Orbit Validation On Navigation Satellites Using Satellite Laser Ranging

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Outline

- Introduction
- Models and parameter configuration
- Results
- Summary and Discussion

Introduction

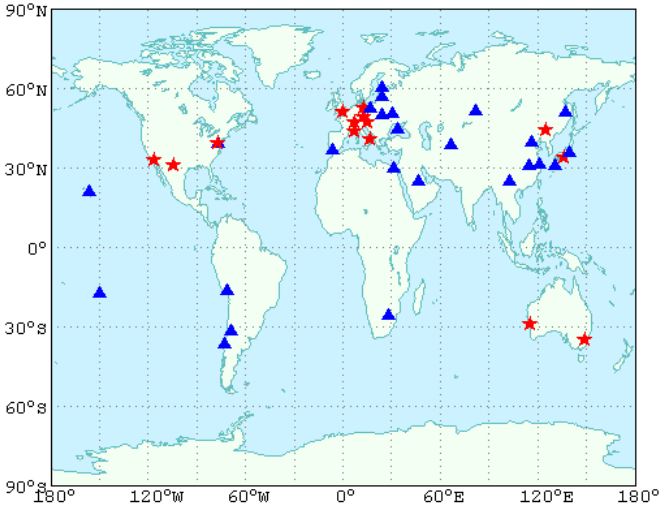
Unique feature of SLR

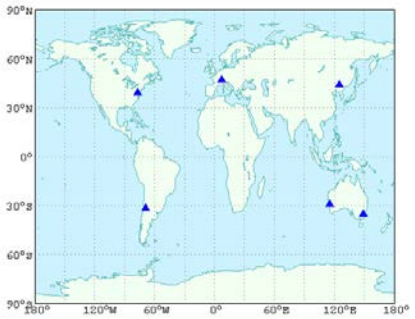
- SLR has been taken as a completely independent way of external calibration on orbits obtained by other POD means. For navigation satellites, SLR is the only tracking method with accuracy higher than microwave measurements.
- Multi navigation satellite constellations are equipped with LRAs and have obtained **long-term** SLR observation.
- Long-term microwave monitoring and POD for navigation satellites have been carried out.
- It is possible to reveal characters from long-term SLR validation which may seem random in short-term comparison.

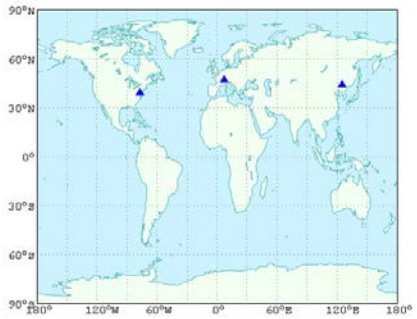
Introduction

SLR tracking network

- 14 **core** stations / 42 stations



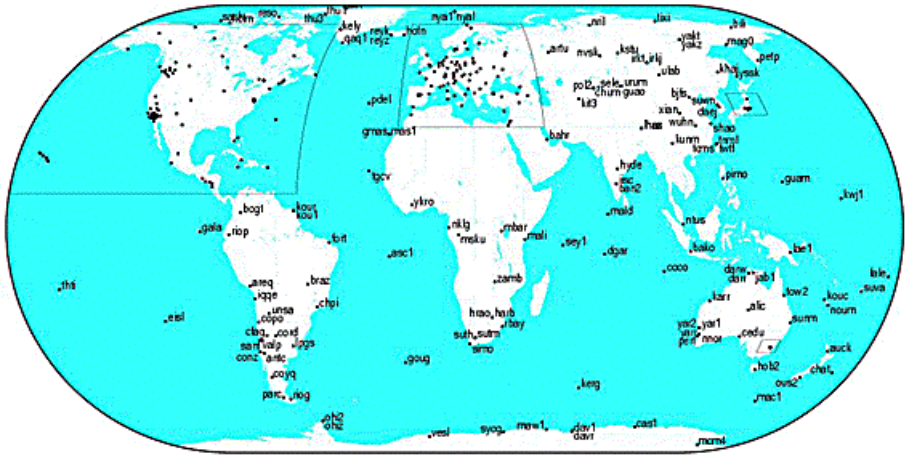




Introduction

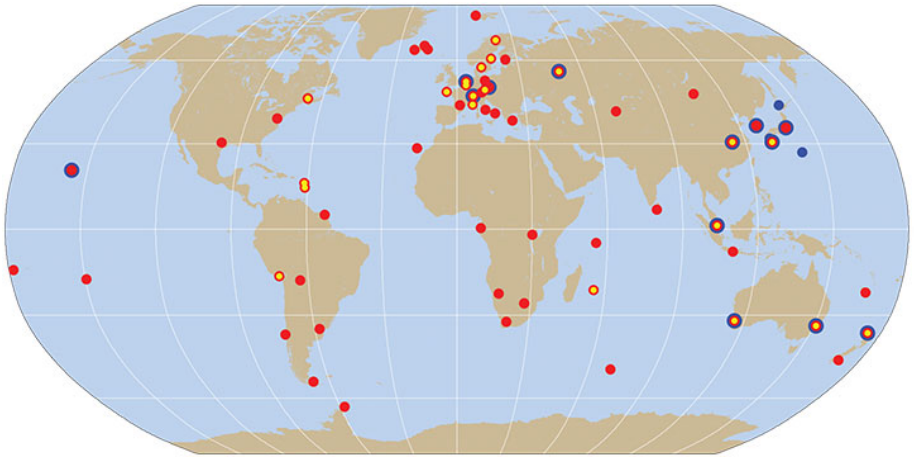
Microwave tracking network

- IGS



http://igscb.jpl.nasa.gov

- MGEX



- Galileo
- QZSS
- BeiDou

www.gpsworld.com

Models and parameter configuration

For SLR validation:

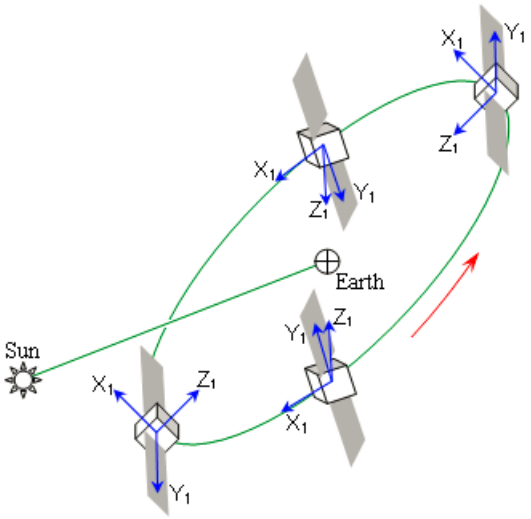
$$\Delta = \rho_{obs} - (\rho_c + \Delta\rho_{tides} + \Delta\rho_{oloading} + \Delta\rho_{trop} + \Delta\rho_{rel} + \Delta\rho_{com} + \Delta\rho_{ecc} + \Delta\rho_{tec} + \varepsilon)$$

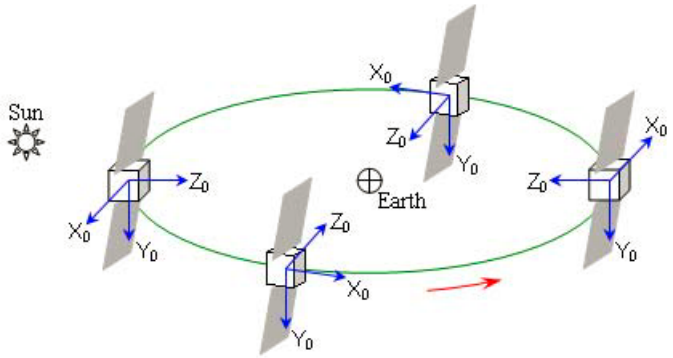
- **Station coordinates :** ITRF2008
- **Station eccentricities :** ILRS
- **Tidal correction :** Wahr solid tide / CSR4.0 ocean tide loading / IERS 2003 pole tide
- **Tropospheric refraction :** Marini-Murry model
- **General relativity time delay :** IERS 2003
- **Center-of-mass offset :** attitude-related

Models and parameter configuration

Center-of-mass offset

- **yaw-steering (YS) .vs. orbit-normal (ON)**



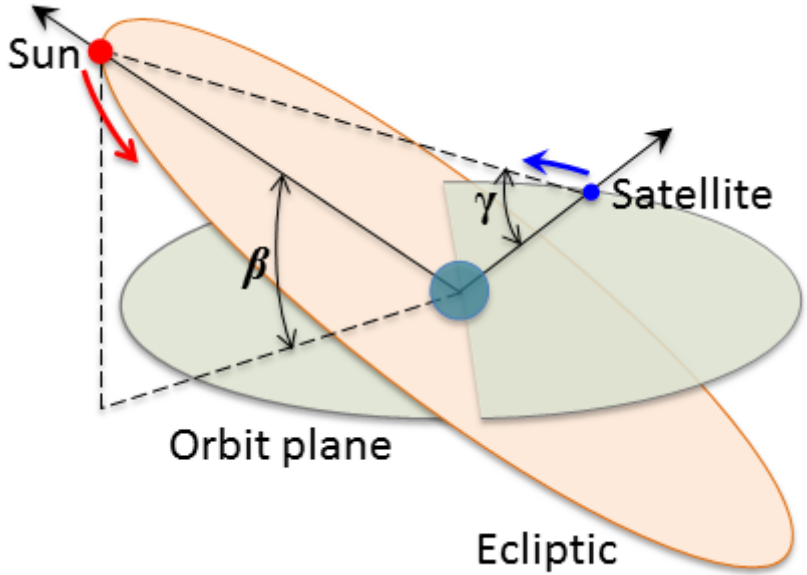


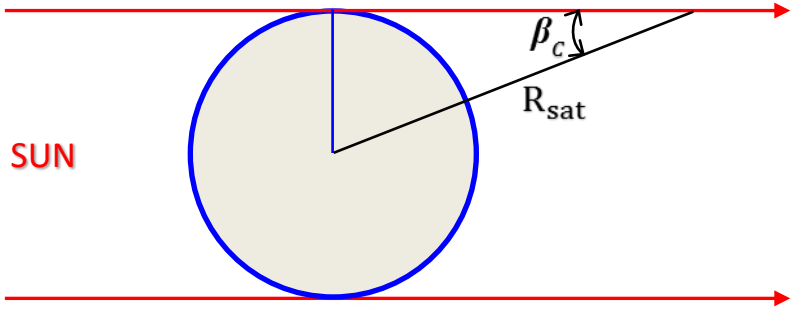
- GPS: yaw-steering
- Galileo: yaw-steering
- Glonass: yaw-steering
- QZSS: yaw-steering (β > 20deg) / orbit-normal (β < 20deg)
- BeiDou: yaw-steering (β > 4 deg) / orbit-normal (β < 4deg)

Models and parameter configuration

Definition:

- $\boldsymbol{\beta}$: sun's elevations above satellite orbital plane
- $\boldsymbol{\beta_C}$: critical β. Eclipse if $\beta < \beta_C$
- $\boldsymbol{\gamma}$: sun-satellite-earth elongation





Results

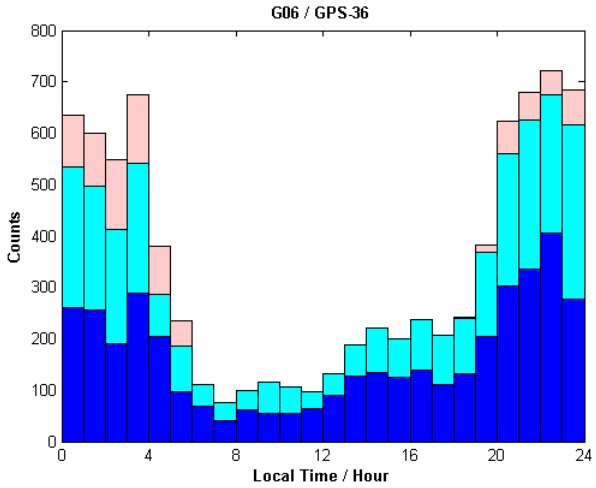
Brief summary

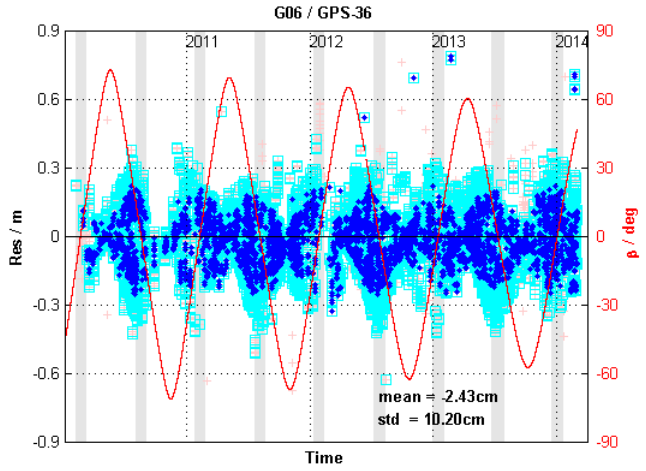
- stations: 14
  error limitation: 1m
  cut-off elevation: 60deg (20deg for BD-G1)

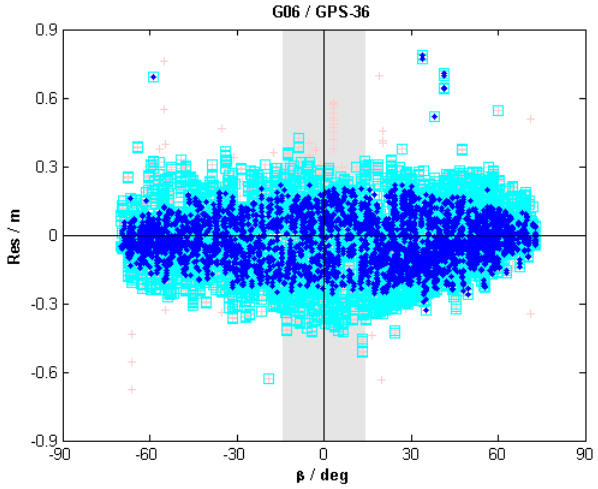
System	Ref Orbit	Satellite	Duration	Num of obs	Mean of res [cm]	Dispersion of res [cm]	Type of sat
GPS	IGS	G06	5.1yrs (2010.02 - 2014.03)	4026	-2.43	10.20	MEO
		G30	1.4yrs (2011.12 - 2013.05)	410	-0.55	10.85	
Galileo	MGEX / COM	E11	3.0yrs (2012.05 - 2015.05)	4605	-4.81	7.50	MEO
		E12		4551	-5.27	7.18	
		E19	2.4yrs (2012.12 - 2015.05)	3868	-4.28	7.78	
		E20	1.4yrs (2012.12 - 2014.05)	2346	-4.88	7.42	
Glonass	MGEX / COM	R07	3.0yrs (2012.05 - 2015.05)	5910	-1.52	3.55	MEO
		R12		3472	-2.15	4.75	
		R17	2.9yrs (2012.05 - 2015.04)	4631	-1.65	3.75	
BeiDou	MGEX / WUM	C01	2.0yrs (2013.01-2014.12)	2063	-42.29	25.66	GEO
		C08		963	-3.78	7.99	IGSO
		C10		525	-3.88	8.34	
		C11		1817	-0.20	8.62	MEO

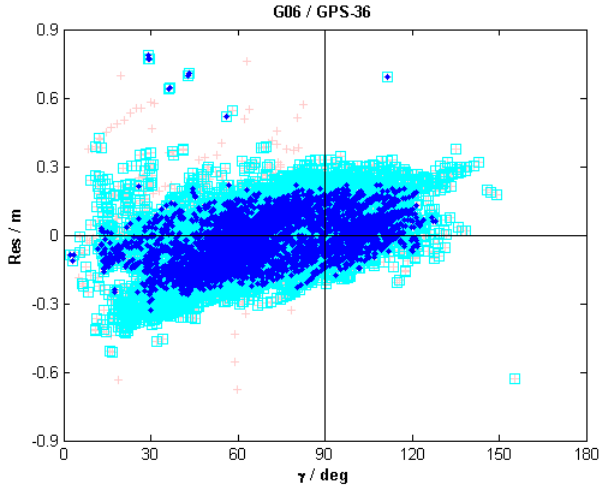
Results - GPS

all sta. core sta. core sta & EL>60deg eclipse (YS mode)



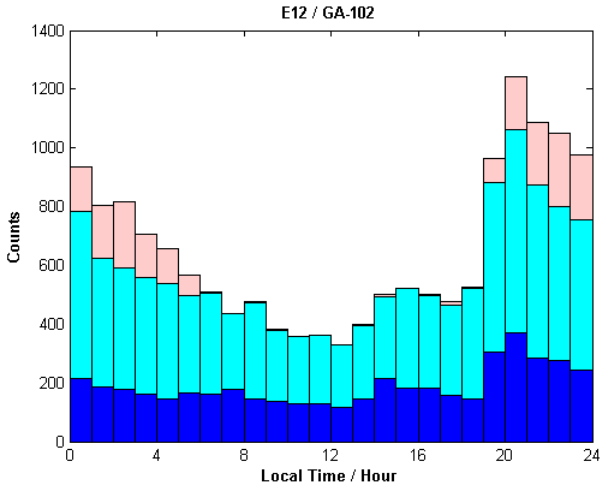


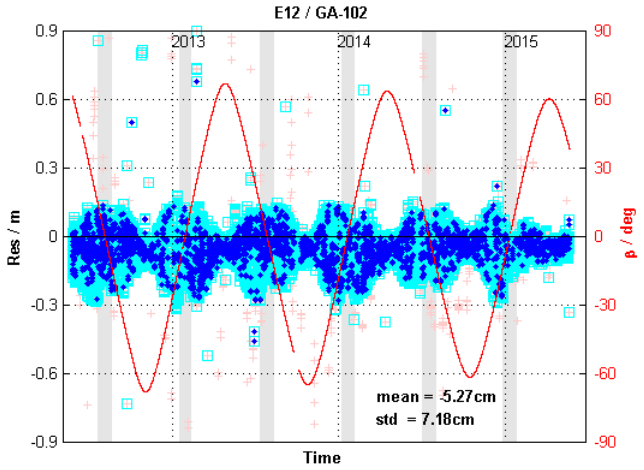


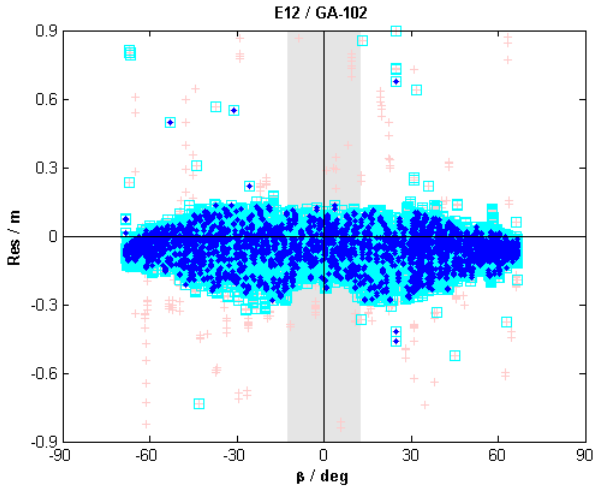


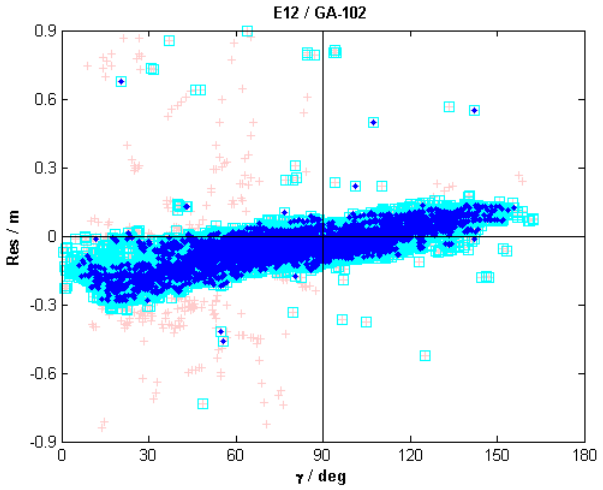
Results - Galileo

all sta. core sta. core sta & EL>60deg eclipse (YS mode)



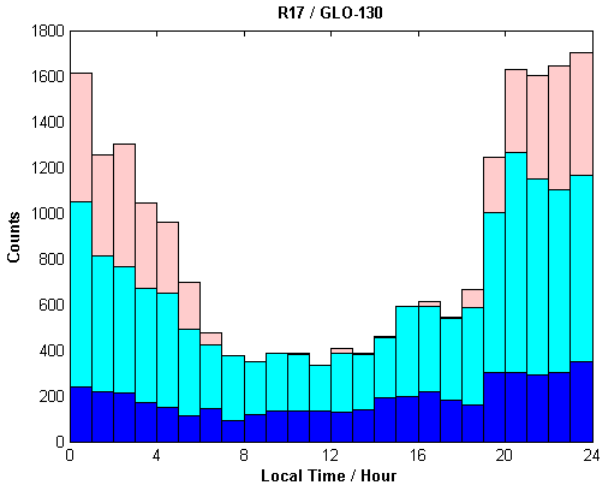


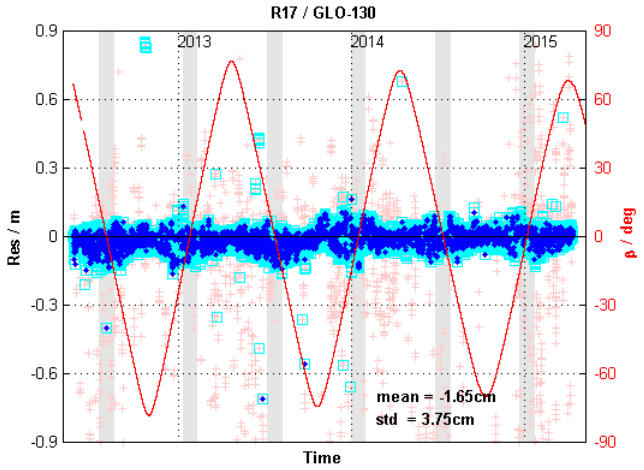


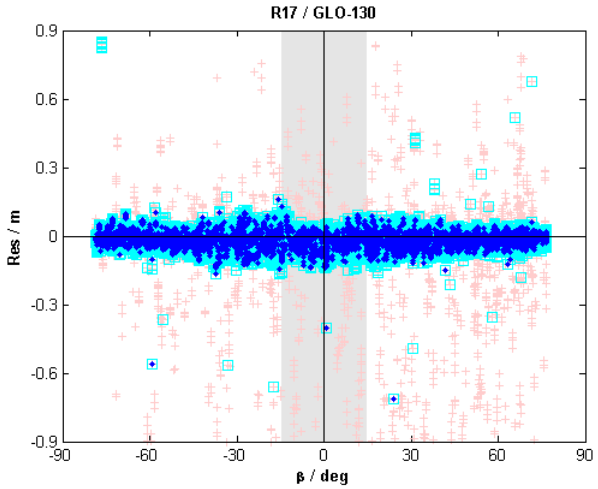


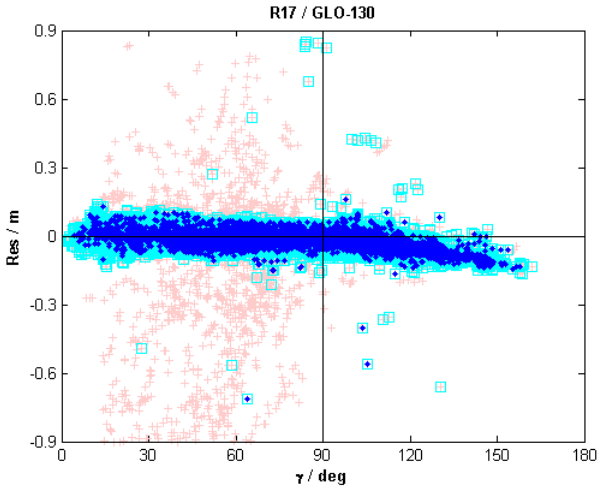
Results - Glonass (I)

all sta. core sta. core sta & EL>60deg eclipse (YS mode)



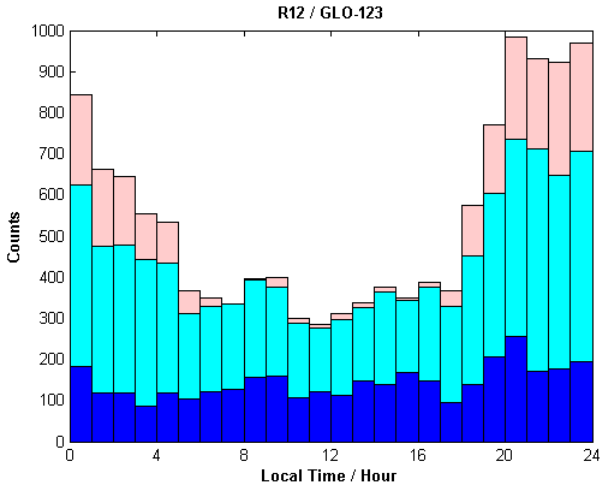


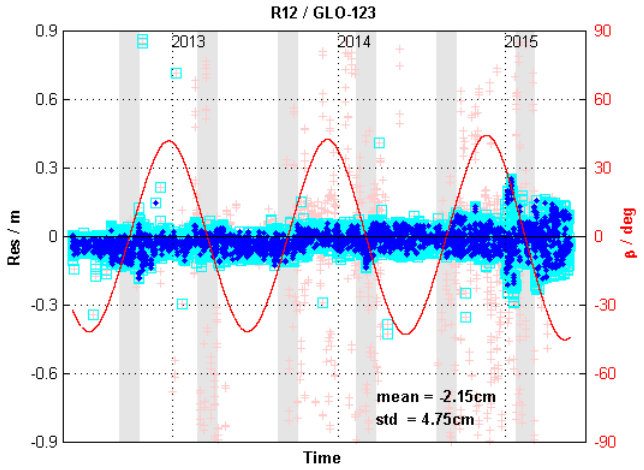


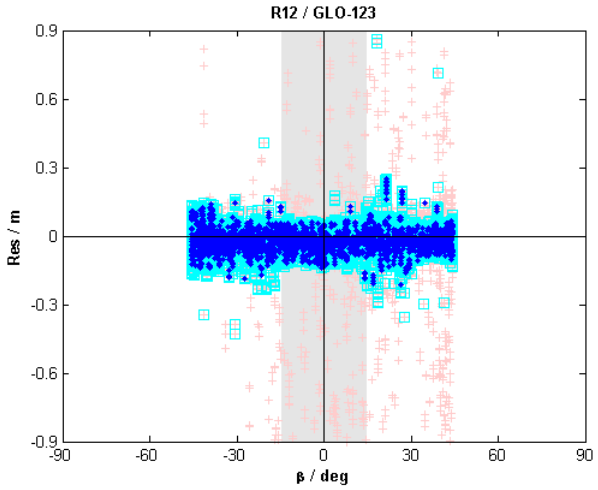


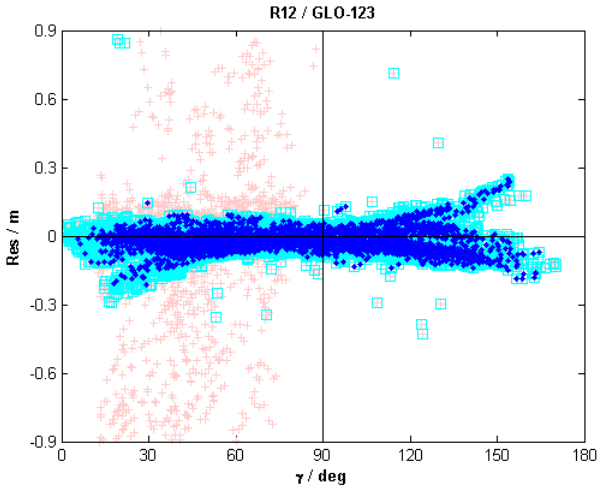
Results - Glonass (II)

all sta. core sta. core sta & EL>60deg eclipse (YS mode)



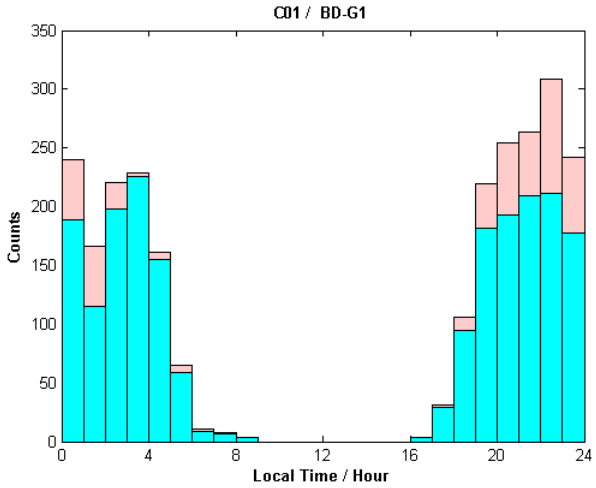


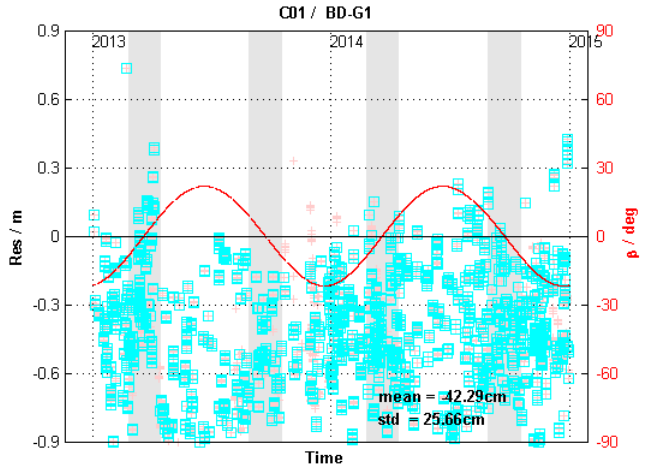


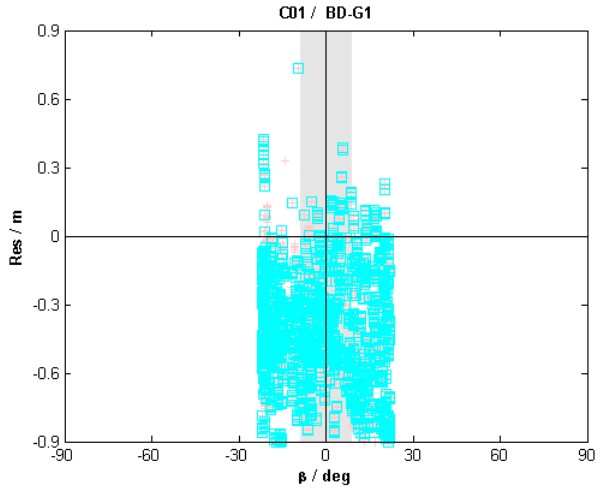


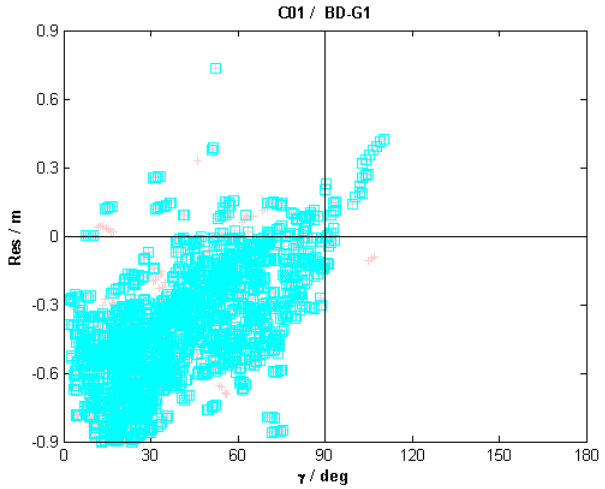
Results – BeiDou G1

all sta. core sta. core sta & EL>60deg eclipse (ON mode)



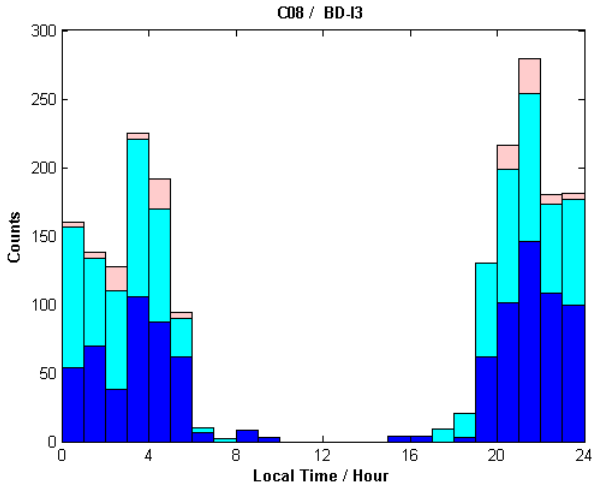


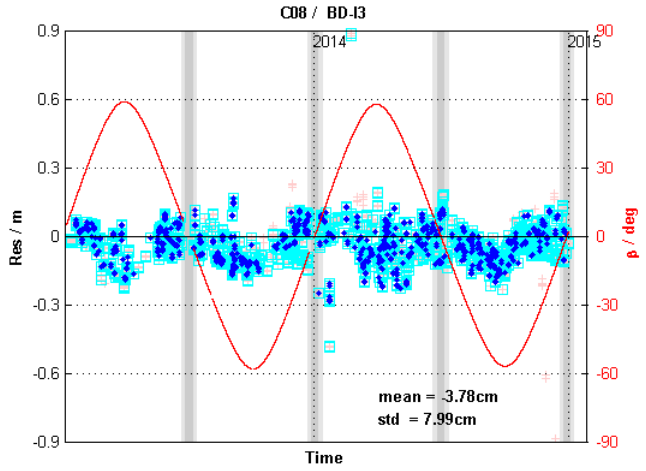


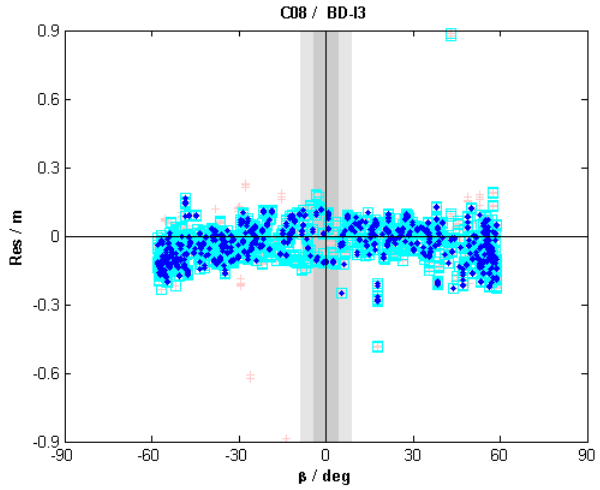


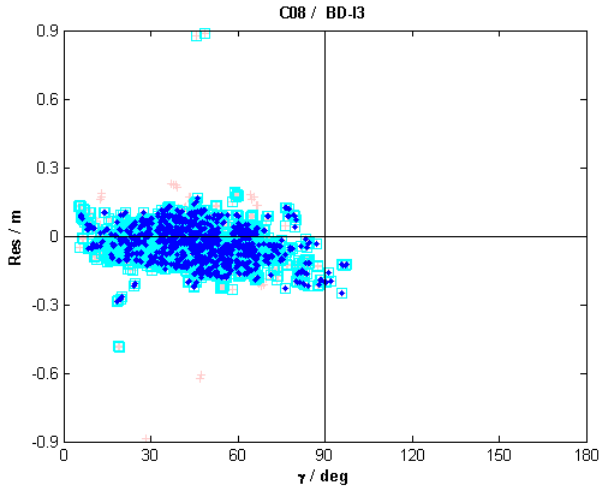
Results – BeiDou I3

all sta. core sta. core sta & EL>60deg eclipse (YS mode) ON mode



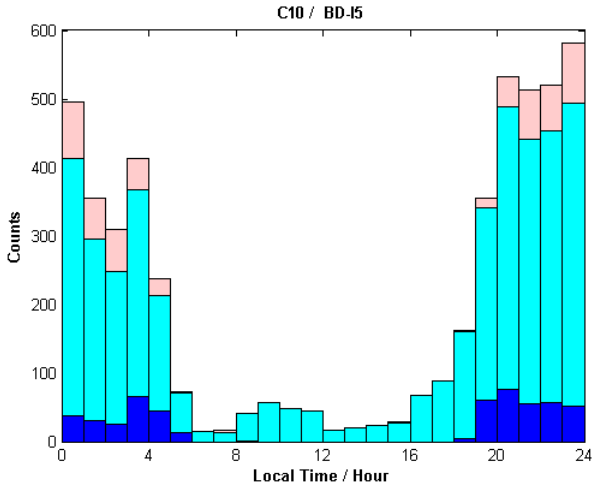


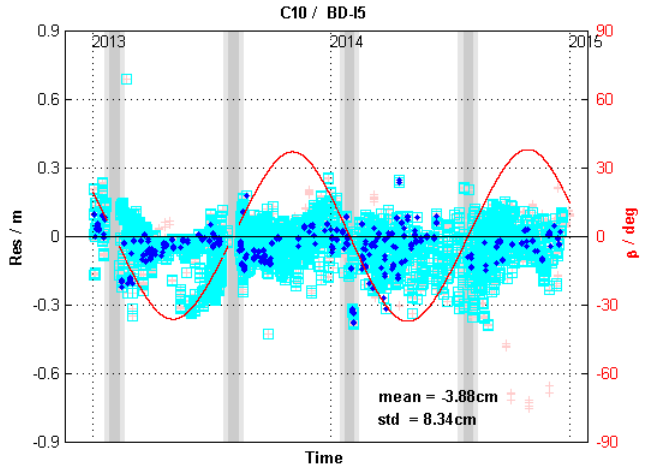


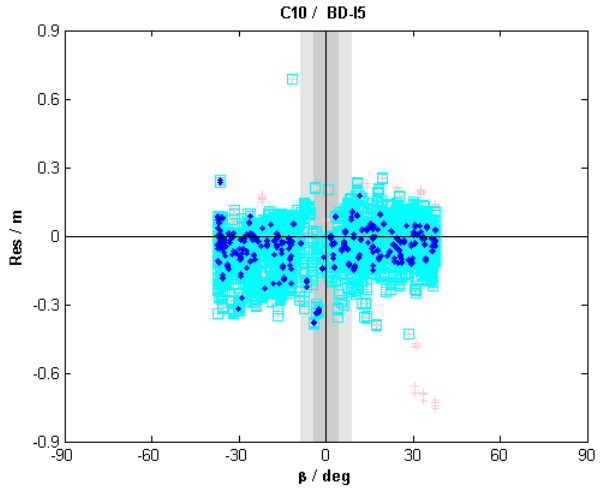


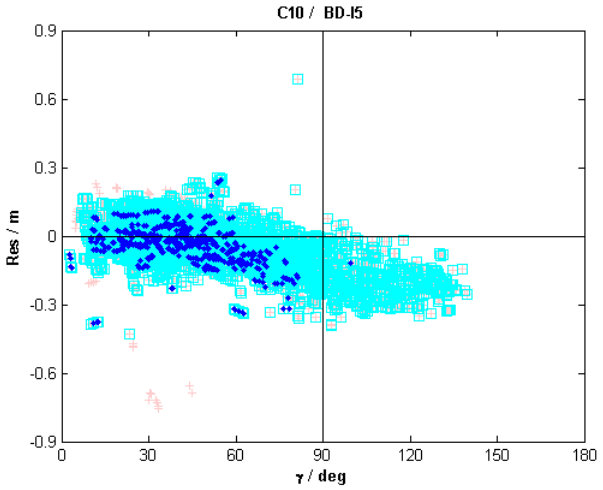
Results – BeiDou I5

all sta. core sta. core sta & EL>60deg eclipse (YS mode) ON mode



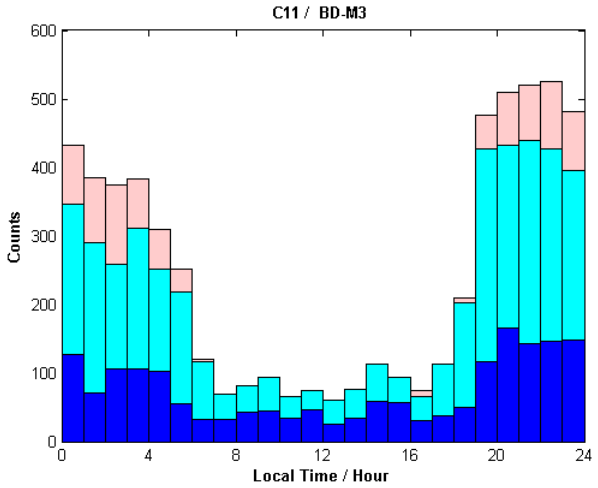


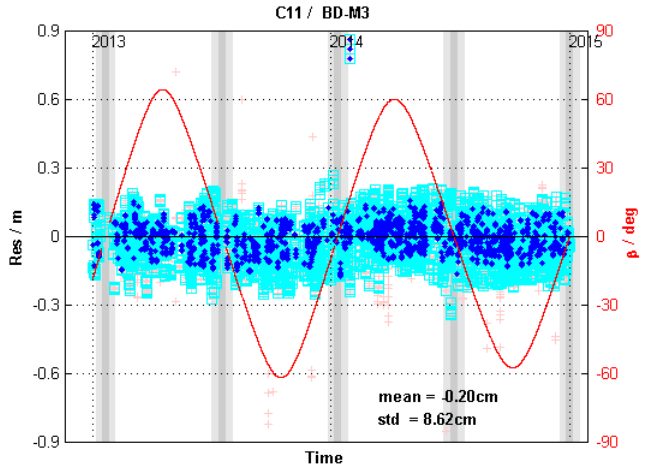


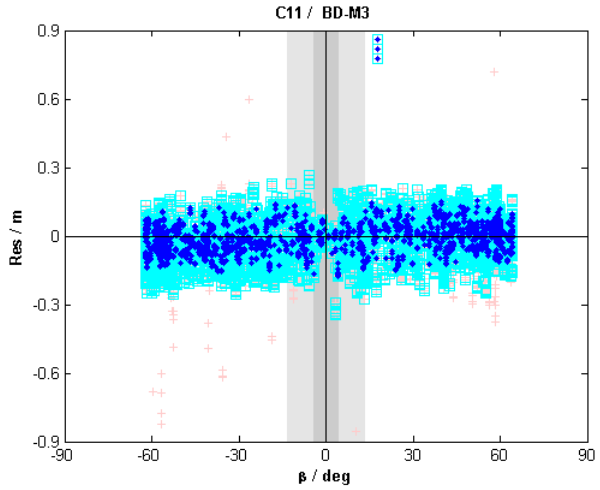


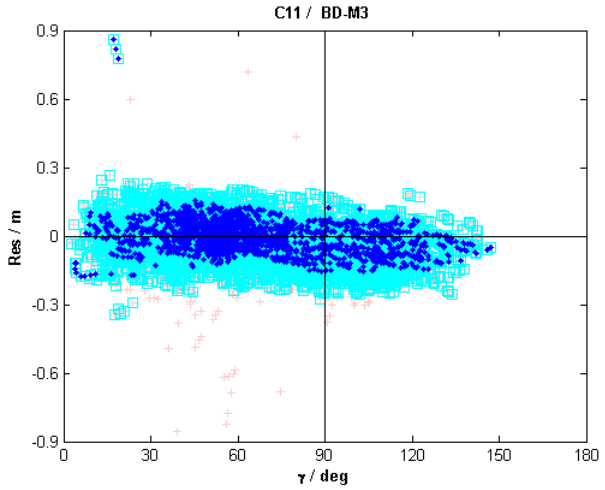
Results – BeiDou M3

all sta. core sta. core sta & EL>60deg eclipse (YS mode) ON mode









Summary

- A bias about 2-5cm for navigation satellites (MEO) between microwave orbits and SLR measurements with dispersion about 4-10cm (*satellite-type dependent*).
- Correlation between SLR residuals and sun's elevation: strong (negative) in GPS / Galileo; weak in Glonass; poor in BeiDou.
- Local minimum residuals during eclipse season: significant in Galileo / Glonass; not apparent in GPS / BeiDou.
- Correlation between SLR residuals and sun-satellite-earth elongation: positive in GPS / Galileo; negative or positive in Glonass; weak in BeiDou.

Discussion

- Bias between microwave orbits and SLR measurements still hasn't been fully understood.
- Current empirical or semi-empirical SRP models described the periodicity with angles can't explain total SLR residuals, and remains few cm still larger than SLR measurement noise level, thus SRP model should be further refined.

- (β) elev of sun above orbital plane : rel. pos. of sun to orbital plane
- (γ) sun-satellite-earth elongation : rel. pos. of earth-sat-sun
- (u) arg. of lat. of sat : orbital pos. of sat
- (u_0) arg. of lat. of sun in orb plane : rel. pos. of sun and sat. in orbital plane

Discussion

- Possible sources of SLR validation errors:
  - single-shot measurement error : random
  - correction model error : unrelated with $\boldsymbol{\beta}$ (geophysical origin)
  - ephemeris error : perturbation model error, microwave propagation error.
- *Comments*
  - Empirical SRP model is a phenomenological model in a sense. It is on the basis of long-term fitting to observation.
  - Microwave propagation is related to ionosphere. The ion model and SRP model both have regularly varying signals with similar phases in most of time.
  - More investigation should be pushed forward.

Thanks for your attention !