2Oth International Workshop on Laser Ranging
Understanding and addressing SLR station systematics

Ranging error determination using geodetic satellites in support of altimeter missions POD

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INTRODUCTION

Satellite Laser Ranging (SLR) data, made available by the International Laser Ranging Service (ILRS), is essential to validate and quantify the orbit precision of the altimeter satellites.

It is the only independent and non ambiguous validation method that can provide the absolute radial orbit accuracy by means of high elevation passes in particular.

The SLR data are considered unbiased in the altimeter satellites' orbit validation process (i.e., range or time bias are not estimated). As a consequence, unknown or not communicated errors in the ranging data directly affect the validation results.

This study describes the current status of range biases encountered with Jason-2 Precise Orbit Determination (POD) validation at CNES.

CONTENT

- **MEAN RANGE BIASES ESTIMATION**
  - Are there permanent biases ?
  - Are they satellite-dependent ?
  - Effect of ILRS-provided corrections ? (Data Handling File)
- **SLR FOR ALTIMETRY AT CNES**
  - Bias stability over time for their « core stations » set
  - Comparison with biases found with Jason-2 SLR ranging
- **SUMMARY**

MEAN RANGE BIASES (2005-2008)

Objective

- Systematic biases identification

  This is not a replay of the Pilot Project, which is used as a benchmark. The conditions are not exactly the same (background models, arc length, etc) but the results can be compared.

Output

- Weighted average of range bias for the most prolific stations

Computation

- 5-day arcs
- Partials for station coordinates and 1 range bias (σ = 1 m) per station are computed -> normal equations
- Normal equations are cumulated by month
- Station positions and range biases are solved simultaneously per month, per satellite

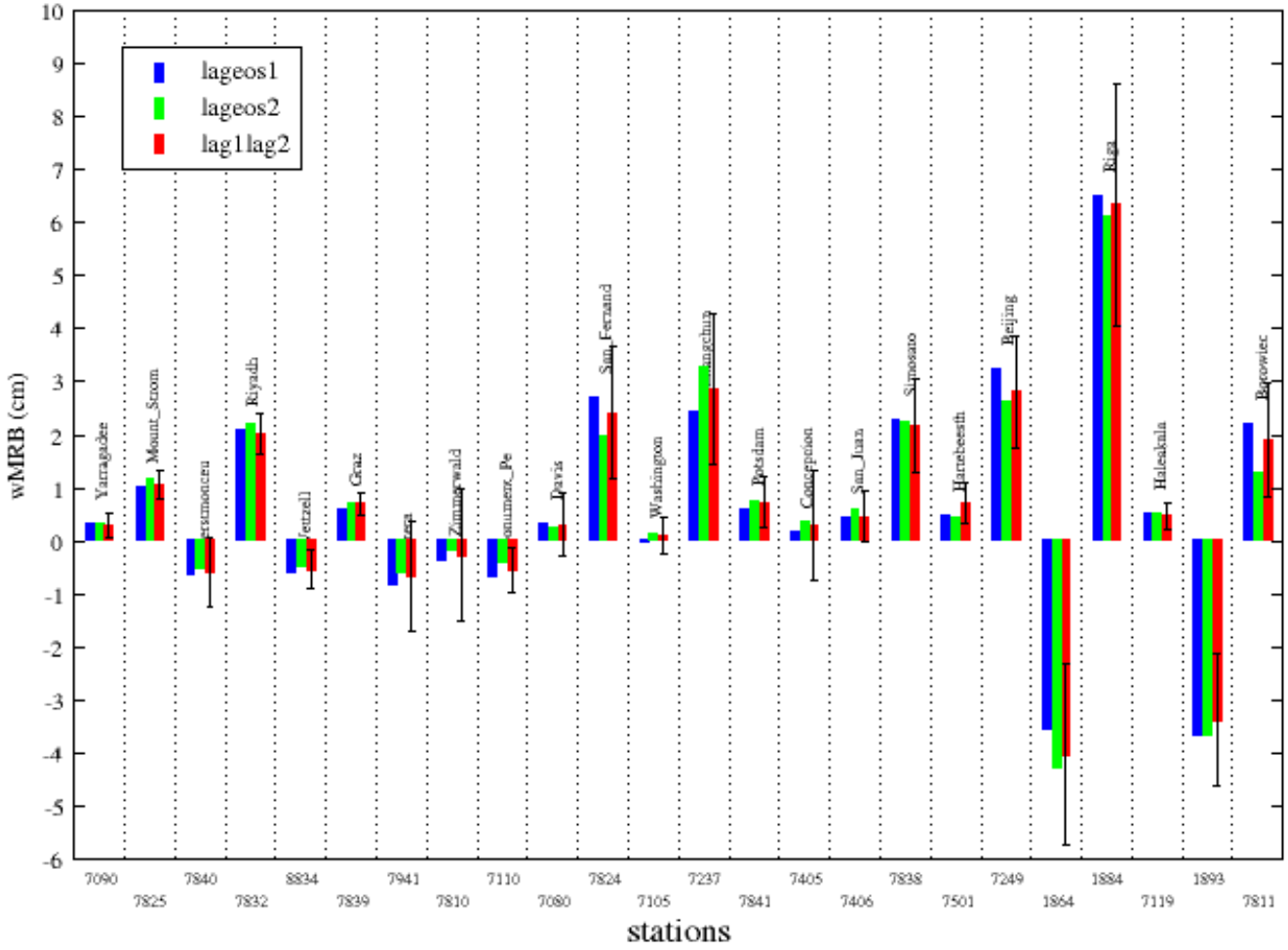
BACKGROUND MODELS

Gravity potential	EIGEN GRGS RL03 (variable up to d/o 80)
Ocean tides	FES2014 with admittances
Atmospheric tides	ECMWF with Bode-Biancale model
Ocean pole tides	DESAI 2002
Solid Earth tides	IERS 2003
Ocean dealiasing	TUGO
Atmospheric dealiasing	3-hour ECMWF
Mean Pole	IERS 2010
Earth Orientation Parameters	IERS 0h
Tropospheric correction	Mendes
Drag	DTM 2013
Relativistic accelerations	Schwartzschild / Lense Thirring
Station coordinates	ITRF2014 with post-seismic relaxation coefficients
Data Handling	ILRS_Data_Handling_File + GRGS managed file (*range biases removed*), system dependent CoM corrections for LAG1/2

Ocean + atmospheric loading

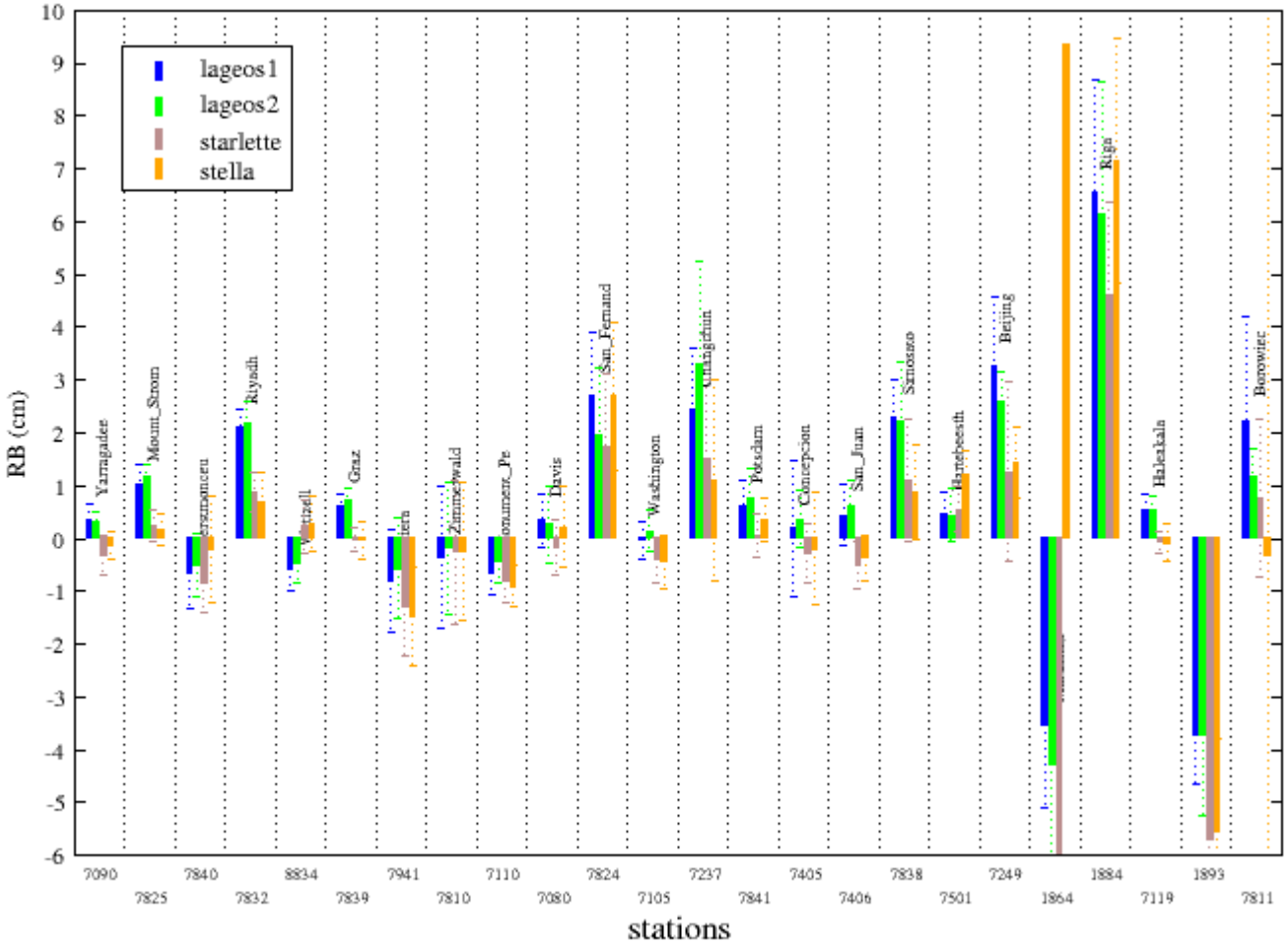
MEAN RANGE BIASES (2005-2008) – LAGEOS 1

MEAN RANGE BIASES (2005-2008) – LAGEOS 1/2



Range biases solved for Lageos1, Lageos2, then for Lageos1+Lageos2

MEAN RANGE BIASES (2005-2008)



Starlette and Stella added. The range bias for Starlette/Stella is generally several millimeters lower that Lageos1/2. This will be discussed later in the presentation

ADVERTISED CORRECTIONS FOR 2005-2008

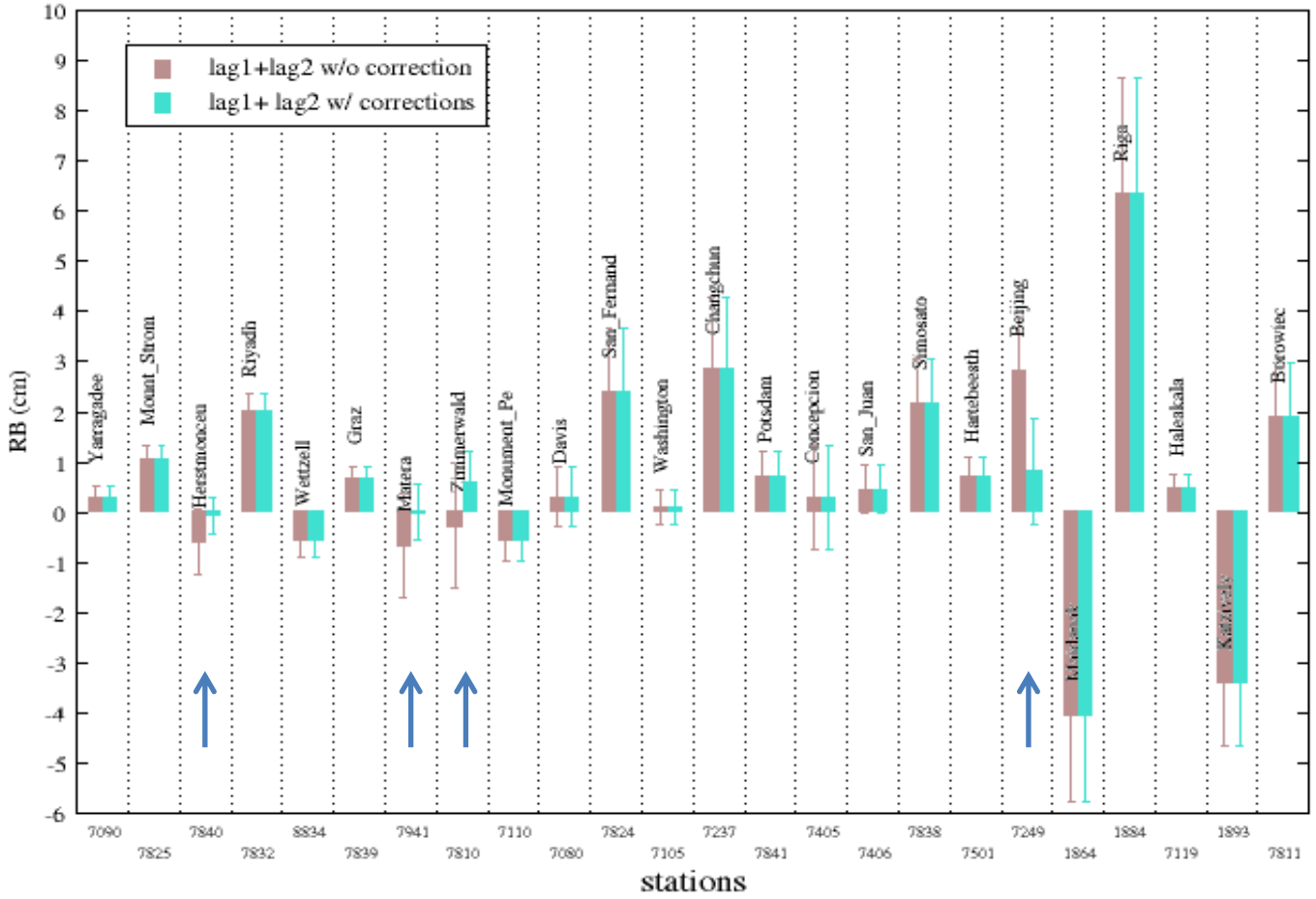
ILRS_Data_Handling_File.snx [2016/05/12]

```
7249 --- mm   A 01:020:00000 12:001:00000 R       20.000
7810 --- mm   B 04:363:00000 06:037:00000 R       -26.00
7820 --- mm   A 00:293:00000 12:001:00000 R       -20.00
7840 --- mm   A 02:032:00000 07:042:00000 R        -9.00          ILRS/AWG 09/05/06
7941 --- mm   A 07:047:00000 07:053:00000 R       -14.00    0.00 engineering bias
7941 --- mm   A 07:053:00000 07:187:39600 R       -28.00    2.00 engineering bias
7941 --- mm   A 07:187:39600 07:241:28800 R       -22.00    2.00 engineering bias
7941 --- mm   A 07:242:00000 07:295:50400 R       -25.00    3.00 engineering bias
```

Merged file (SINEX file + GINS log file)

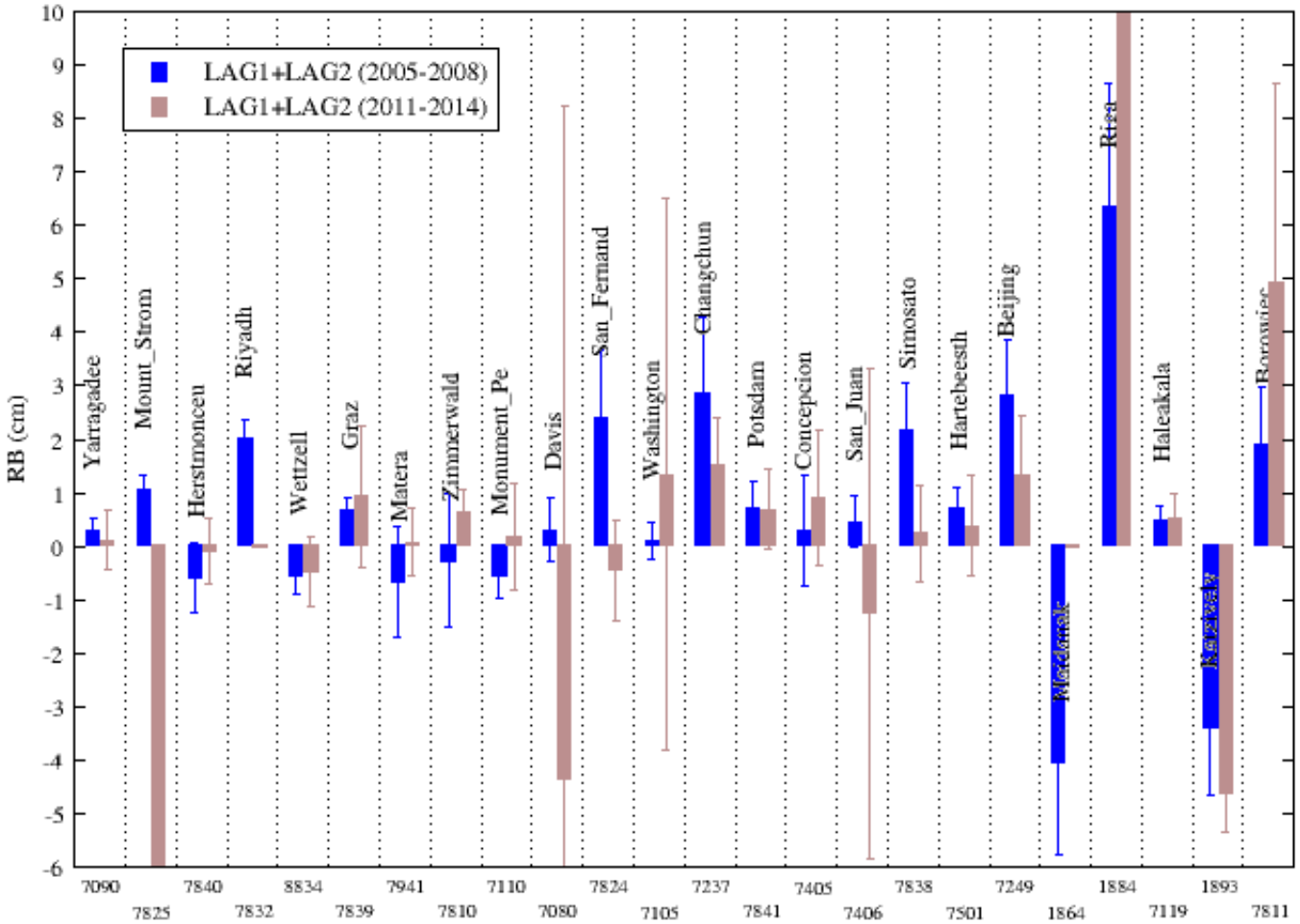
Station	start	stop	sat	corr	value (cm)
72496101 (Beijing)	20010120 00:00	20120101 00:00	all	R	2.0
78106801 (Zimmerwald)	20041228 00:00	20060206 00:00	all	R	-2.6
78208201 (Kunming)	20001019 00:00	20120101 00:00	all	R	-2.0
78403501 (Herstmonceux)	20020201 00:00	20070211 00:00	all	R	-0.9
79417701 (Matera)	20070216 00:00	20070222 00:00	all	R	-1.4
79417701 (Matera)	20070222 00:00	20070706 11:00	all	R	-2.8
79417701 (Matera)	20070706 11:00	20070829 08:00	all	R	-2.2
79417701 (Matera)	20070830 00:00	20071022 14:00	all	R	-2.5

MEAN RANGE BIASES (2005-2008) - w/ and w/o correction



Herstmonceux's and Matera's biases drop to nearly 0. Beijing's bias is lower too. Zimmerwald's bias seems to increase.

MEAN RANGE BIASES (2005-2008 vs 2011-2014) – LAG 1 + 2



Yarragadee, Wettzell, Graz, Potsdam, Haleakala are stable and show a small RB.
Other stations like Herstmonceux, Matera, Monument Peak, Changchun, Beijing, San Fernando have improved (decreased) the range bias

SLR FOR ALTIMETRY AT CNES

Status

- POD was initially performed using Doris, SLR and GNSS

- POD is now performed with Doris and GNSS only
- SLR is used for external validation
- Very reduced set of core stations : Yarragadee (7090), Greenbelt (7105), Zimmerwald (7810), Graz (7839), Herstmonceux (7840), Matera (7941)
- Applied range biases : LPOD v19 (March 6, 2013) by John Ries – for ITRF2005 but biases are still valid.
- SLRF2008

SLR FOR ALTIMETRY

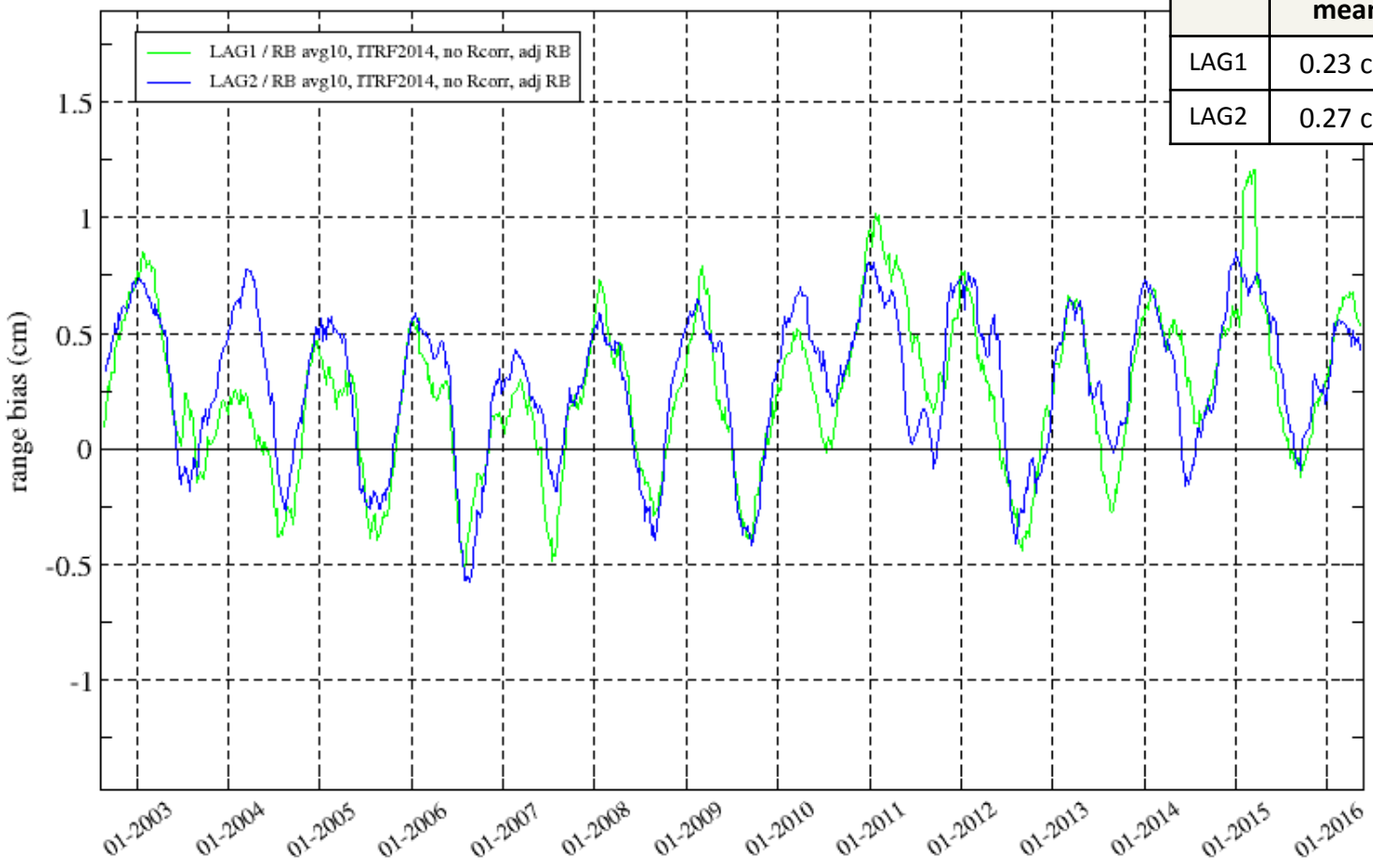
Test of the 6 core stations

- 5-day arcs
- Time frame : 2003-2016
- ITRF 2014
- Same background models as in first study
- No range **error** correction applied (the **CoM** corrections are applied)
- Station positions are not adjusted, 1 range bias is adjusted per station/per arc
- 4 geodetic satellites (Lageos 1&2, Starlette, Stella)

- The range bias time series are compared with the mean residuals for Jason-2

  Note : The orbit is determined by GNSS and DORIS

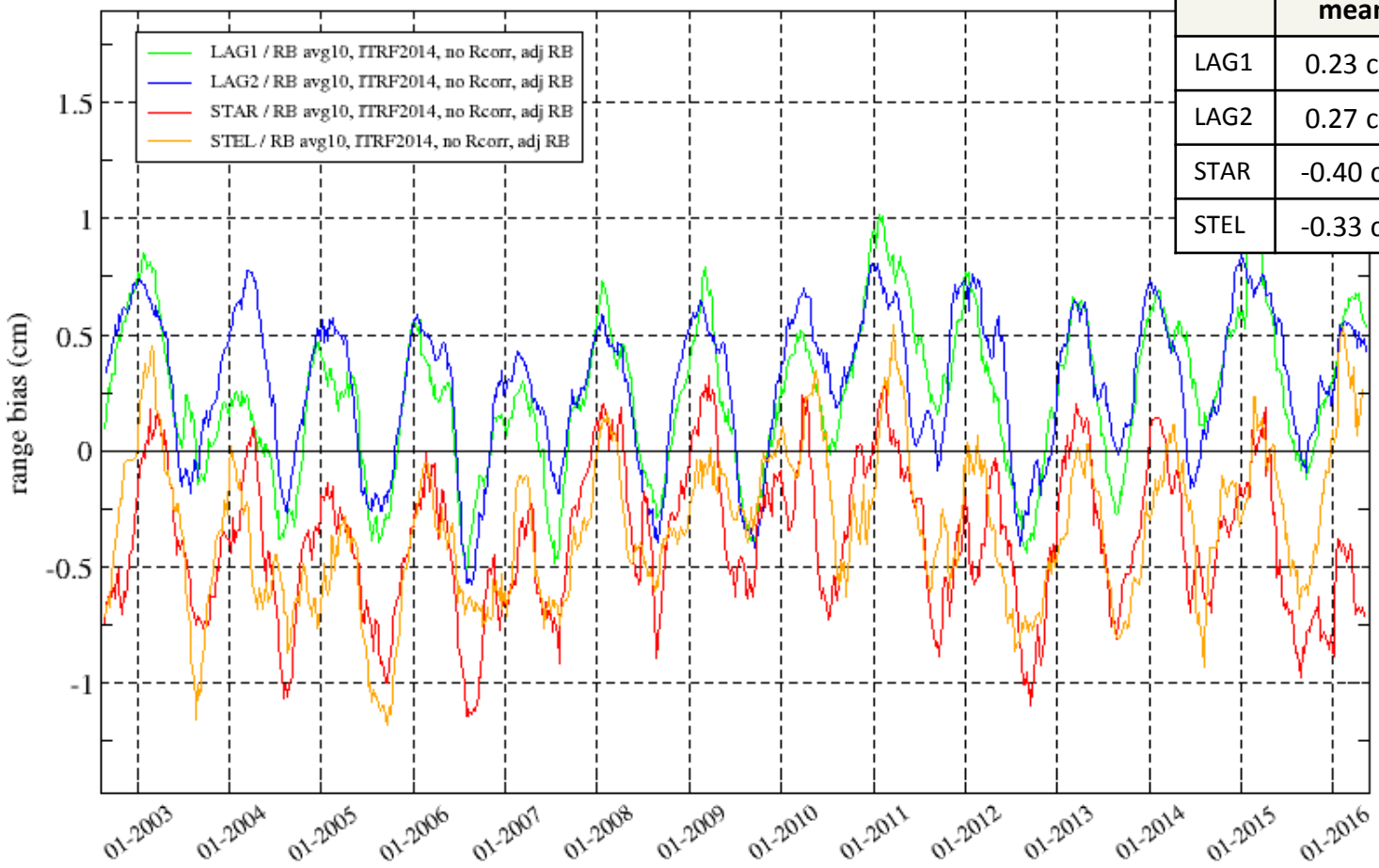
GRAZ (7839)



	mean	std dev
LAG1	0.23 cm	0.46 cm
LAG2	0.27 cm	0.42 cm

Small range bias (2-3 mm). An annual signature is visible

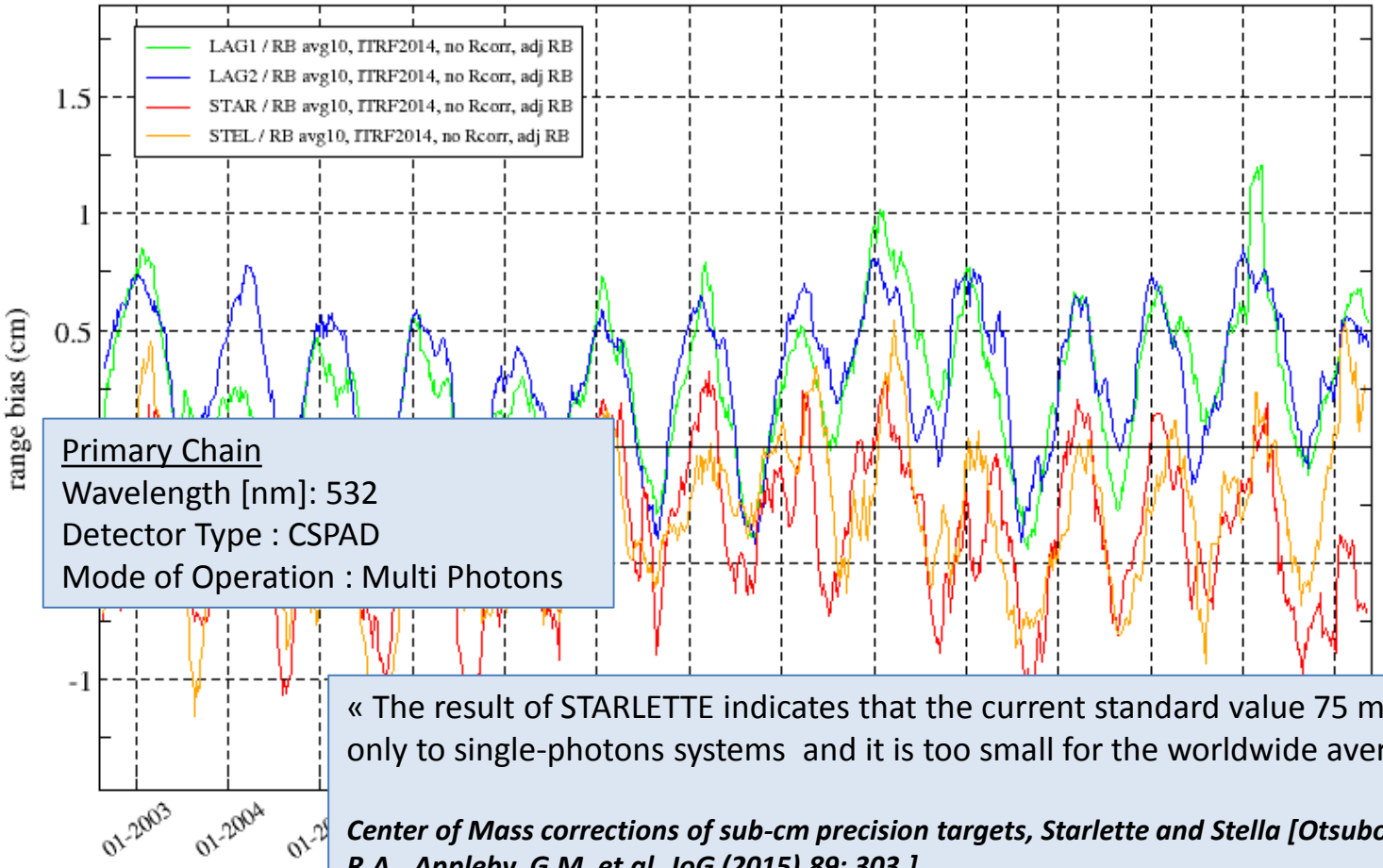
GRAZ (7839)



	mean	std dev
LAG1	0.23 cm	0.46 cm
LAG2	0.27 cm	0.42 cm
STAR	-0.40 cm	0.53 cm
STEL	-0.33 cm	0.55 cm

Starlette/Stella added : offset but good agreement

GRAZ (7839)

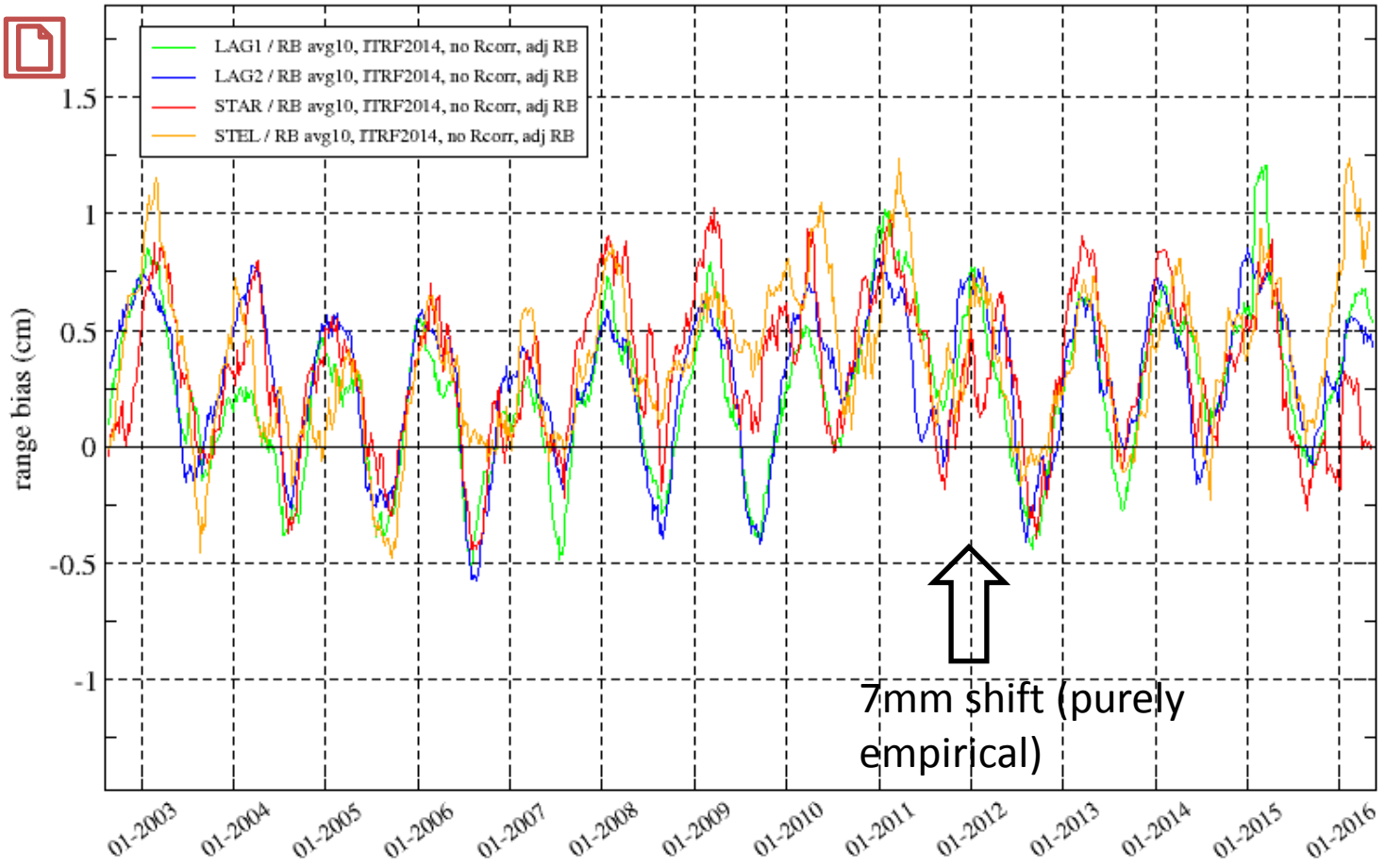


Primary Chain
Wavelength [nm]: 532
Detector Type : CSPAD
Mode of Operation : Multi Photons

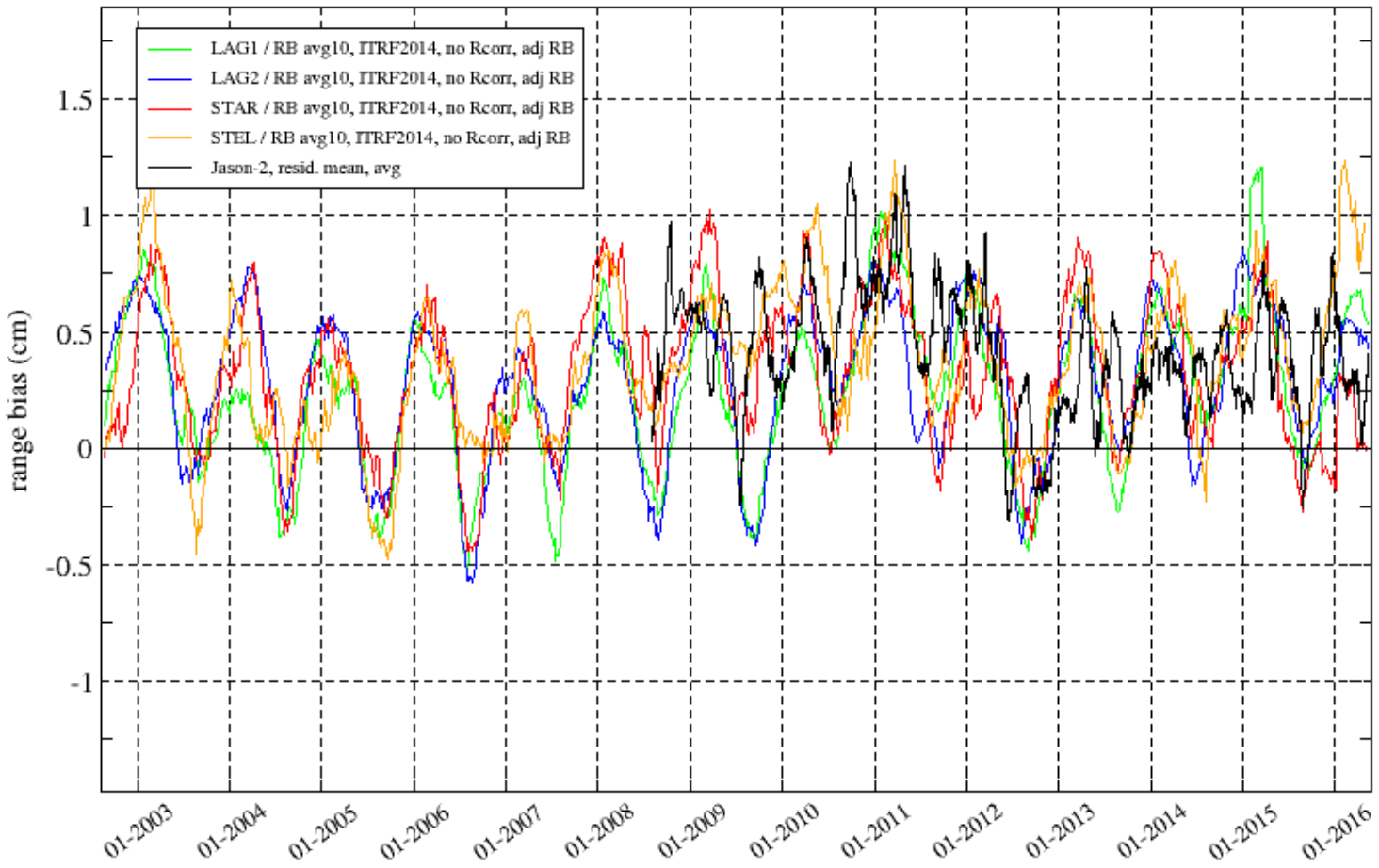
« The result of STARLETTE indicates that the current standard value 75 mm is applicable only to single-photons systems and it is too small for the worldwide average »

Center of Mass corrections of sub-cm precision targets, Starlette and Stella [Otsubo, T., Sherwood, R.A., Appleby, G.M. et al. JoG (2015) 89: 303.]

GRAZ (7839)

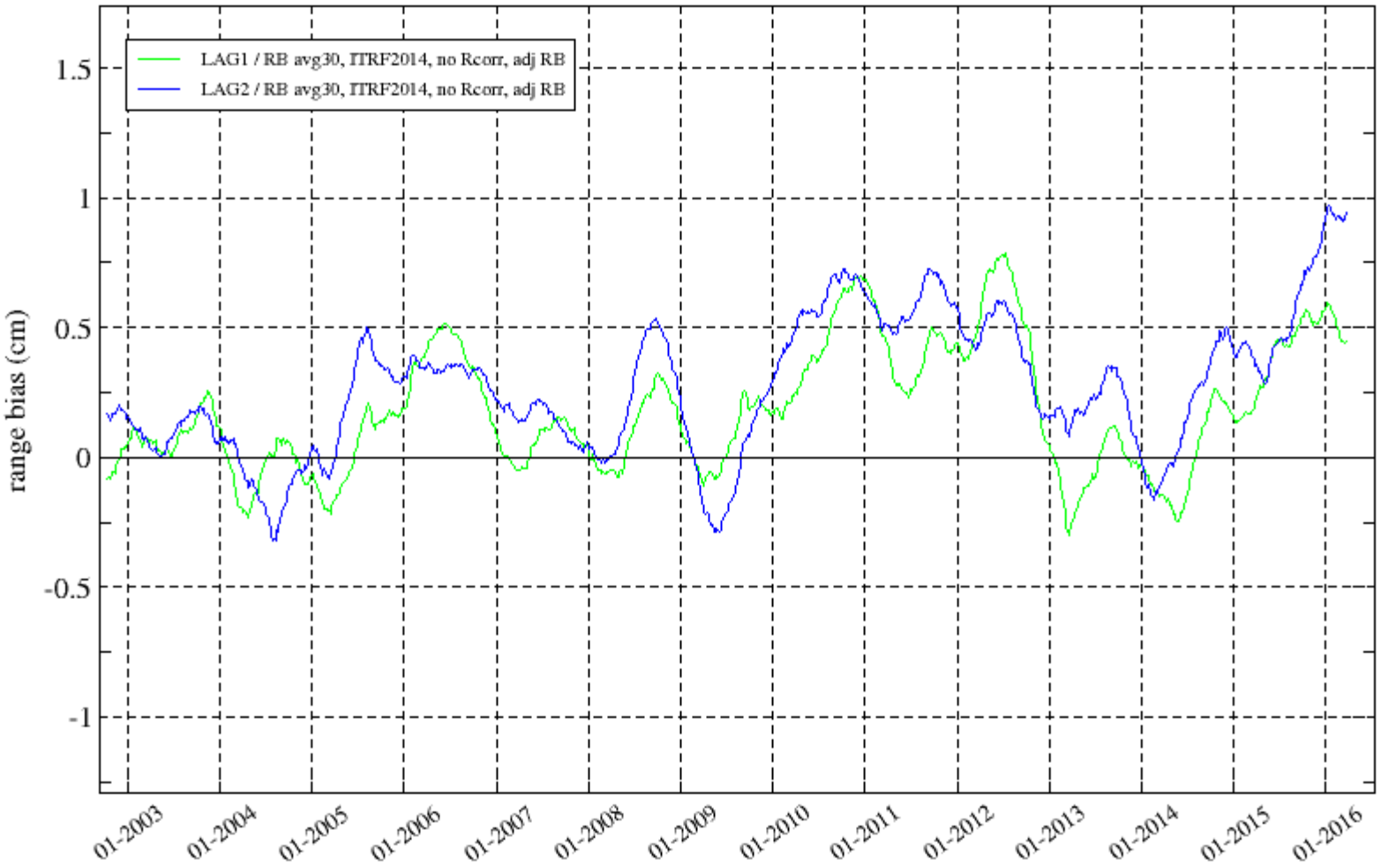

LAG1 / RB avg10, ITRF2014, no Rcorr, adj RB
LAG2 / RB avg10, ITRF2014, no Rcorr, adj RB
STAR / RB avg10, ITRF2014, no Rcorr, adj RB
STEL / RB avg10, ITRF2014, no Rcorr, adj RB
range bias (cm)
1.5
1
0.5
0
-0.5
-1
01-2003
01-2004
01-2005
01-2006
01-2007
01-2008
01-2009
01-2010
01-2011
01-2012
01-2013
01-2014
01-2015
01-2016
7mm shift (purely empirical)

GRAZ (7839)

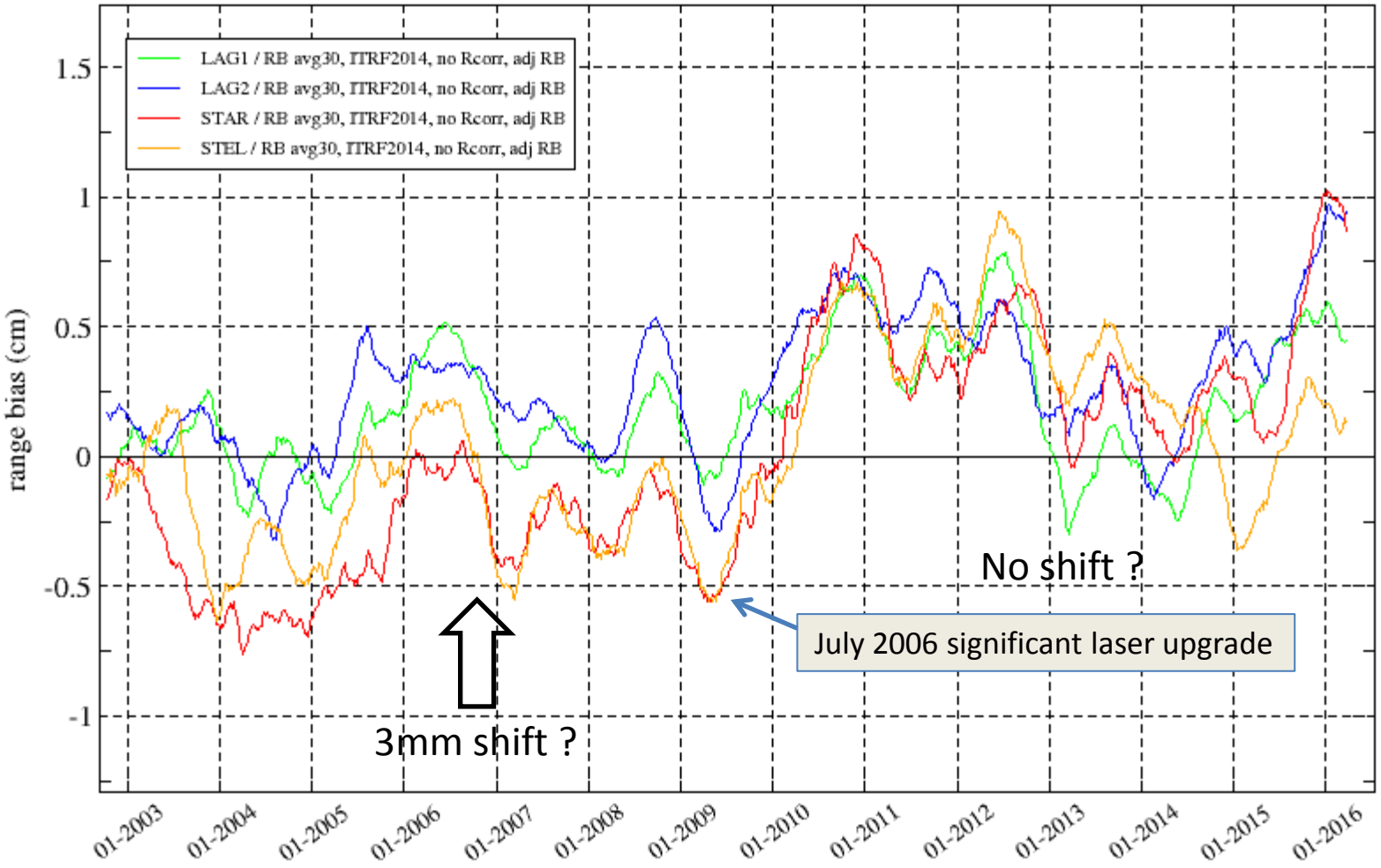


Good match with Jason-2

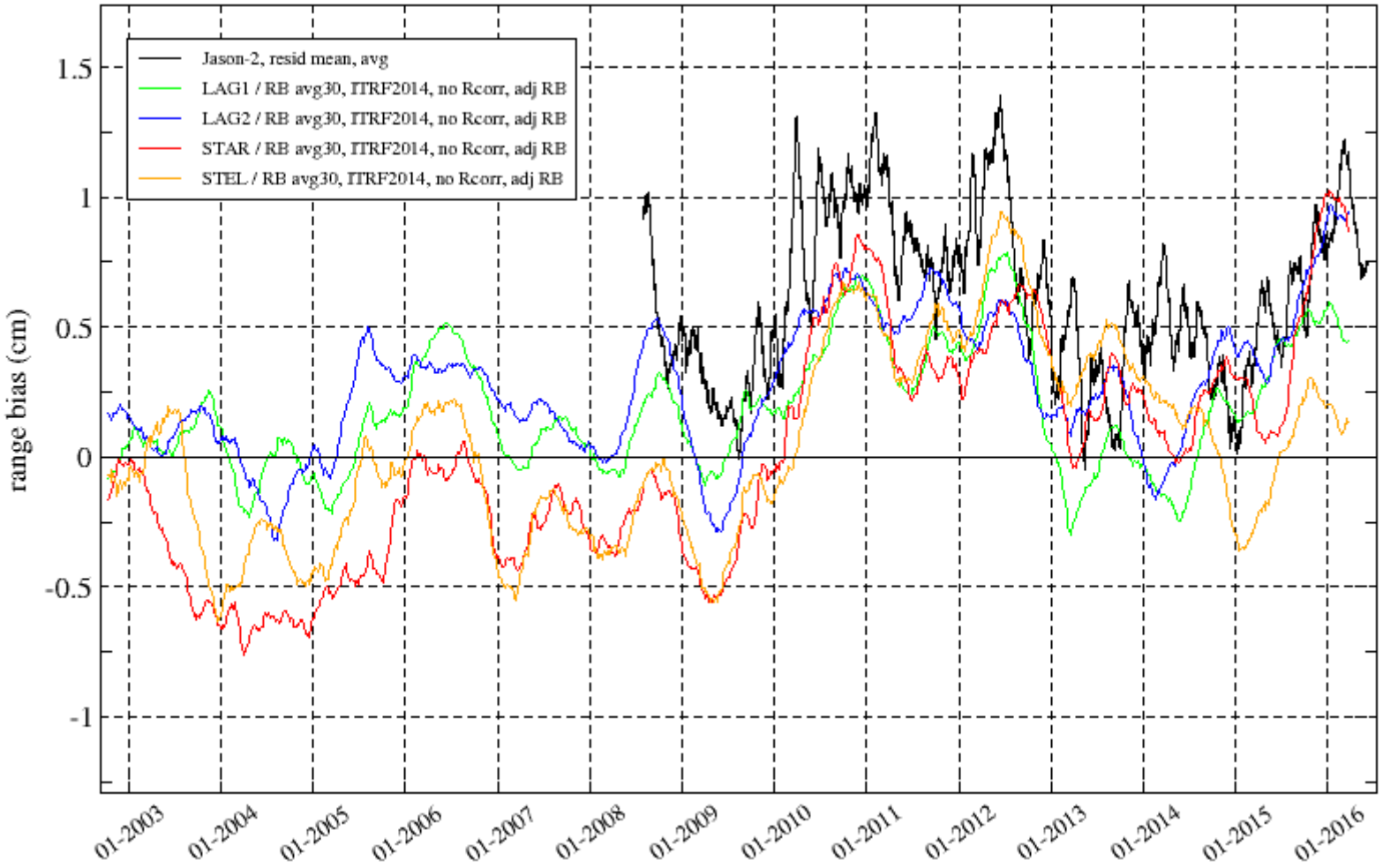
YARRAGADEE (7090)



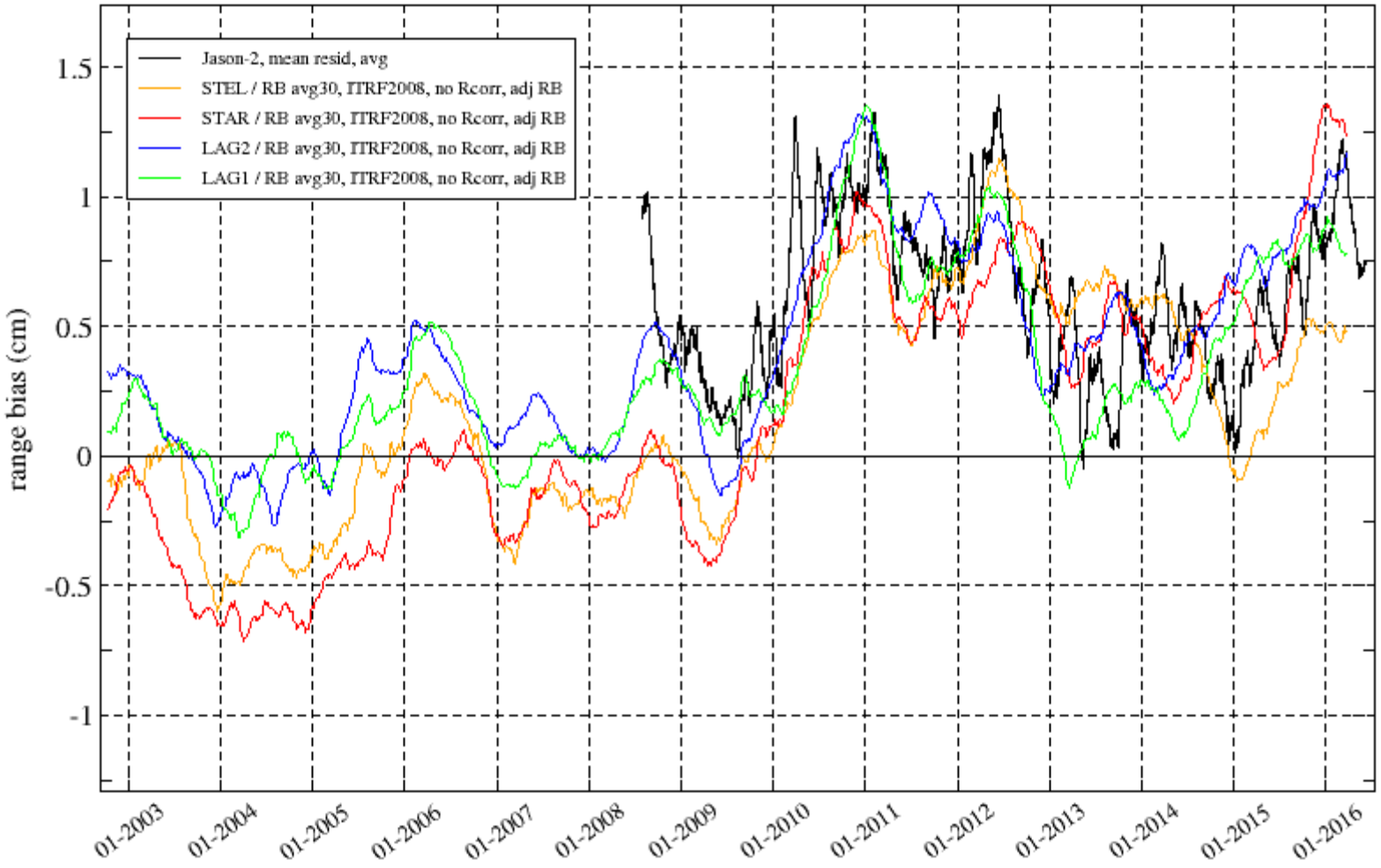
YARRAGADEE (7090)



YARRAGADEE (7090)

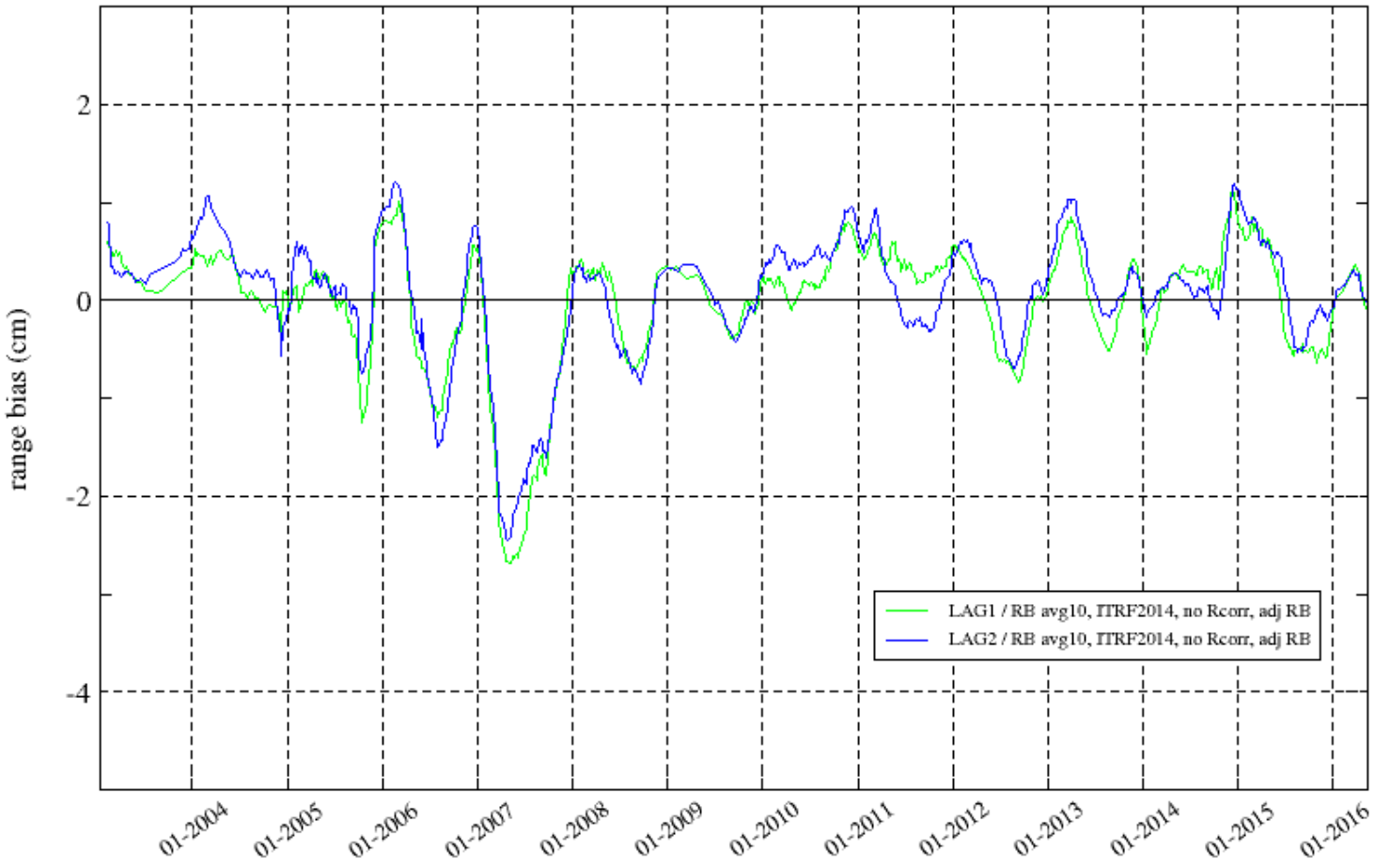


YARRAGADEE (7090)

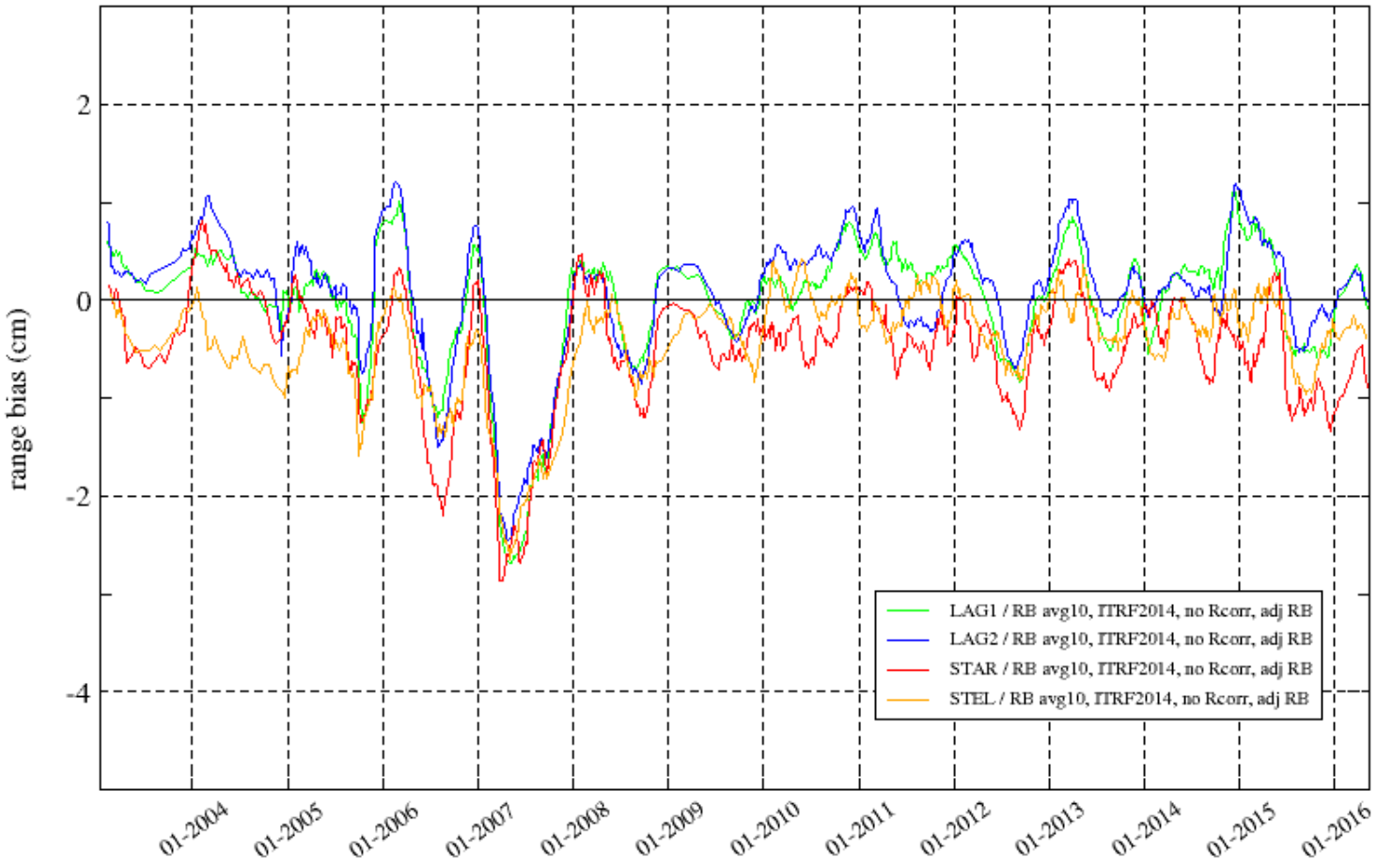


revert to ITRF2008 for consistency → better match

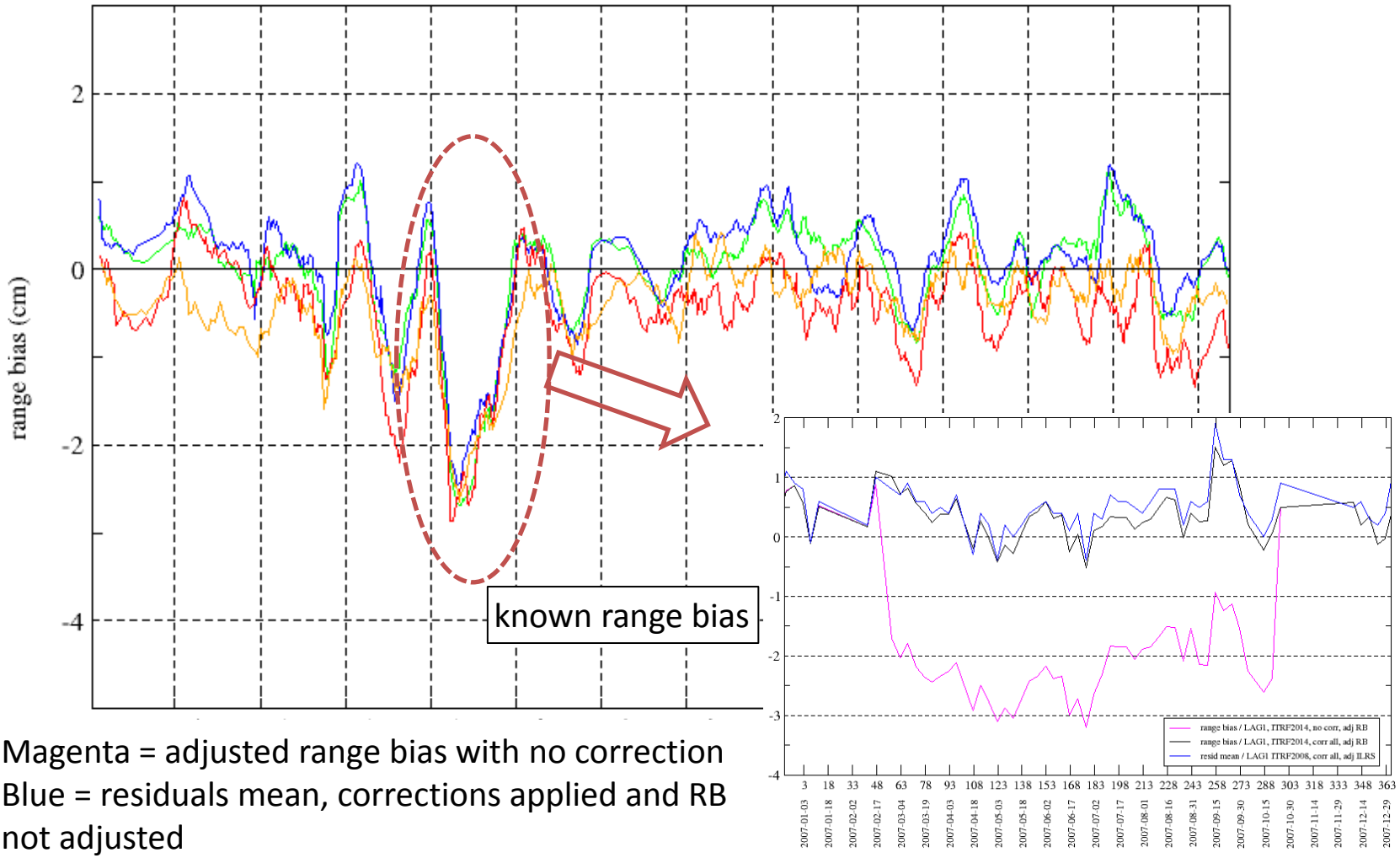
MATERA (7941)


range bias (cm)
2
0
-2
-4
01-2004
01-2005
01-2006
01-2007
01-2008
01-2009
01-2010
01-2011
01-2012
01-2013
01-2014
01-2015
01-2016
LAG1 / RB avg10, ITRF2014, no Rcorr, adj RB
LAG2 / RB avg10, ITRF2014, no Rcorr, adj RB

MATERA (7941)

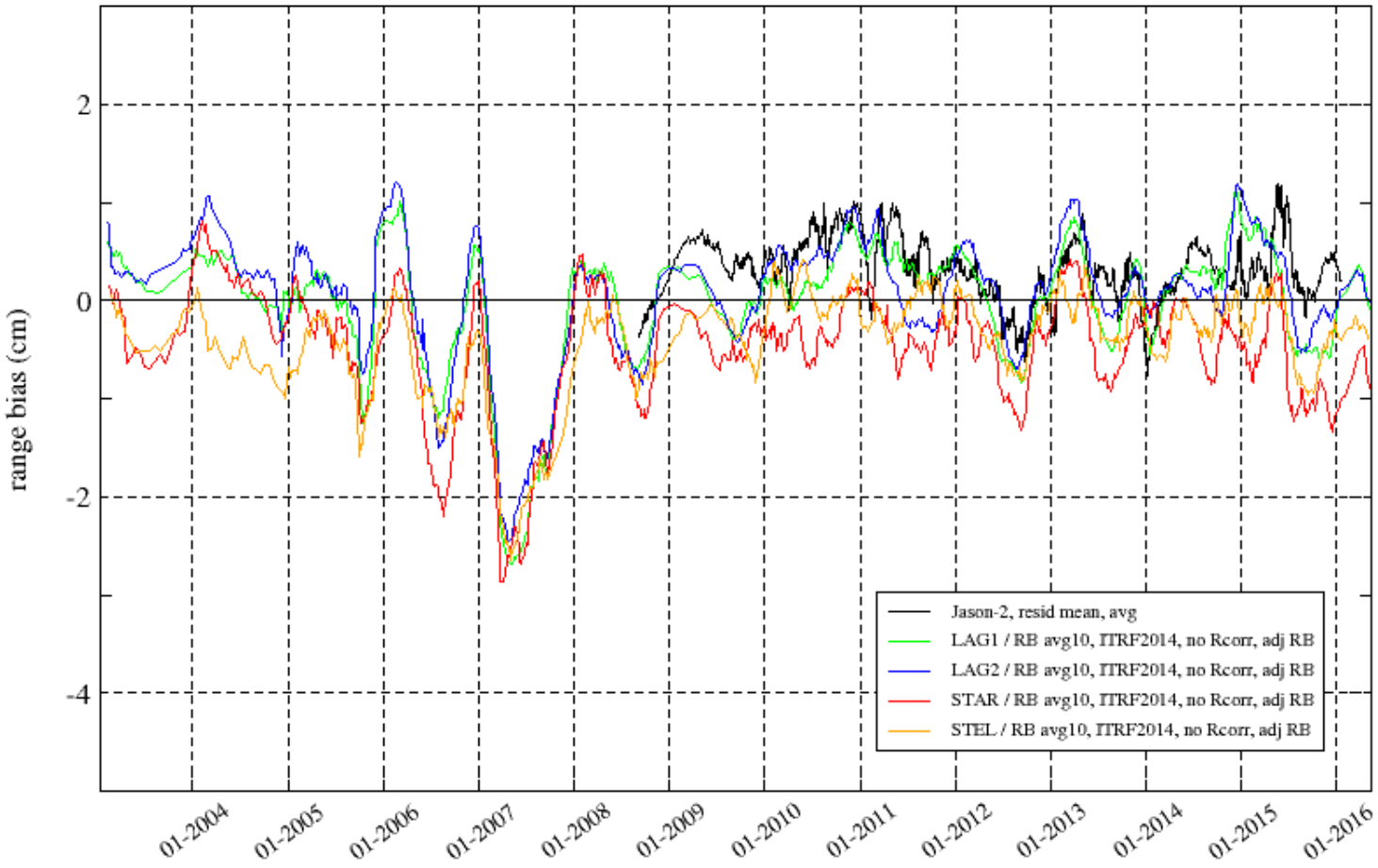

range bias (cm)
2
0
-2
-4
01-2004
01-2005
01-2006
01-2007
01-2008
01-2009
01-2010
01-2011
01-2012
01-2013
01-2014
01-2015
01-2016
LAG1 / RB avg10, ITRF2014, no Rcorr, adj RB
LAG2 / RB avg10, ITRF2014, no Rcorr, adj RB
STAR / RB avg10, ITRF2014, no Rcorr, adj RB
STEL / RB avg10, ITRF2014, no Rcorr, adj RB

MATERA (7941)



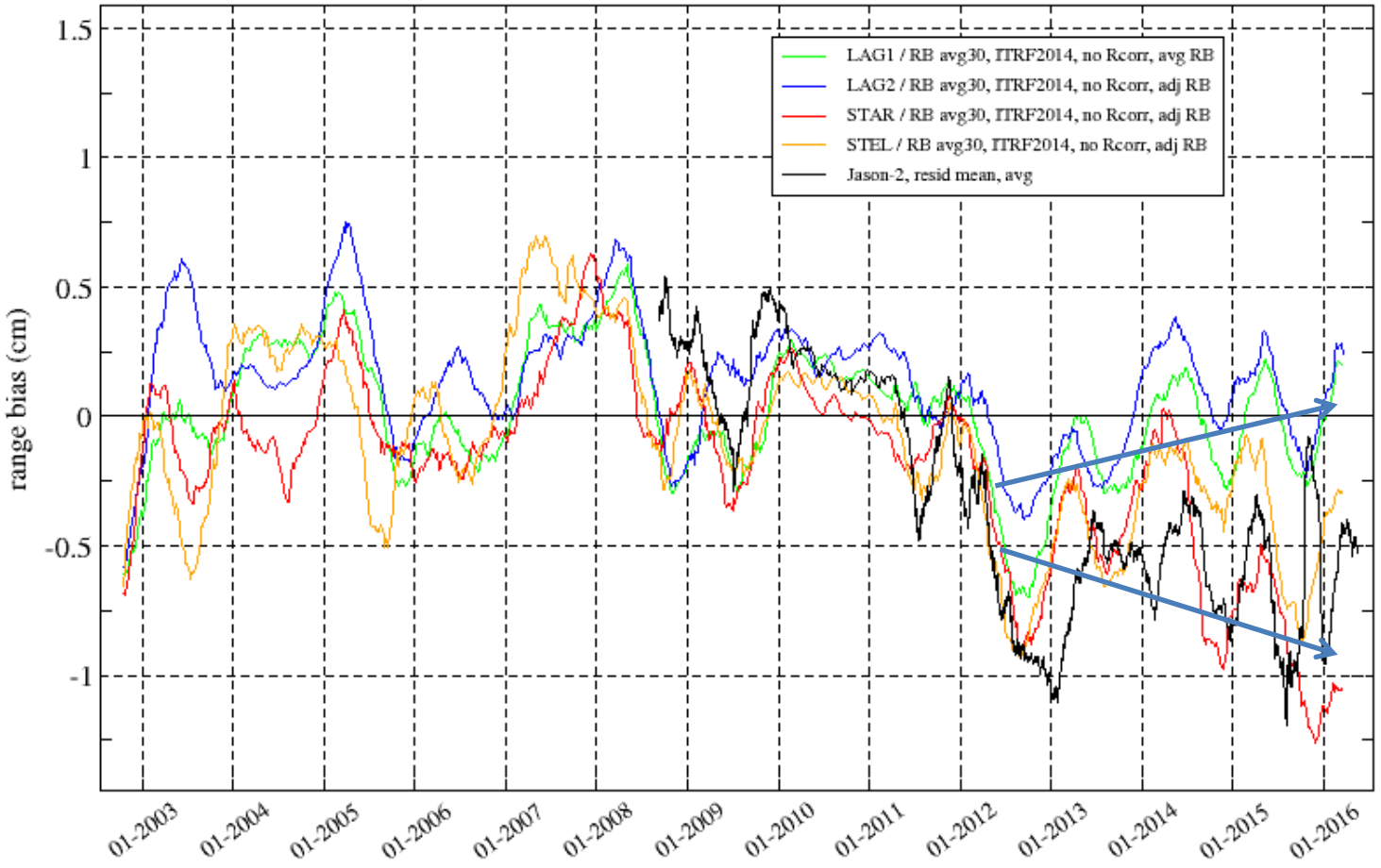
Magenta = adjusted range bias with no correction
Blue = residuals mean, corrections applied and RB not adjusted
Black = adjusted range bias with corrections applied

MATERA (7941)



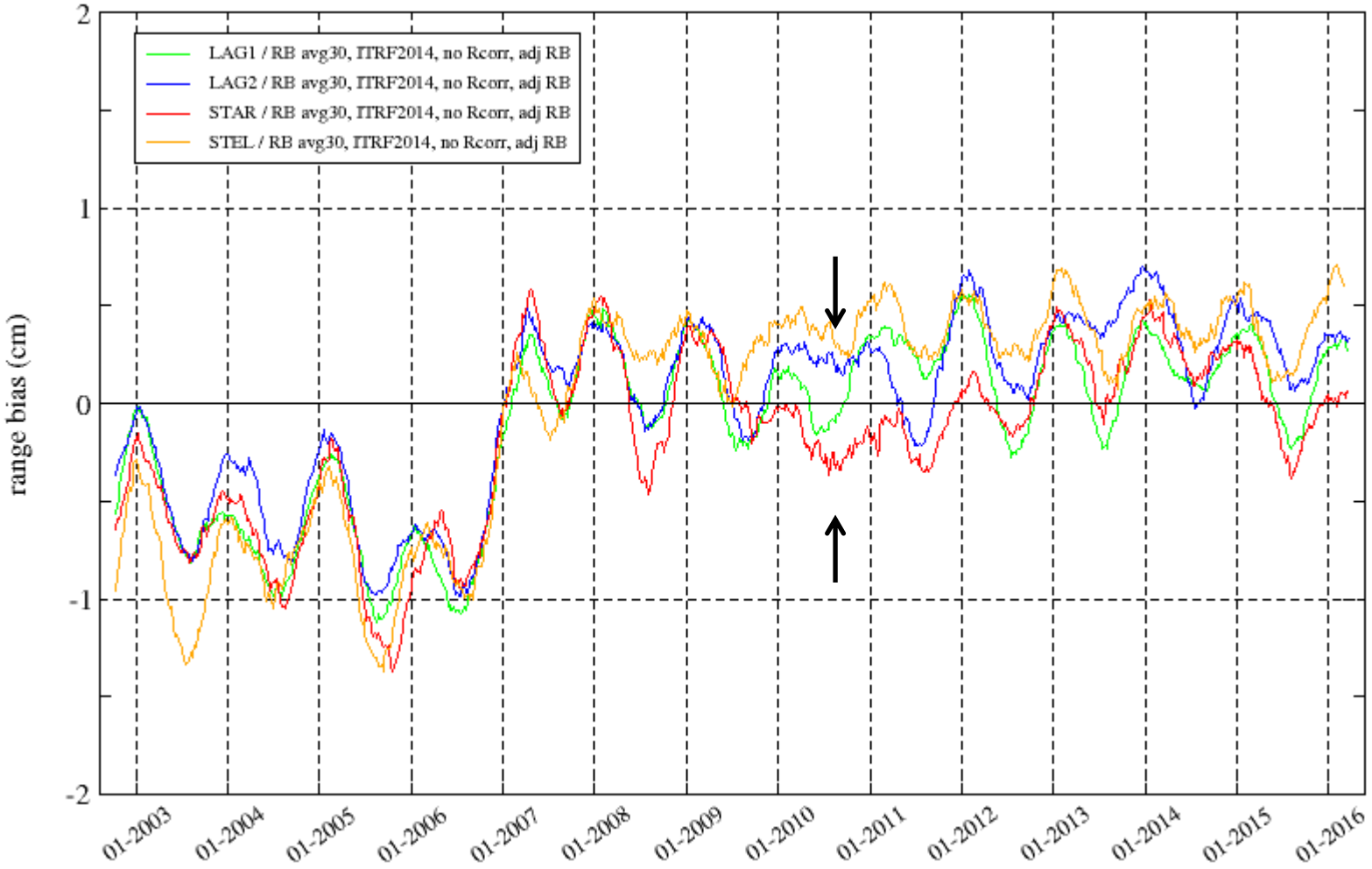
Small range bias, good agreement between Jason-2 and the geodetic satellites. Even better if reverted to SLRF2008 for consistency .

GREENBELT (7105)



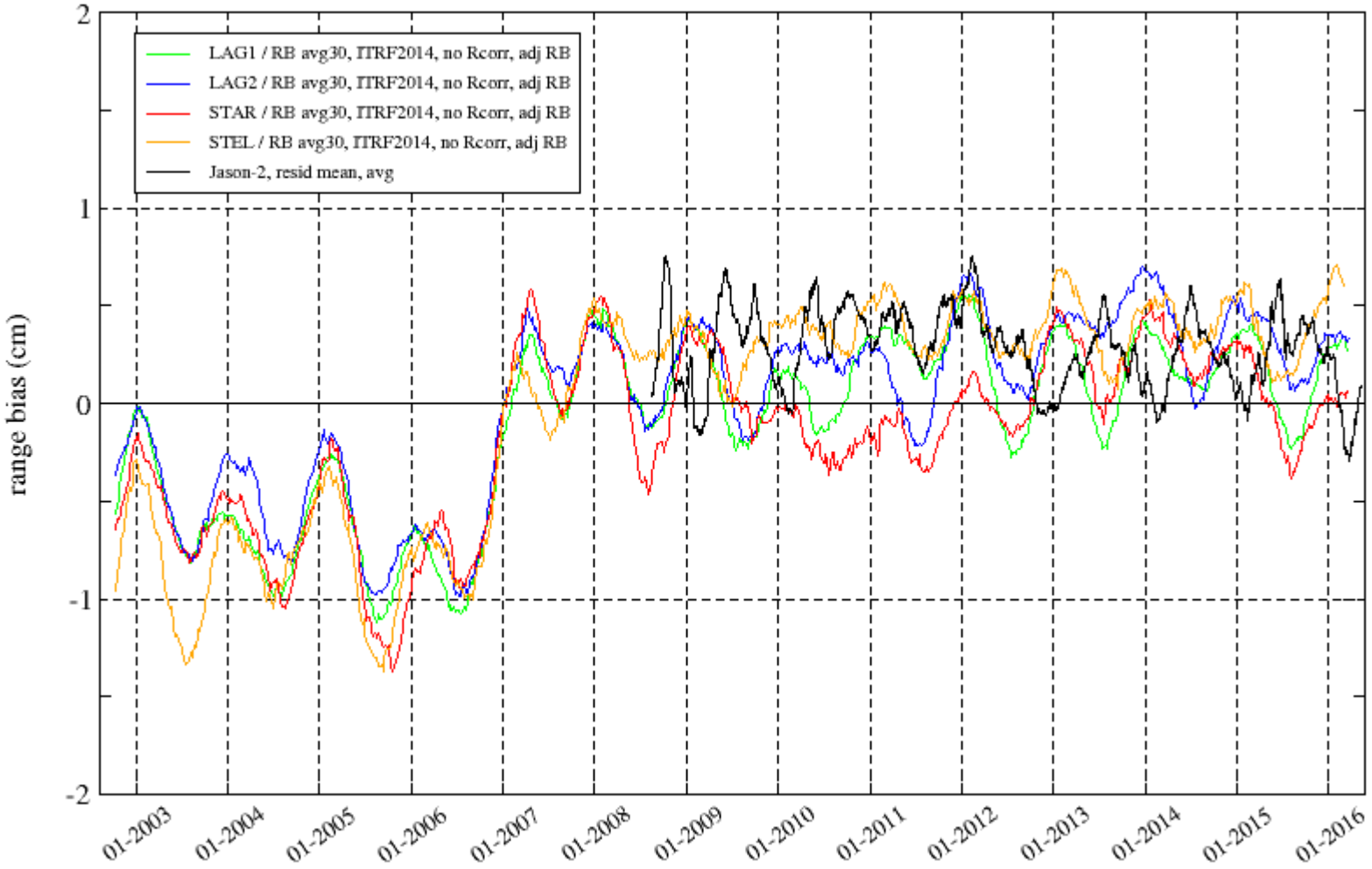
Different behaviour between high- and low-orbit satellites, Jason-2 included

HERSTMONCEUX (7840)

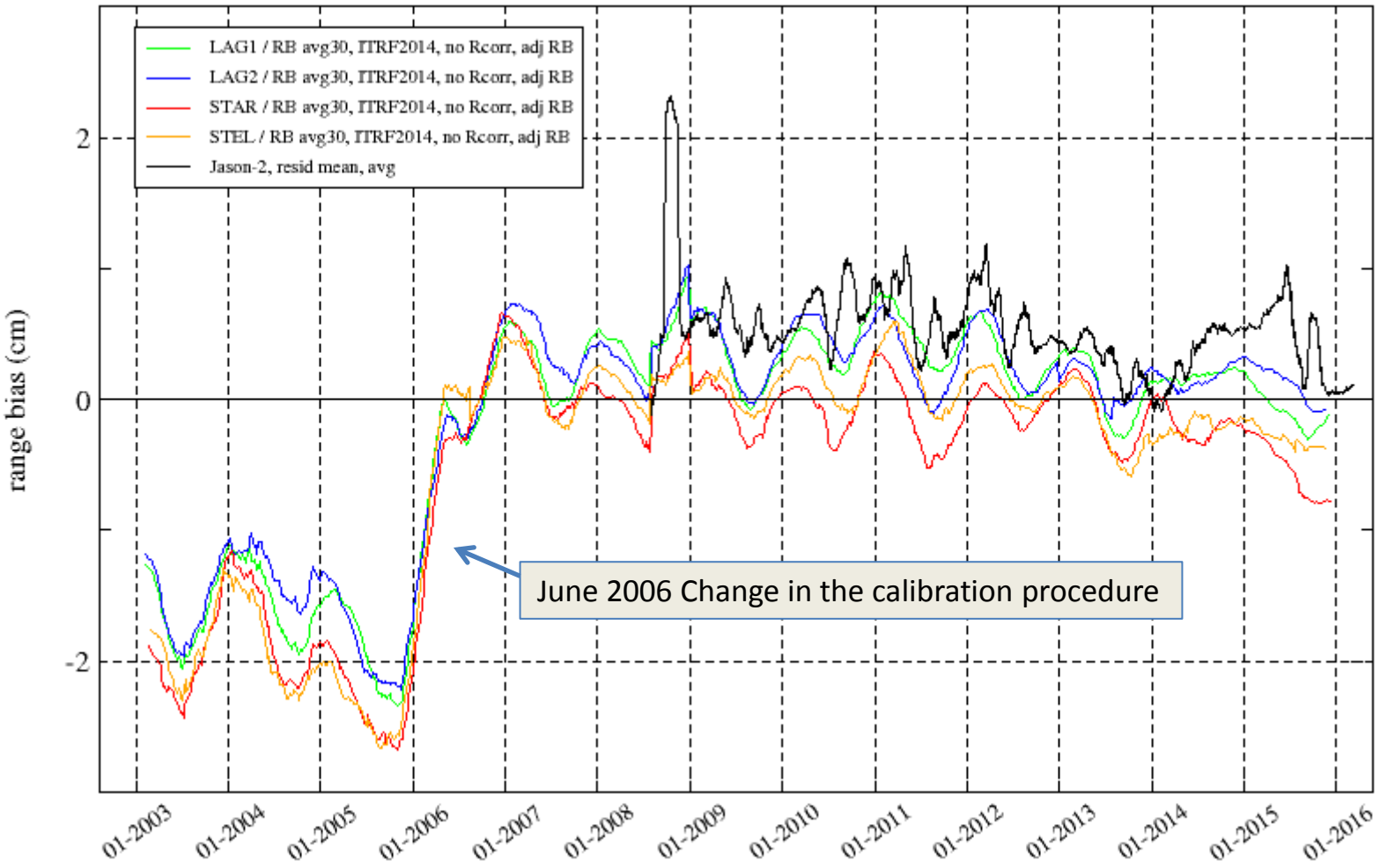


Nice match between high-low satellites, degraded between 2010 and 2012

HERSTMONCEUX (7840)



ZIMMERWALD (7810)



CORE STATIONS SUMMARY

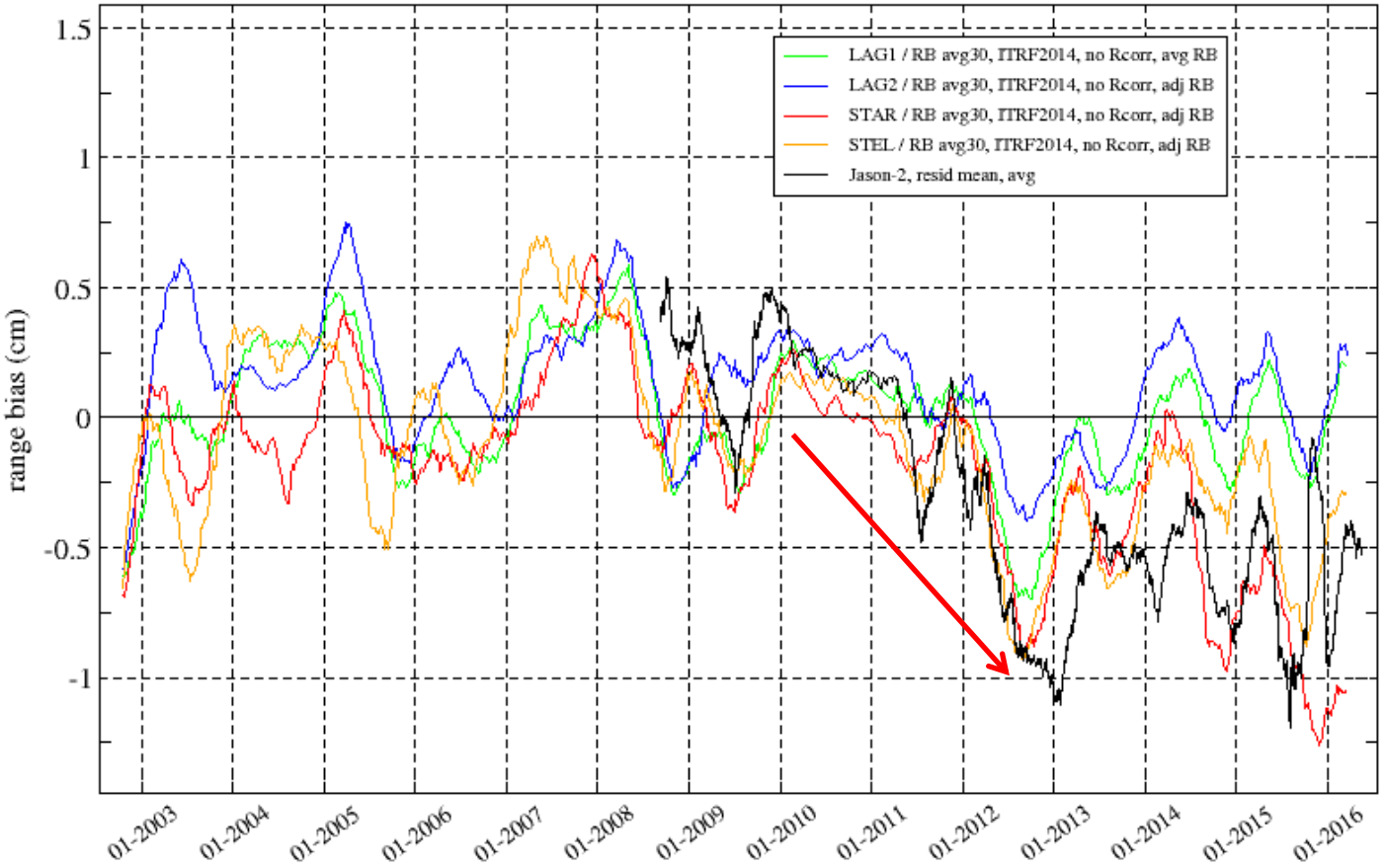
	STAR/STEL vs LAG1/LAG2	Jason-2
Graz (7839)	Good agreement, provided that the CoM correction be increased by several mm	Good agreement
Herstmonceux (7840)	Good agreement, with a slight degradation between 2010 and 2012	Good agreement
Greenbelt (7105)	Divergence after 2014, esp STAR	Follows approx. STAR
Yarragadee (7090)	Good agreement Offset before 2010 ?	Good agreement
Matera (7941)	Good agreement	Good agreement
Zimmerwald (7810)	Good agreement	Good agreement

Good agreement → providing range corrections will be directly usable for altimeter POD

SLR FOR ALTIMETRY

Other stations…

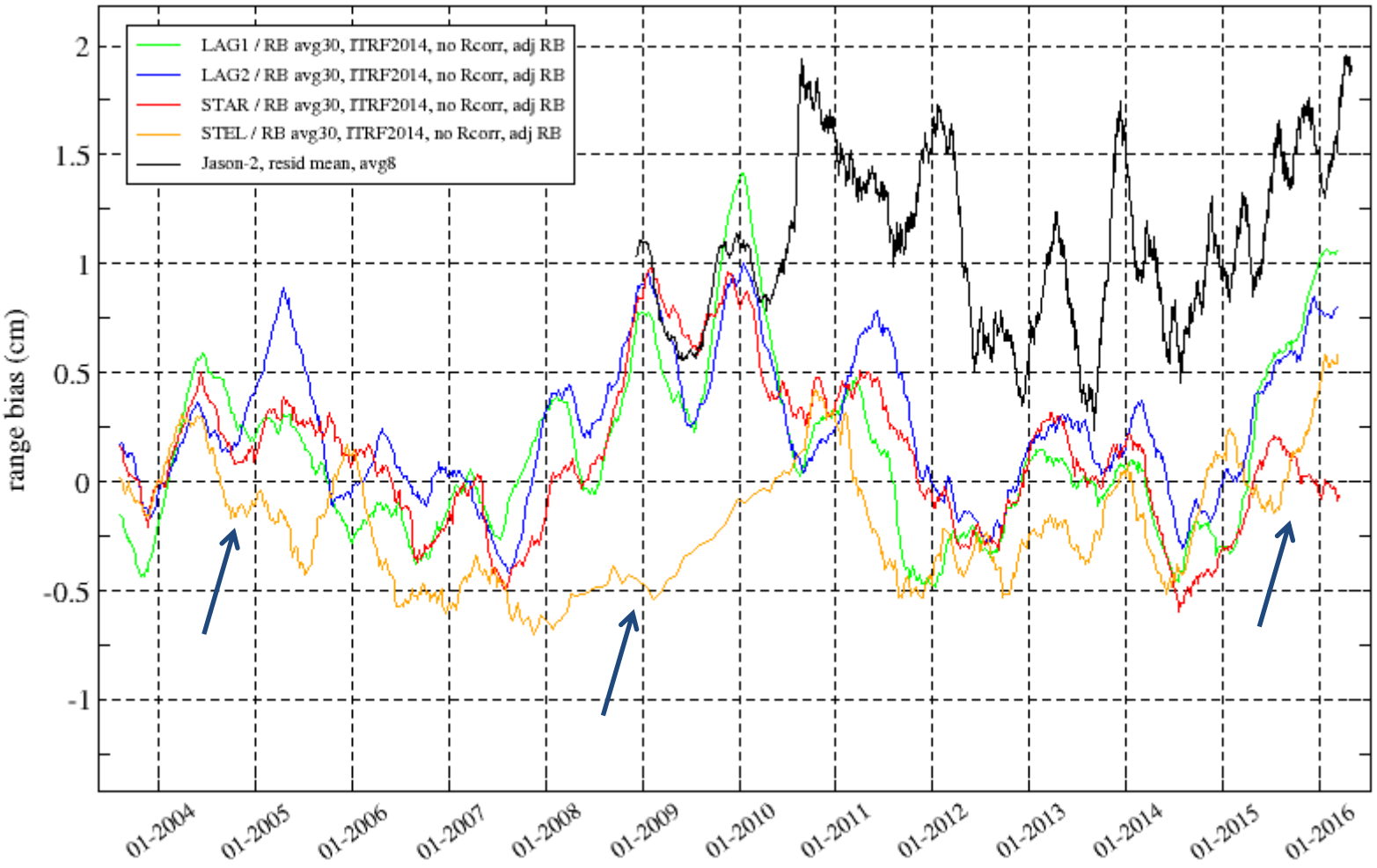
GREENBELT (7105) : BIAS DRIFT



Overall, a good match between Jason-2 and the low-orbit satellites; it is worse with high-orbit satellites, especially after 2014.

A drift of >1 cm over a period of a few years (red arrow) is clearly present and detected with all satellites. No correction is advertised by the ILRS. No bias is present before 2011, and the mean of the SLR residuals on Jason-2 is also centered on zero

MON. PEAK (7110) : LOW-ORBIT SAT. BIASES



Very similar biases for Lageos1/2 and the low-orbit satellite **Starlette**, but different signature with Starlette's twin **Stella** before 2014. Opposite behavior in 2015-2016. Large offset for Jason-2

CONCLUSIONS

Starlette/Stella

- Starlette/Stella are valuable !
- Generally well in agreement with Lageos 1 / 2 ; need help to explain the discrepancies
- CoM corrections are welcome, hopefully may remove the offset / Lageos

Range biases

- Range biases are not stable in time (may even show a drift) ; to be considered station by station, a mere average over decades seems inadequate
- A new version of John Ries' LPOD is needed ; can ILRS provide the equivalent ?

Altimeter POD validation

- Even core stations seem to show biases

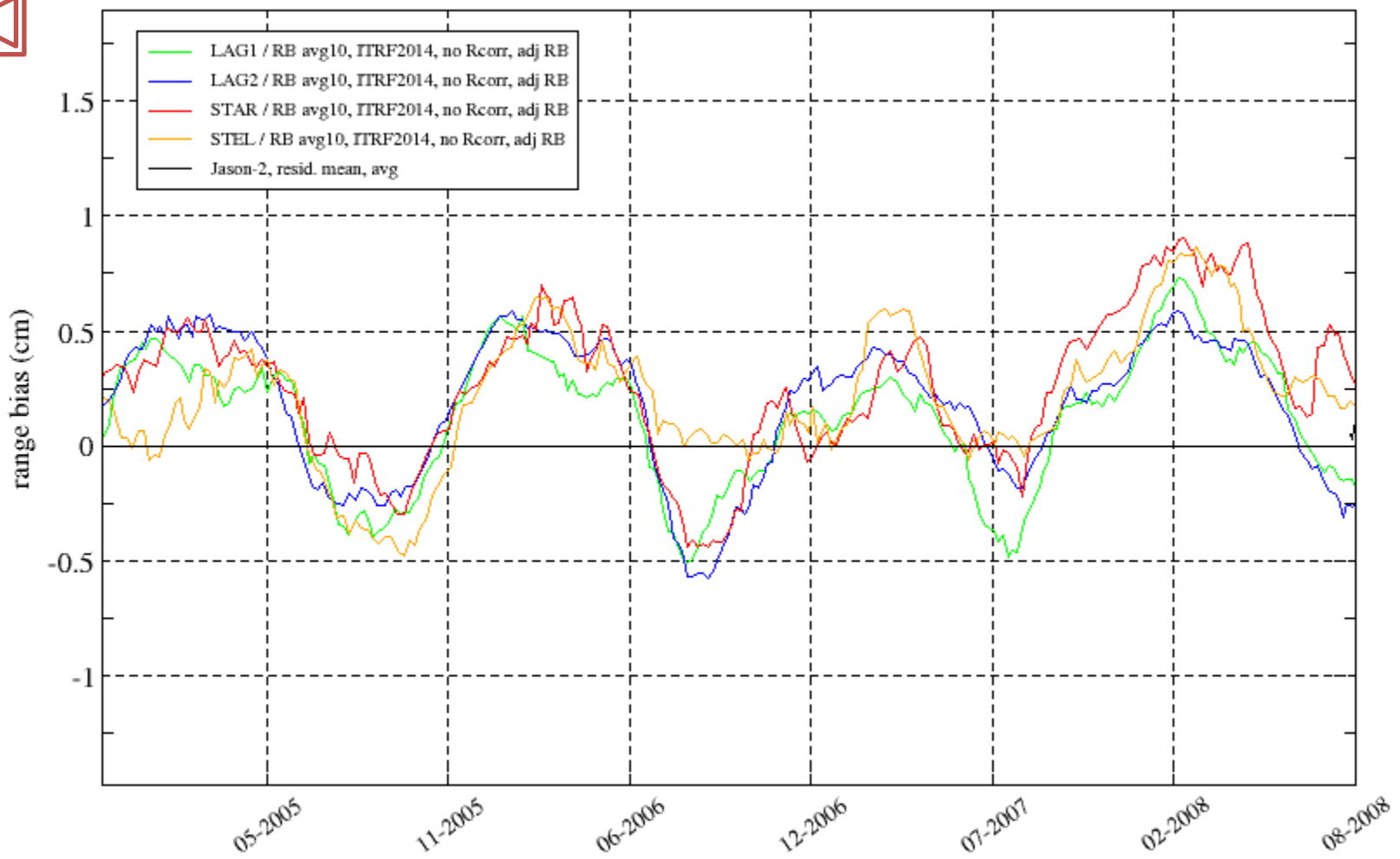
This presentation contains more questions than answers…

Thanks for your attention !

Backup slides…

	perigee	Incl.	exc.	weight	Diam.	CCR
Lageos1	5860 km	109.84	0.0045	407 kg	60 cm	426
Lageos2	5620 km	52.64	0.0135	405 kg	60 cm	426
Starlette	812 km	49.83	0.0206	47 kg	24 cm	60
Stella	800 km	98.6	0.0007	48 kg	24 cm	60
Jason-2	1336 km	66	0	500 kg	n/a	9
Lares	1450 km	69.5	0.0008	396.8 kg	36.4 cm	92

GRAZ (7839) - ZOOM



TRANSIENT PROBLEMS

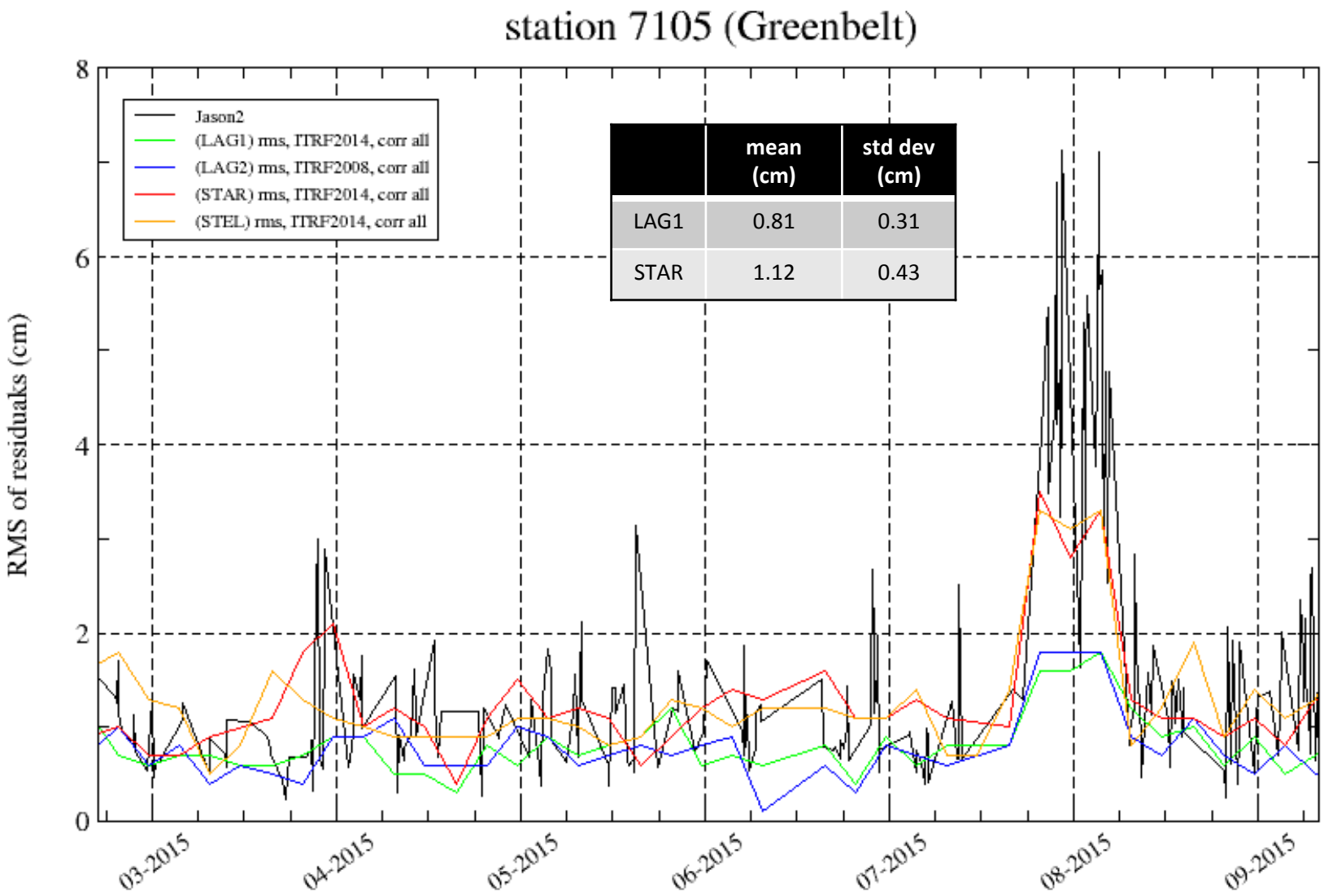
It is not just about range biases : early warning on station problems

Example : degradation of Greenbelt station's residuals in July 2015 (reason : Time Interval Counter replacement on Jul 12.)

Nothing was noticed by the ILRS routine processings (Lageos1/2 and Etalon1/2)

Starlette/Stella show noticeable degradation

TRANSIENT PROBLEMS



	mean (cm)	std dev (cm)
LAG1	0.81	0.31
STAR	1.12	0.43

MEAN RANGE BIASES : STATISTICS

Normal equation count

	LAG1	LAG2	STAR	STEL
7090 - Yarragadee	48	48	48	48
7825 – Mount Stromlo	48	48	48	48
7840 - Herstmonceux	48	48	48	48
7832 - Riyadh	48	48	48	48
8834 - Wettzell	48	48	48	48
7839 - Graz	48	48	48	48
7941 – Matera	47	47	47	46
7810 – Zimmerwald	45	45	45	45
7110 – Monument Peak	48	47	47	45
7080 – Davis	48	48	48	47
7824 – San Fernando	48	47	48	30
7105 – Greenbelt	48	48	48	47
7237 – Changchun	47	43	44	41
7841 – Potsdam	47	47	47	48
7405 - Conception	41	41	39	40

	LAG1	LAG2	STAR	STEL
7406 – San Juan	32	32	32	32
7838 – Simosato	31	30	31	31
7501 – Hartebeesthoek	44	43	45	44
7249 – Beijing	44	44	45	43
1864 – Maidanak	30	29	27	**1**
1884 – Riga	34	27	28	15
7119 – Haleakala	24	25	25	25
1893 – Katzively	31	26	35	20
7811 – Borowiec	30	22	27	13
1873 – Simeiz	39	34	33	20
7308 – Koganei	30	30	29	25
7358 – Tanegashima	28	28	28	11
7821 – Shanghai	26	27	33	31
7124 – Tahiti	23	23	24	13
7403 - Arequipa	20	18	24	23