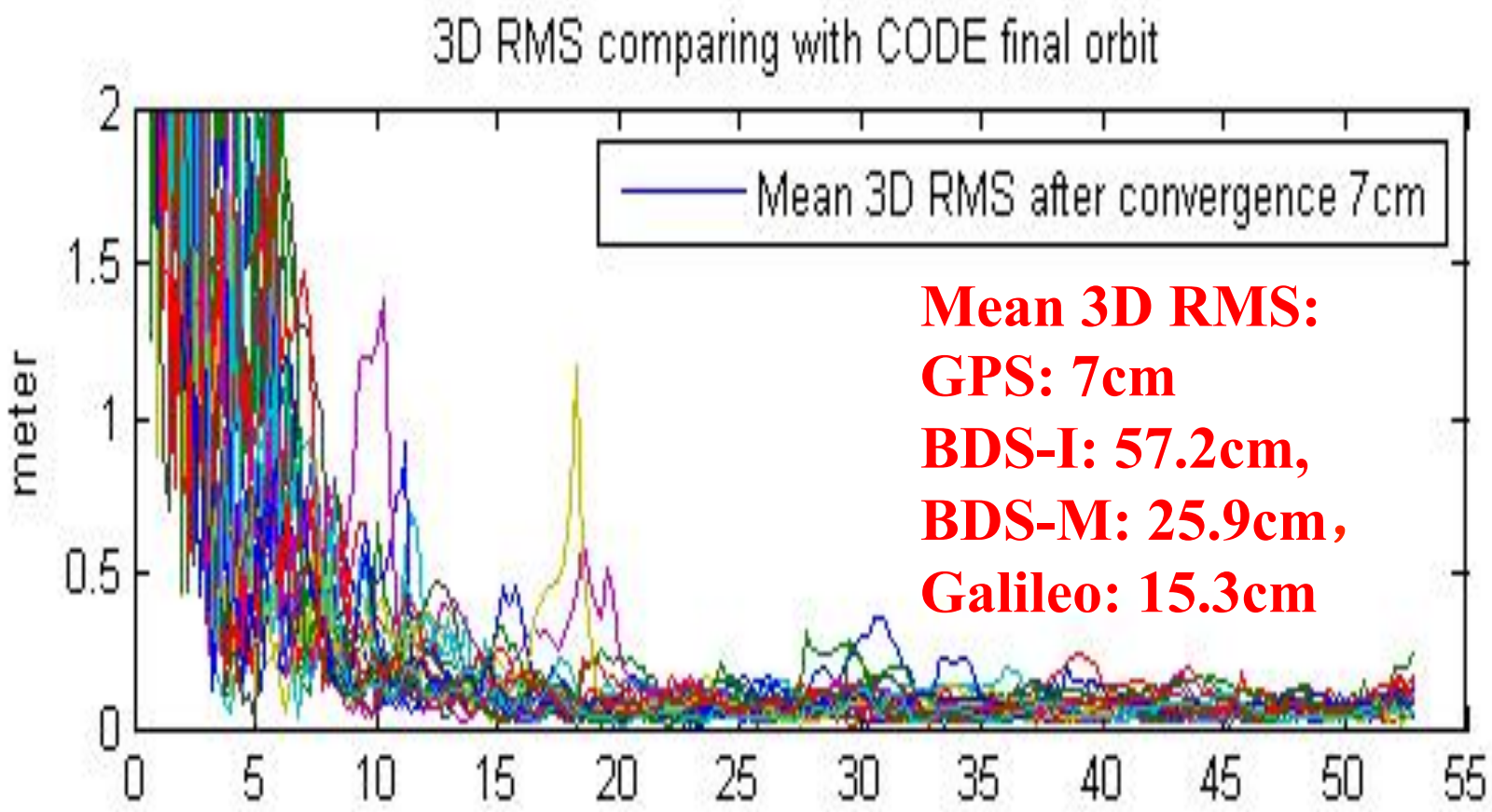
Real-time processing

Comparison between Filter with different interval and LSQ result



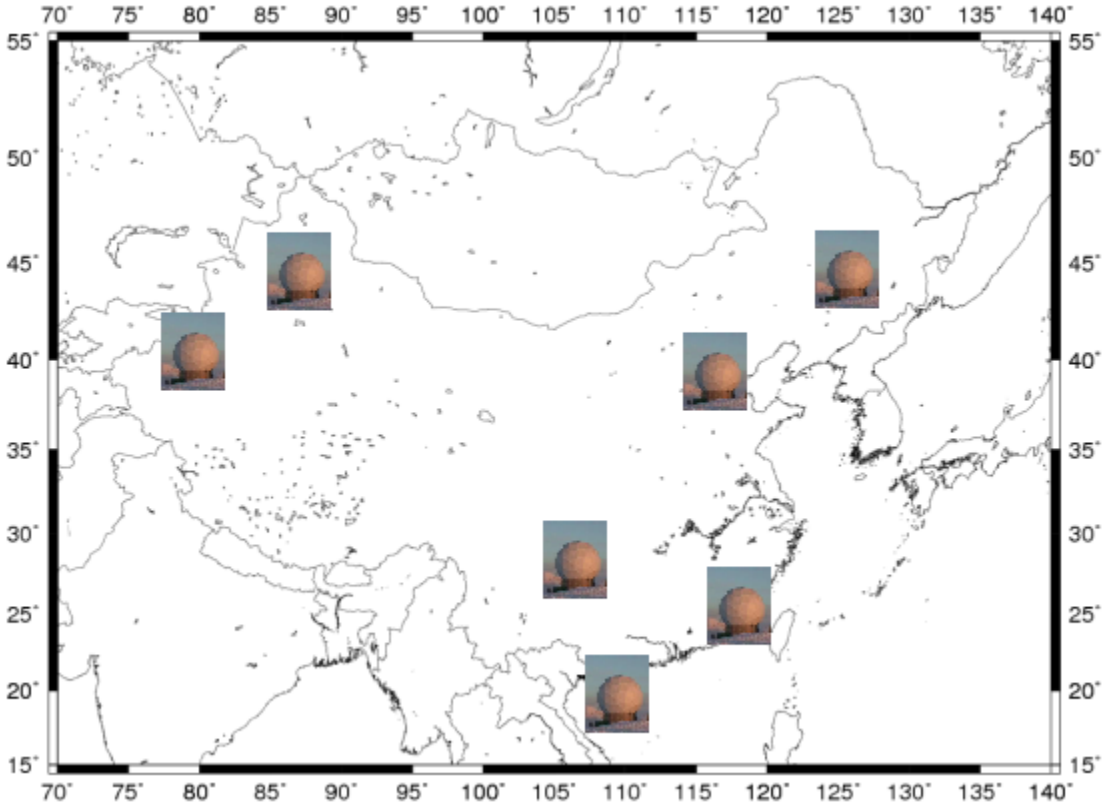
Real-time processing

Compare with Reference post-processing orbits

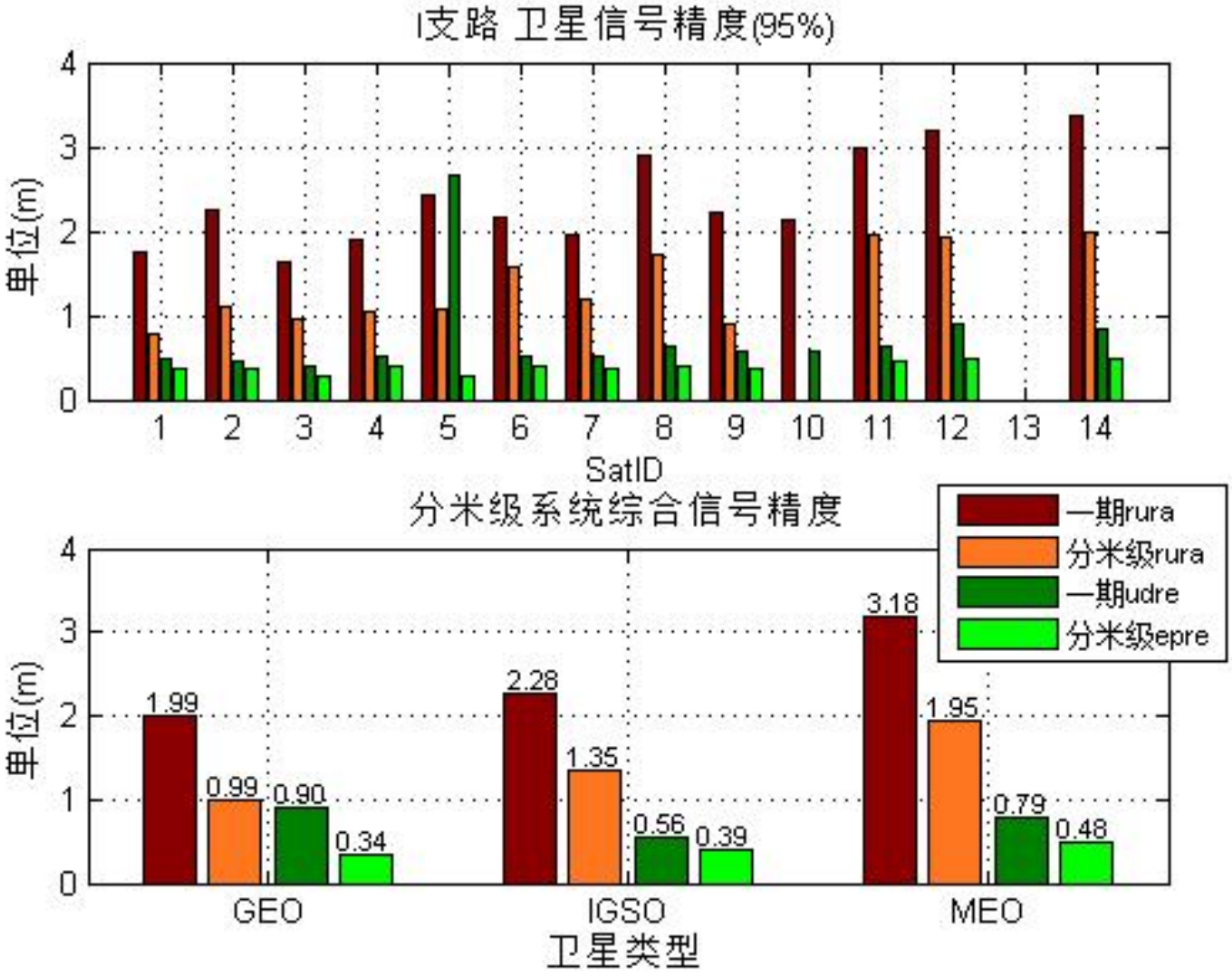


Application to BDS system

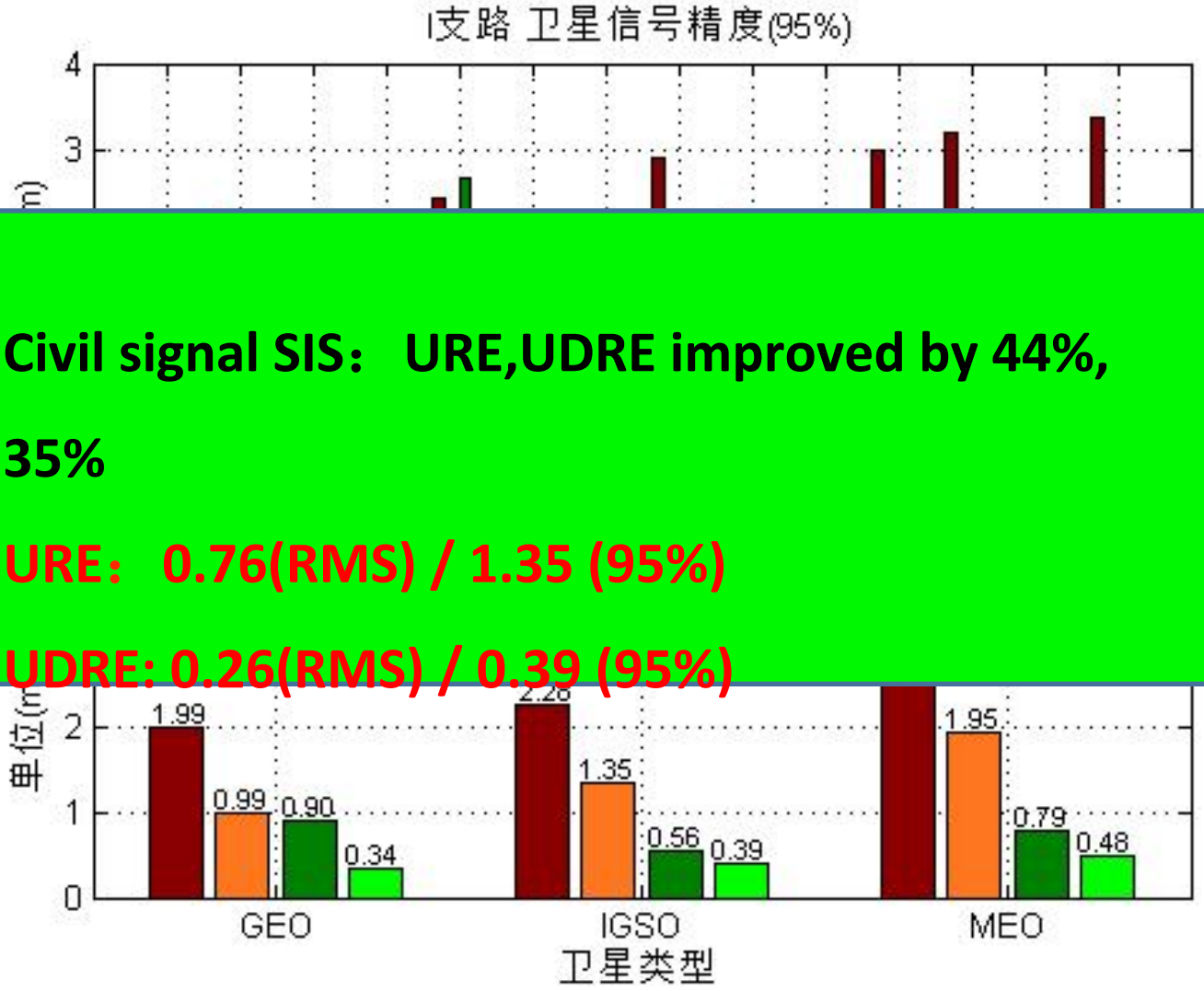
Improving BDS system SIS accuracy.
Data length 2015.12.1-2015.12.28.



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

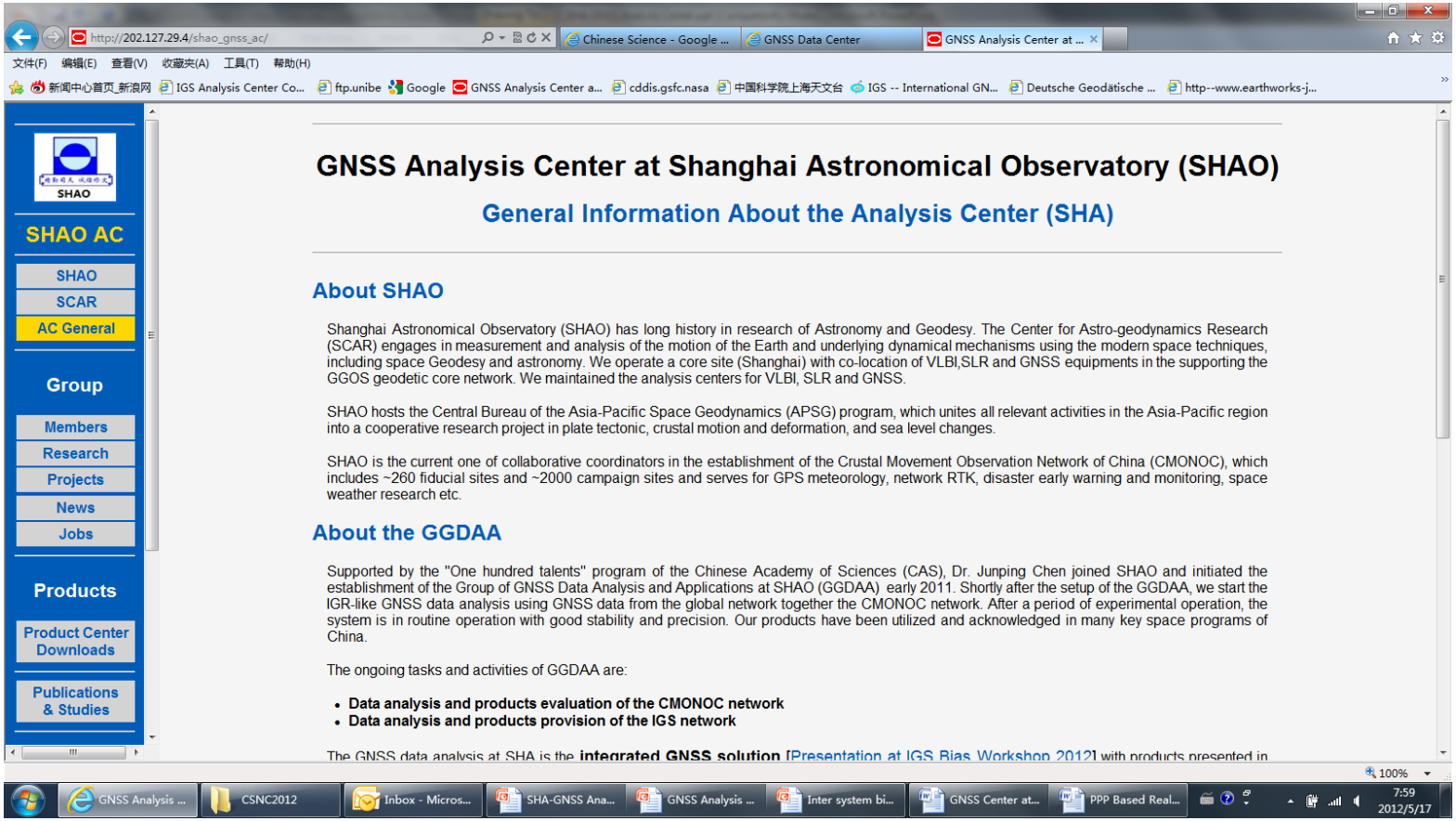
➢ Next steps

•Solar radiation pressure parameter.

•Ambiguity resolution between different constellations.

SHA: GNSS Analysis Center at SHAO

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



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Prof. Urs Hugentobler (TU Munich) and Oliver Montenbruck (DLR) hosted one-year visit and valuable discussions