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GNSS GEO Satellites Precise Orbit Determination Based on Carrier Phase and SLR Observations

**Baoqi Sun^{1,2}, Hang Su^{1,2}, Zhe Zhang^{1,2}, Yao
Kong^{1,2,3}, Xuhai Yang^{1,2}**

- (1. National Time Service Center, Chinese Academy of Sciences;*
- 2. Key Laboratory of Precision Navigation, Positioning and Timing Technology,
Chinese Academy of Sciences;*
- 3. University of Chinese Academy of Sciences)*

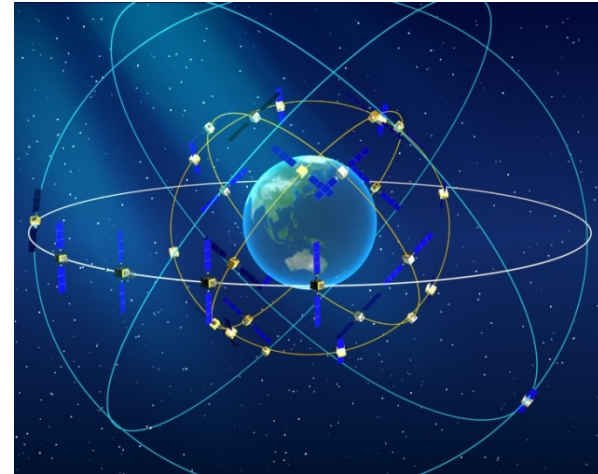


Content

- Motivation
- Data and Methods
- Results and Analysis
- Summary and Outlook

□ GEO satellites in GNSS constellation

- BDS: 5GEO+5IGSO+4MEO
- IRNSS: 3GEO+4IGSO
- WAAS
- EGNOS
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□ Advantages of GEO navigation satellites

- Continuous visibility

□ Challenges for GEO orbit determination

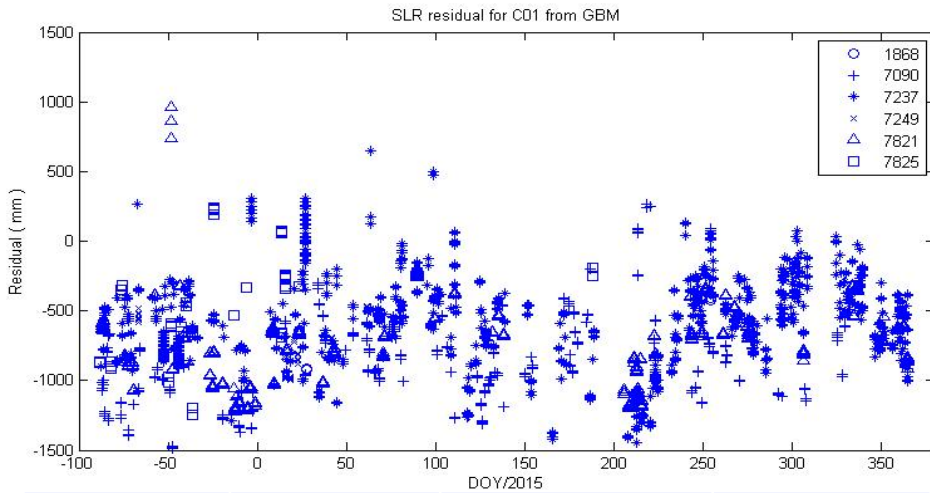
- High altitude, limited tracking stations, very slow movement relative to ground
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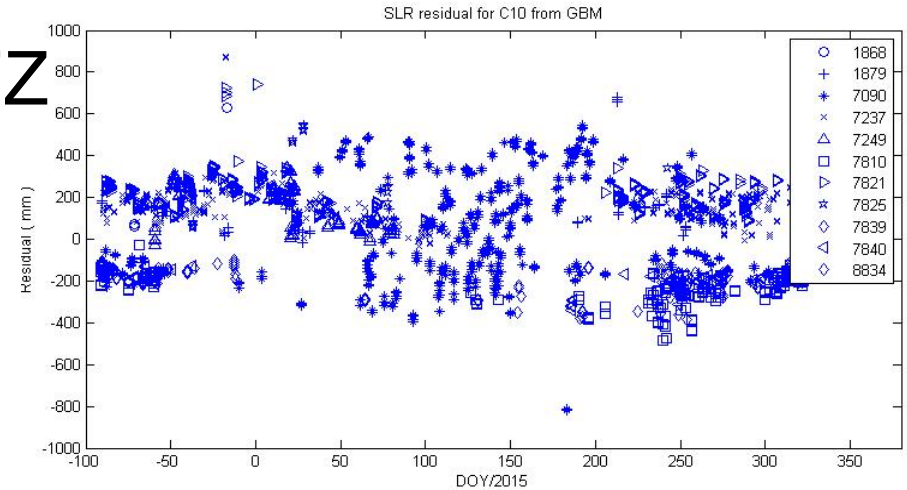
Motivation

□ BDS orbit accuracy: State-of-the-art

➤ MGEX products from GFZ



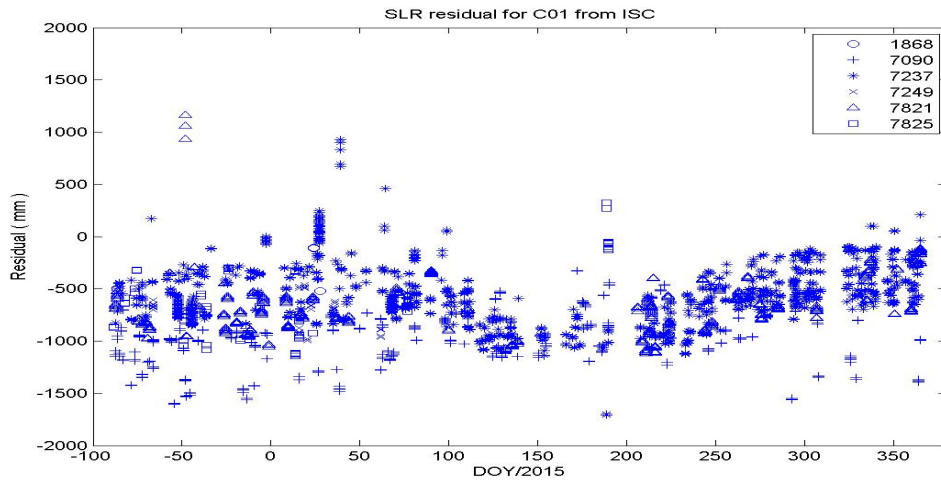
Station	STD(mm)	MEAN(mm)	NP number
1868	231.48	-736.38	11
7090	319.60	-853.91	362
7237	305.12	-560.79	1227
7249	221.11	-792.00	42
7821	307.46	-772.45	369
7825	353.93	-458.01	51
Total	332.42	-653.23	2062



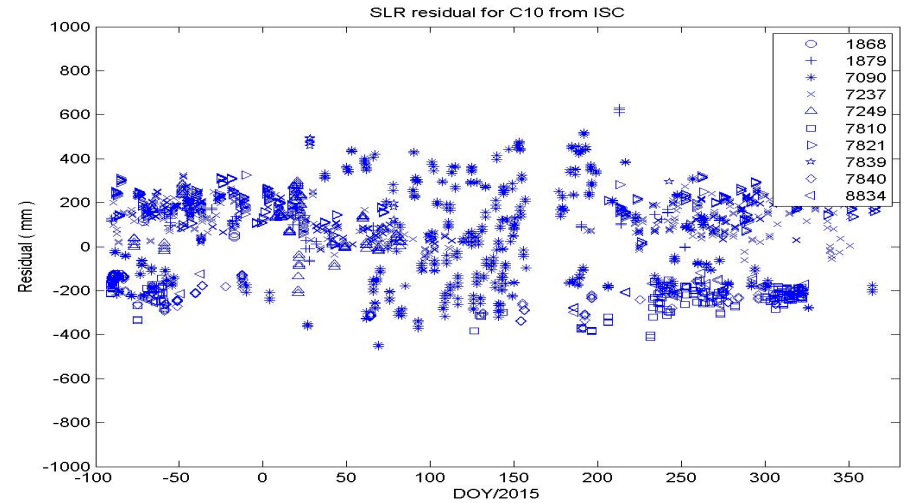
Station	STD(mm)	MEAN(mm)	NP number
1868	258.87	288.13	9
1879	130.54	141.68	70
7090	250.56	61.76	544
7237	85.44	156.05	631
7249	103.16	145.98	108
7821	84.21	231.01	416
7825	189.80	297.51	20
7839	60.22	-183.53	100
7840	48.46	-200.09	73
8834	71.76	-198.90	80
Total	212.52	71.14	2278

□ BDS orbit accuracy: State-of-the-art

➤ iGMAS final orbits



Station	STD(mm)	MEAN(mm)	NP number
1868	325.38	-563.39	9
7090	256.99	-998.63	389
7237	286.26	-552.69	1226
7249	158.99	-726.76	46
7821	276.29	-682.23	384
7825	366.17	-623.30	61
Total	325.90	-664.10	2115



Station	STD(mm)	MEAN(mm)	NP number
1868	48.76	109.22	9
1879	124.03	129.68	67
7090	236.91	40.99	506
7237	81.62	133.30	616
7249	116.68	98.51	113
7821	68.20	191.56	393
7825	169.07	216.71	20
7839	45.83	-211.18	91
7840	40.42	-200.60	64
8834	68.47	-216.96	82
Total	197.82	47.48	2179



Motivation

❑ Large Bias Detected in GEO SLR residuals

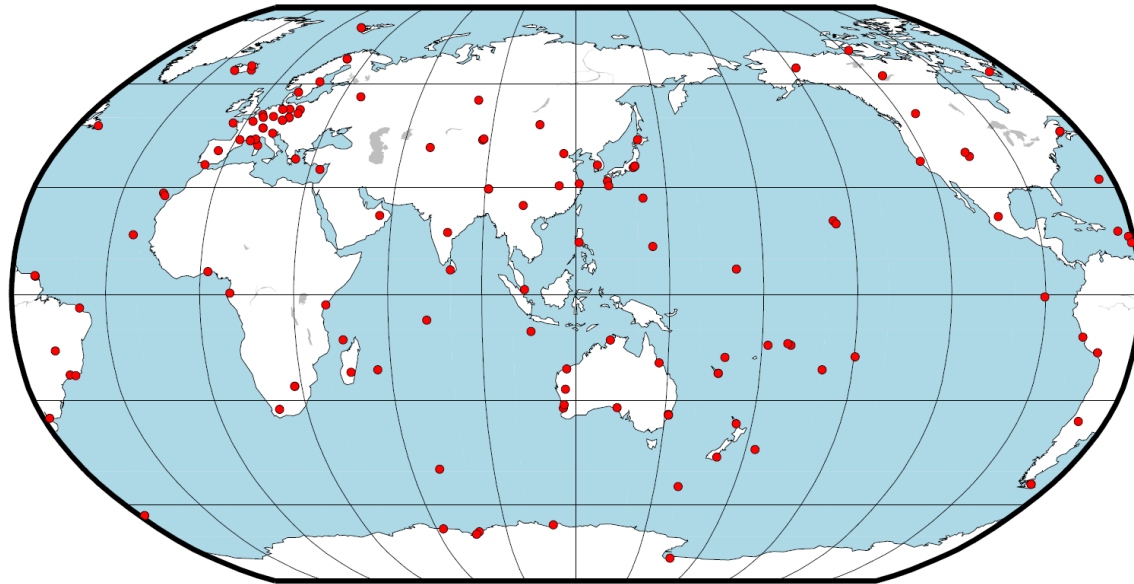
- Reflects the orbit error in line-of-sight direction (assume there is no dramatic bias in SLR range)
- Depresses the accuracy of precise positioning and timing, particularly for relative positioning

❑ Possible solutions to reduce or remove

- Long arc GNSS solution: ?
- Carrier-phase only solution: ?
- SLR only solution: ?
- Carrier-phase + SLR solution: ?

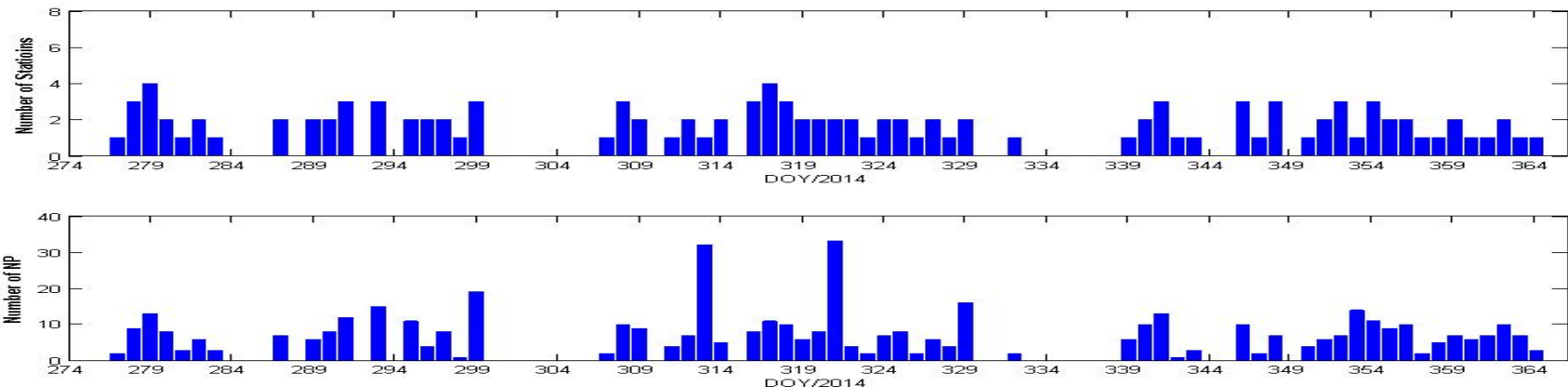
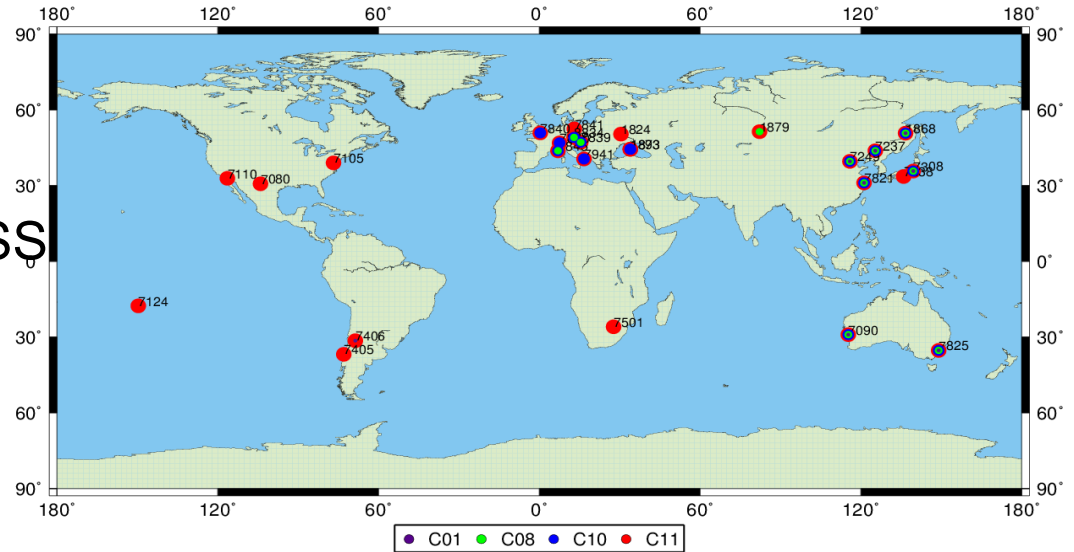
□ GNSS data

- IGS MGEX + iGMAS(136 stations in which about 60 stations have BDS observations)
- Data span: 1/10/2014 (DOY 274)~31/12/2014(DOY 365)
- GPS+BDS



□ SLR data

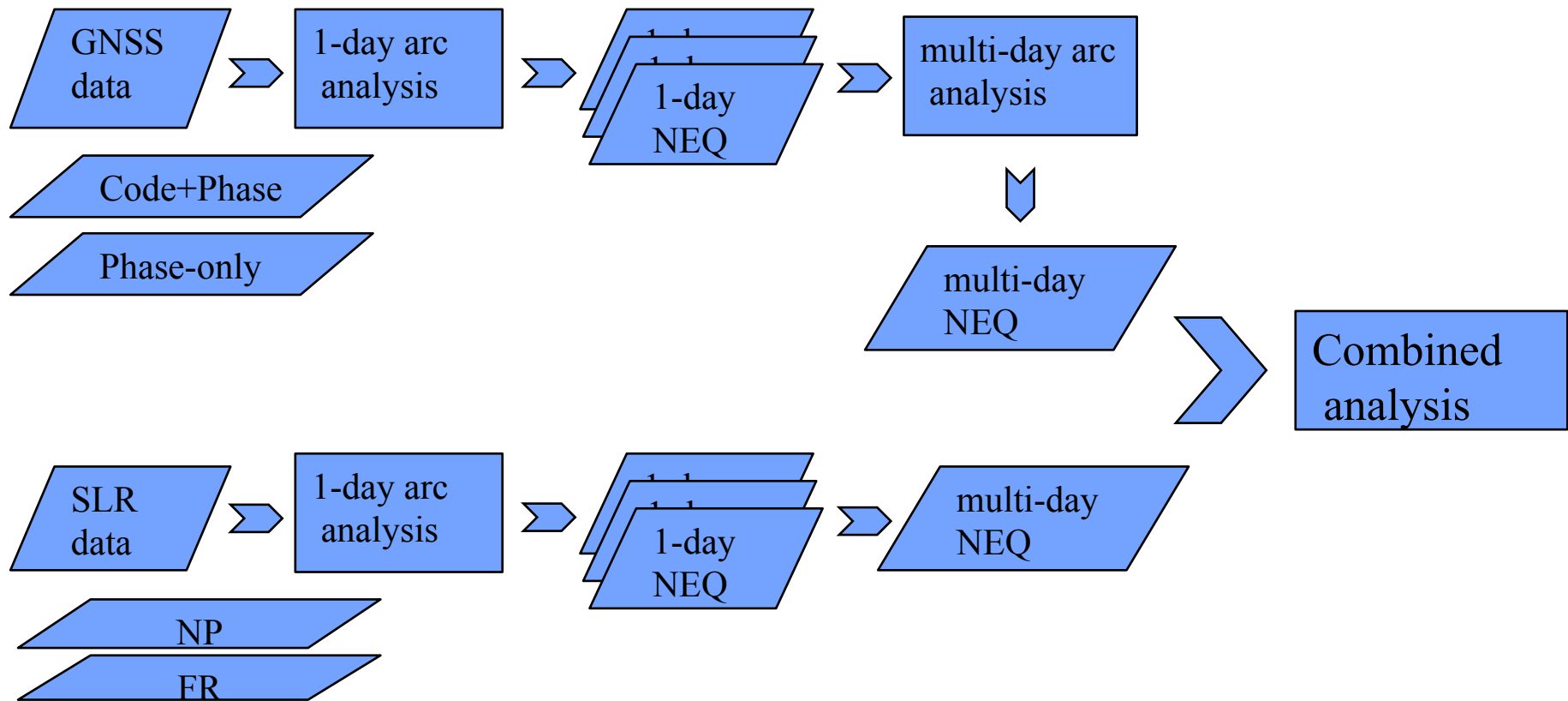
- ILRS network
- Data Span: Same as GNSS
- NP files: 11 stations
(C01: 6, C08:10, C10:11)
- FR files: 6 stations
(C01: 3, C08:4, C10:6)



Tracking stations and normal points per day for C01
(DOY 274/2014 - DOY 365/2104)

Processing flow chart

➤ Based on NEQ combination





Data and Methods

□ Experiments design

- According to the types of observations, 6 POD solutions were introduced
- For each solution different arc were investigated
- Orbit accuracy was evaluated by comparison between each other, SLR residuals

Solutions	Data	Arc-length
GNSS-only	CODE + Phase	3-day, 5-day, 7-day
Phase-only	Phase	3-day, 5-day
SLR-only NP	NP SLR	3-day, 5-day, 7-day, 9-day
SLR-only FR	FR SLR	3-day, 5-day
Phase + SLR_NP	Phase + NP SLR	3-day, 5-day
Phase + SLR_FR	Phase + FR SLR	3-day, 5-day



Data and Methods

□ GNSS 1-day analysis strategy

Measurement model	Description
Basic observables	DD of ionosphere-free LC
Data sampling rate	300 sec
Elevation mask	5
Elevation-dependent weighting	$1/\cos^2Z$
Ionosphere	Ionosphere-free LC
Troposphere a priori model	GMF model
Satellite phase center	IGS MGEX conventions



Data and Methods

□ GNSS 1-day analysis strategy

Force model	Description
Gravity field model	EGM2006_SMALL(12×12)
Third-body	Sun, Moon, Jupiter JPL DE405
SRP model	ECOM 5 model for GPS and BDS; attitude for GEOs considered; No a prior model for BDS satellites
Tides	Solid earth tides, ocean tides, pole tides, IRES convention 2010
Relativistic effects	IRES convention 2010



Data and Methods

□ GNSS 1-day analysis strategy

Estimated Parameters	Description
Station coordinate	One set of coordinate per session
Phase ambiguities	Float solution
Troposphere	ZTD in interval of 2 hours, mapped with GMF; 1 horizontal gradients per session
Orbit parameters	6 osculating orbital elements plus 5 solar radiation pressure coefficients, no constraints
Earth rotation parameters	X and Y coordinates of Pole, UT1-UTC as piece-wise-linear function with 2hour spacing

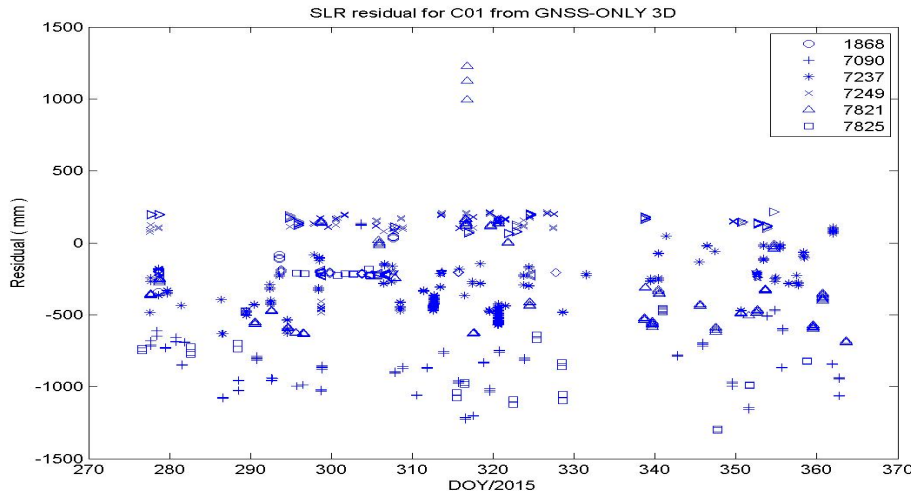


Data and Methods

□ SLR 1-day analysis strategy

- Force models are the same as GNSS
- Only 6 + 5 orbit dynamical parameters estimated
- Station coordinates fixed to SLRF 2008
- ERP fixed to the *a priori* values
- No range and time bias corrected
- Outliers were detected by O-C rather than post residuals (Because of the very few observations)

GNSS-only solution



3-day arc

Station	STD(mm)	MEAN(mm)	NP number
1868	1.70	-341.90	2
7090	175.39	-872.16	124
7237	174.32	-358.47	197
7249	24.33	-449.87	7
7821	294.10	-408.70	118
7825	241.08	-836.81	33
Total	312.81	-537.30	481

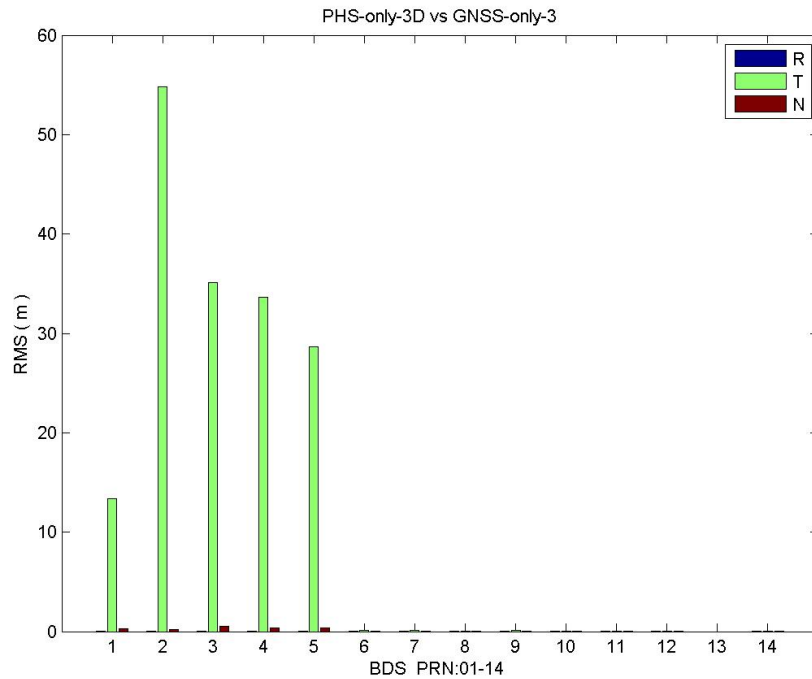
5-day arc

Station	STD(mm)	MEAN(mm)	NP number
7090	193.67	-862.48	122
7237	173.43	-353.07	199
7249	24.79	-411.06	7
7821	342.19	-437.11	108
7825	242.42	-787.17	29
Total	319.38	-534.18	465

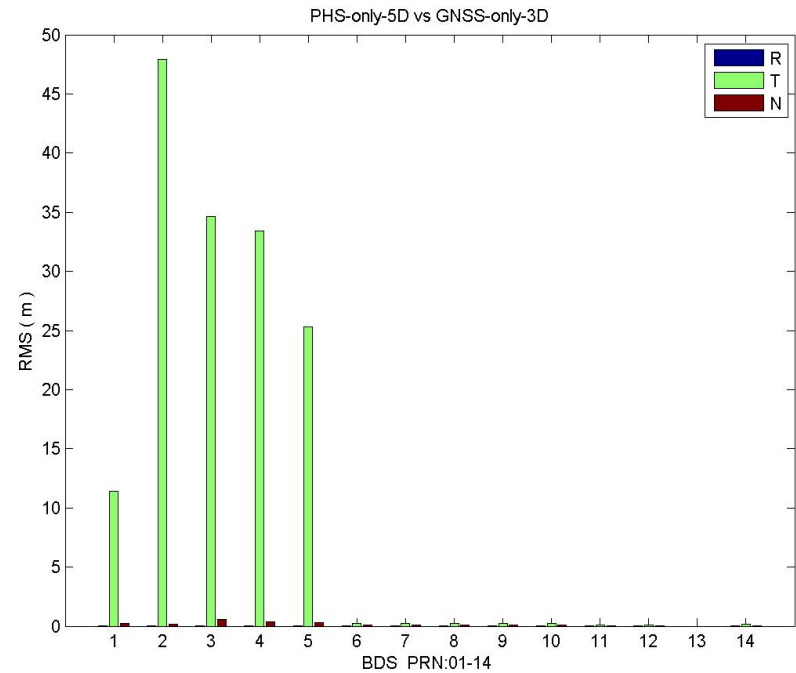
7-day arc

Station	STD(mm)	MEAN(mm)	NP number
1868	1.34	-370.95	2
7090	202.36	-853.32	119
7237	180.34	-355.56	201
7249	24.57	-433.44	7
7821	339.51	-432.18	111
7825	285.35	-768.24	29
Total	319.17	-526.73	469

Phase-only solution

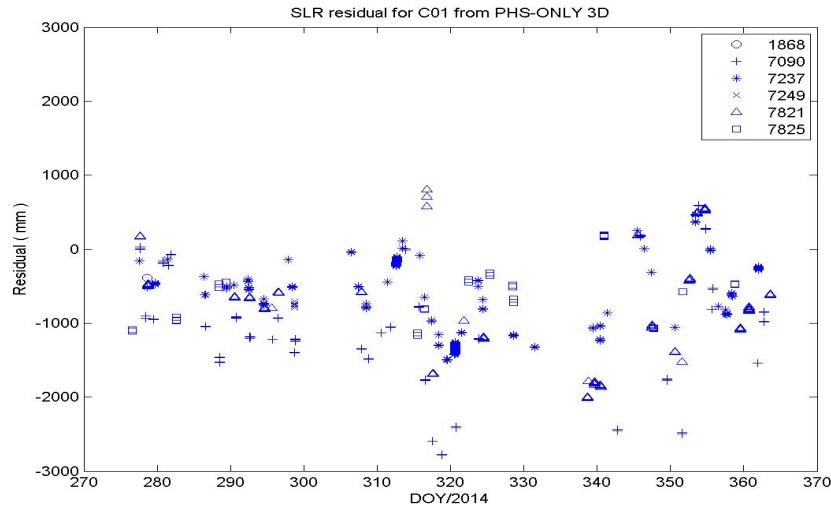


3-day arc

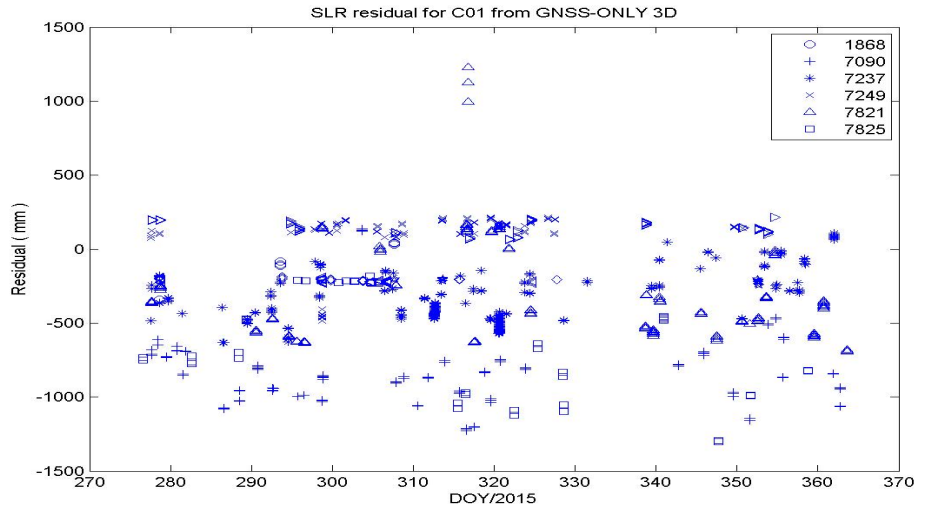


5-day arc

Phase-only solution

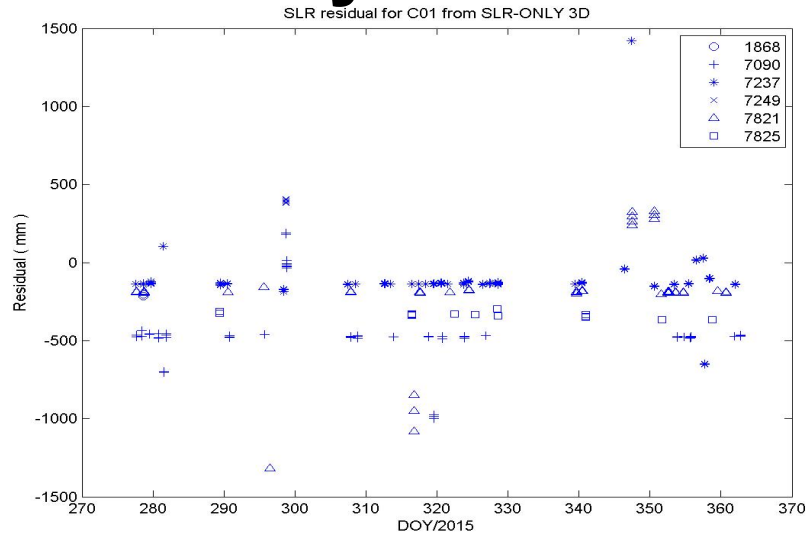


Station	STD(mm)	MEAN(mm)	NP number
1868	1.70	-391.10	2
7090	783.04	-1098.16	121
7237	498.86	-672.76	197
7249	25.05	-754.30	7
7821	720.47	-735.65	118
7825	387.66	-596.52	33
Total	653.98	-790.72	478



Station	STD(mm)	MEAN(mm)	NP number
1868	1.70	-341.90	2
7090	175.39	-872.16	124
7237	174.32	-358.47	197
7249	24.33	-449.87	7
7821	294.10	-408.70	118
7825	241.08	-836.81	33
Total	312.81	-537.30	481

SLR-only solution with NP



3-day arc

Station	STD(mm)	MEAN(mm)	NP number
1868	9.83	-209.45	2
7090	207.85	-437.95	79
7237	139.63	-127.82	175
7249	9.23	395.59	7
7821	351.74	-139.85	95
7825	20.59	-337.85	22
Total	267.06	-198.25	380

5-day arc

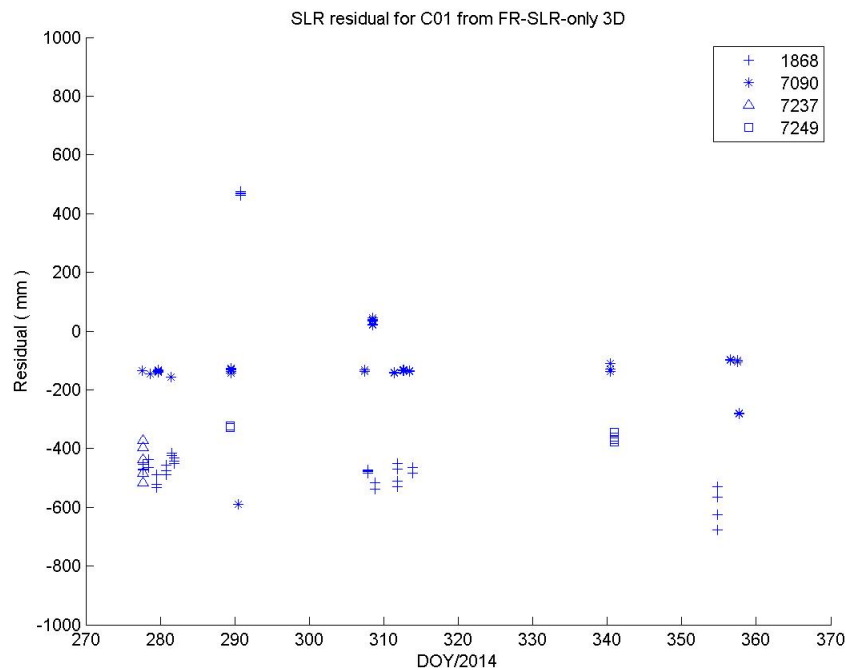
Station	STD(mm)	MEAN(mm)	NP number
1868	9.69	-206.85	2
7090	151.56	-508.75	75
7237	4.75	-135.01	138
7821	3.44	-190.37	71
7825	12.75	-336.97	19
Total	171.59	-252.85	305

7-day arc

Station	STD(mm)	MEAN(mm)	NP number
7090	105.89	-491.25	59
7237	5.05	-134.78	114
7249	12.22	-224.69	7
7821	306.01	-129.15	51
7825	14.15	-335.69	15
Total	212.68	-233.92	246

□ SLR-only solution with FR

3-day arc

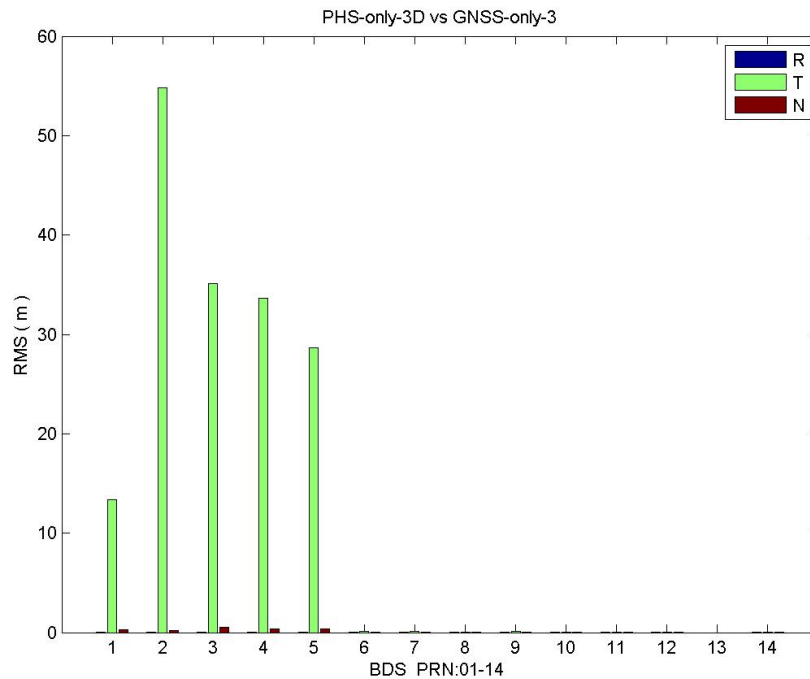


Station	STD(mm)	MEAN(mm)	NP number
7090	351.02	-347.51	40
7237	94.29	-137.09	75
7821	59.15	-441.22	5
7825	22.42	-350.80	6
Total	236.45	-226.14	126

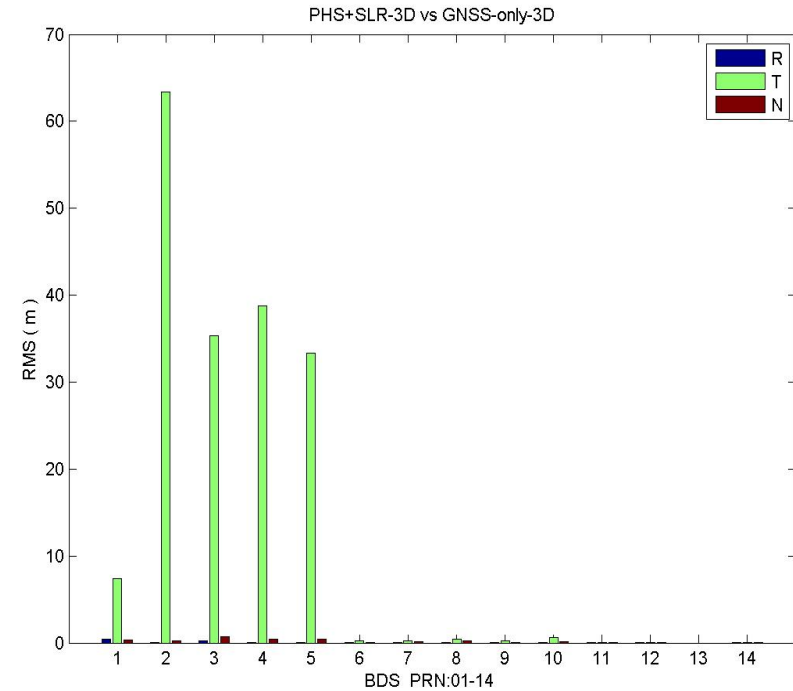
5-day arc

Station	STD(mm)	MEAN(mm)	NP number
7090	90.07	-517.72	33
7237	15.93	-135.95	71
7821	561.72	-309.22	15
Total	260.61	-263.66	119

Phase-only + SLR-only with NP

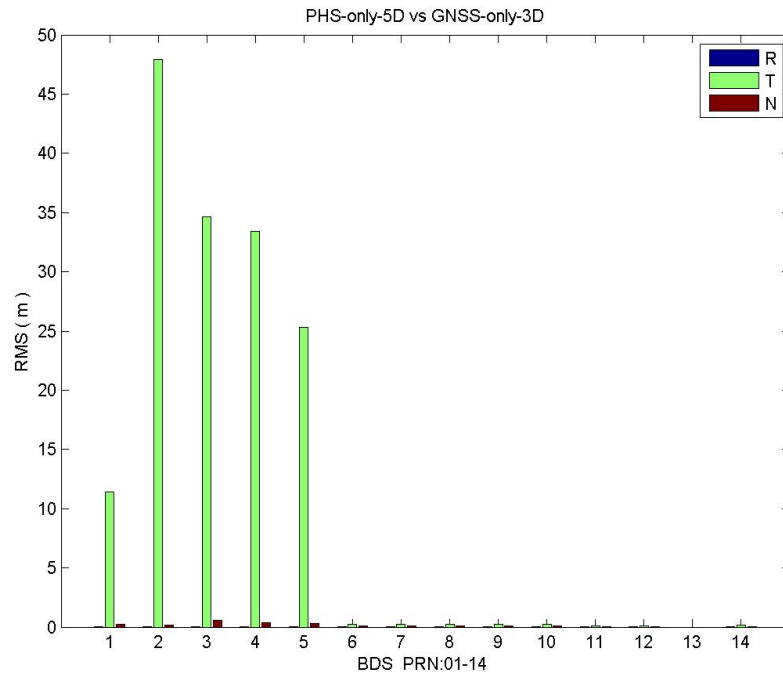


phase-only 3-day arc

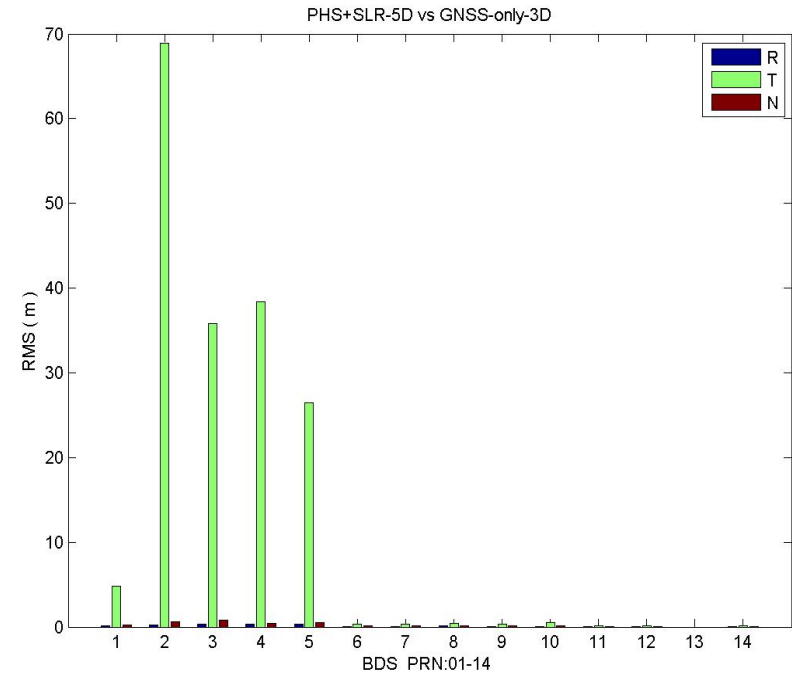


Phase-only + SLR-only with NP 3-day arc

Phase-only + SLR-only with NP



phase-only 5-day arc

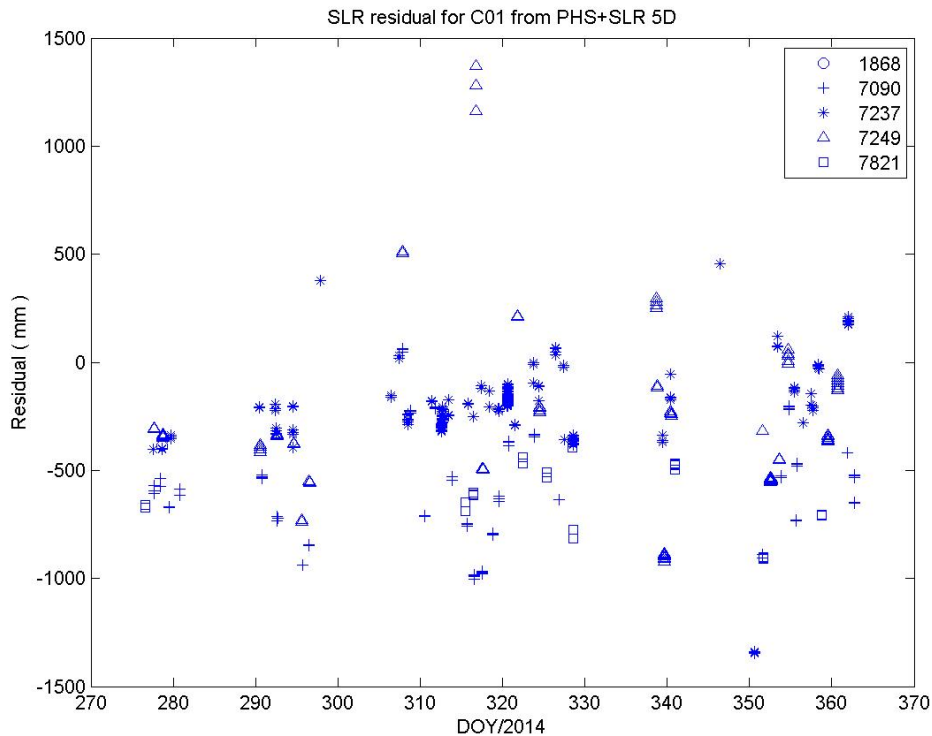


Phase-only + SLR-only with
NP 5-day arc



Results and Analysis

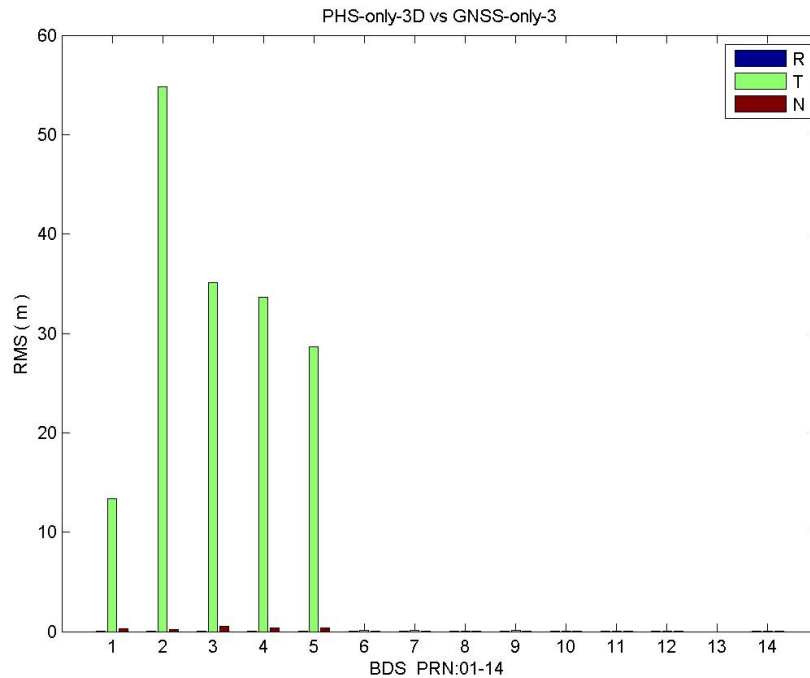
Phase-only + SLR-only with NP



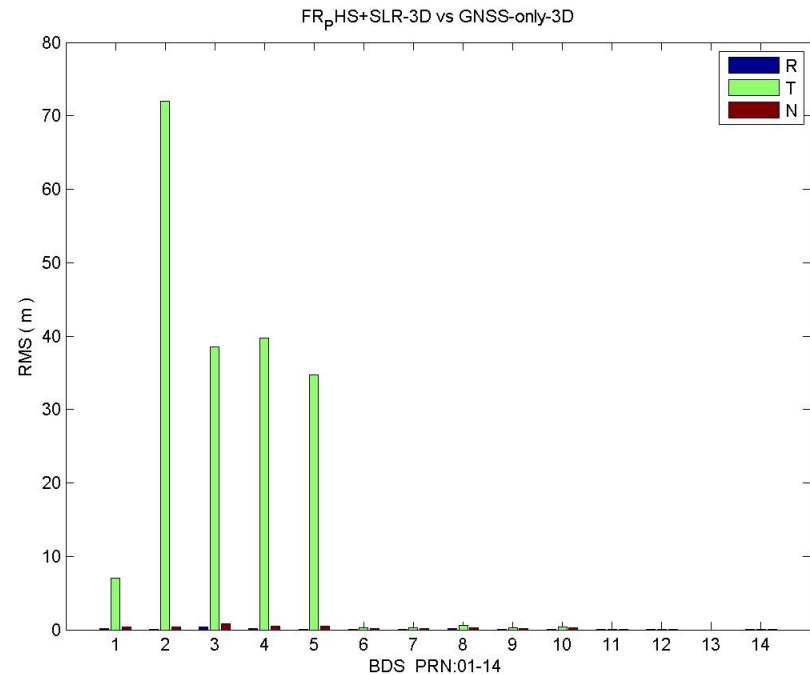
5-day arc

Station	STD(mm)	MEAN(mm)	NP number
1868	0.64	-386.95	2
7090	260.62	-560.53	94
7237	216.28	-201.93	186
7821	405.32	-286.24	103
7825	161.35	-618.54	24
Total	323.03	-330.93	409

Phase-only + SLR-only with FR

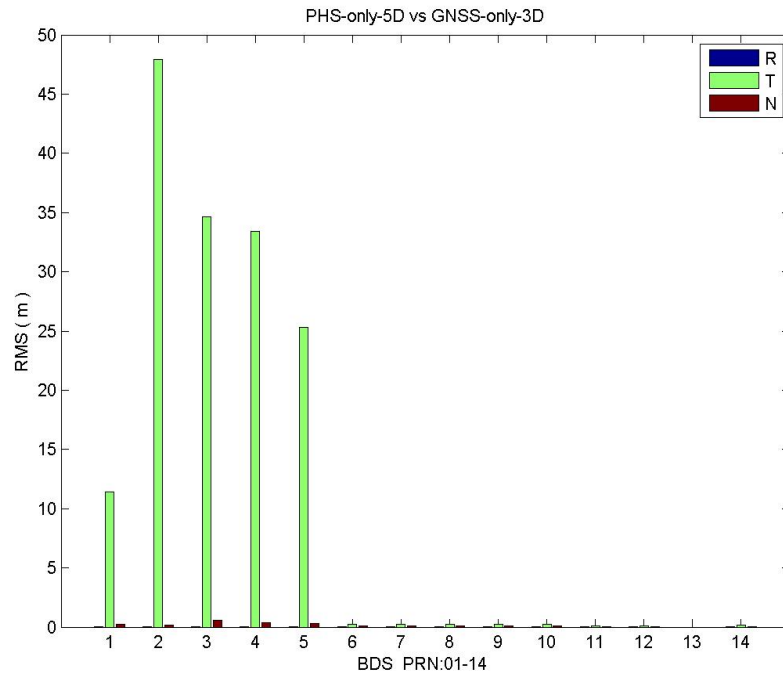


phase-only 3-day arc

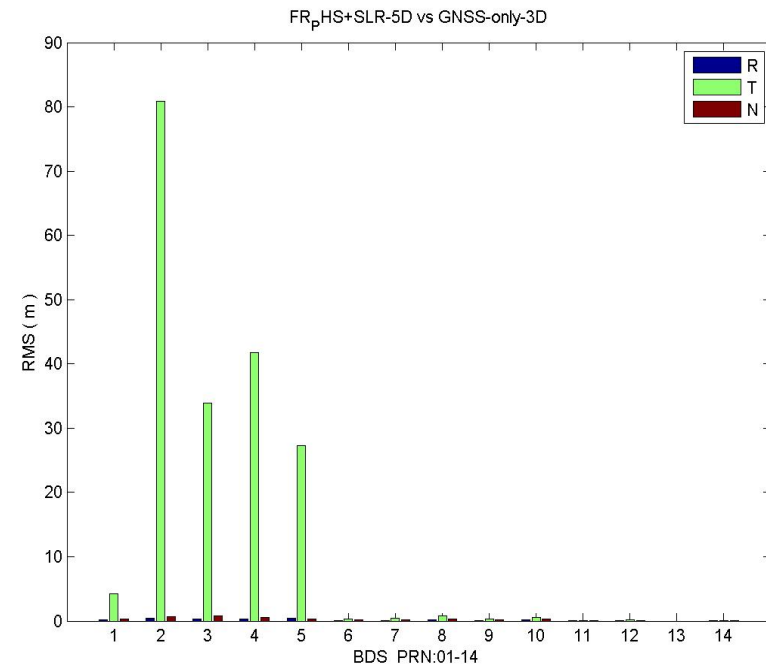


Phase-only + SLR-only with FR
3-day arc

Phase-only + SLR-only with FR

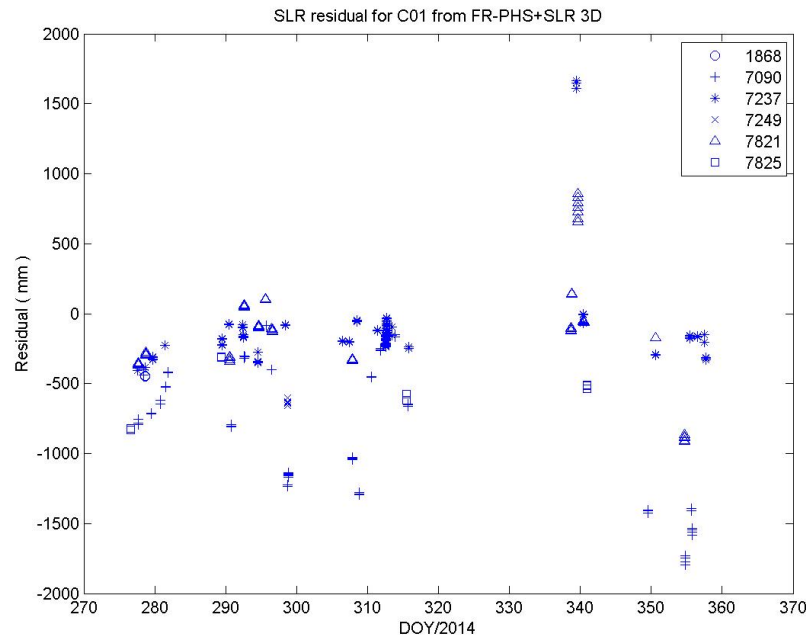


phase-only 5-day arc



Phase-only + SLR-only with FR
5-day arc

Phase-only + SLR-only with FR



Station	STD(mm)	MEAN(mm)	NP number
1868	2.26	-448.00	2
7090	461.57	-852.99	75
7237	318.37	-128.27	106
7249	15.88	-632.54	7
7821	403.28	-109.69	60
7825	175.09	-554.24	10
Total	500.45	-365.46	260



Summary and Outlook

Summary:

- Large bias detected in GEO SLR residuals
- Several solutions were introduced in order to reduce this bias
- SLR-only and Phase-SLR combination solutions were conducted by NEQ combinations
- The bias was reduced from 0.5m to 0.3m by Phase and SLR combined solution

Further investigation:

- Improve SLR analysis strategy particular for data edit
- the origin of bias in GEO SLR residual? Is it SLR range bias/time bias? more GNSS and SLR data will be processed

Suggestion:

- Add other GNSS GEO satellites to ILRS tracking schedule



**Thanks for your
attention !**