Processing 20 years of SLR observations to GNSS satellites

K. Sośnica (1), R. Dach (1), D. Thaller (2),
A. Jäggi (1), G. Beutler (1), D. Arnold (1)

(1) Astronomical Institute, University of Bern, Switzerland

(2) Federal Agency for Cartography and Geodesy, Frankfurt/Main, Germany

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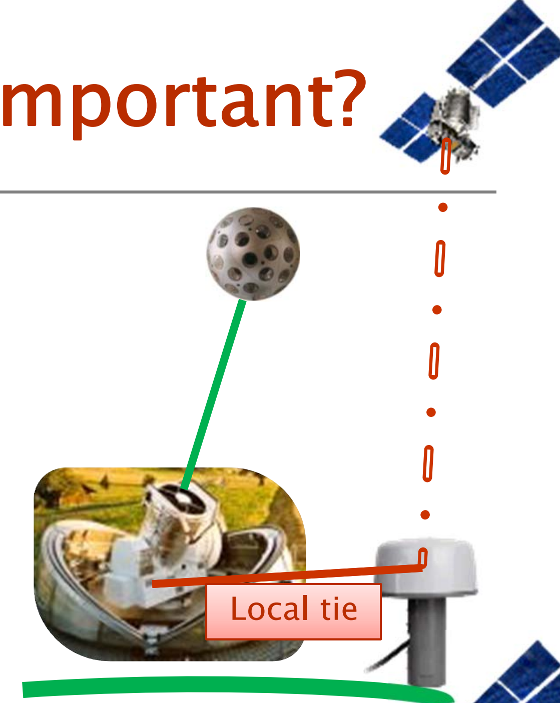
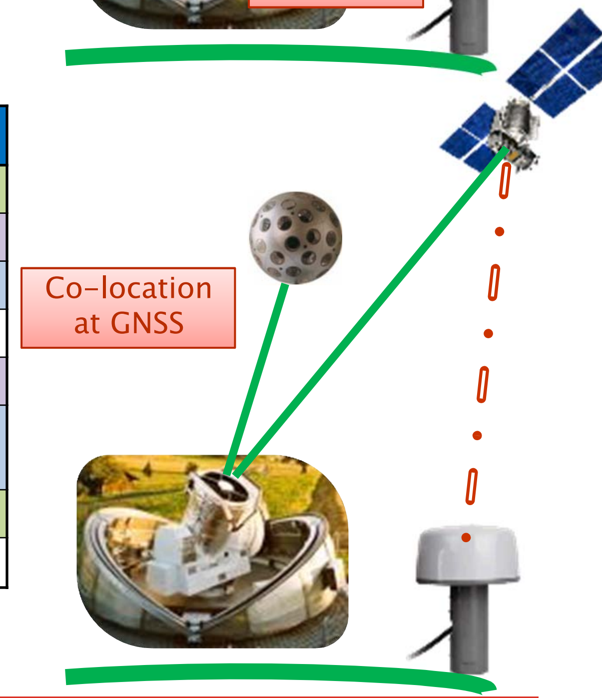
Why is the SLR tracking of GNSS important?

Microwave GNSS	LAGEOS+Etalon
GNSS Station Coordinates	SLR Station Coordinates
-	Geocenter coordinates
GPS and GLONASS orbits	LAGEOS and Etalon orbits
Earth Rotation Parameters (X pole, Y pole, Length-of-Day)	
Phase-code, Inter-system, Inter-frequency Biases	Range Biases (1-3 stations)
APL Scaling Factors	APL Scaling Factors
Troposphere Delays	-

«Classical» co-location on the ground using local ties



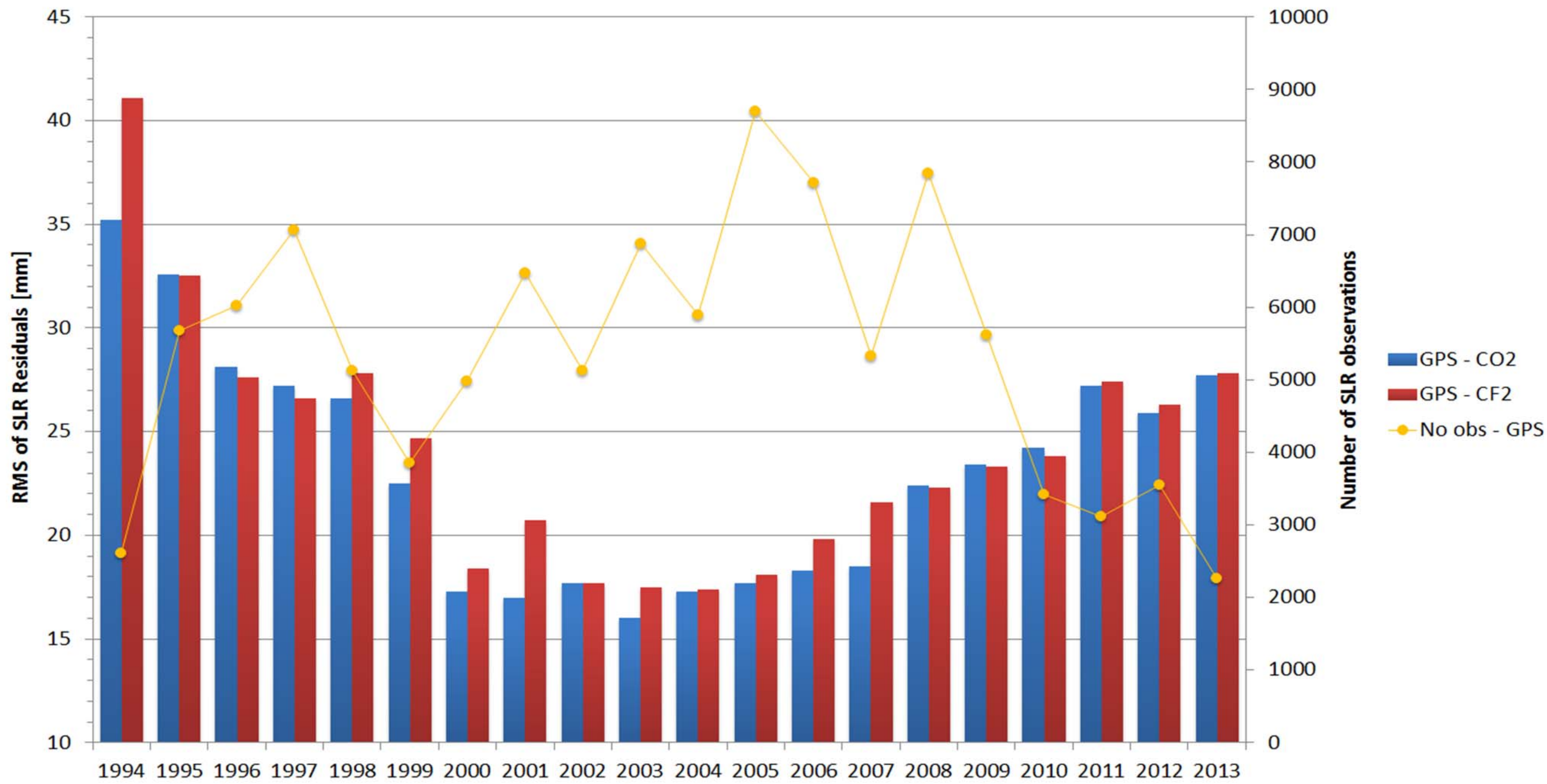
Microwave GNSS	SLR@GNSS	LAGEOS+Etalon
GNSS Station Coordinates	SLR Station Coordinates	
Geocenter Coordinates		
GPS and GLONASS orbits		LAGEOS, Etalon orbits
Antenna Offset	LRA Offset	-
Earth Rotation Parameters (X pole, Y pole, Length-of-Day)		
Phase-code, Inter-system, Inter-frequency Biases	Range biases (all stations)	Range Biases (1-3 stations)
APL Scaling Factors	APL Scaling Factors	
Troposphere Delays	-	



Co-location in space: SLR observations to GNSS are needed

SLR validation of GPS orbits

RMS of SLR residuals to GPS – CODE repro2 orbits



3-day orbit solutions (C02) perform better than the 1-day orbits (CF2), especially in the earlier years.
After 2008 the process of the ageing of GPS satellites and of the ageing of the reference frame (new stations and stations affetected by earthquakes) is visible.

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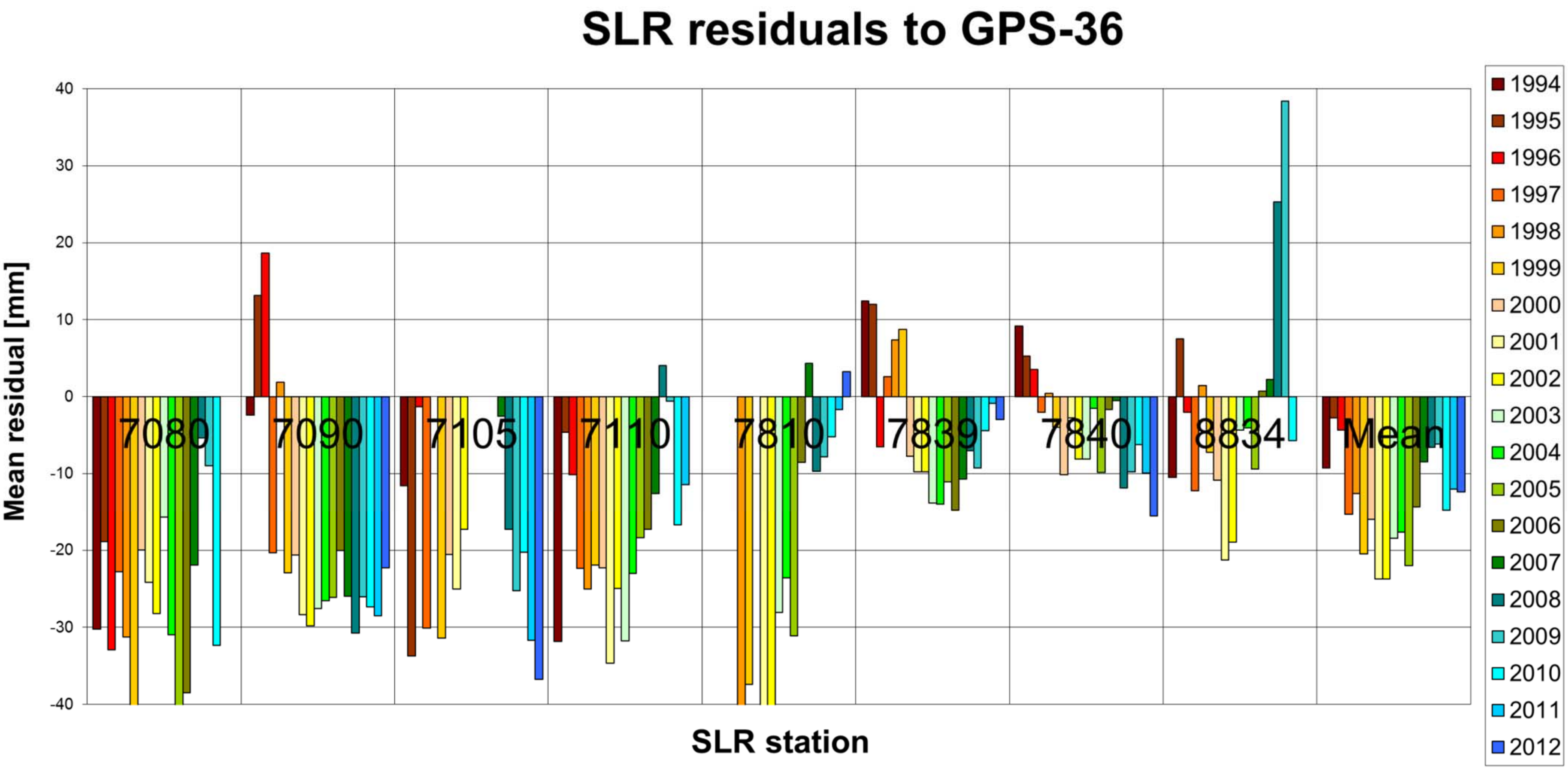
RMS of SLR residuals to GPS



The SLR mean residuals are clearly station-, satellite-, and time-dependent (they depend on the equipment used at a SLR station).

SLR validation of GLONASS orbits

RMS of SLR residuals to GLONASS

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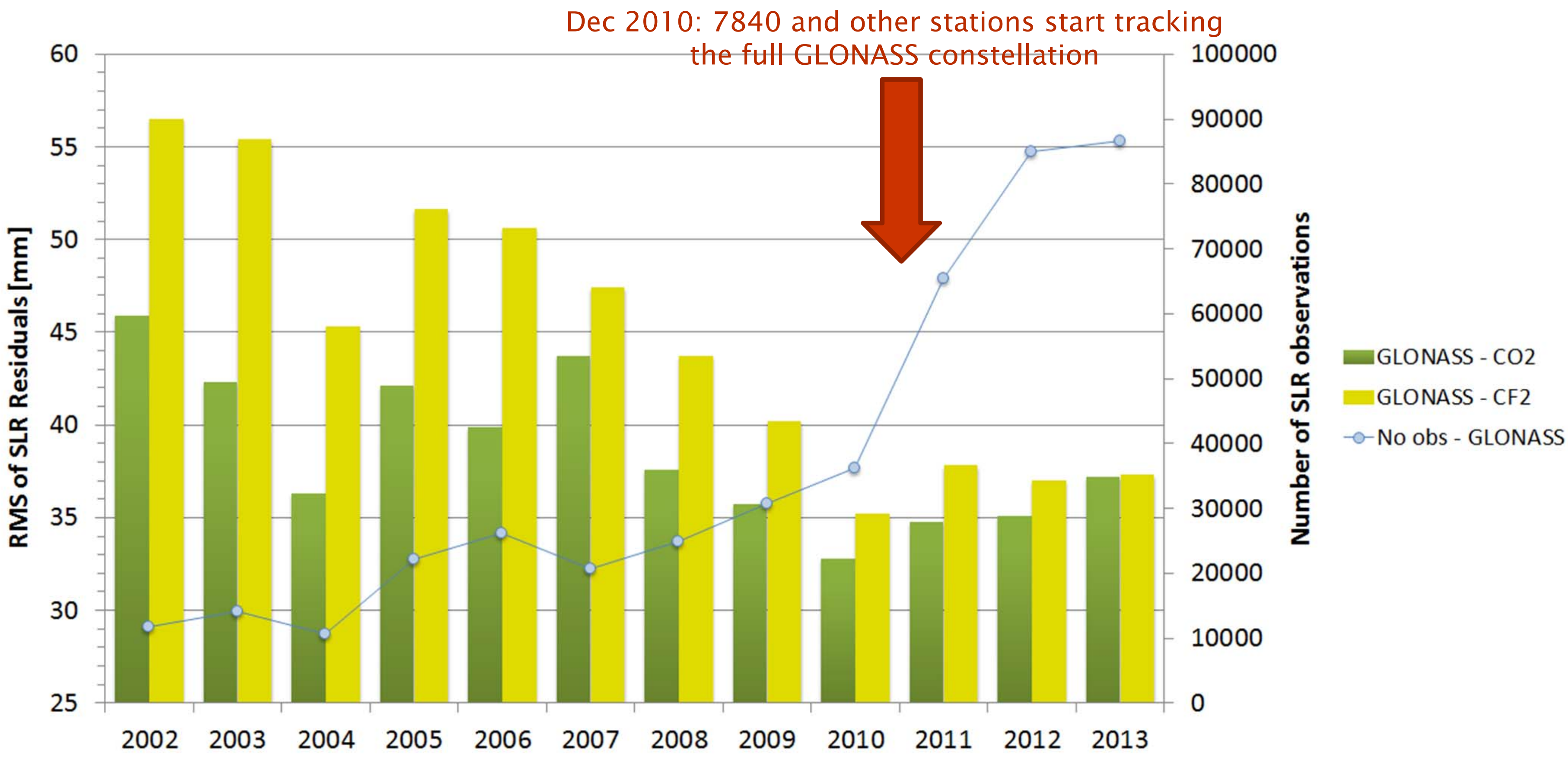
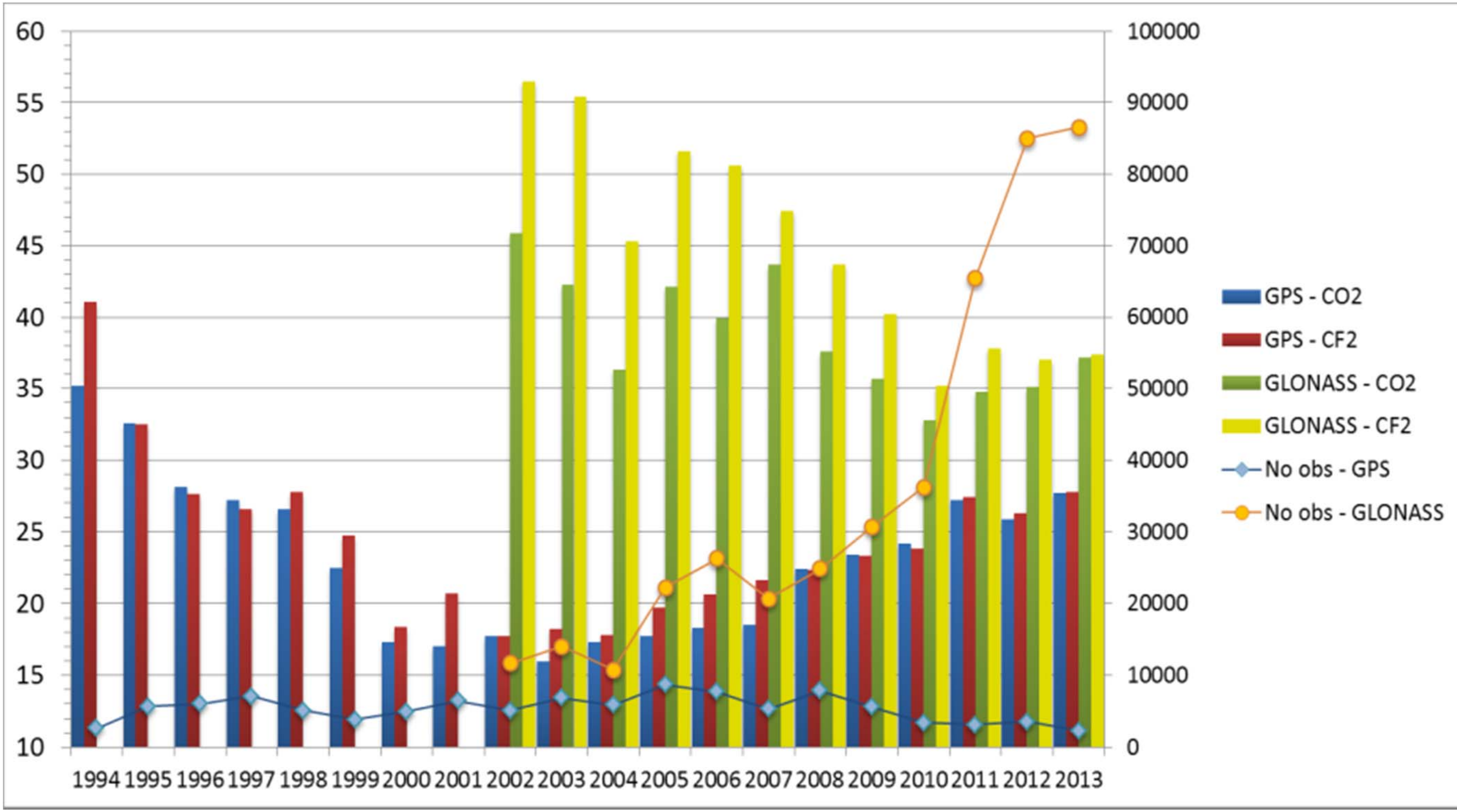


3-day orbit solutions (C02) perform much better than the 1-day orbits (CF2), especially in the earlier years.

After 2010 the number of SLR observations to GLONASS increases rapidly.

RMS of SLR residuals to GPS/GLONASS



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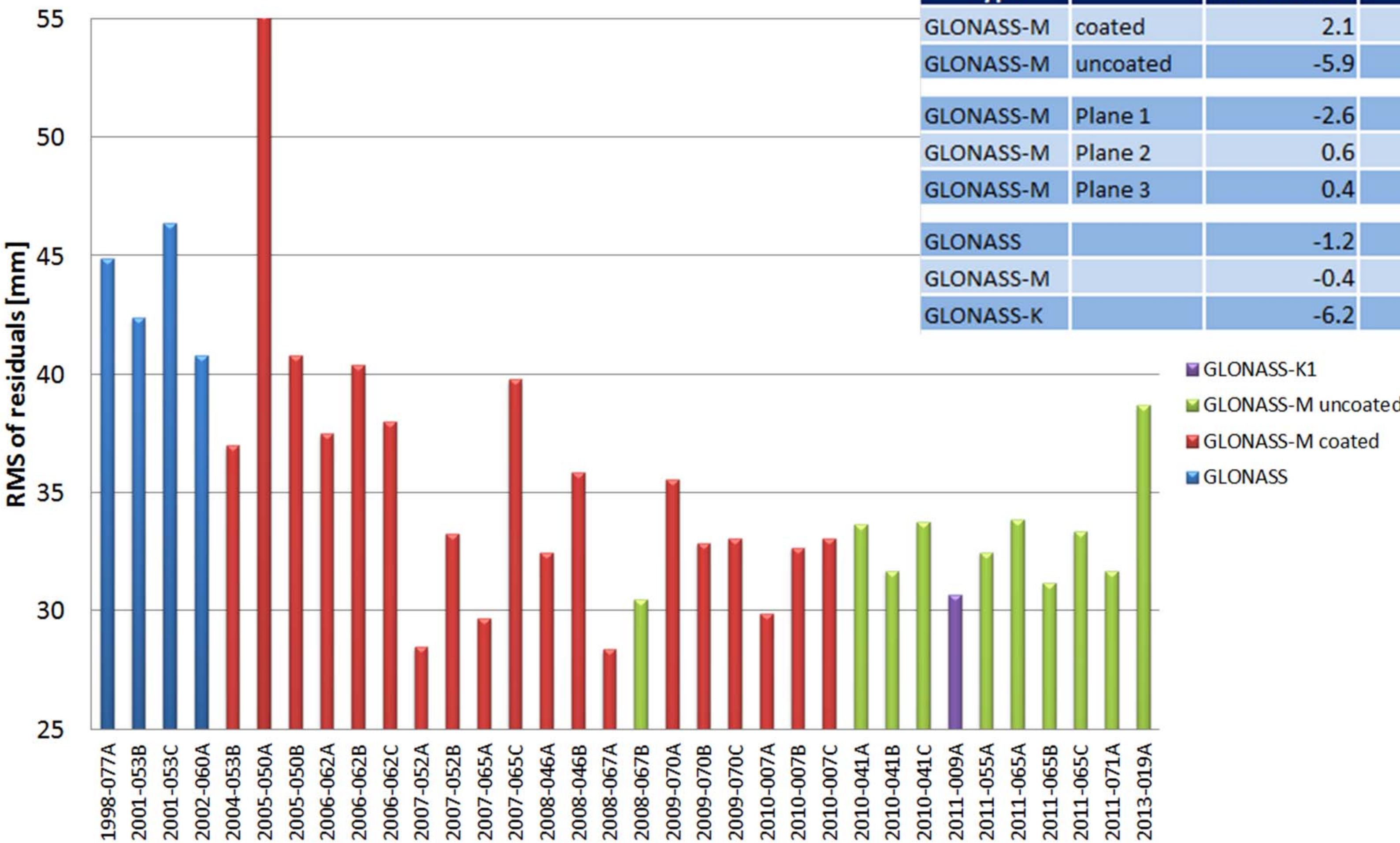
Types of GLONASS satellites

Type	ILRS No	SVN No	Slot	COSPAR	Plane	Coating	LRA Shape	No cubes	From	To	No obs	Mean offset	RMS
-	82	779	R01	1998-077A	1	Aluminium	Irregular planar	396	2002	2002	1194	2.6	44.9
-	86	790	R06	2001-053C	1	Aluminium	Hollow Greek Cross	124	2002	2002	4643	8.5	46.4
-	87	789	R03	2001-053B	1	Aluminium	Hollow Greek Cross	124	2002	2007	38546	-0.6	42.4
-	89	791	R22	2002-060A	3	Aluminium	Irregular planar	396	2003	2007	32509	-3.4	40.8
M	95	712	R08	2004-053B	1	Aluminium	Rectangular	112	2005	2013	23005	6.9	37.0
M	99	713	R24	2005-050B	3	Aluminium	Rectangular	122	2007	2009	18883	-2.5	40.8
M	100	714	R18	2005-050A	3	Aluminium	Rectangular	122	2009	2011	1686	11.2	55.2
M	101	715	R14	2006-062C	2	Aluminium	Rectangular	122	2009	2013	5345	4.2	38.0
M	102	716	R15	2006-062A	2	Aluminium	Rectangular	122	2007	2013	48798	12.1	37.5
M	103	717	R10	2006-062B	2	Aluminium	Rectangular	122	2009	2013	6002	13.0	40.4
M	105	719	R20	2007-052B	3	Aluminium	Rectangular	122	2009	2013	5108	6.5	33.3
M	106	720	R19	2007-052A	3	Aluminium	Rectangular	122	2009	2013	5248	5.8	28.5
M	107	721	R13	2007-065A	2	Aluminium	Rectangular	122	2009	2013	5757	-0.3	29.7
M	109	723	R11	2007-065C	2	Aluminium	Rectangular	122	2008	2013	41748	-12.8	39.8
M	110	724	R18	2008-046A	3	Aluminium	Rectangular	122	2009	2013	17985	0.8	32.5
M	111	725	R21	2008-046B	3	Aluminium	Rectangular	122	2009	2013	4535	3.0	35.9
M	113	728	R03	2008-067A	1	Aluminium	Rectangular	122	2009	2013	4603	-18.5	28.4
M	115	729	R08	2008-067B	1	**NO**	Rectangular	122	2009	2012	37183	-15.5	30.5
M	116	730	R01	2009-070A	1	Aluminium	Rectangular	122	2010	2013	5781	3.4	35.6
M	117	733	R06	2009-070B	1	Aluminium	Rectangular	122	2010	2013	4797	4.7	32.9
M	118	734	R05	2009-070C	1	Aluminium	Rectangular	122	2010	2013	19813	6.3	33.1
M	119	731	R22	2010-007A	3	Aluminium	Rectangular	122	2010	2013	4679	-0.4	29.9
M	120	732	R23	2010-007C	3	Aluminium	Rectangular	122	2010	2013	13249	1.2	33.1
M	121	735	R24	2010-007B	3	Aluminium	Rectangular	122	2010	2013	5535	6.6	32.7
M	122	736	R09	2010-041C	2	**NO**	Rectangular	122	2011	2013	2856	2.3	33.8
M	123	737	R12	2010-041B	2	**NO**	Rectangular	122	2010	2013	9769	-2.1	31.7
M	124	738	R16	2010-041A	2	**NO**	Rectangular	122	2011	2013	8780	1.3	33.7
K	125	801	R26	2011-009A	3	Aluminium	Hollow Circle	123	2011	2013	2969	-6.2	30.7
M	126	742	R04	2011-055A	1	**NO**	Rectangular	122	2011	2013	7204	1.8	32.5
M	127	743	R05	2011-065C	1	**NO**	Rectangular	122	2012	2013	3068	2.1	33.4
M	128	744	R03	2011-065A	1	**NO**	Rectangular	122	2011	2013	7678	-0.5	33.9
M	129	745	R07	2011-065B	1	**NO**	Rectangular	122	2011	2013	13820	-0.8	31.2
M	130	746	R17	2011-071A	3	**NO**	Rectangular	122	2011	2013	16738	-4.8	31.7
M	131	747	R02	2013-019A	1	**NO**	Rectangular	122	2013	2013	1655	6.6	38.7

Types of GLONASS satellites

Type		Mean offset	RMS
GLONASS-M	coated	2.1	36.3
GLONASS-M	uncoated	-5.9	31.8
GLONASS-M	Plane 1	-2.6	32.8
GLONASS-M	Plane 2	0.6	37.1
GLONASS-M	Plane 3	0.4	34.4
GLONASS		-1.2	42.0
GLONASS-M		-0.4	34.9
GLONASS-K		-6.2	30.7



GLONASS with uncoated LRA have typically negative mean bias (similar to that of GPS satellites) and smaller RMS of residuals as compared to GLONASS with coating.

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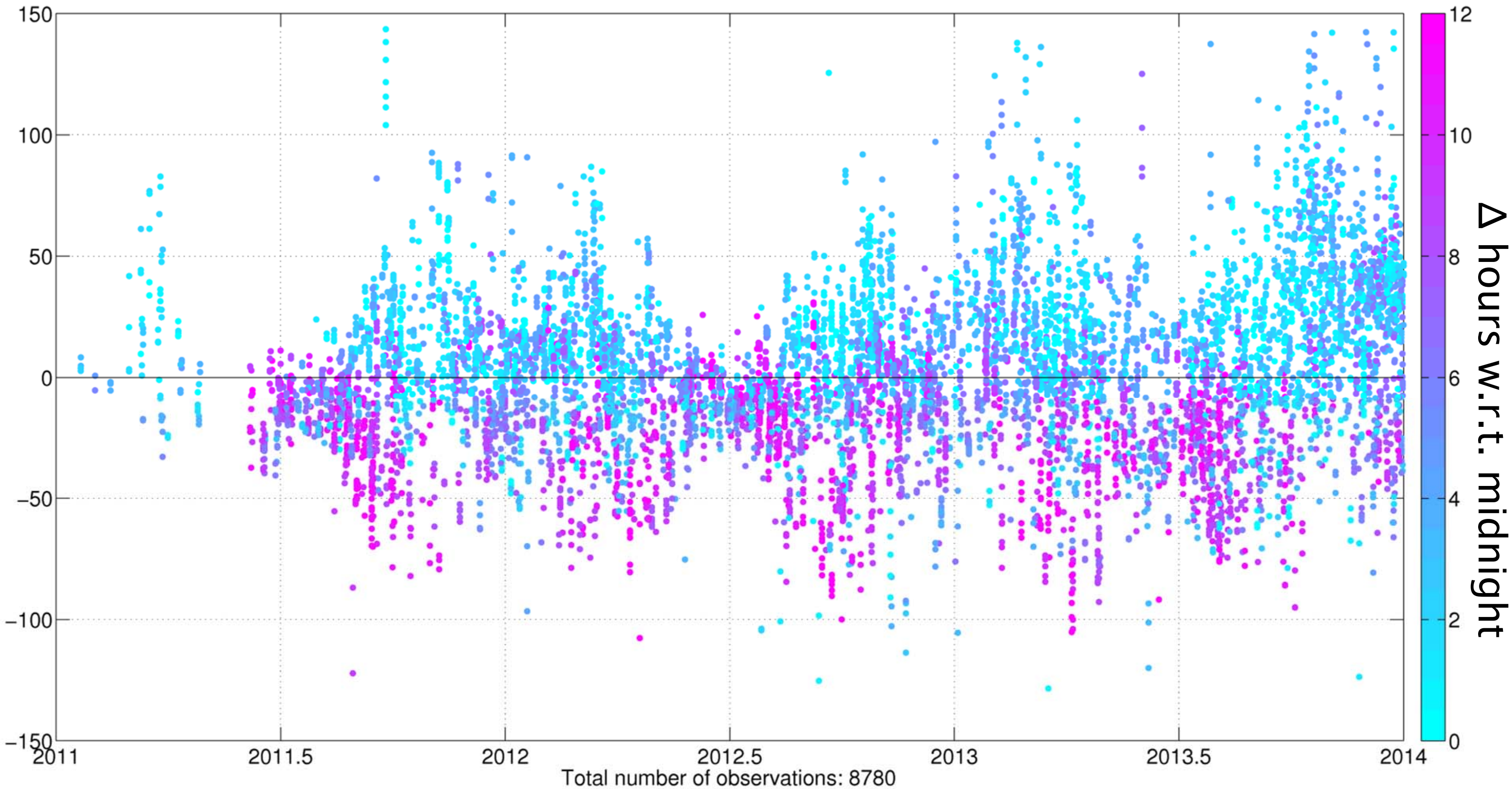
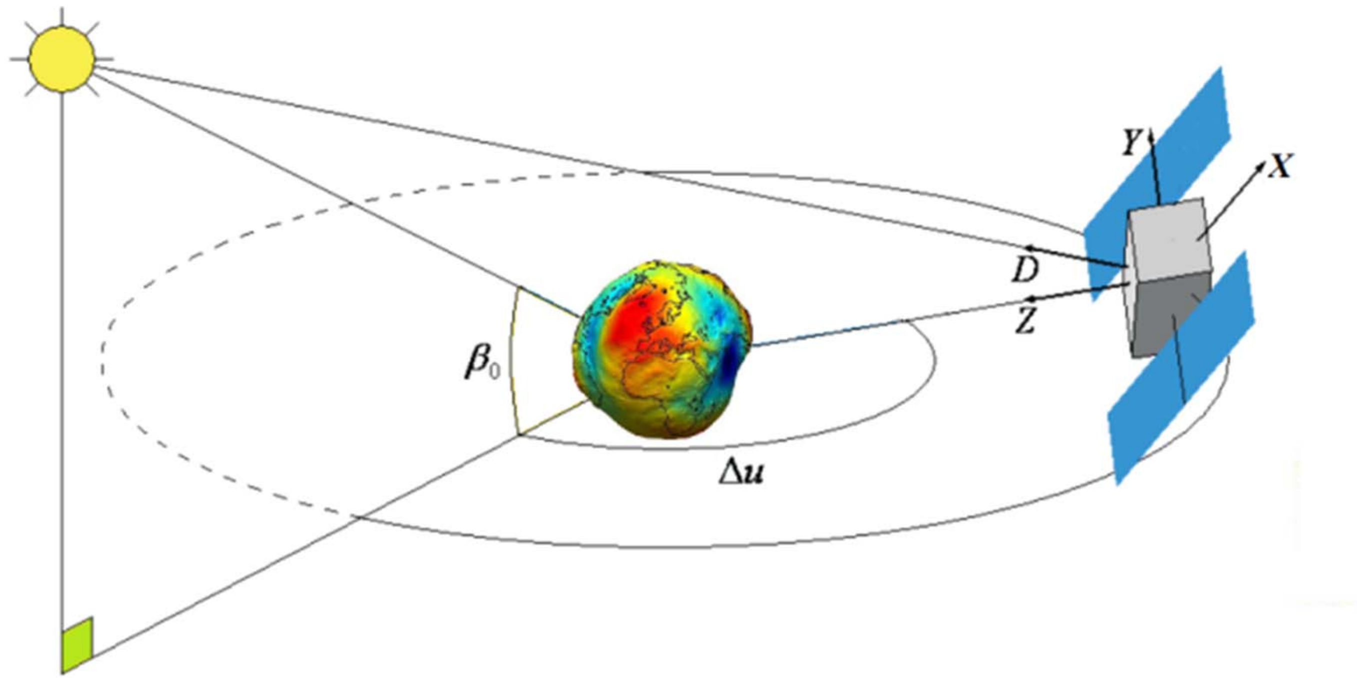
Satellite Orbit Modeling Issues

Nighttime vs. Daytime Observations



Difference between nighttime and daytime SLR residuals: Problem of the stations or of the orbit modeling?

GNSS orbit modeling



GNSS dynamic orbit parameters in reduced ECOM model:

$$\begin{pmatrix} D \\ Y \\ X \end{pmatrix} = \begin{pmatrix} D_0 \\ Y_0 \\ X_0 + X_C \cos u + X_S \sin u \end{pmatrix}$$

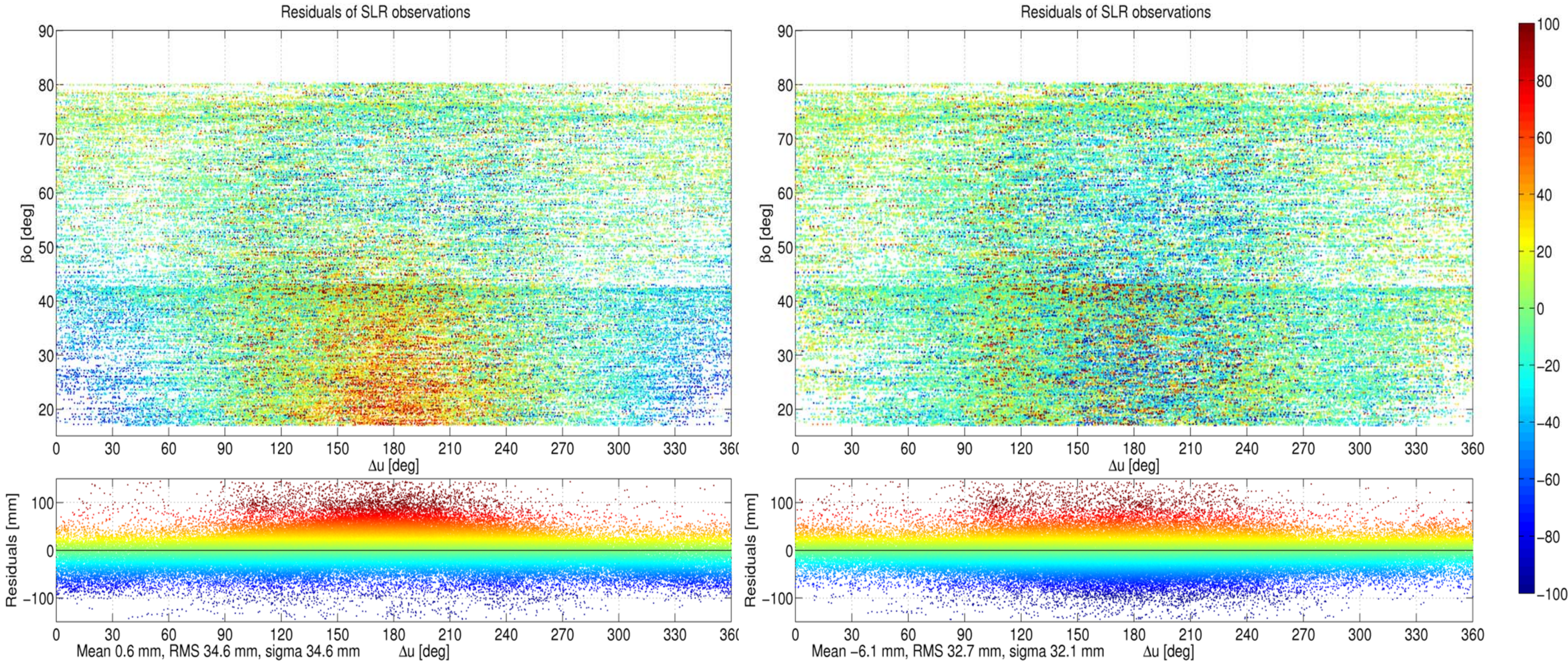
old empirical CODE model

$$\begin{pmatrix} D \\ Y \\ X \end{pmatrix} = \begin{pmatrix} D_0 + D_{2C} \cos 2\Delta u + D_{2S} \sin 2\Delta u \\ Y_0 \\ X_0 + \{X_C \cos \Delta u + X_S \sin \Delta u\} \end{pmatrix}$$

new CODE model (one out of several options)

SLR observations to GLONASS : orbit modeling issues

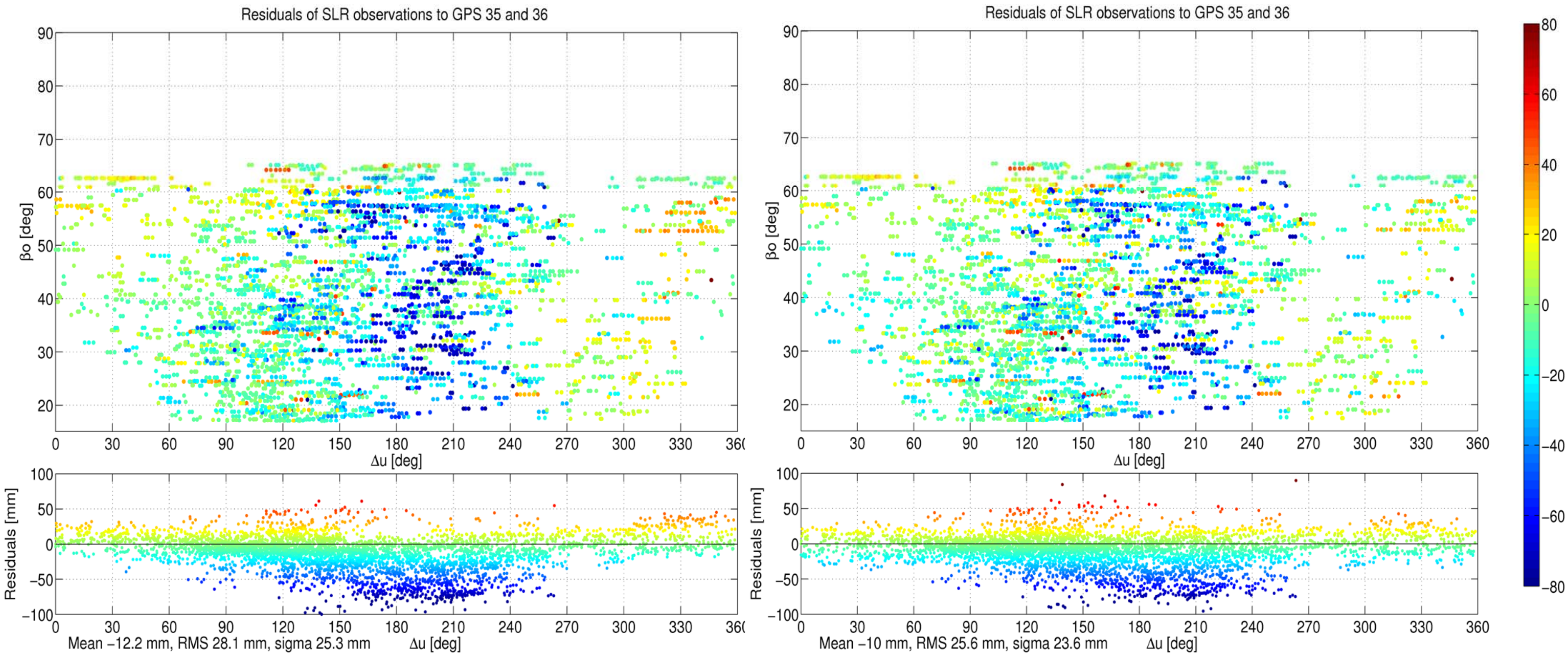
The problem of the difference between nighttime and daytime SLR residuals can be explained by satellite orbit modeling issues.



COF (old model) **TB4 (new model)**

For details see: D. Arnold, M. Meindl, G. Beutler, R. Dach, S.Schaer, S. Lutz, L. Prange, K. Sosnica, L.Mervart, A. Jäggi (2014) CODE's new empirical orbit model for the International GNSS Service.

SLR observation to GPS: orbit modeling issues



COF (old model) **TB4 (new model)**

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Summary

SLR residuals depend on many constituents, e.g., on:
(1) GNSS satellite type/block,
(2) shape and size of LRA, and number of corner cubes in LRAs,
(3) LRA coating,
(4) equipment used at SLR stations including laser and detector types,
(5) (problems in) satellite orbit modeling.

SLR observations of GNSS satellites yield a remarkably important tool in a sense of the validation of GNSS orbits and the assessment of deficiencies in solar radiation pressure modeling.
SLR tracking of GNSS is also essential for the co-location of the techniques of satellite geodesy in space.

SLR confirmed that the CODE's new empirical orbit model with estimated twice-per-revolution parameters in D direction remarkably reduces the spurious behavior of most of GLONASS satellites, and as a results, substantially improves GNSS solutions.

Thank you
for your attention

Backup slides

CODE as the ILRS Associate Analysis Centers

Center for Orbit Determination in Europe (CODE, hosted at AIUB) is the ILRS Associate Analysis Center, which provides:

- Satellite orbit predictions for all active GLONASS satellites (and also GPS satellites if any of them is active),
- GNSS Residual Analysis Reports, i.e., a comparison of SLR observations w.r.t. CODE microwave GNSS orbits. Reports are generated on a daily basis.

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Center for Orbit Determination in Europe (CODE)
Astronomical Institute, University of Bern (AIUB)

GNSS Quick-Look Residual Analysis Report
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Remarks: - The quick-look residuals are referred to the SLRF2008.
         - Reflector offsets used are given in slrmail No.1483,
           and as available on ILRS website.
         - GPS satellites (if any) are indicated with the character 'G',
           GLONASS satellites with the character 'R'.
         - A character 'E' behind the PRN number indicates that the
           satellite was observed during eclipse or within 30 min
           after returning into sunlight.
         - The SLR residuals are calculated w.r.t. official microwave
           CODE rapid 3-day GNSS orbits.
         - For more information see slrmails No.1203 and 2223.
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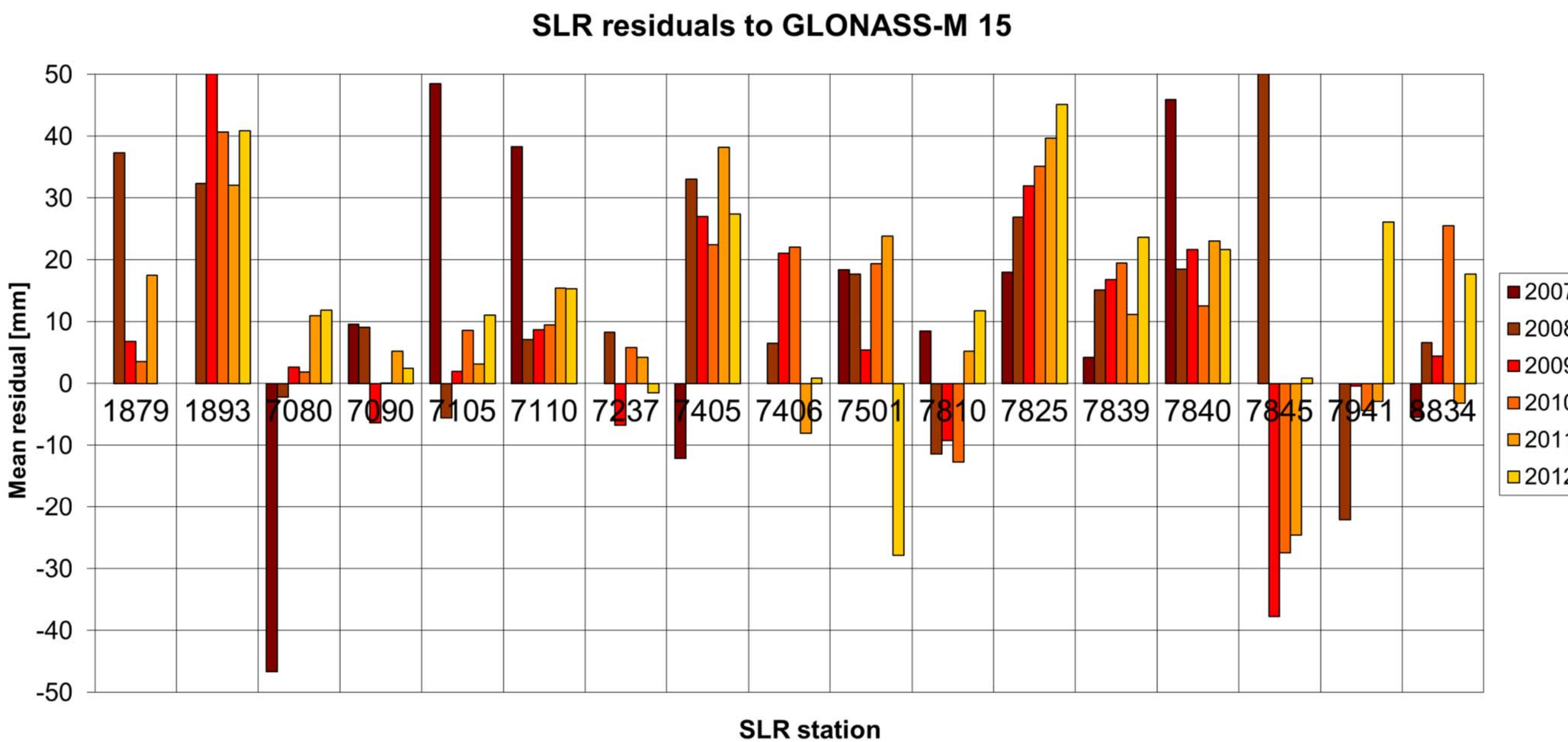
STATION	ID	SAT PRN	START PASSAGE yy/mm/dd	hh:mm	DUR (min)	#OBS GOOD	MEAN (mm)	STD (mm)	#OBS BAD	MEAN (m)	STD (m)
1873	12337S003	R11	14/10/11	02:20	33	5	-170	58			
1873	12337S003	R21	14/10/11	02:34	22	4	-55	36			
1886	12373S001	R11	14/10/11	01:14	72	4	-14	20			
1886	12373S001	R11	14/10/12	22:09	13	4	10	5			
1886	12373S001	R11	14/10/13	19:28	108	4	-4	26			
1886	12373S001	R11	14/10/14	17:29	123	4	-3	11			
1886	12373S001	R21	14/10/11	01:39	4	2	-11	16			
1886	12373S001	R21	14/10/12	01:22	0	1	69	0			
1886	12373S001	R05	14/10/11	16:58	19	5	83	11			
1886	12373S001	R16	14/10/11	18:19	72	8	81	19			
1886	12373S001	R16	14/10/12	17:28	8	3	80	3			
1886	12373S001	R16	14/10/13	15:38	3	2	67	13			
1886	12373S001	R06	14/10/11	18:43	3	2	97	4			
1886	12373S001	R06	14/10/12	17:08	12	4	59	7			

Mean SLR residuals to GLONASS



The SLR residuals are clearly station-, satellite-, and time-dependent. SLR obervations are also sensitive to orbit modeling issues.

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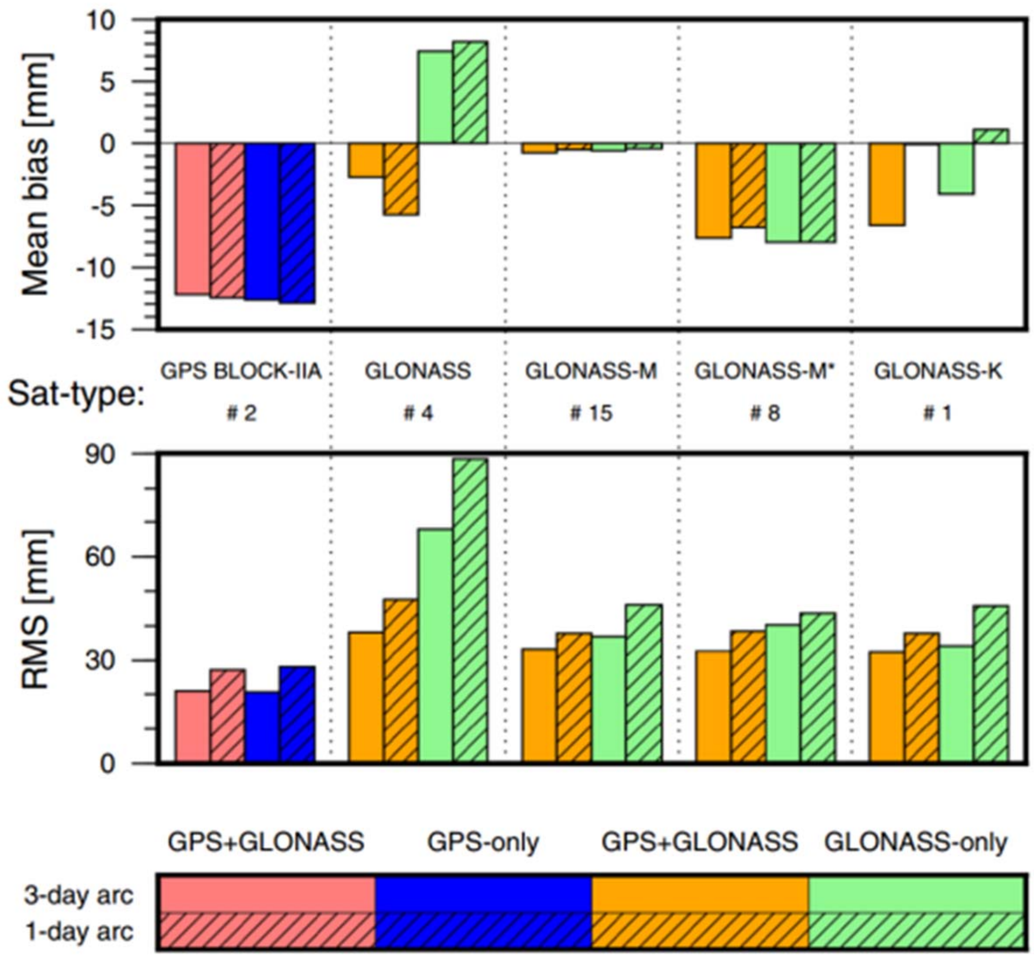
RMS of SLR residuals to GPS/GLONASS



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