ILRSA AC&CC
Status of the combination products

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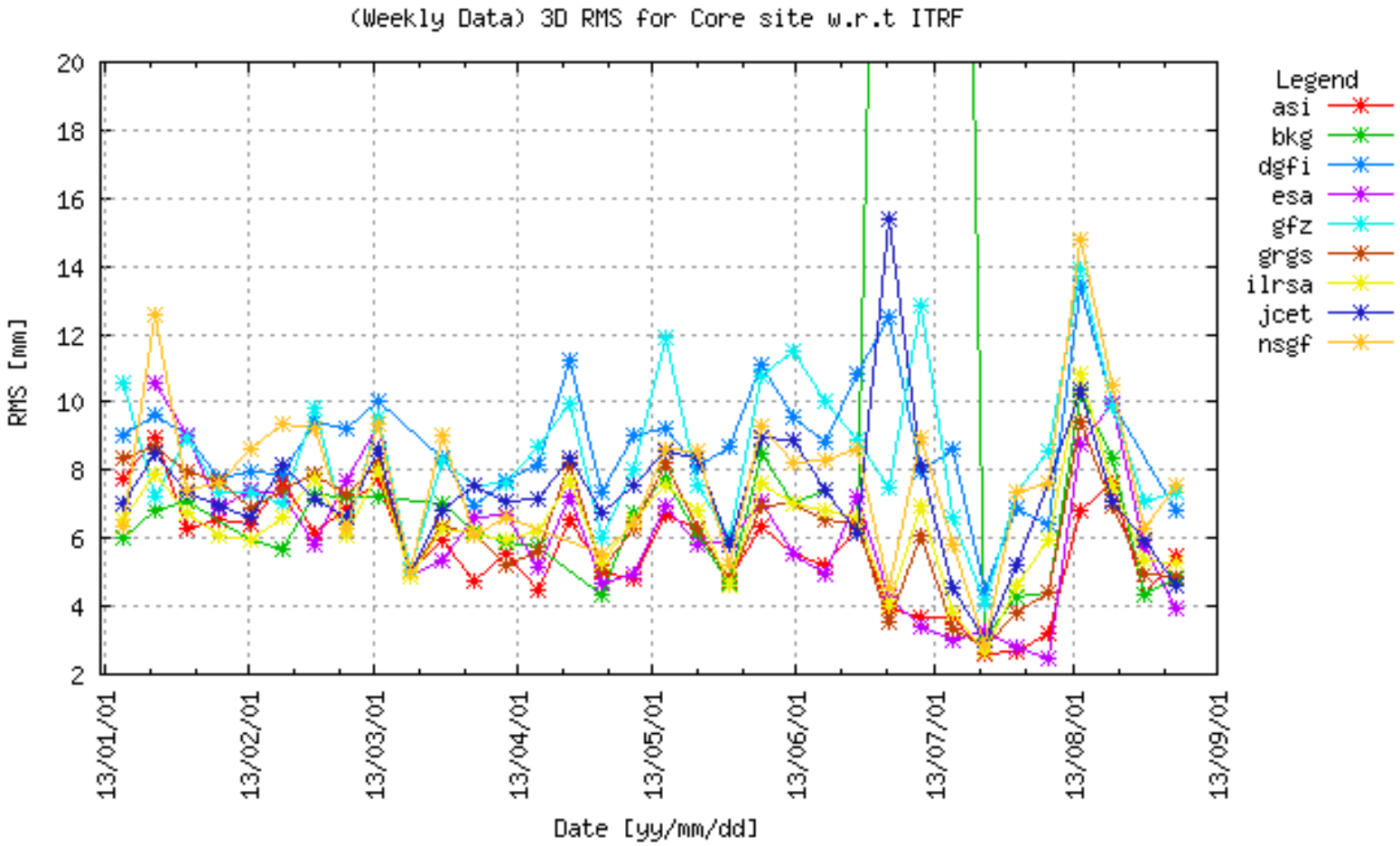
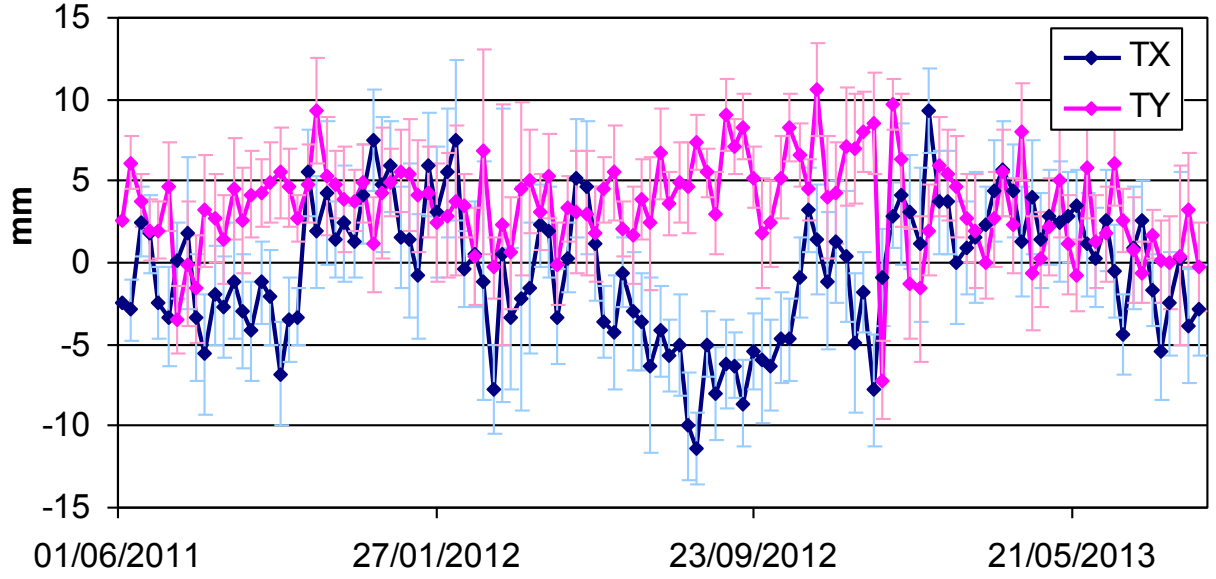
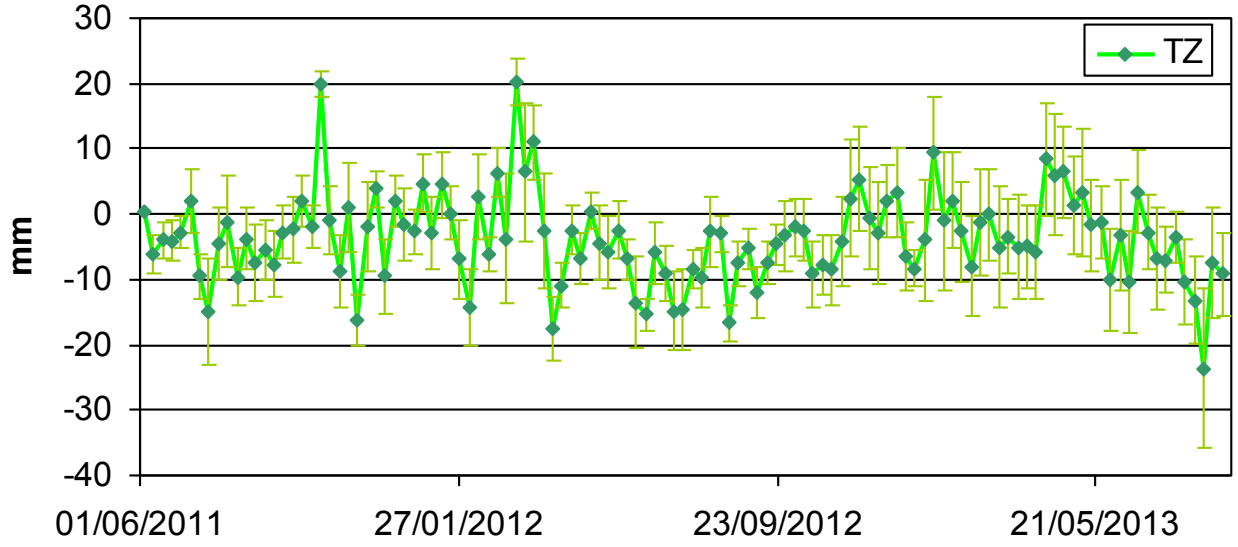
ILRS AWG Meeting, 1 September 2013, Potsdam

Site Coordinates

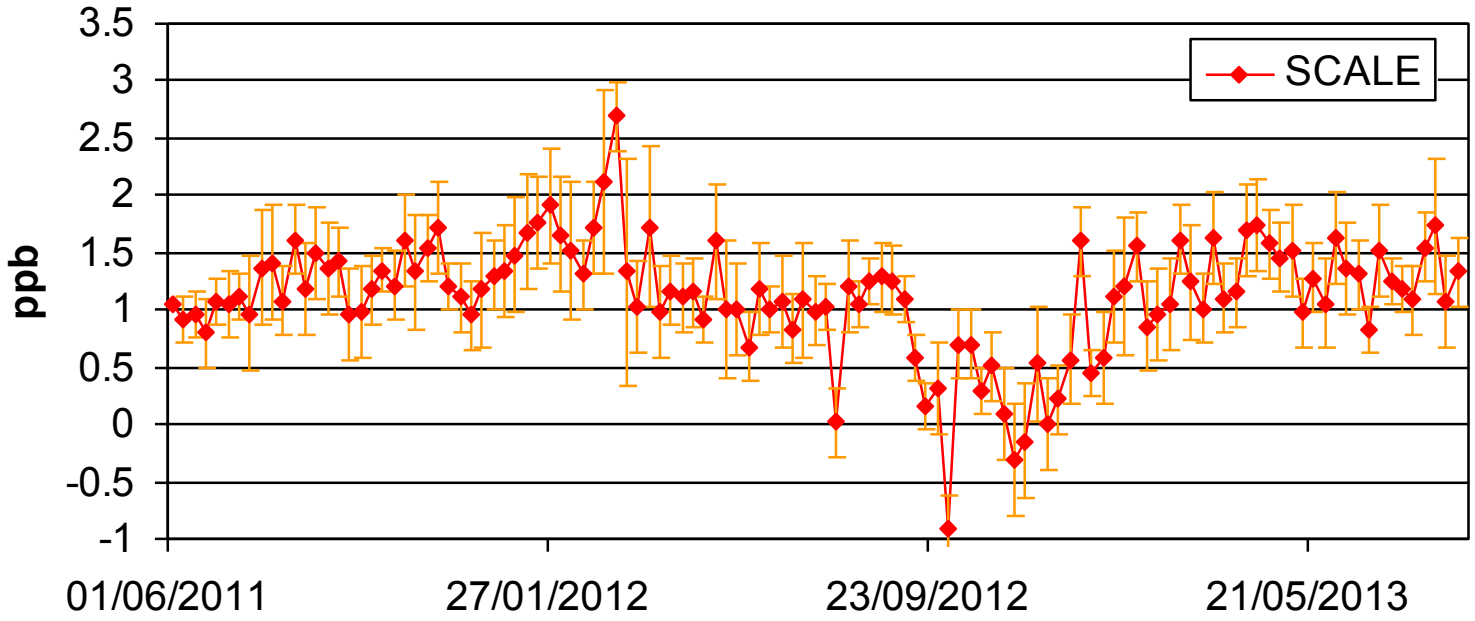


Reference Frame: translations w.r.t. ITRF2008

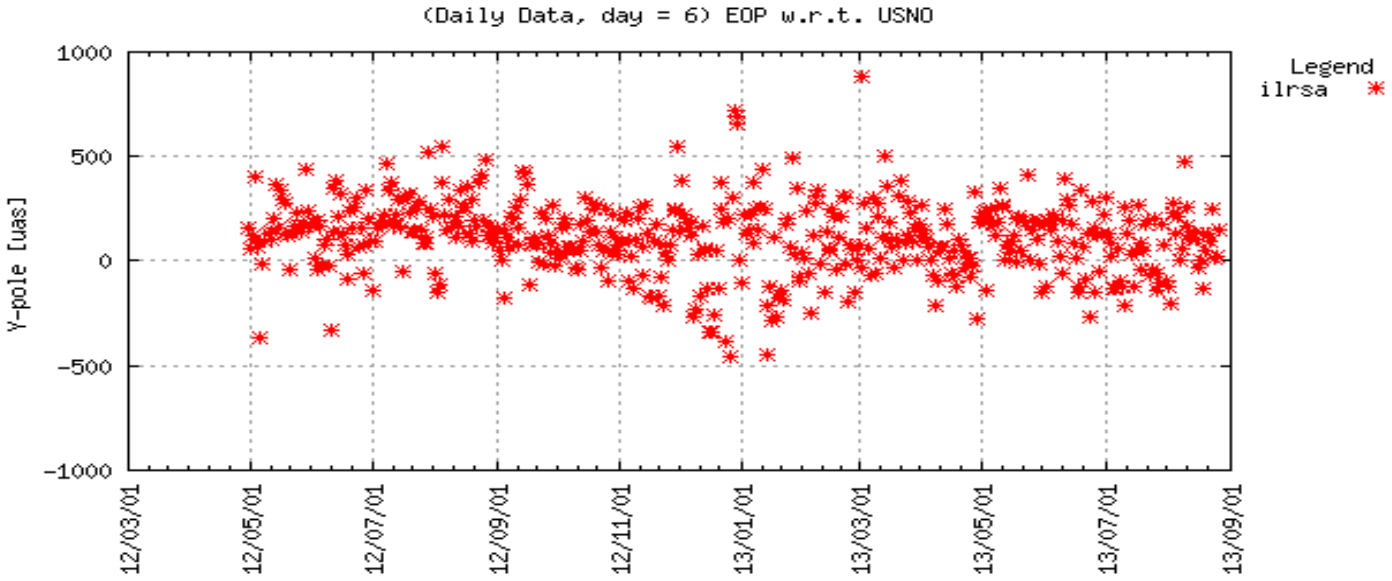


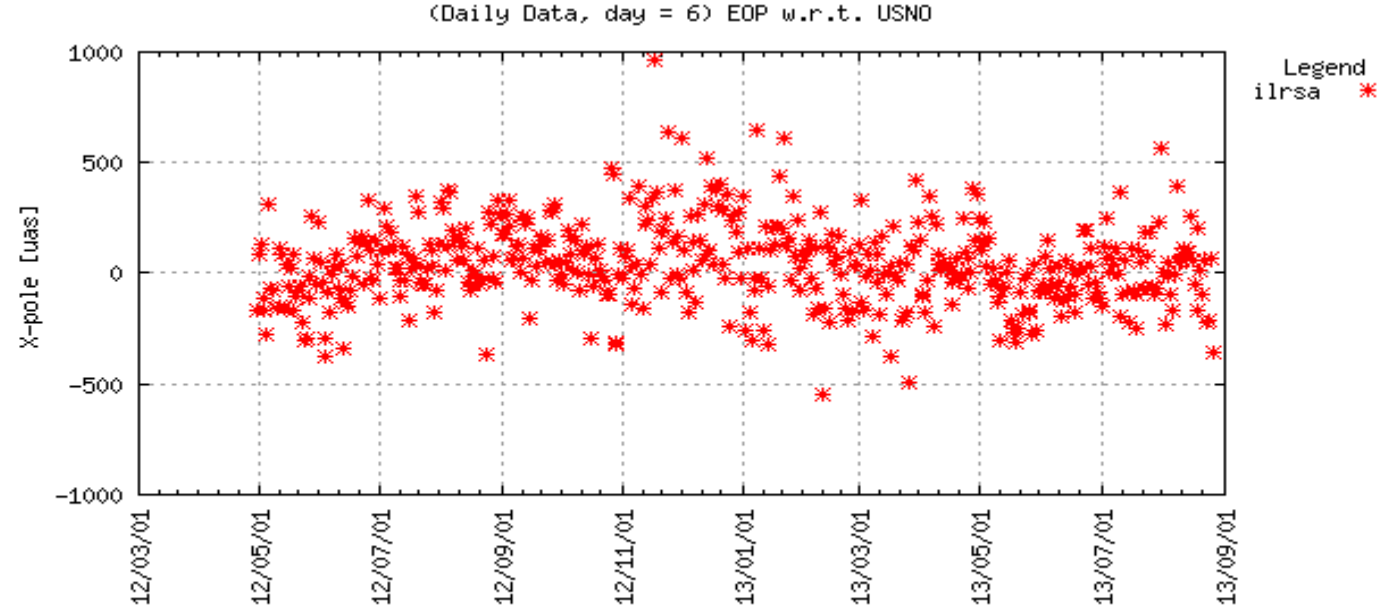


Reference Frame: scale w.r.t. ITRF2008

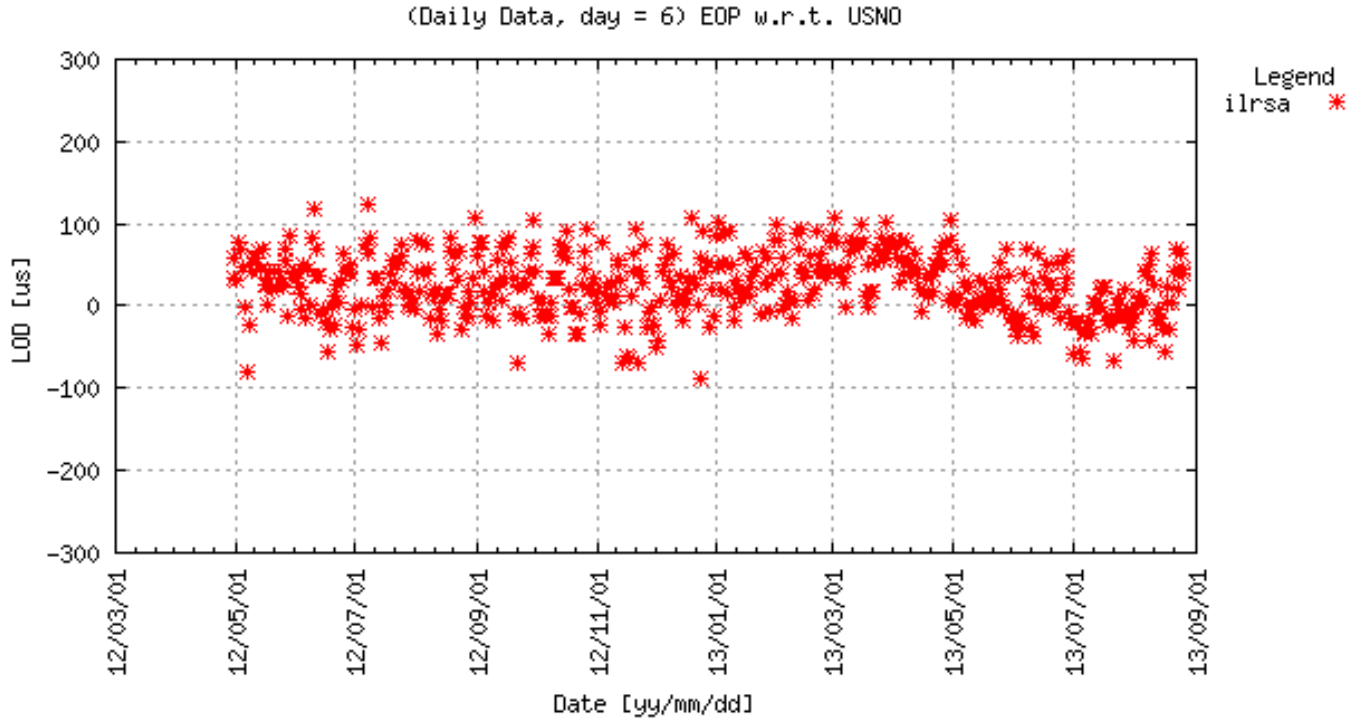


EOP w.r.t. USNO finals





LOD w.r.t. USNO finals



AC weekly orbit - present status

			Comments/notes
ASI	L51	X	OK
	L52	X	
	L53	X	
	L54	X	
BKG	L51	x	OK
	L52	X	
	L53	X	
	L54	X	
DGFI	L51	x	OK
	L52	X	
	L53	X	
	L54	X	
ESA	L51	X	OK L53, L54 every 5'
	L52	X	
	L53	X	
	L54	X	
JCET	L51	X	*OK*
	L52	X	
	L53	X	
	L54	X	

			Comments/notes
GFZ	L51	X	No Etalon orbits
	L52	X	
	L53	-	
	L54	-	
GRGS	L51	-	Not available since Oct 2012
	L52	-	
	L53	-	
	L54	-	
NSGF	L51	X	*OK*
	L52	X	
	L53	X	
	L54	X	

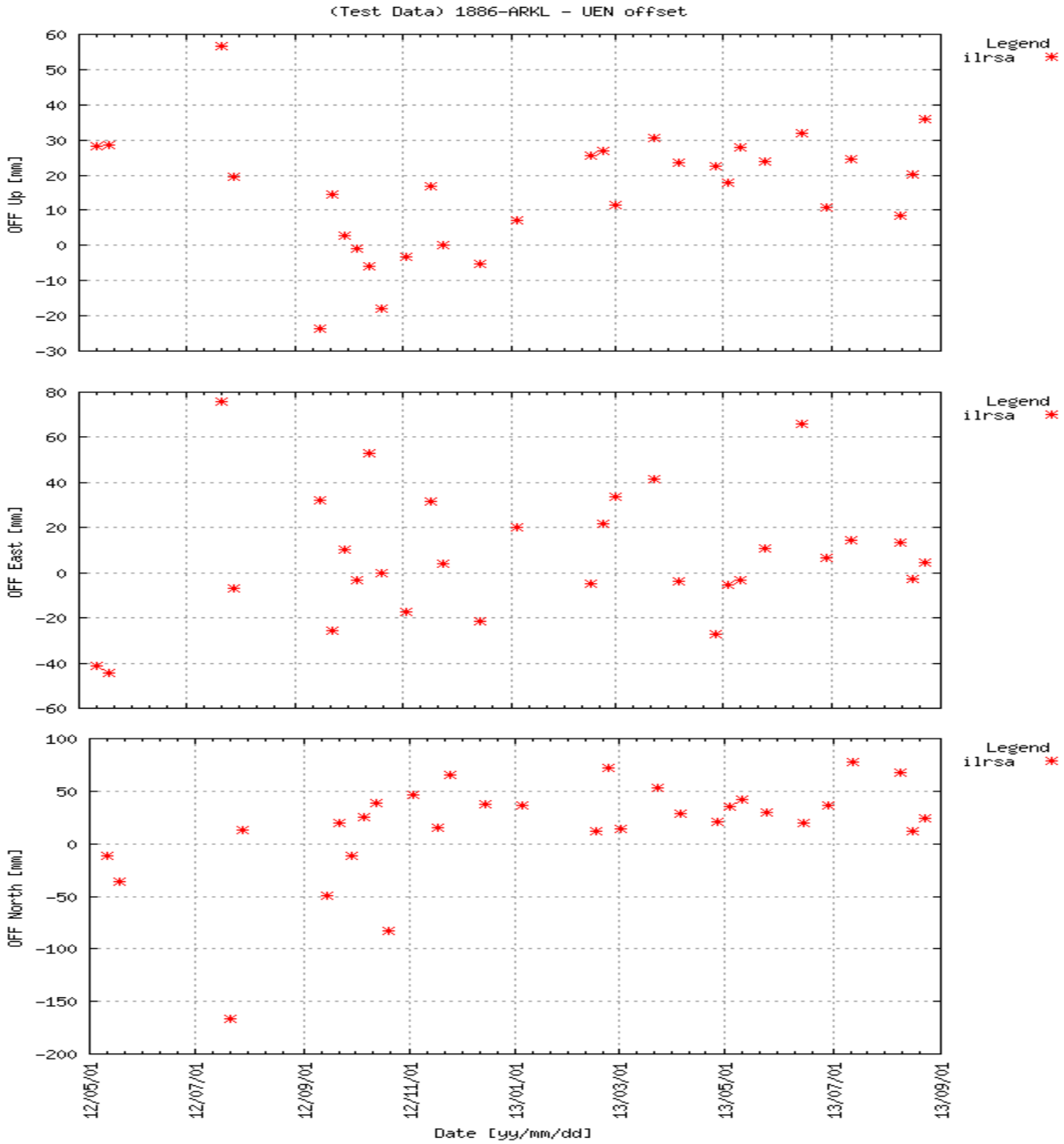
SP3c files – remarks (@ April 2013)

- L51/L52 asi, bkg, dgfi, esa, gfz, jcet, nsgf
- L53/L54 asi, bkg, dgfi, esa, jcet, nsgf
- Format check: esa orbit for L53/L54 at 5’
- asi, bkg, gfz, nsgf coherent (~2-4cm C-A L51/L52)
- dgfi shows discrepancies in the A component
- jcet shows big differences in the C component
- esa shows ~10 cm rms in the C component and ~ 5 cm bias in the A component

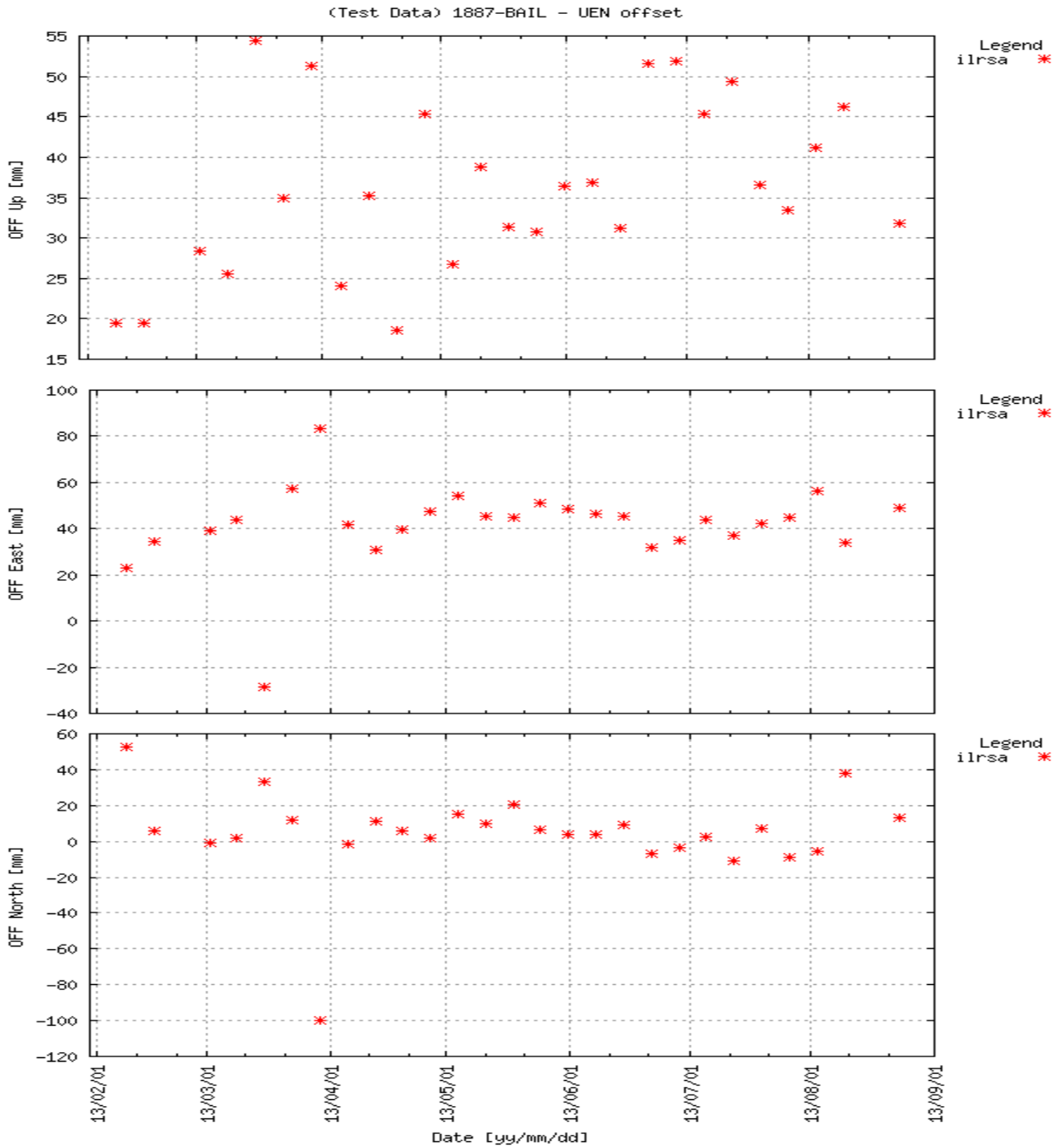
Station coordinates

- New stations: 1886, 1887, 1888,1889, 1890 (new coordinates needed)
- Station experiencing earthquakes: 7403, 7405, 7406, 7308, 7838 (new coordinates needed)
- Station with discontinuities: 1873, 1879, 7080, 7090(?), 7105, 7110, 7237, 7825, 7841, 8834

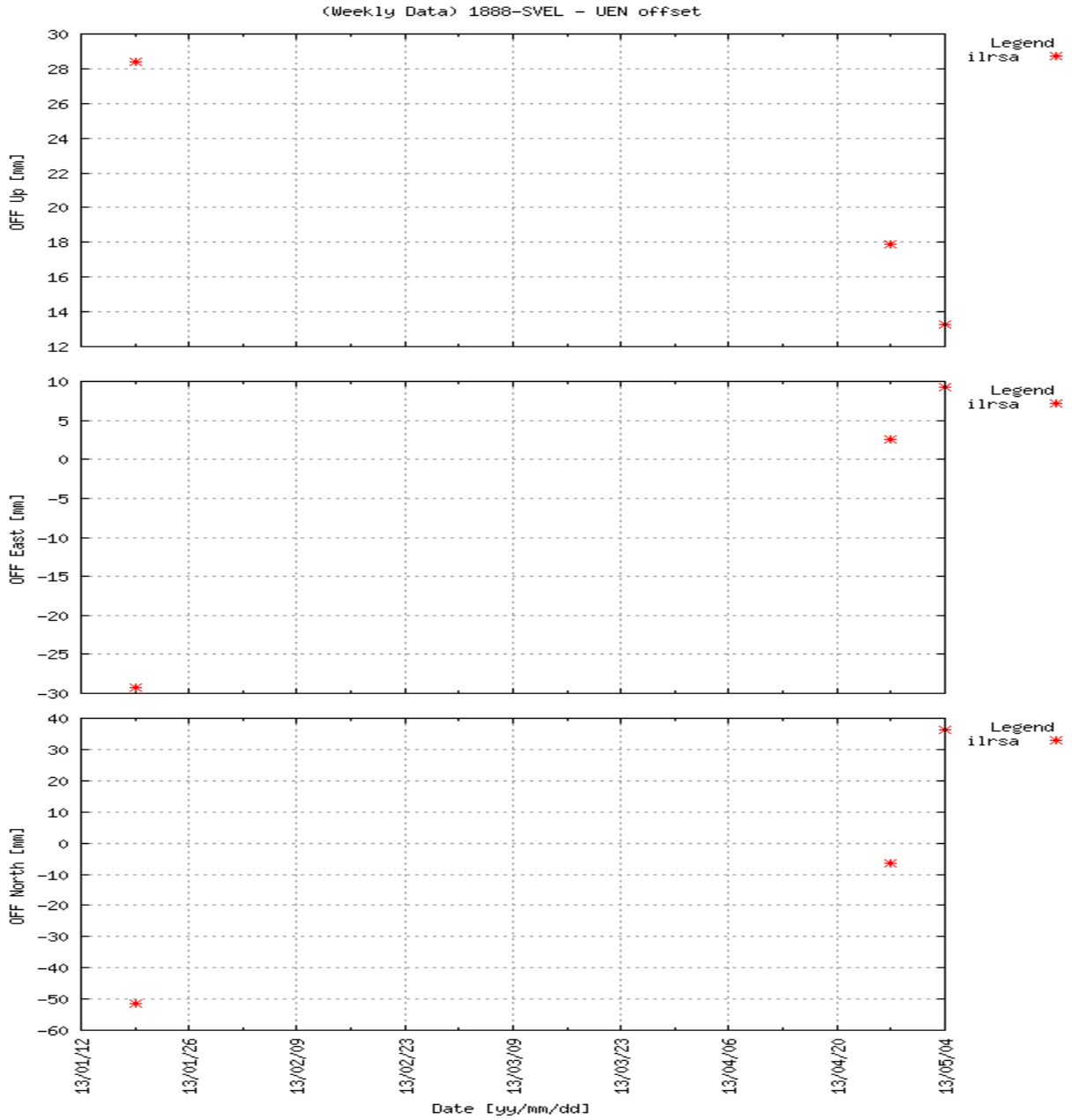
1886 : new site



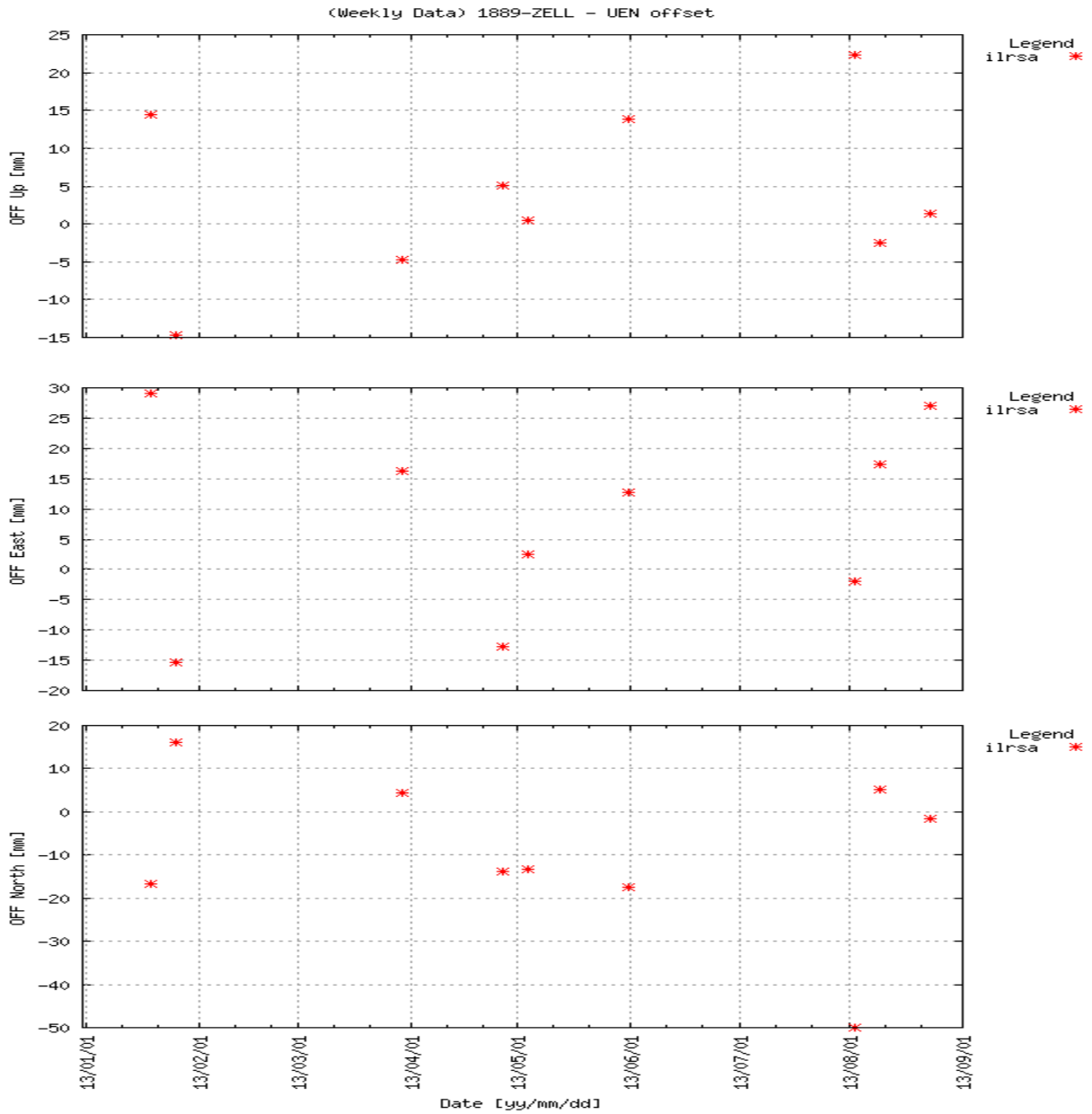
1887 : new site



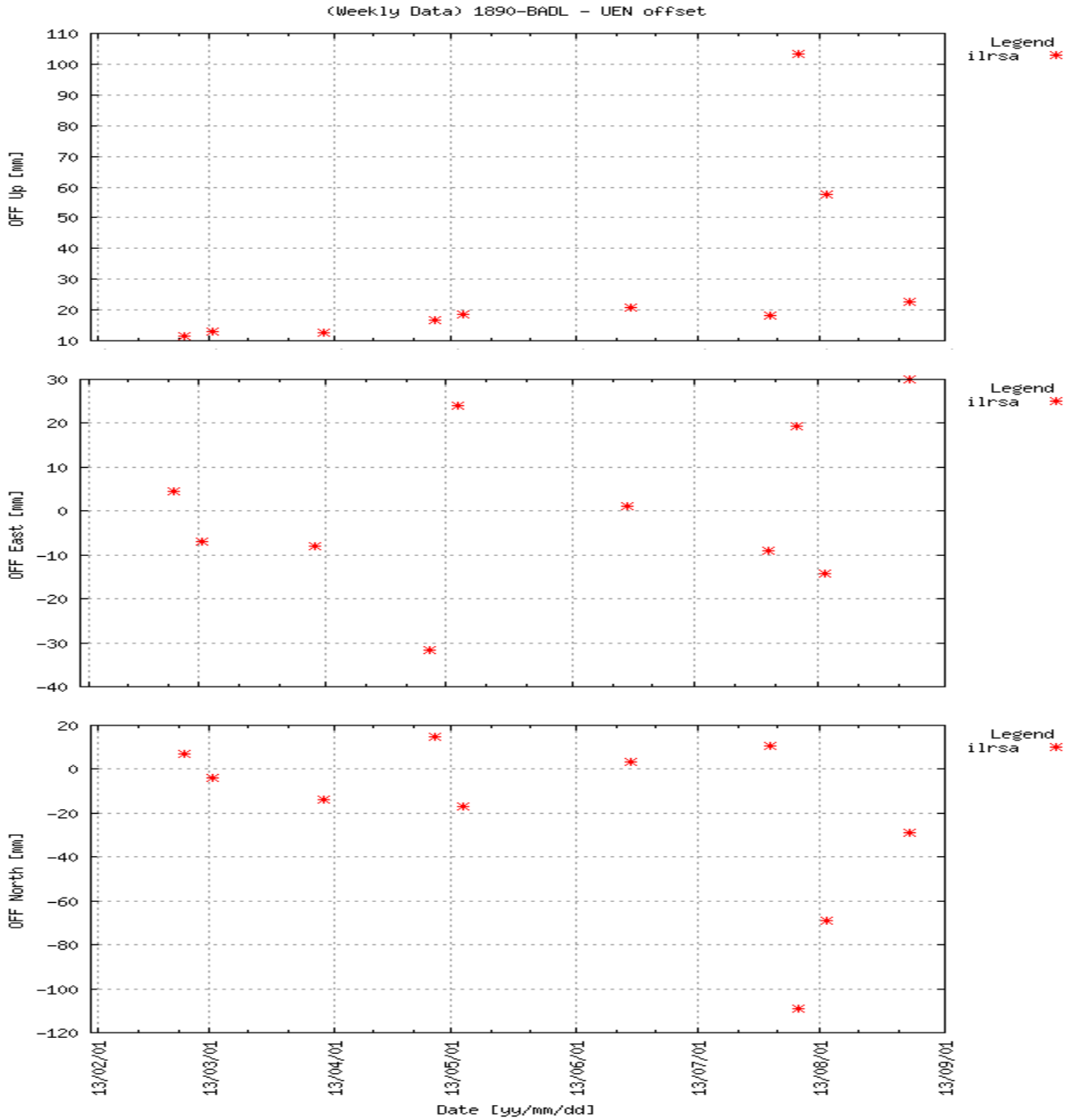
1888 : new site



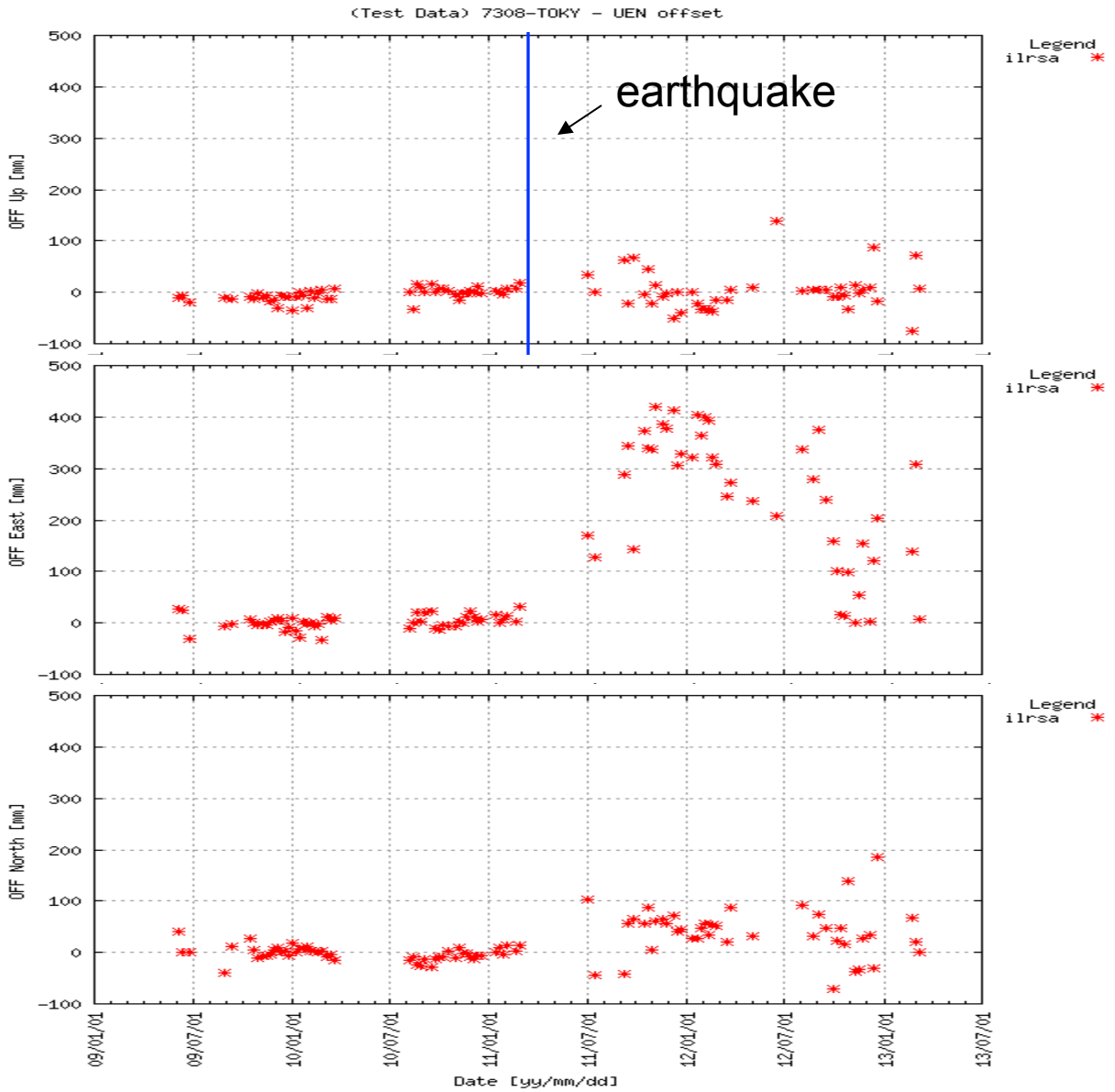
1889 : new site



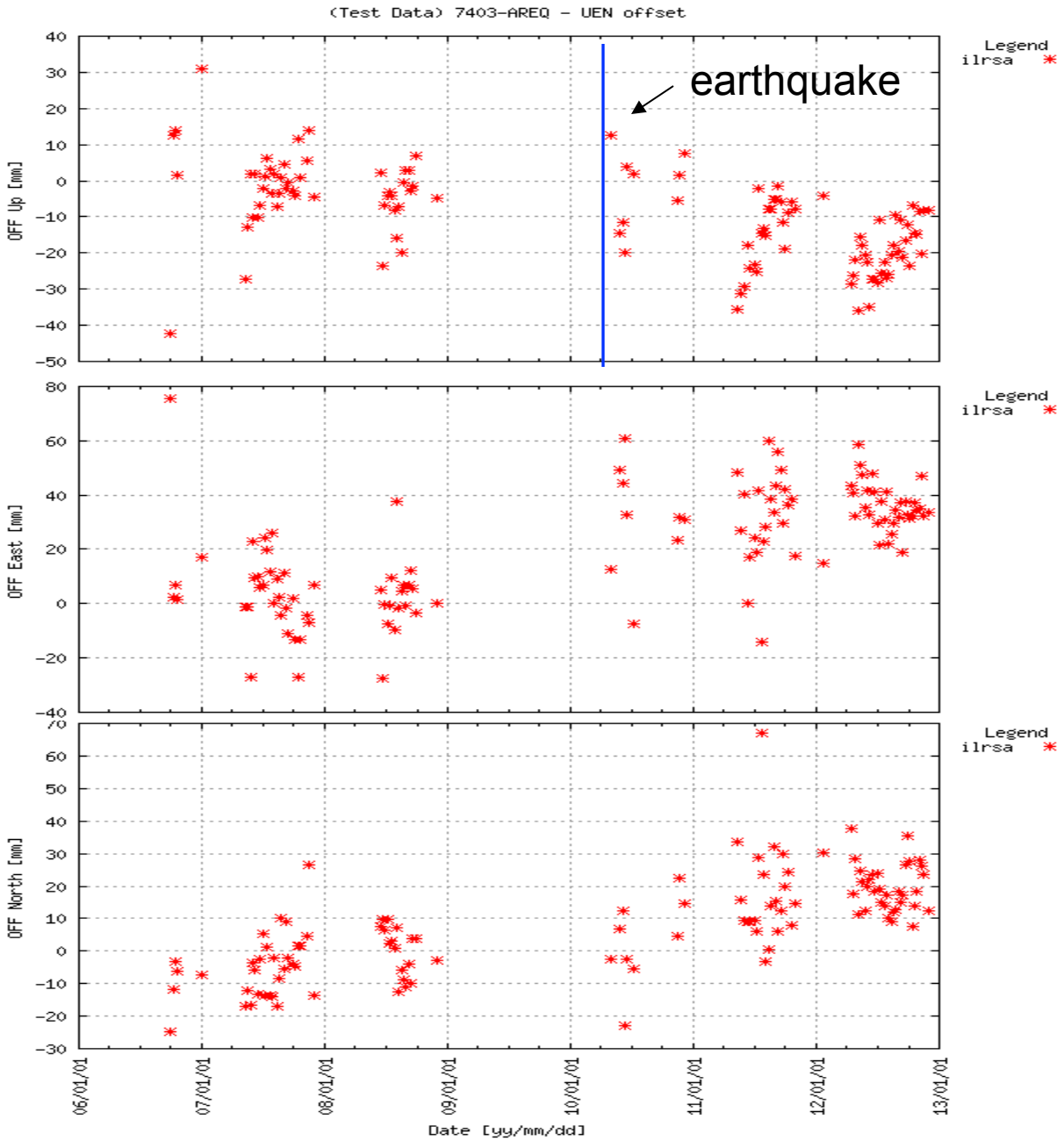
1890 : new site



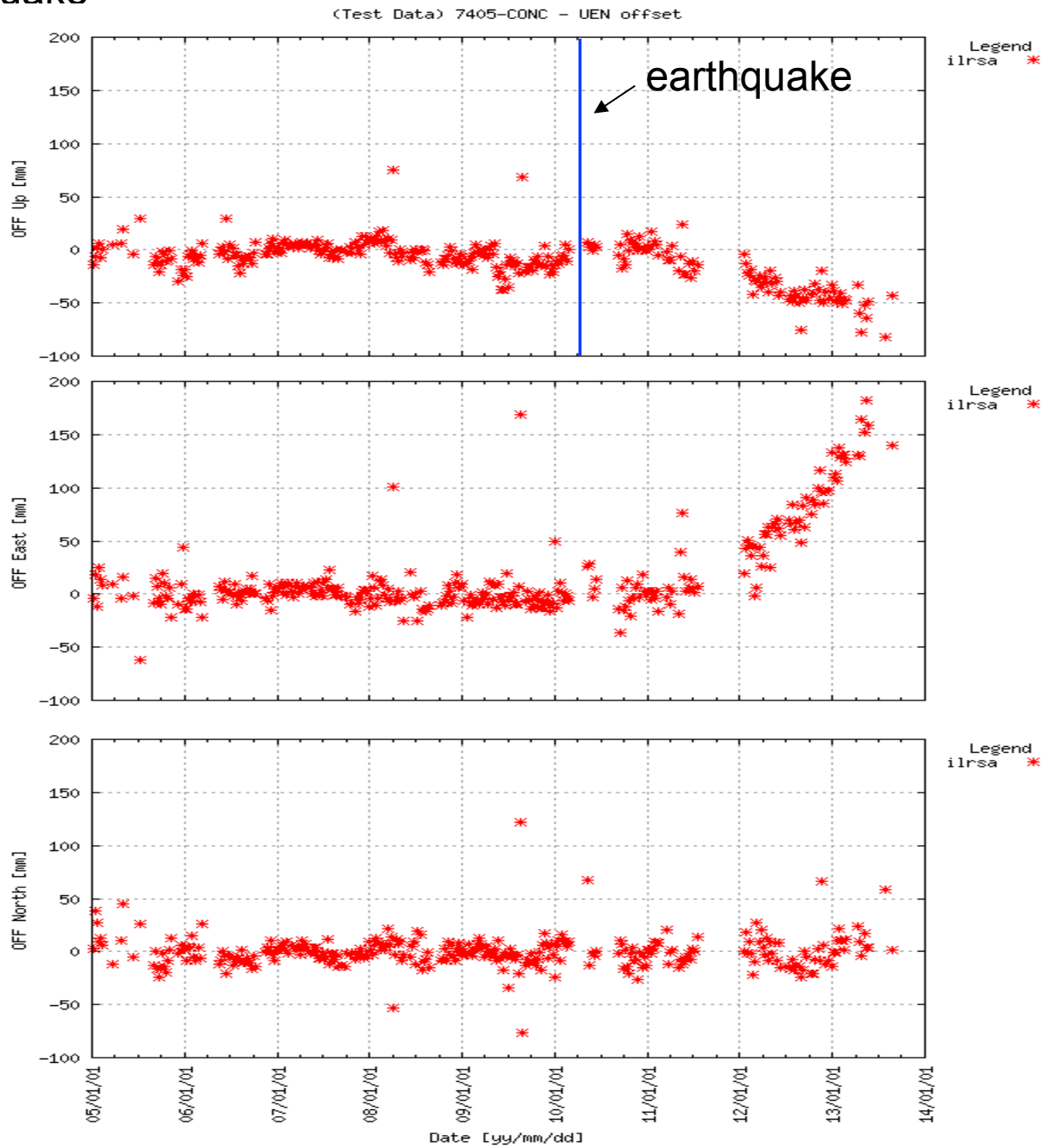
7308 : earthquake



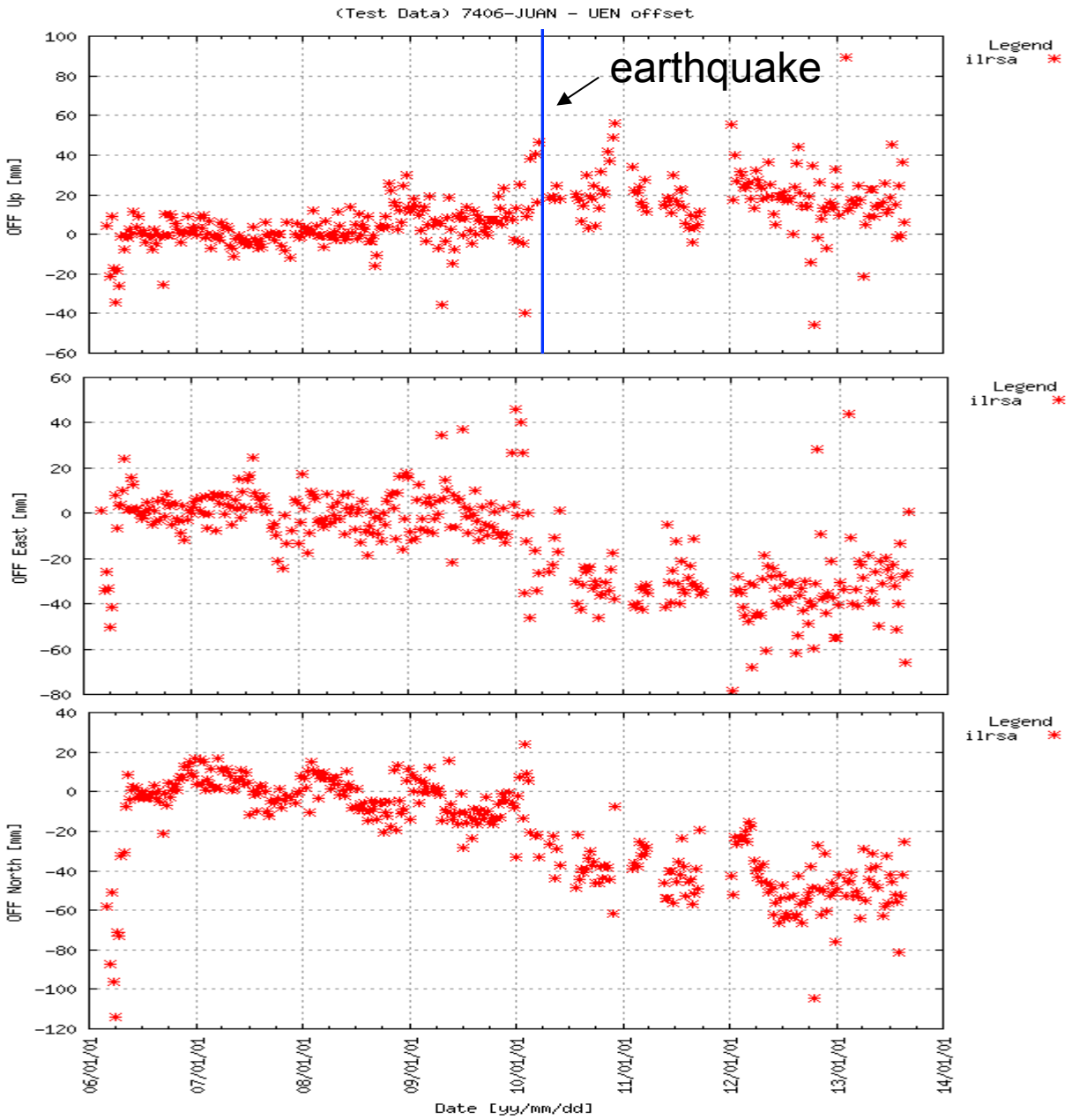
7403 : earthquake



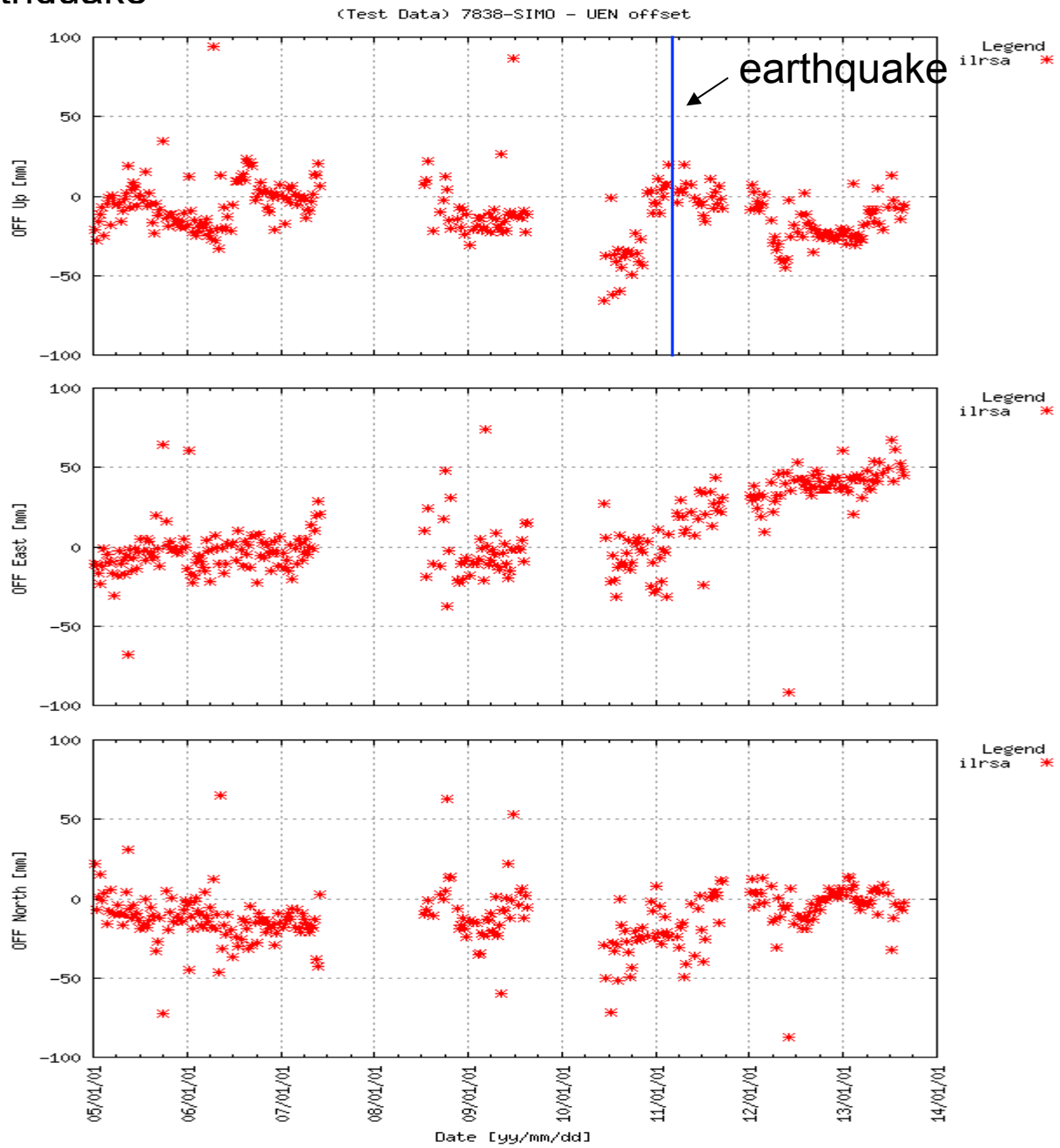
7405 : earthquake



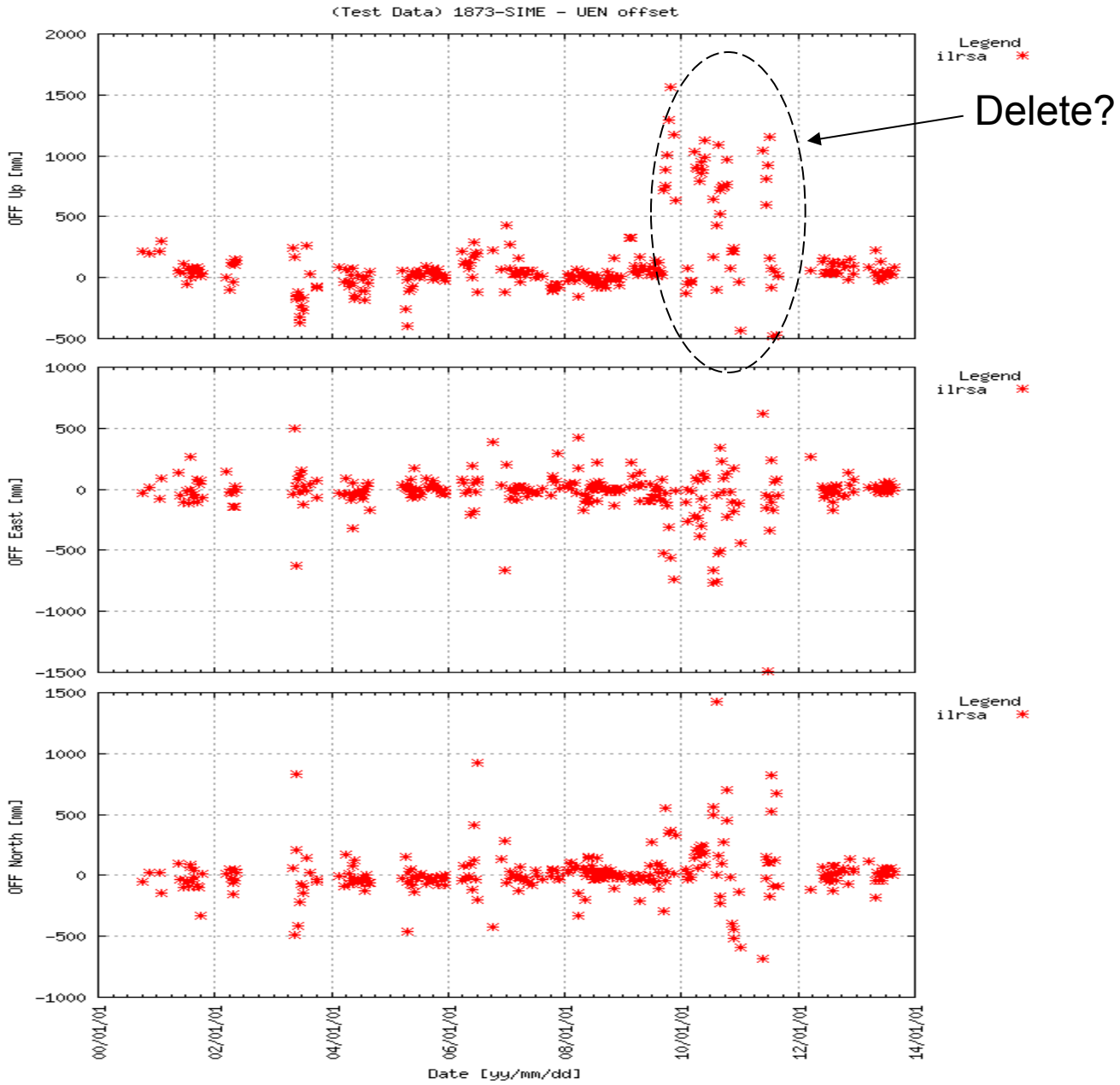
7406 : earthquake



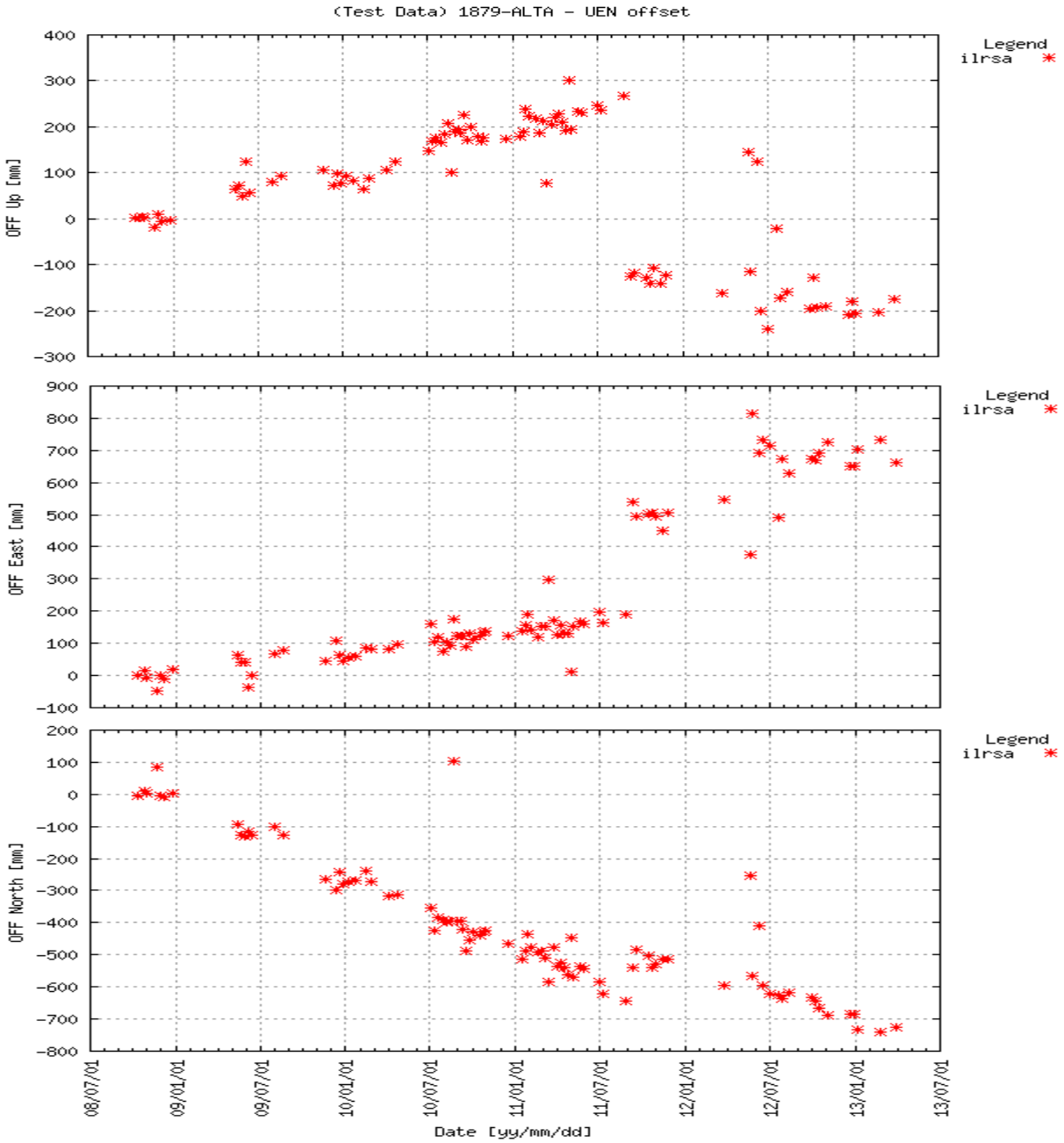
7838 : earthquake



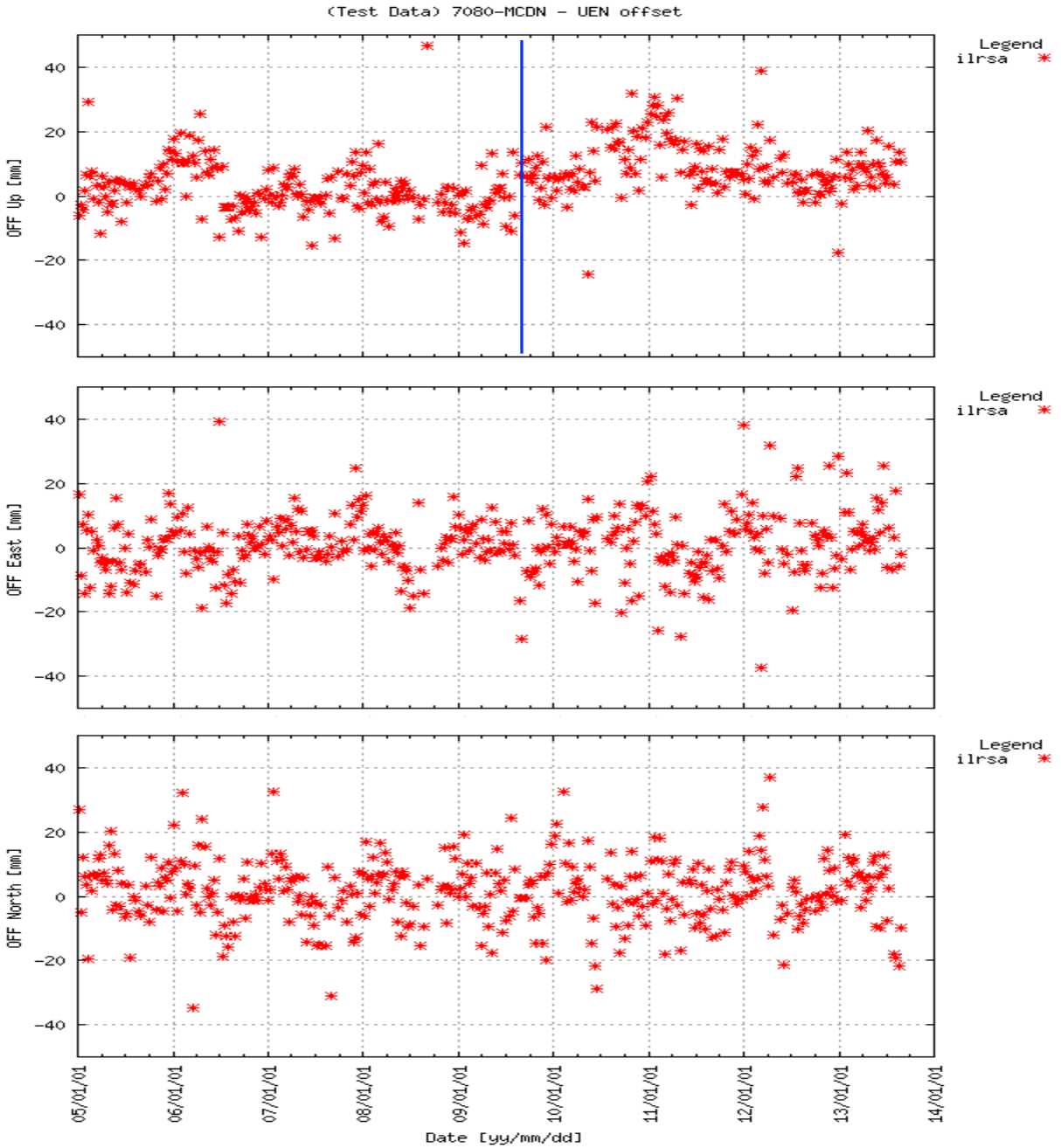
1873 : data problem



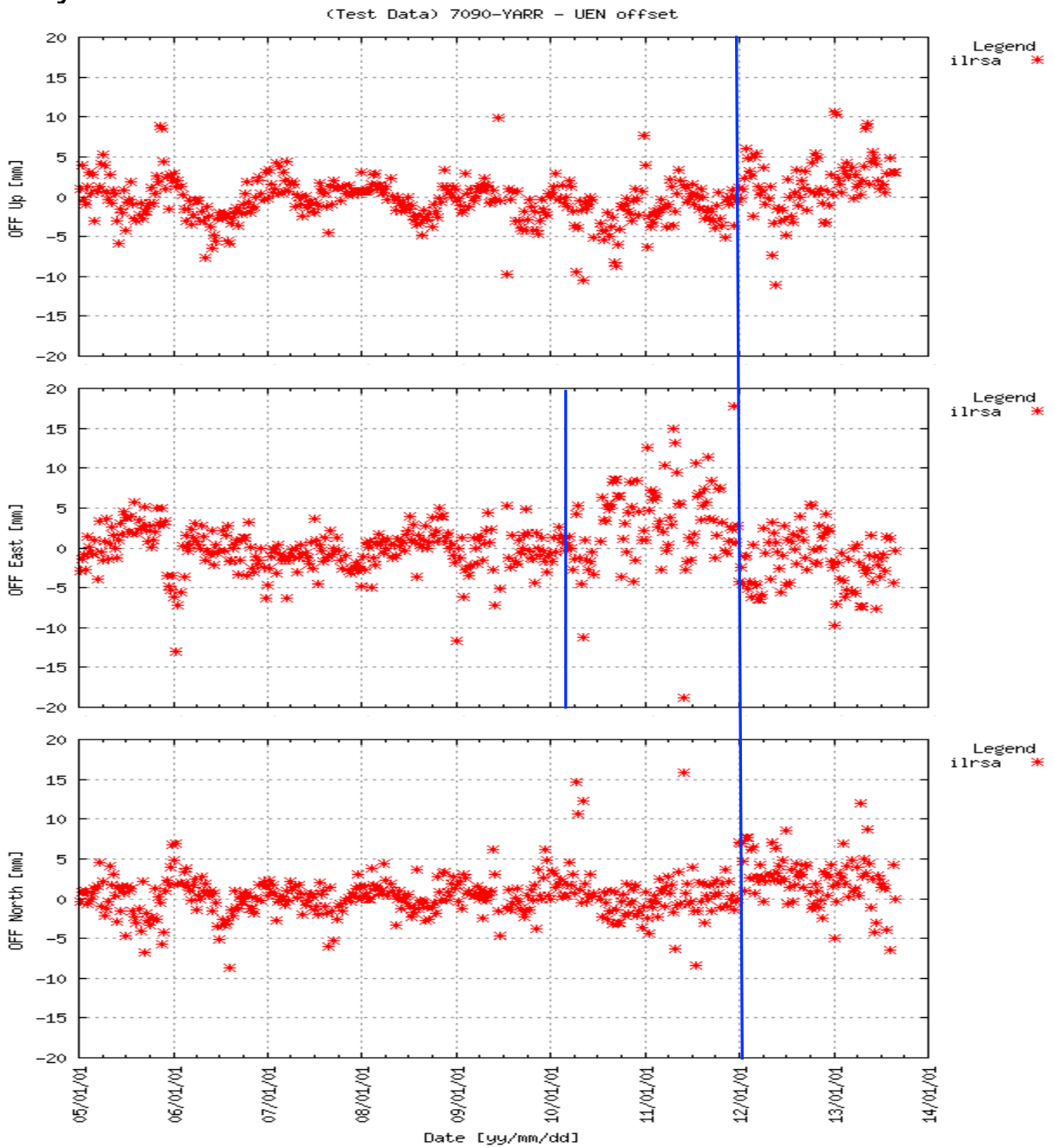
1879 : discontinuity



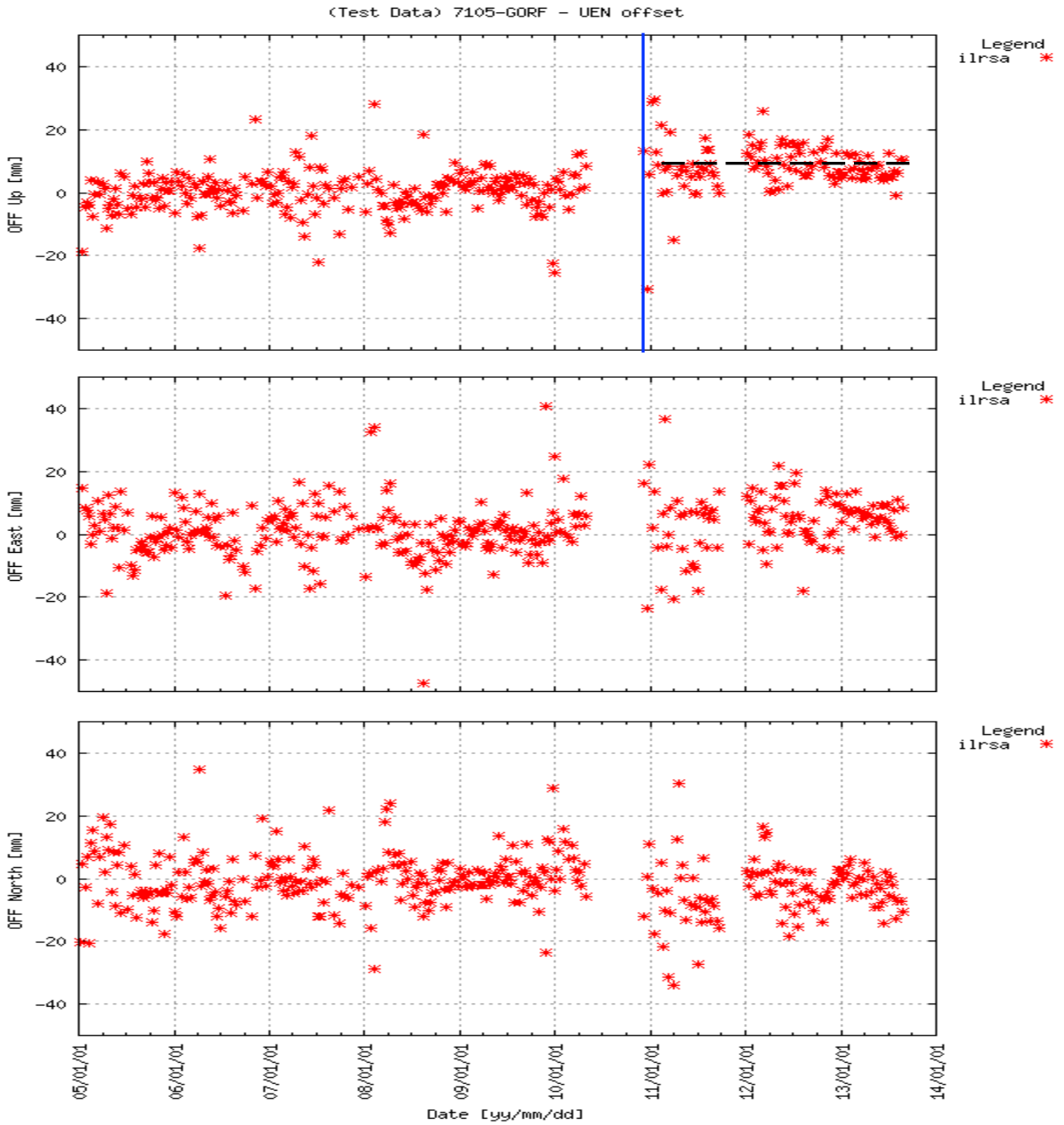
7080 : discontinuity



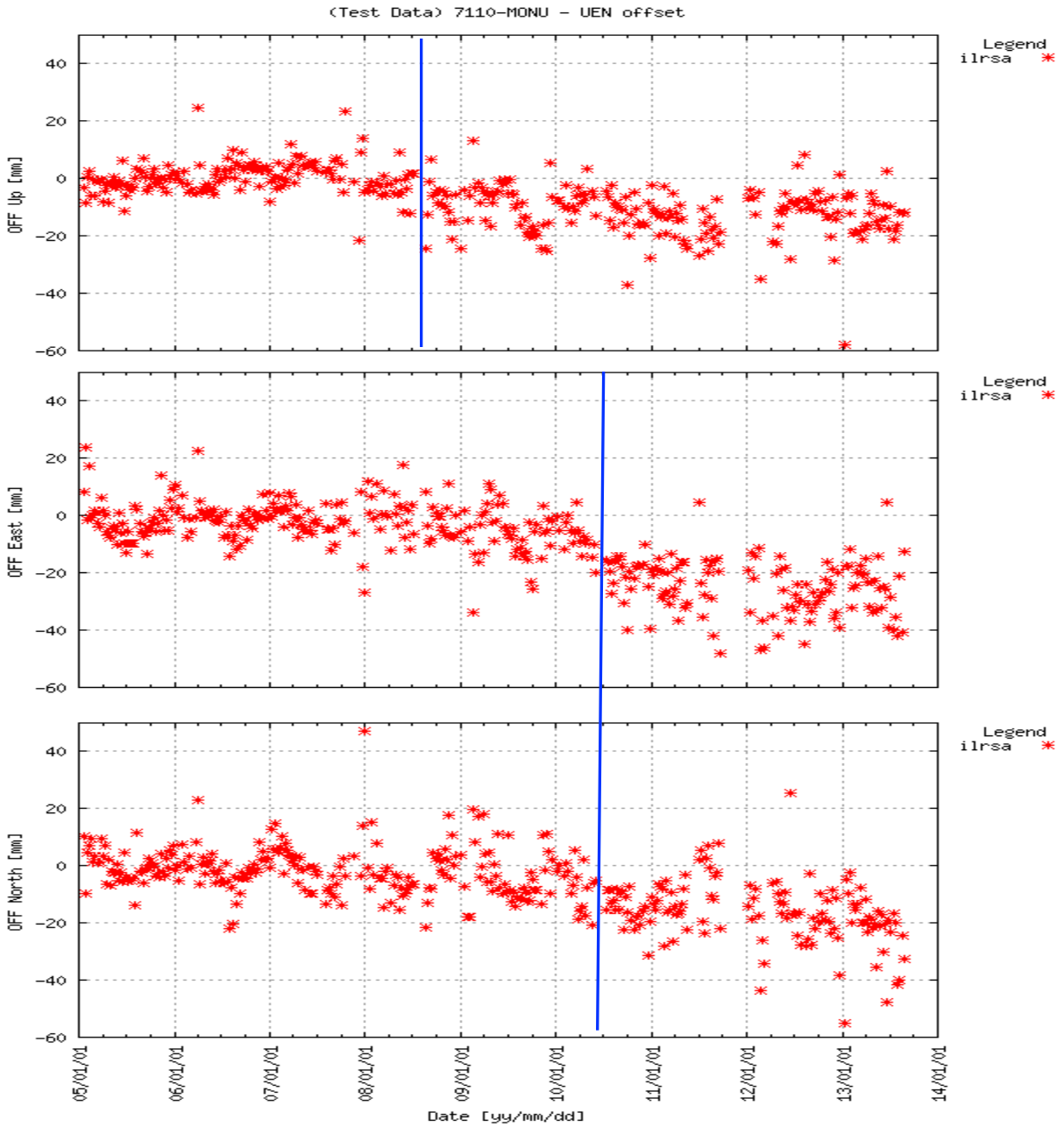
7090 : discontinuity



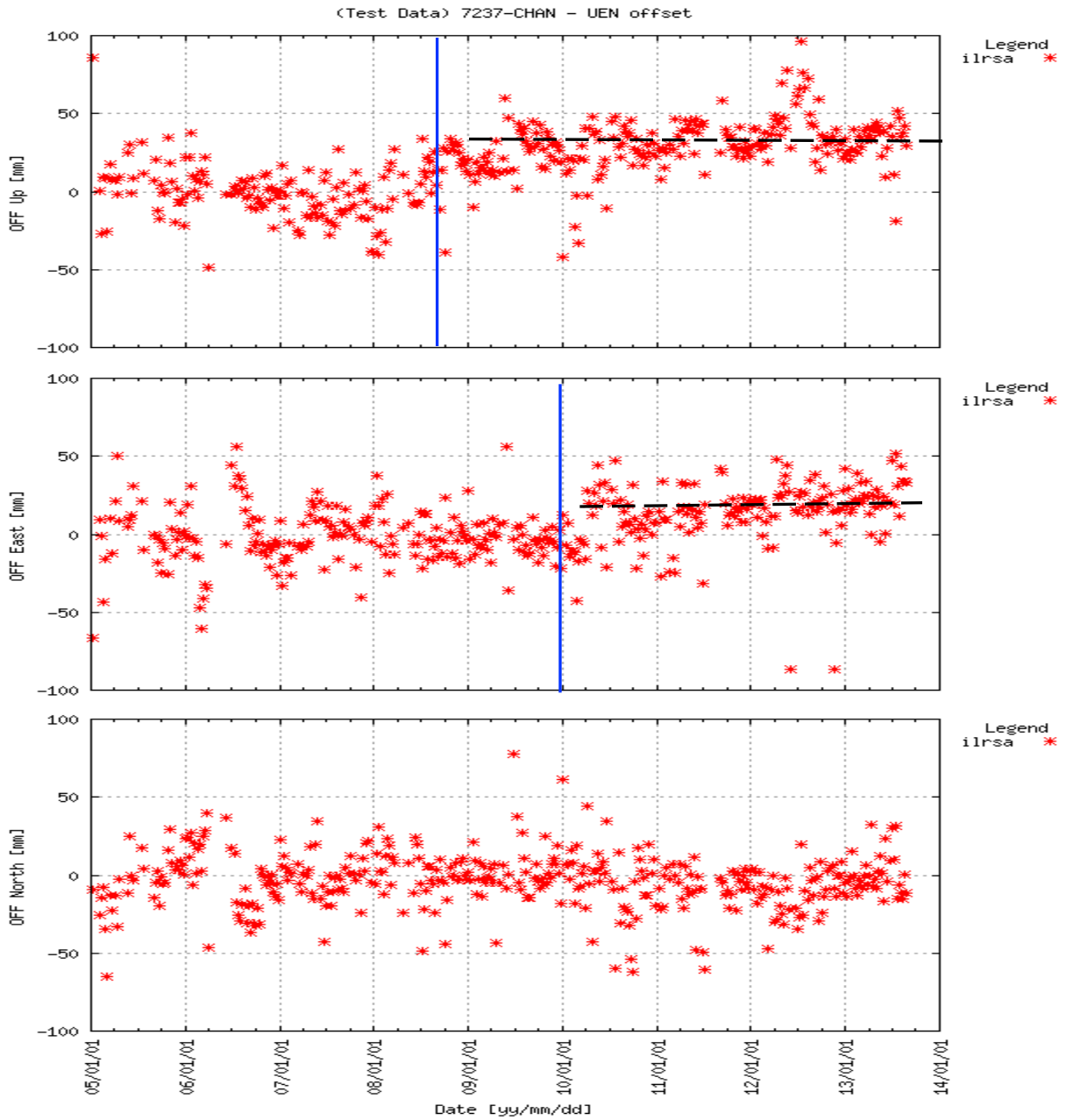
7105 : discontinuity



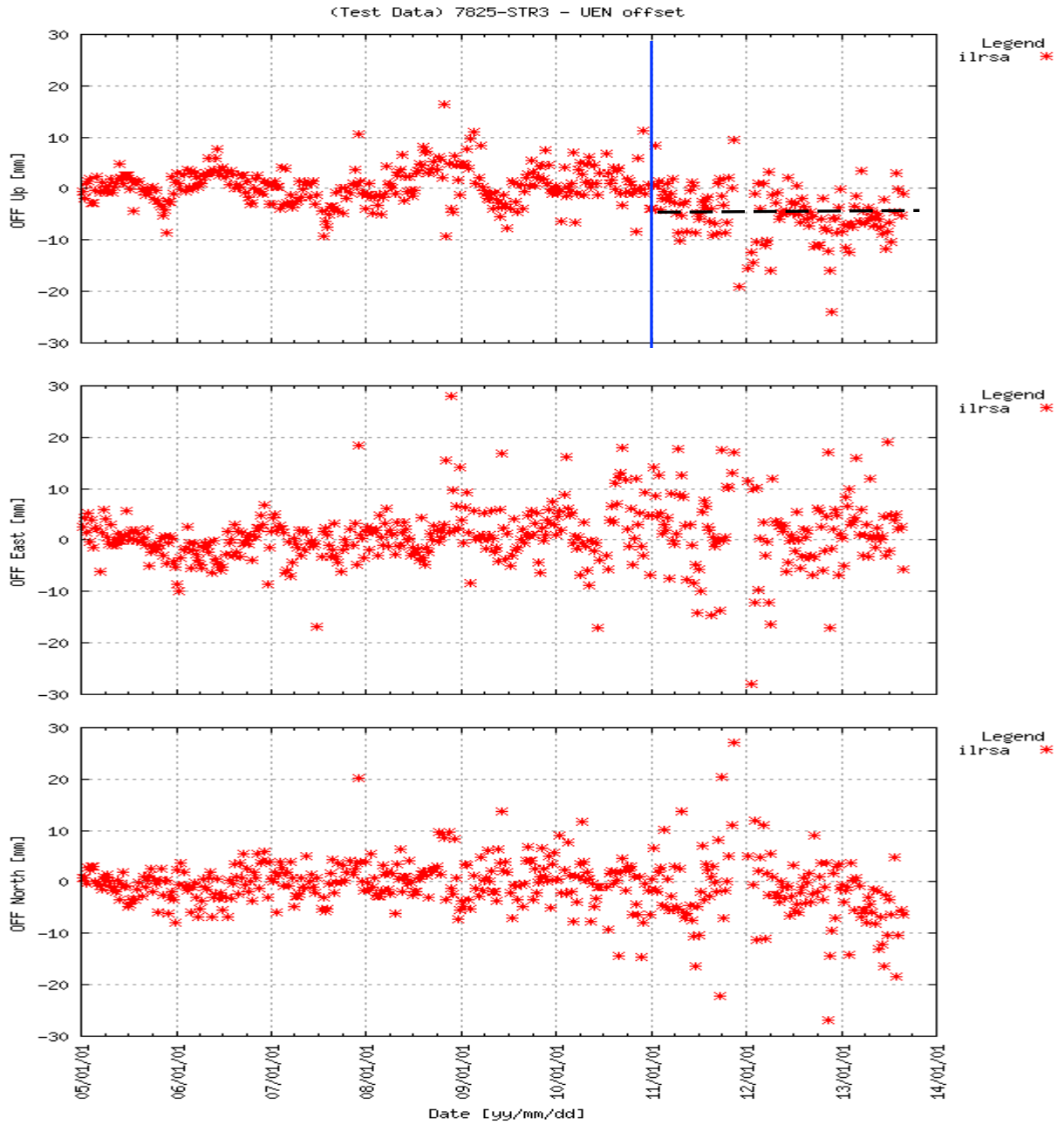
7110 : discontinuity



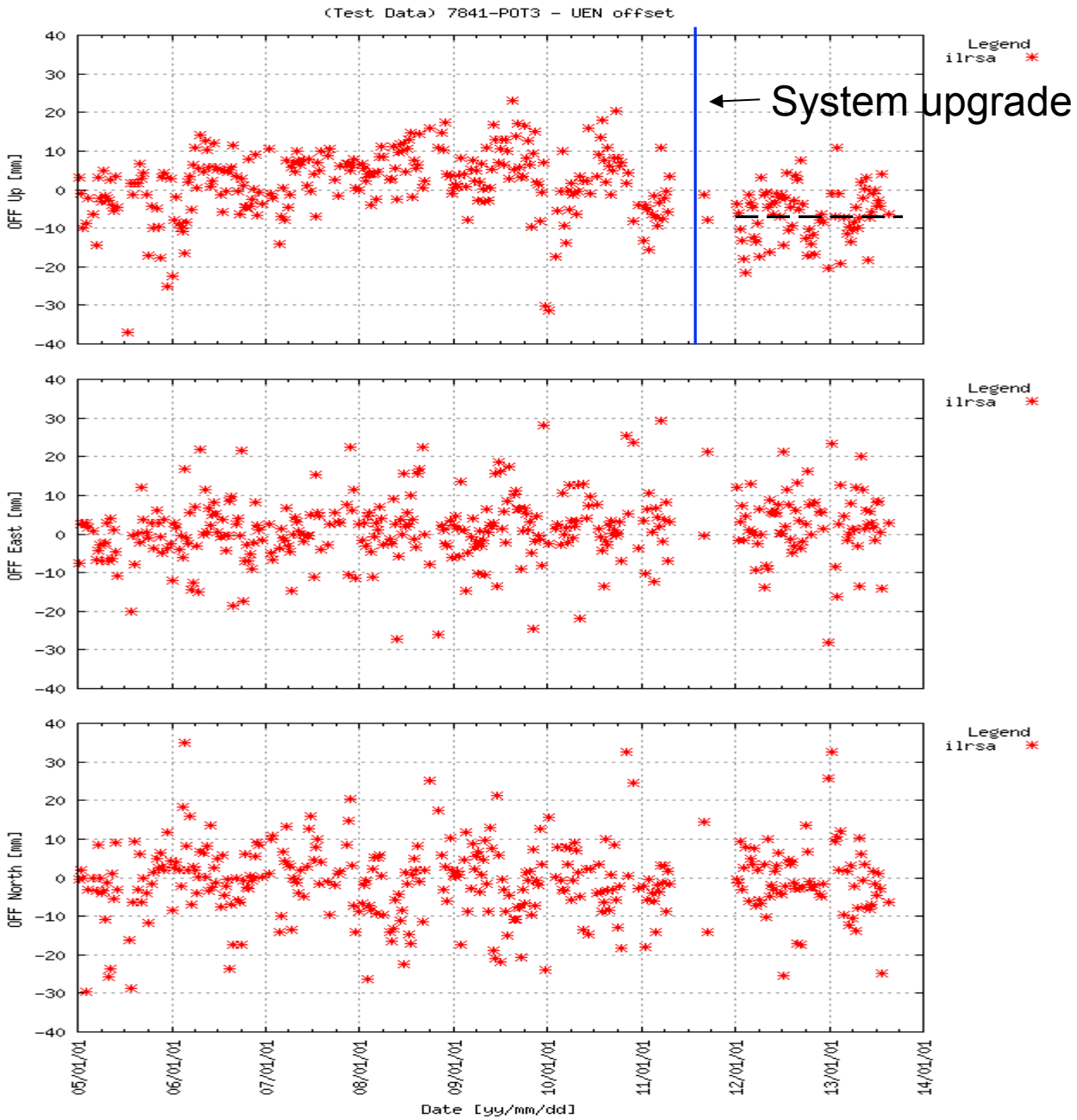
7237 : discontinuity



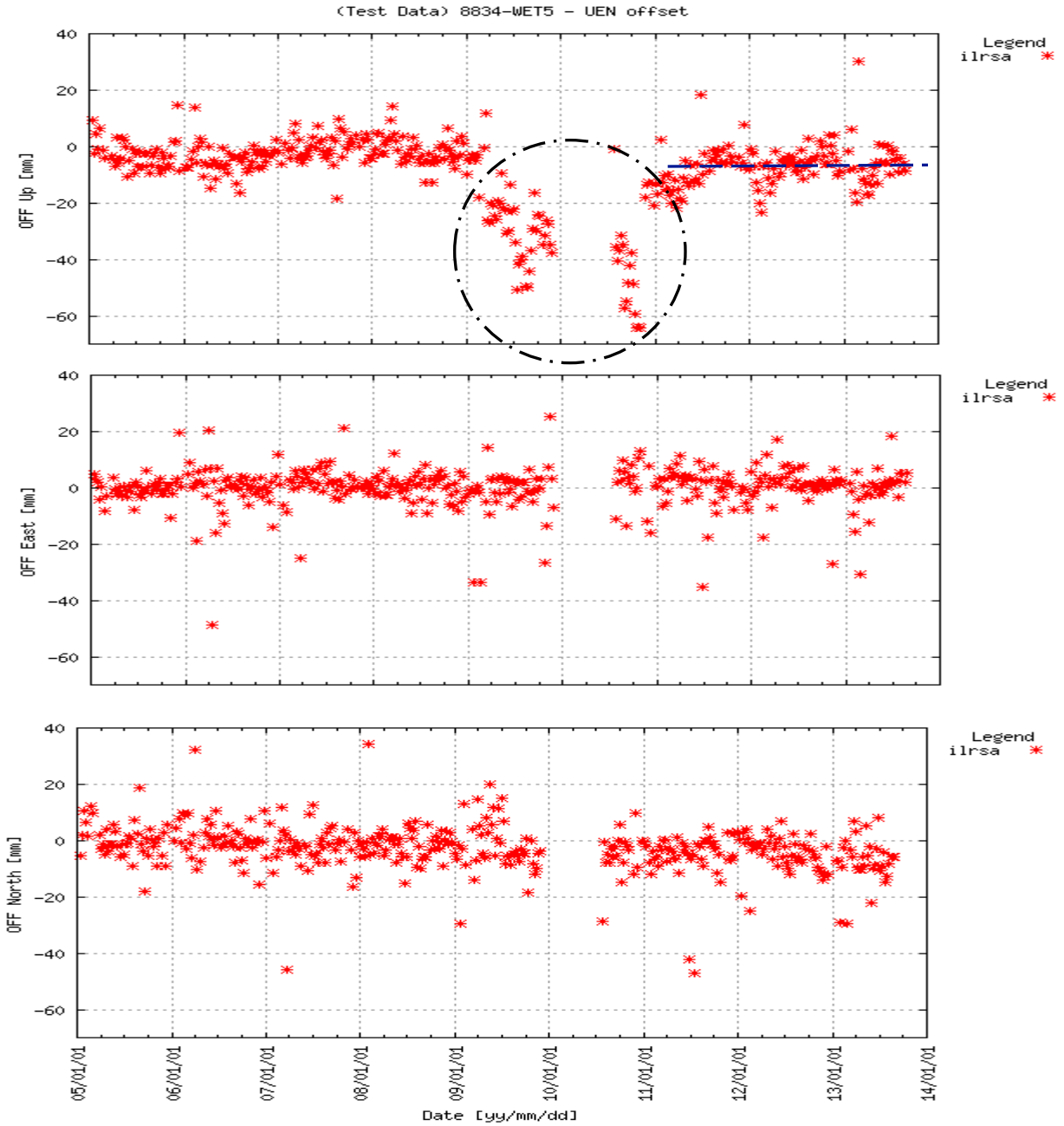
7825 : discontinuity



7841 : discontinuity



8834 : discontinuity



BKG ITRF REPRO with Bernese SW_SLR

Data from CDDIS and EDC

Never ending questions

/pub/slr/data/npt/allsat
4096 Jun 17 2004 1995
4096 Jun 17 2004 1996
4096 Jun 17 2004 1997
4096 Jun 17 2004 1998
4096 Jun 17 2004 1999
4096 Jun 17 2004 2000
4096 Oct 05 2009 2001
4096 Oct 05 2009 2002
4096 Oct 05 2009 2003
20480 Jan 17 2007 2004
4096 Mar 15 2006 2005
4096 Mar 19 2008 2006
4096 Mar 31 2010 2007
4096 Apr 06 2010 2008
20480 Apr 15 2010 2009
286720 Jan 03 2011 2010
307200 Dec 31 2011 2011
135168 Dec 31 2012 2012

dir=1995:
3776007 Jun 16 2004 allsat.9508.Z
7859624 Jun 16 2004 allsat.9509.Z
8711863 Jun 16 2004 allsat.9510.Z
3651267 Jun 16 2004 allsat.9511.Z
424333 Jun 16 2004 allsat.9512.Z

dir=1997:
1122449 Jun 16 2004 allsat.9701.Z
1320631 Jun 16 2004 allsat.9702.Z
1399662 Jun 16 2004 allsat.9703.Z
1738409 Jun 16 2004 allsat.9704.Z
1883931 Jun 16 2004 allsat.9705.Z
1716789 Jun 16 2004 allsat.9706.Z
1687022 Jun 16 2004 allsat.9708.Z
2246769 Jun 16 2004 allsat.9709.Z
1243149 Jun 16 2004 allsat.9711.Z
944185 Jun 16 2004 allsat.9712.Z

EDC
/pub/slr/data/npt/hy2a/2011
150023 Nov 15 2011 hy2a.201110
218361 Dec 01 2011 hy2a.201111
165958 Jan 02 2012 hy2a.201112

/pub/slr/data/npt/hy2a/2012
206062 Feb 01 2012 hy2a.201201
166689 Jul 07 2012 hy2a.201202
258618 Jul 07 2012 hy2a.201203
169134 Jul 07 2012 hy2a.201204
183980 Jun 01 2012 hy2a.201205
59001 Jul 02 2012 hy2a.201206
81246 Aug 01 2012 hy2a.201207
55465 Sep 02 2012 hy2a.201208
37889 Oct 02 2012 hy2a.201209
32842 Oct 31 2012 hy2a.201210
14668 Nov 30 2012 hy2a.201211
10432 Jan 01 2013 hy2a.201212

For ILRS work useful:

-Monthly files „allsat“
CDDIS ~EDC

-Daily files „allsat“
CDDIS~EDC

-Time delay for generating monthly allsat files ?

Important:
What files are of the same content daily at ?? o‘clock UTC?

ILRS Pilots with BERNESE SW

AIUB: supports by development of codes, introduction of new models, procedures, tests of new features (e.g. GGFC call, CoM_PP)

↓

BKG: update of BSW, get compiled & familiar with new procedures.

↓

Tailoring an adequate program running scheme for the ILRS_PP.
Necessary : Experiences with data, models, program scheme, update of program running scheme, develop needed tools for data compilation, quality checks, analysis etc.
READY for ILRS_PP -> working on solutions für ILRS_PP

It takes just more time to submit the required solutions.

ILRS Analysis Working Group Meeting, Potsdam, September 1, 2013

Report DGFI AC

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Products

- Delivered regularly daily v130
  - Problems with new stations (DGFI is not solving for biases, follows rules given in the data handling file), some other AC solve for biases
  - Editing of observation is differs to other centers, eventually harmonization or comparison of data editing, or at least edit criteria. For stations with only few observations this has big influence on the coordinates solved.

- Weekly products V40 and v35
  - Lageos and Etalon orbits for version v40 delivered in sp3 format, along track problem not yet solved.

- Contribution to pilot projects
  - Sinex and .cor files version 42 and 37 for CoM
  - Sinex files version 45 for ncep
  - Products delivered with DOGS-OC 5.0 extended
  - current version 5.2 includes non tidal atmospheric loading and station dep. CoM as standard.
  - DOGS-OC 5.2 follows IERS 2010 conventions,
  - Products use eigen6c2 gravity field and FES2004 ocean tides, estimation of low-degree SH of the gravity field is possible

Biases

Biases are critical especially for stations with poor station coordinates

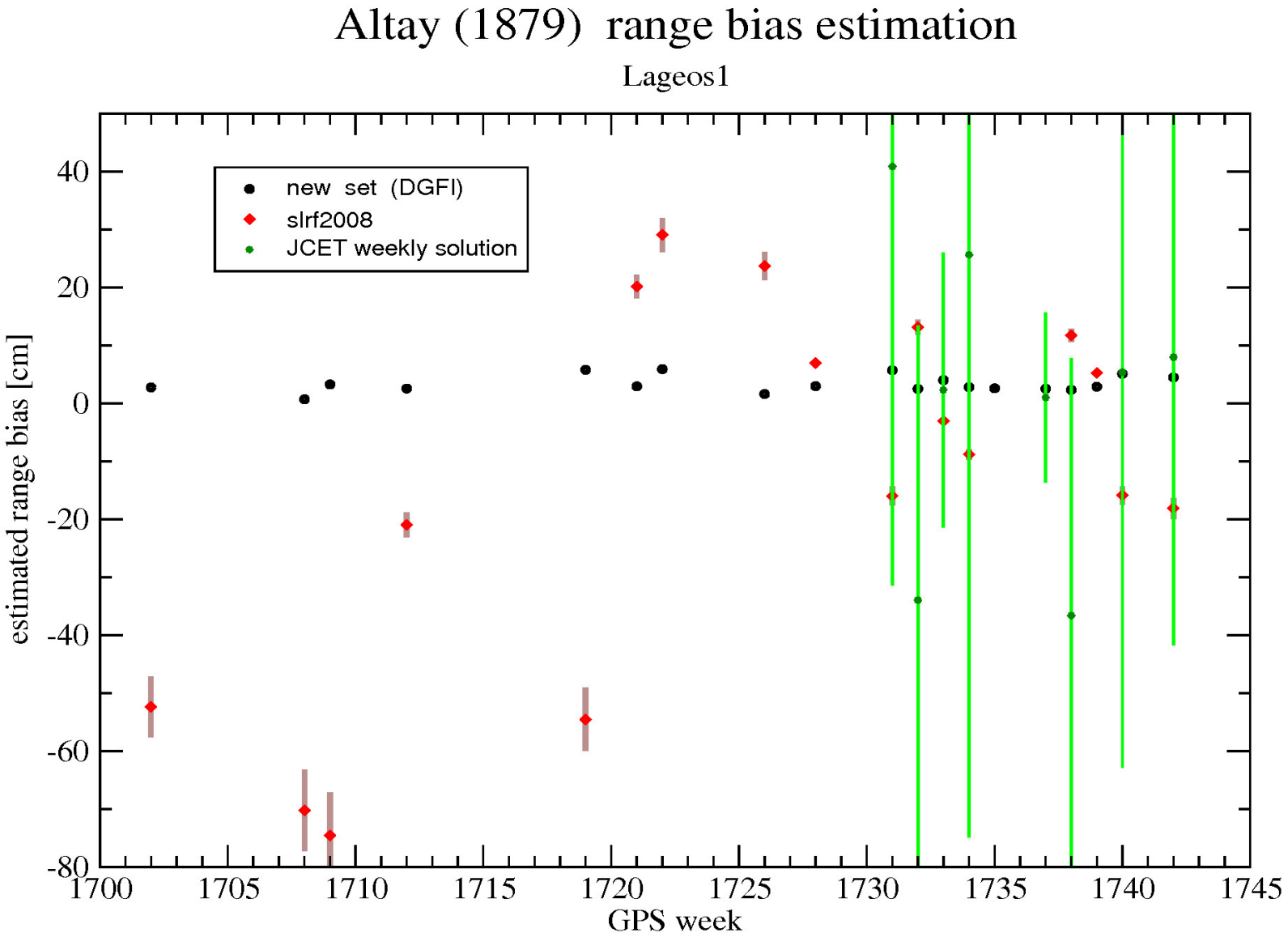
The following slides show as example Altay Mountains (1879) with bad SLRF2008 coordinates and velocities. In this example station coordinates and biases are solved simultaniously with the SLRF2008 coordinates resp. a new set of coordinates, computed by DGFI. The biases differ completely and are, with bad coordinates, useless. For comparison the biases reported by JCET in the weekly solution are included. For other stations the results is simlar but the difference depends on the quality of the SLRF2008 coordinates

The problem with can only be solved if all ACs use the same set bias parameters *and* the station coordinates are good enough. For a number of stations, either new or in tectonic regions, SLRF2008 needs an update.

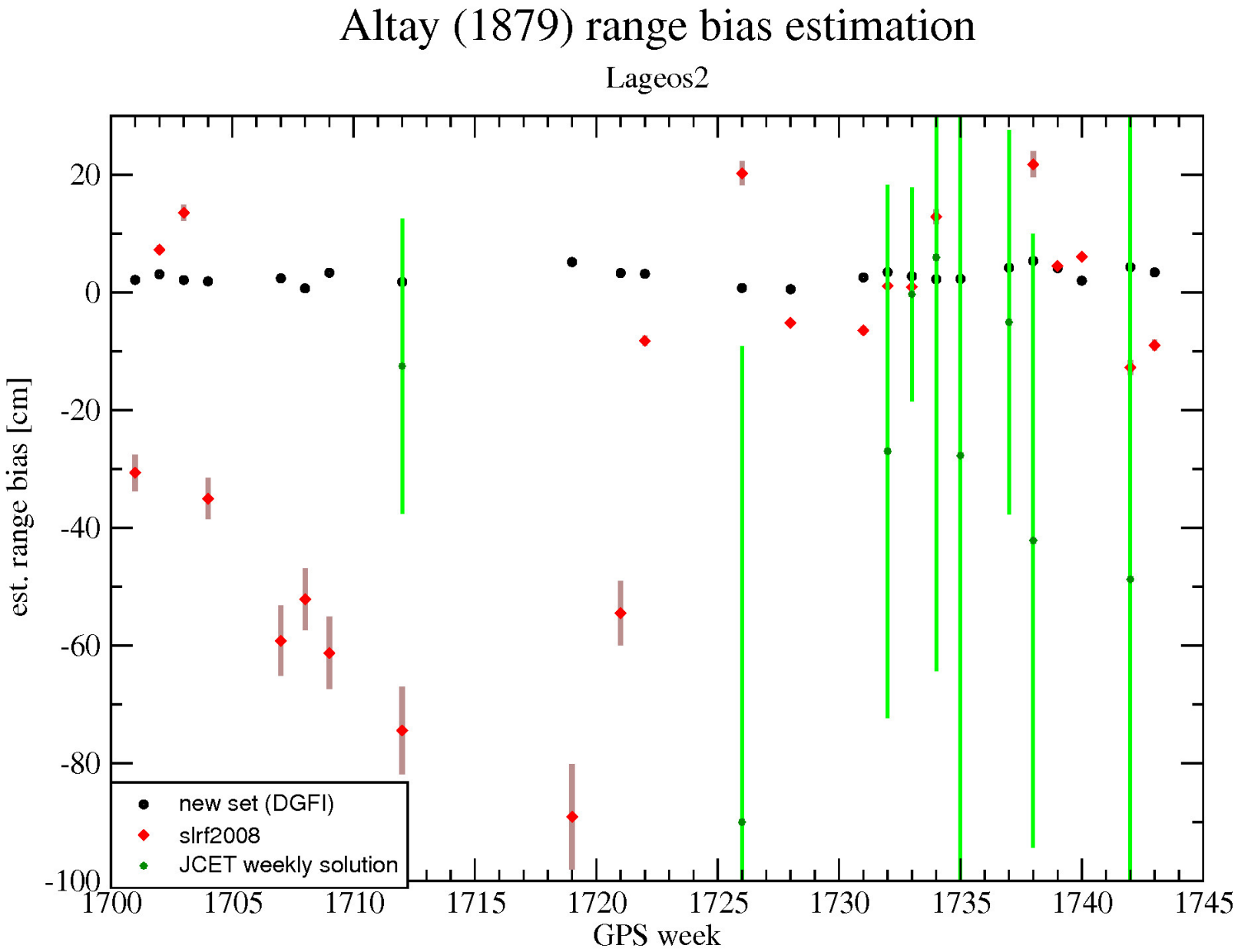
For harmonization all ACs should follow rules defined by the data handling file.

A new bias parameters as used for the combined solution, and for the ITRF2008 computaion, should be estimated with good coordinates (common bias for Lageos1 and Lageos2 ?)

Biases


Altay (1879) range bias estimation
Lageos1
new set (DGFI)
slrf2008
JCET weekly solution
estimated range bias [cm]
GPS week
40
20
0
-20
-40
-60
-80
1700
1705
1710
1715
1720
1725
1730
1735
1740
1745

Biases


Altay (1879) range bias estimation
Lageos2
est. range bias [cm]
GPS week
20
0
-20
-40
-60
-80
-100
1700
1705
1710
1715
1720
1725
1730
1735
1740
1745
new set (DGFI)
slrf2008
JCET weekly solution

ILRS Data Handling File

The ILRS data handling file maintained at DGFI should be mandatory for all ACs, to have a homogeneous product. But the files needs some updates and addenda.

- New flag **Q** for stations in quarantine
- New flag **N** for „not reliable“ stations, like Simeiz (1873) or San Juan (7406), which should not be used for standard products but can be used for other analysis
- New flag **P** for stations with only preliminary coordinates, for these stations it is not recommended to solve for biases and they should not be used in the official products until a coordinate update is possible.

At the moment San Juan, Simeiz and Kunming(7820) seems to have problems with the data they deliver. Kunming is in quarantine but Simeiz and San Juan should not be used.

The bias values listed in the file need a revision for the ILRS contribution to ITRF2013.

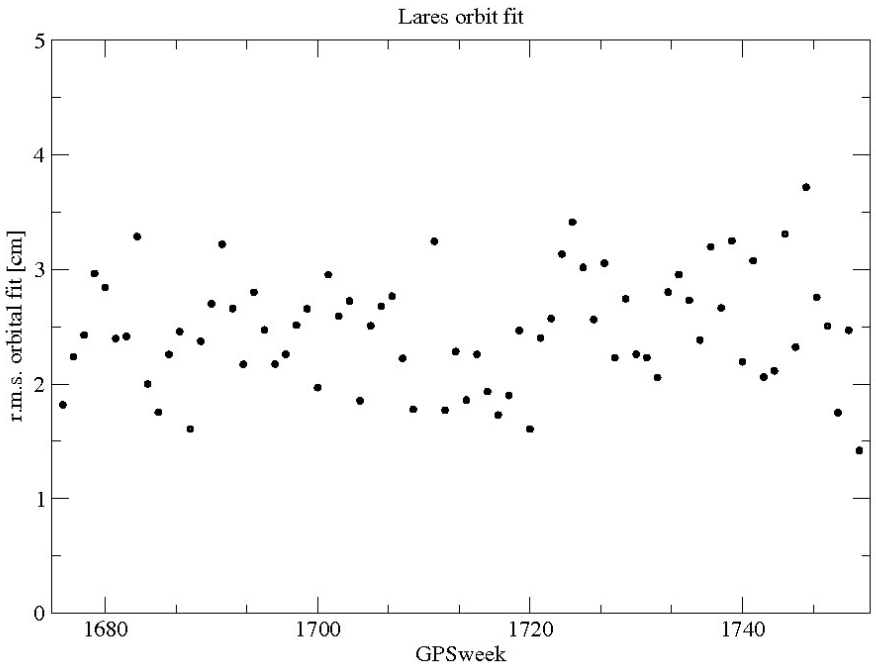
LARES

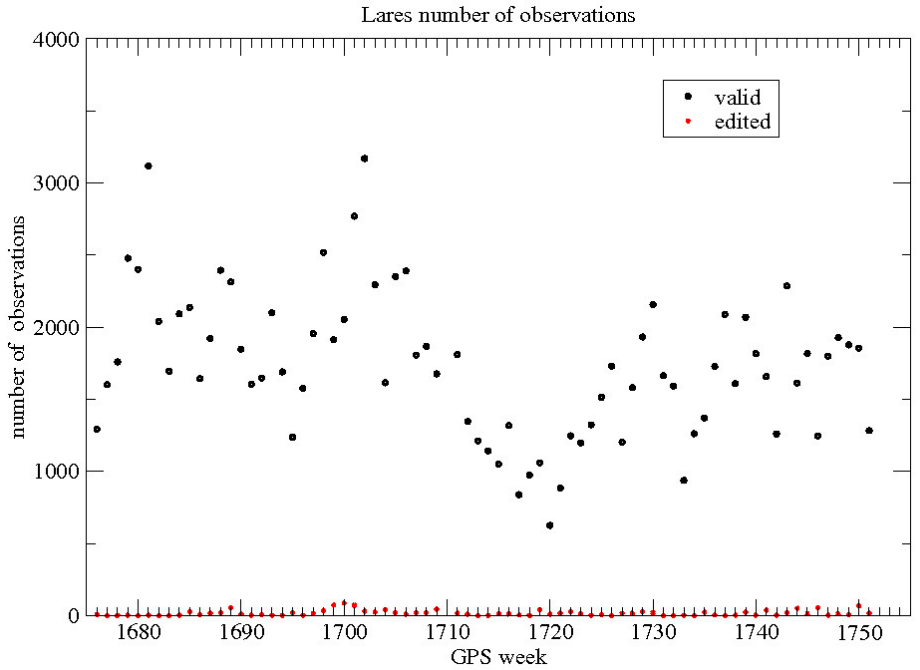
Lares, launched Feb. 2012 is a good target to improve the quality of the ILRS products

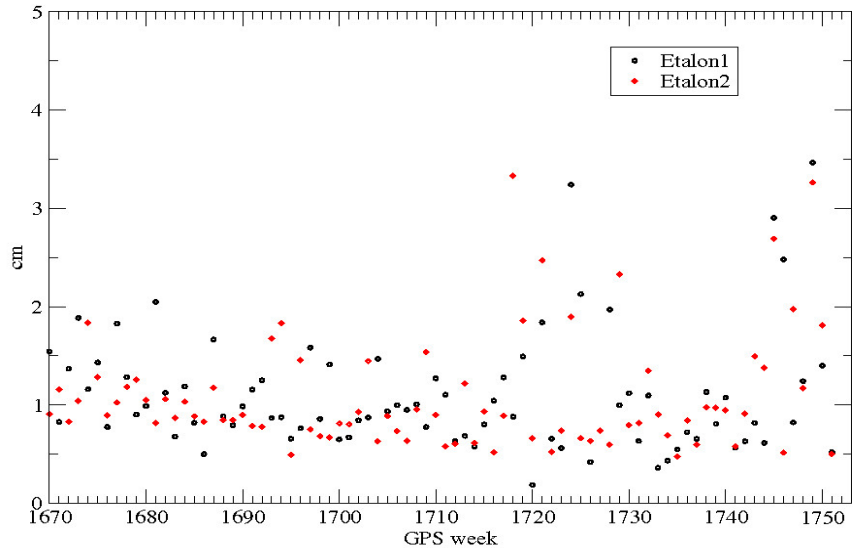
- Heavy satellite > small a/m value
- No need to model drag force of the high atmosphere, simple empirical force is suffcient
- Low enough to solve for low degree harmonics
- Good number of observation, mean 1750 per week, sometime > 2000, and more than lageos1
- Good orbital fit ~ 2.5 cm without solving for spherical harmonic coefficients (see graph)

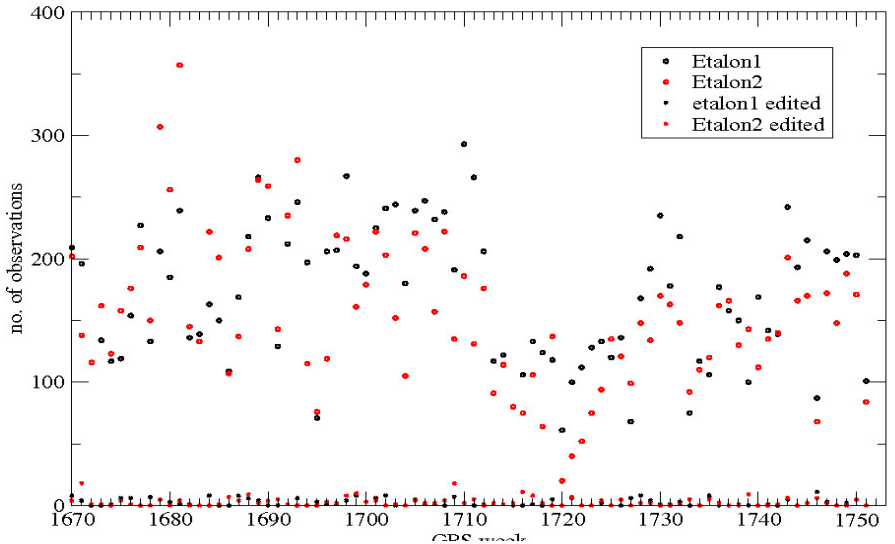
Etalon1/2 have a decreasing number of observations ~200 Etalon1 and ~150 Etalon2 presently. Sometimes < 100 observations/week. This does not allow a good and reliable orbit computation. (see graph)
Either we get more etalon observations or we should remove Etalon from the satellites used for the ILRS products.

LARES vs. Etalon



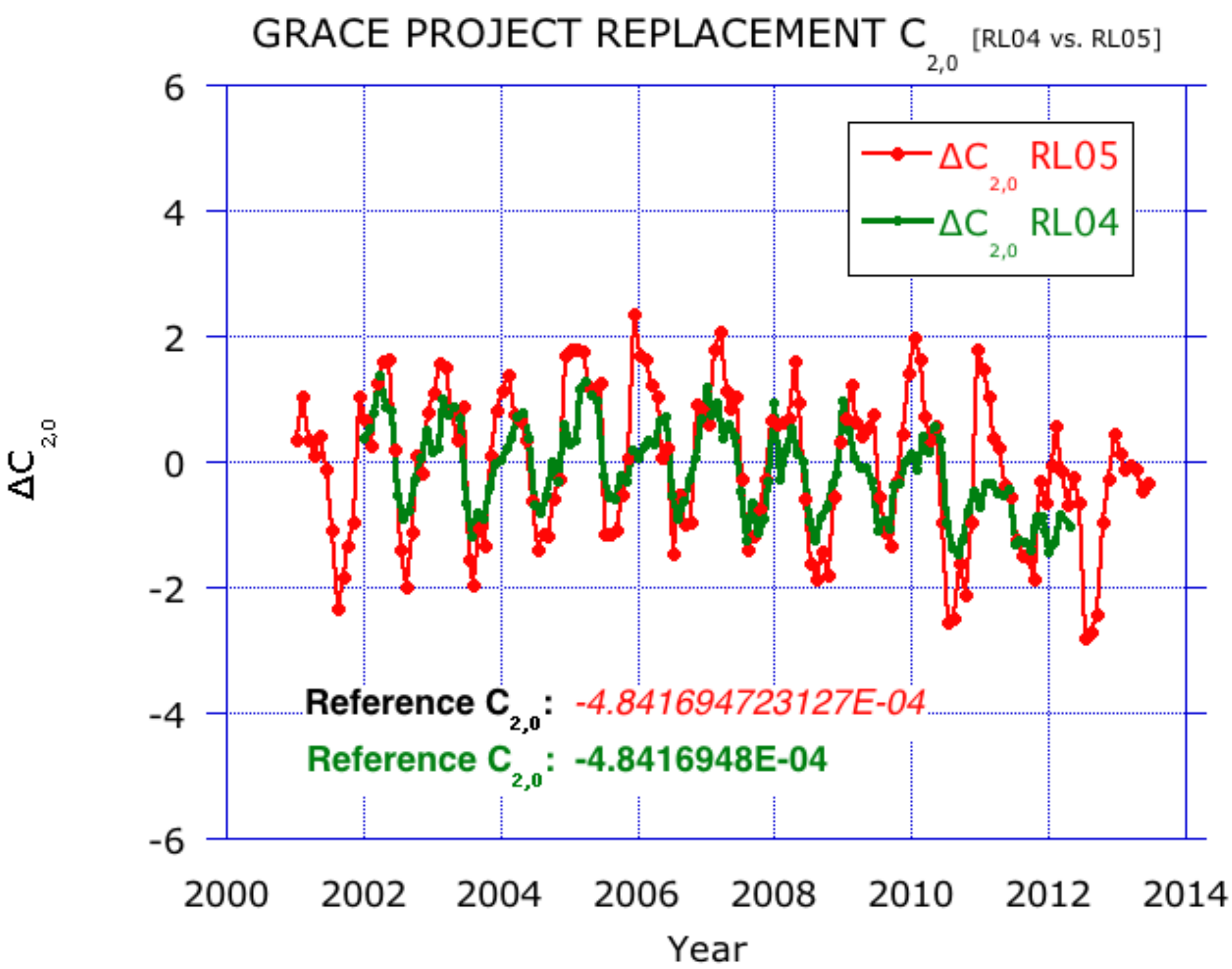




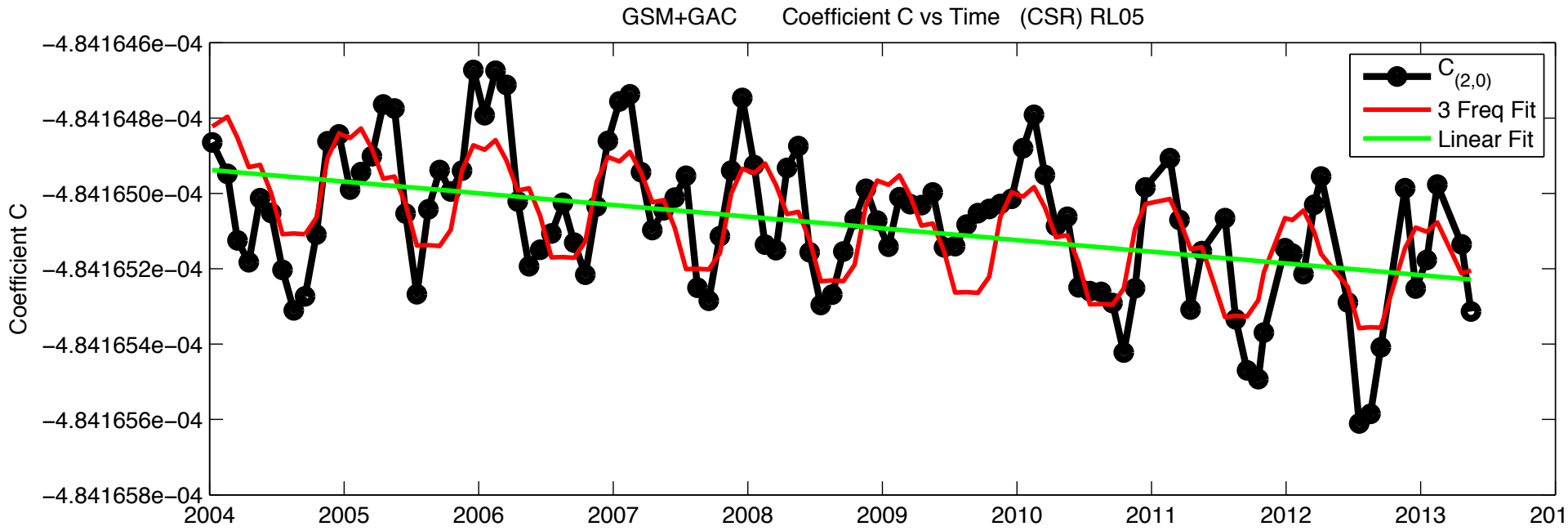


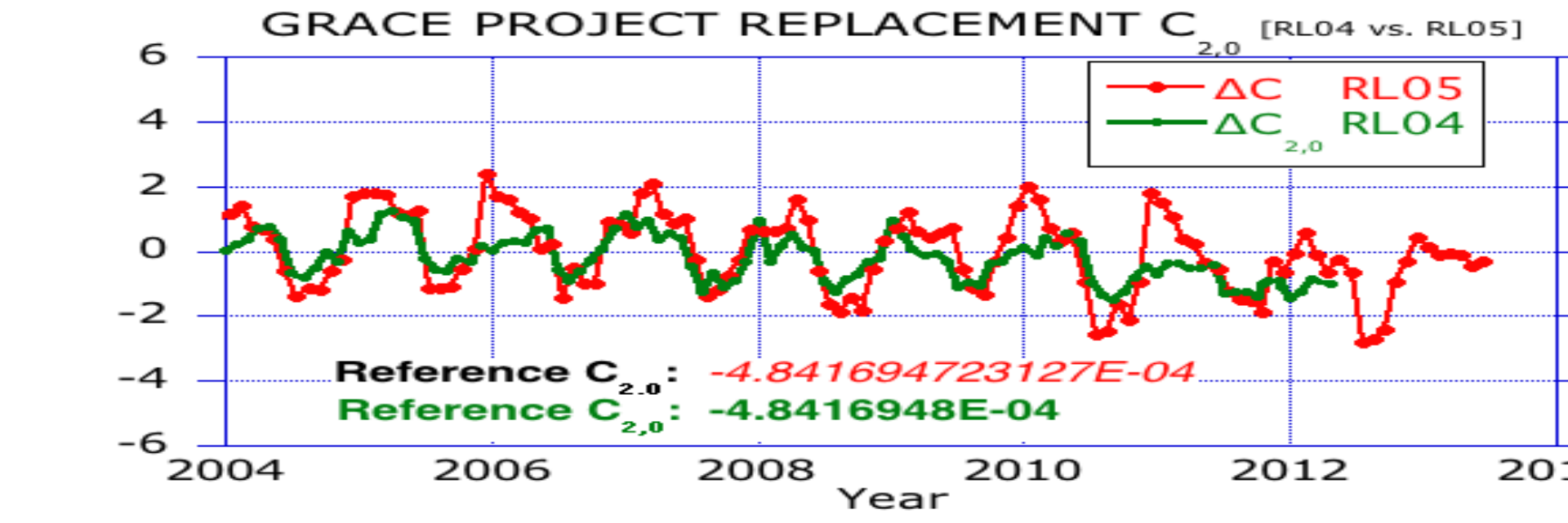
ILRS AWG Fall 2013

JCET AC/CC

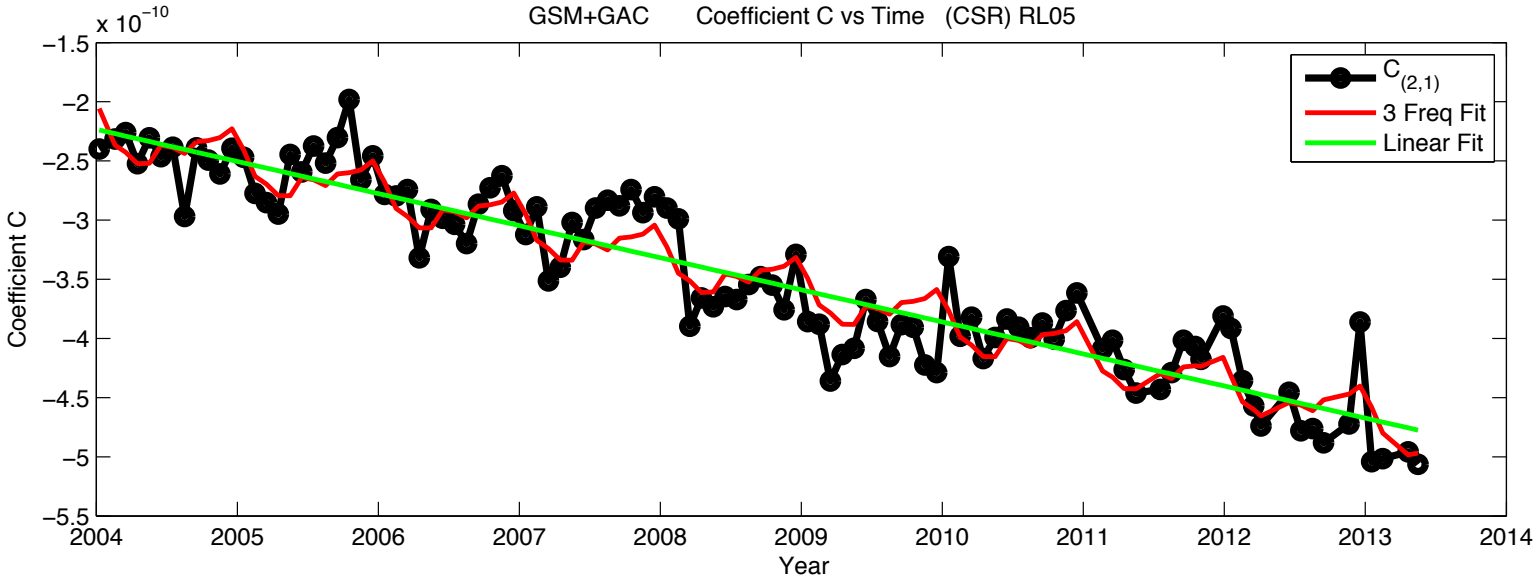

GRACE PROJECT REPLACEMENT C2,0 [RL04 vs. RL05]
ΔC2,0 RL05
ΔC2,0 RL04
ΔC2,0
6
4
2
0
-2
-4
-6
2000
2002
2004
2006
2008
2010
2012
2014
Year
Reference C2,0: -4.841694723127E-04
Reference C2,0: -4.8416948E-04

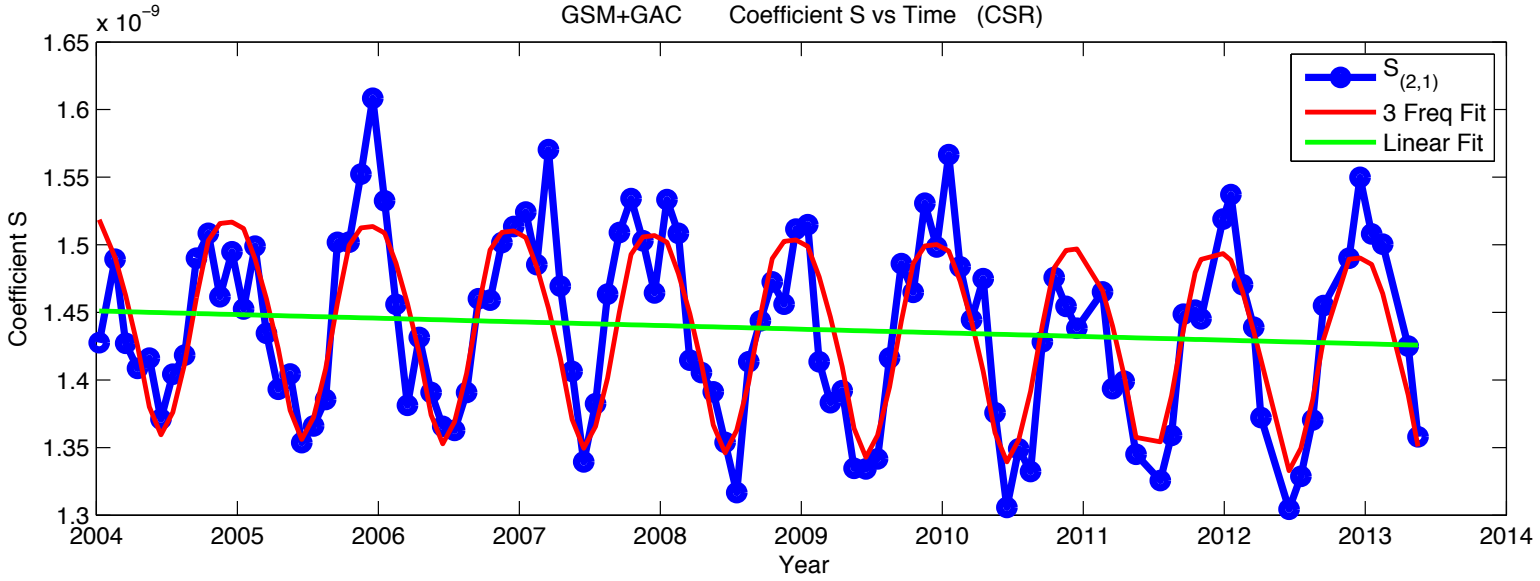
GRACE(CSR RL05) $C_{2,0}$ + AOD1B (avg)



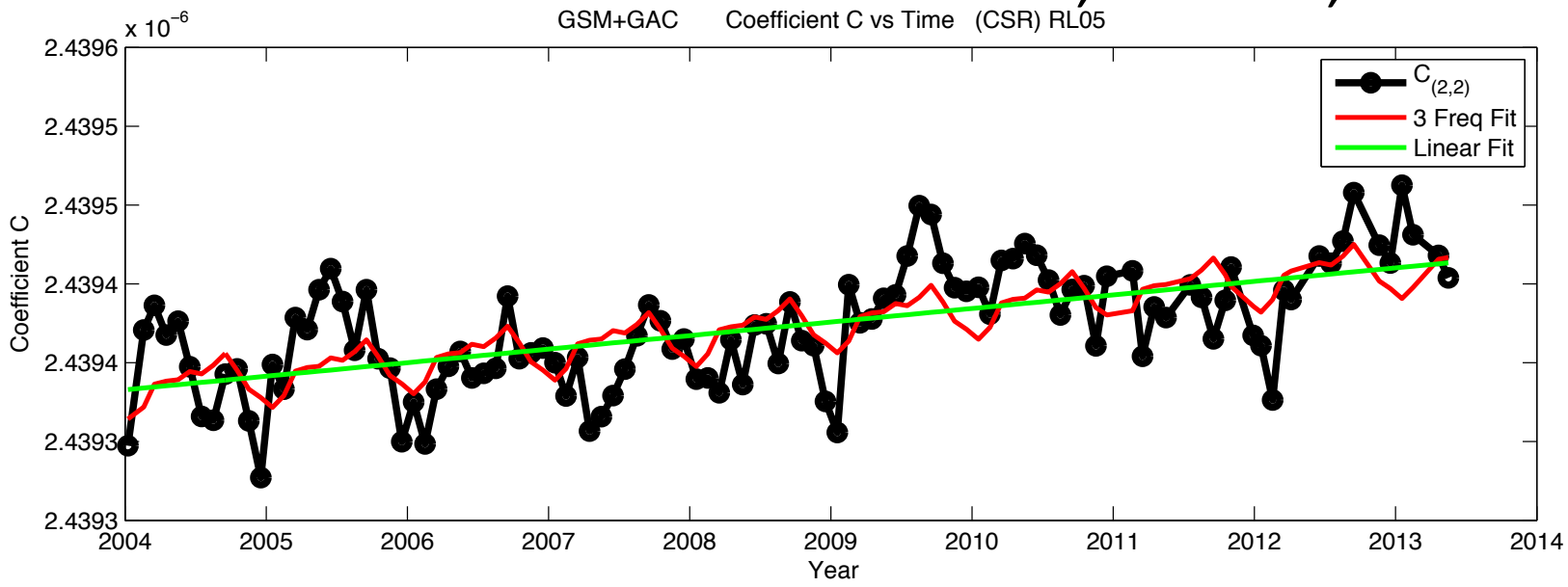


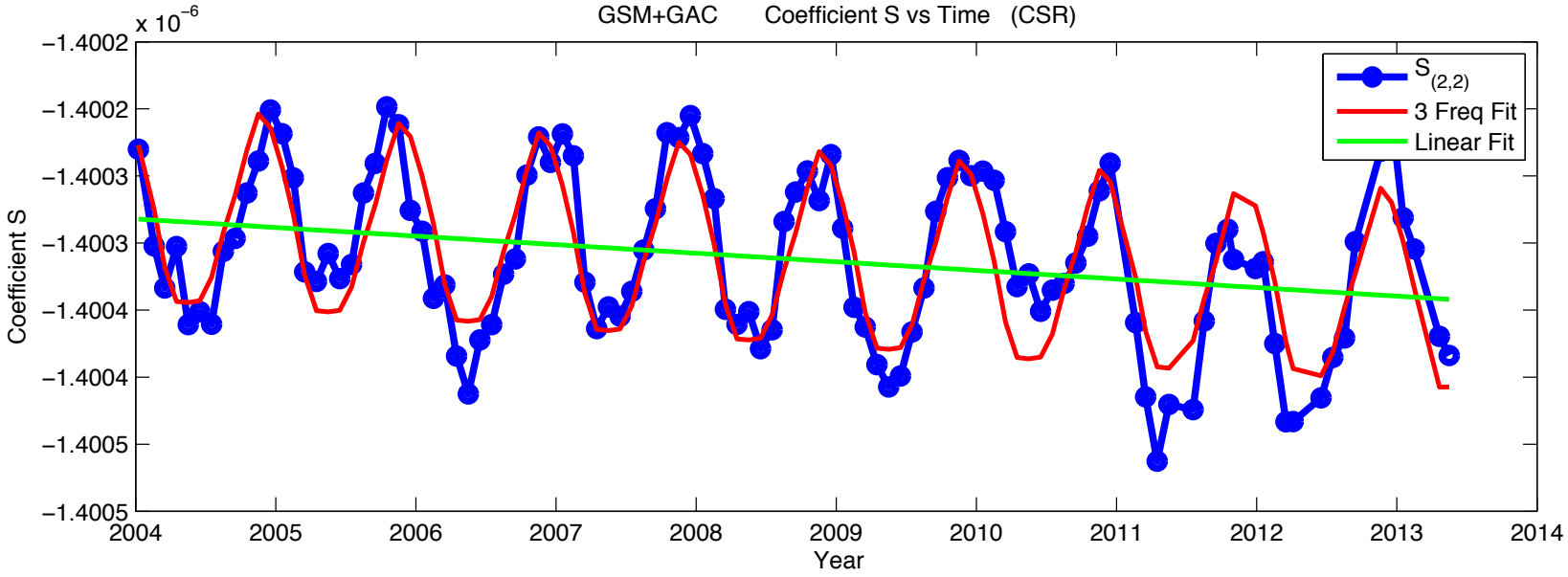
GRACE (CSR RL05) $C_{2,1}$ & $S_{2,1}$





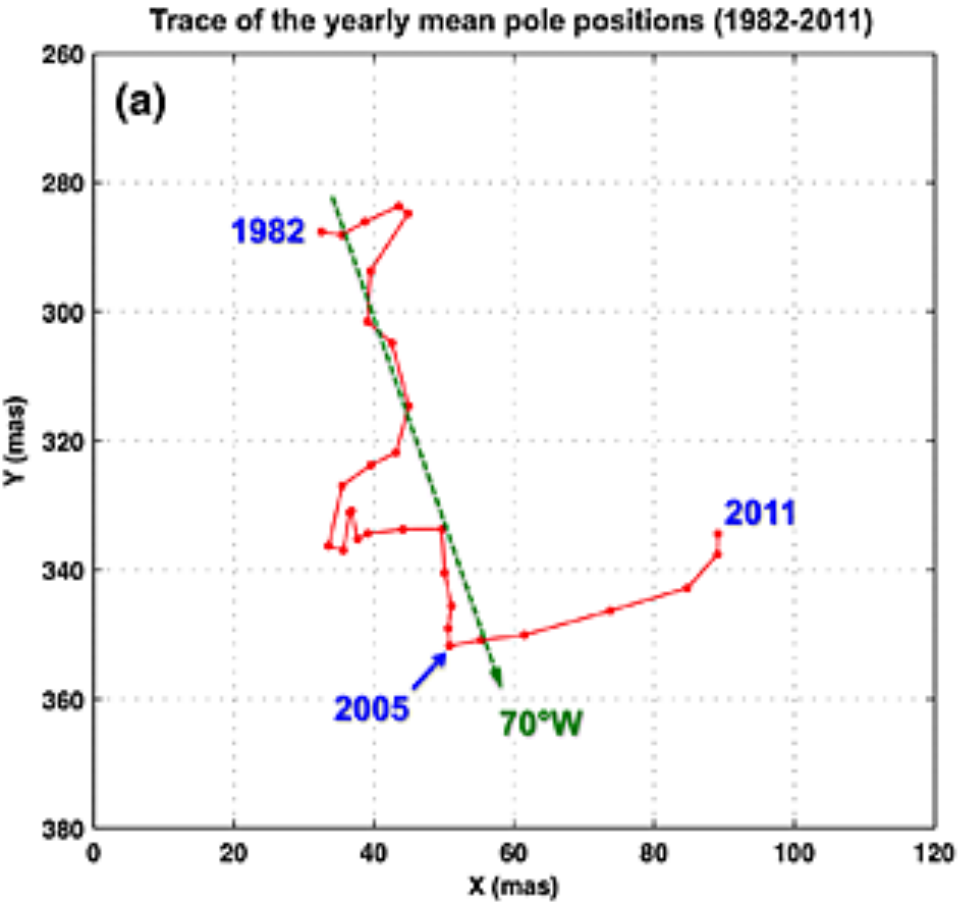
GRACE (CSR RL05) $C_{2,2}$ & $S_{2,2}$

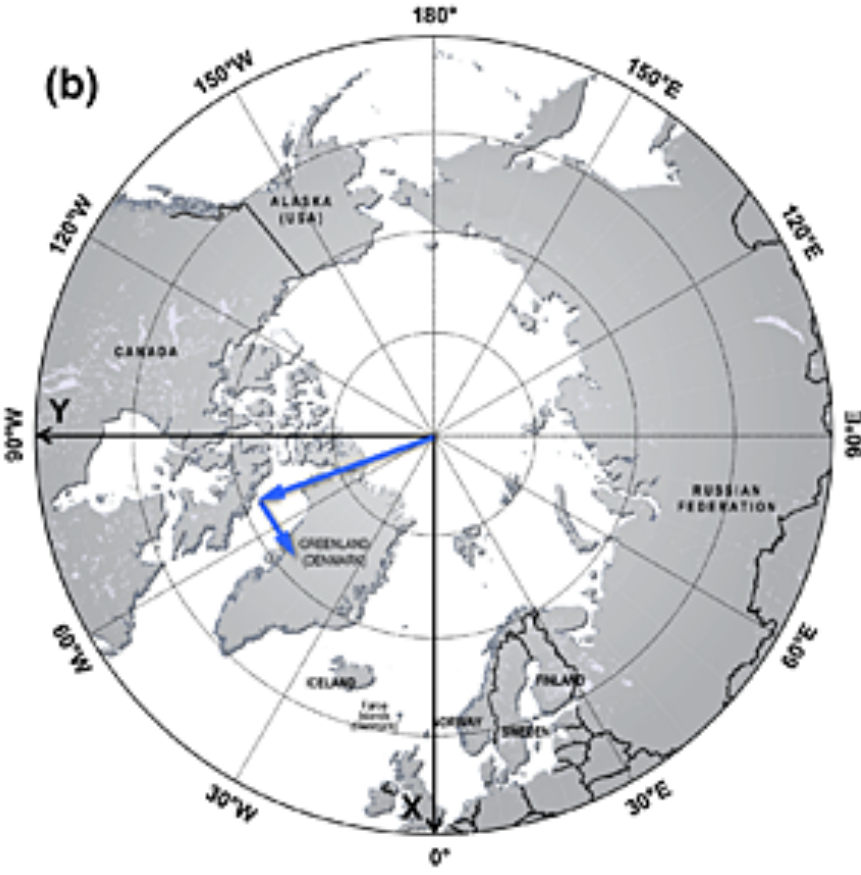


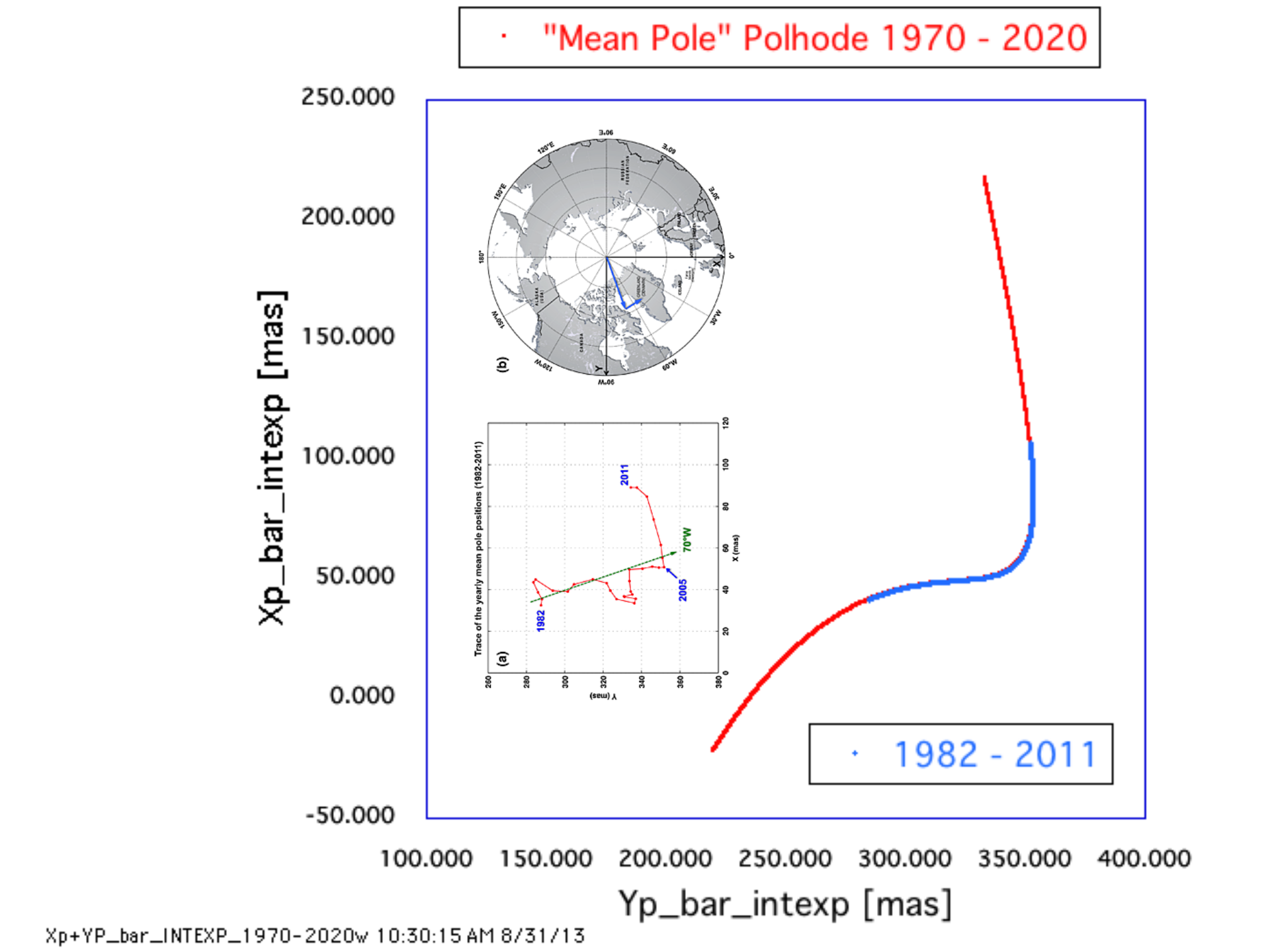


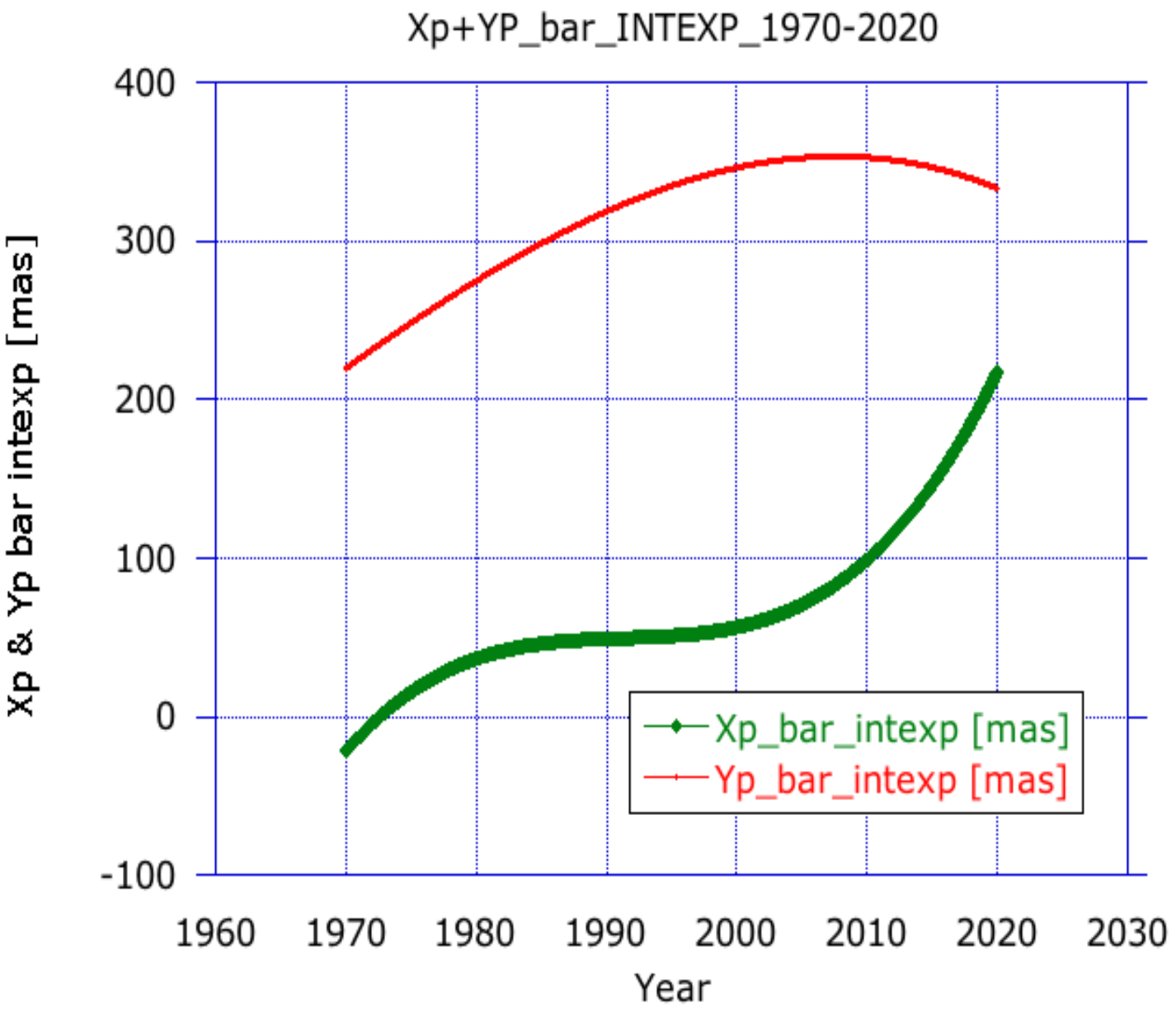
Rapid ice melting drives Earth's pole to the east

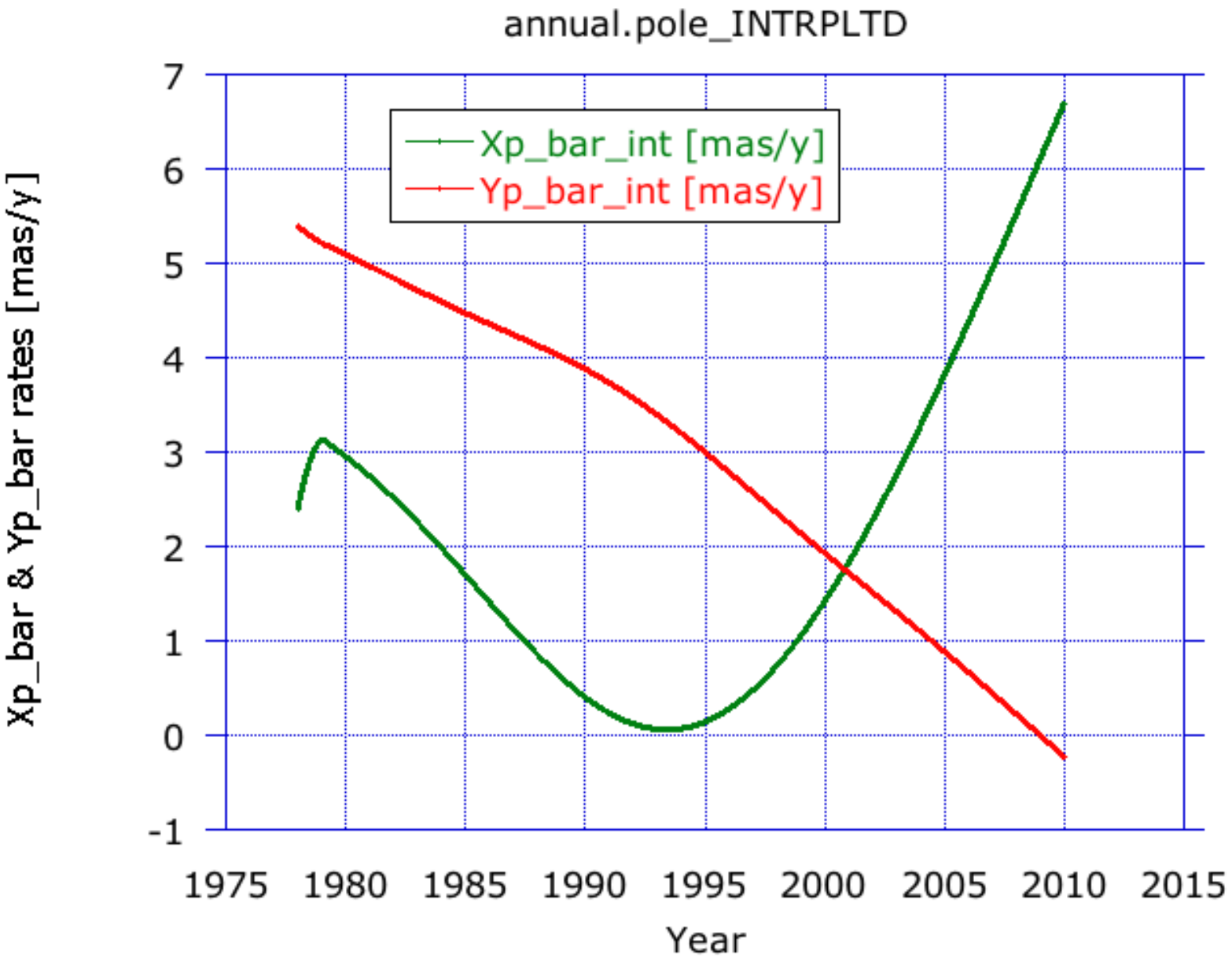
J. L. Chen[1,*], C. R. Wilson[1,2], J. C. Ries[1], B. D. Tapley[1]






"Mean Pole" Polhode 1970 - 2020
1982 - 2011
Xp_bar_intexp [mas]
Yp_bar_intexp [mas]
250.000
200.000
150.000
100.000
50.000
0.000
-50.000
100.000
150.000
200.000
250.000
300.000
350.000
400.000
(a)
(b)
Trace of the yearly mean pole positions (1982-2011)
1982
2011
2005
70°W
X (mas)
Y (mas)
Xp+YP_bar_INTEXP_1970-2020w 10:30:15 AM 8/31/13


Xp+YP_bar_INTEXP_1970-2020
Xp & Yp bar intexp [mas]
400
300
200
100
0
-100
1960
1970
1980
1990
2000
2010
2020
2030
Year
Xp_bar_intexp [mas]
Yp_bar_intexp [mas]

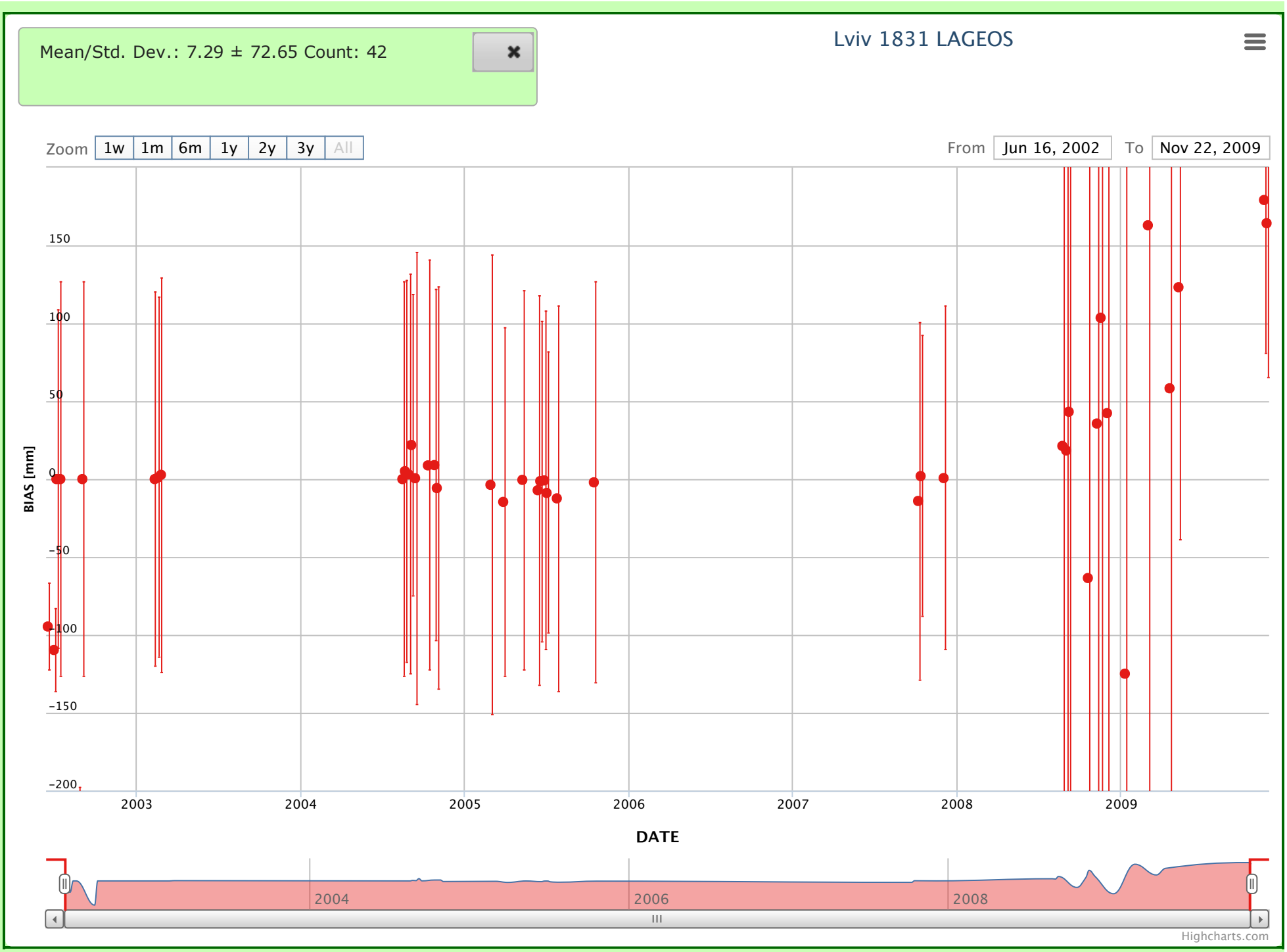

annual.pole_INTRPLTD
Xp_bar_int [mas/y]
Yp_bar_int [mas/y]
Xp_bar & Yp_bar rates [mas/y]
Year
7
6
5
4
3
2
1
0
-1
1975
1980
1985
1990
1995
2000
2005
2010
2015

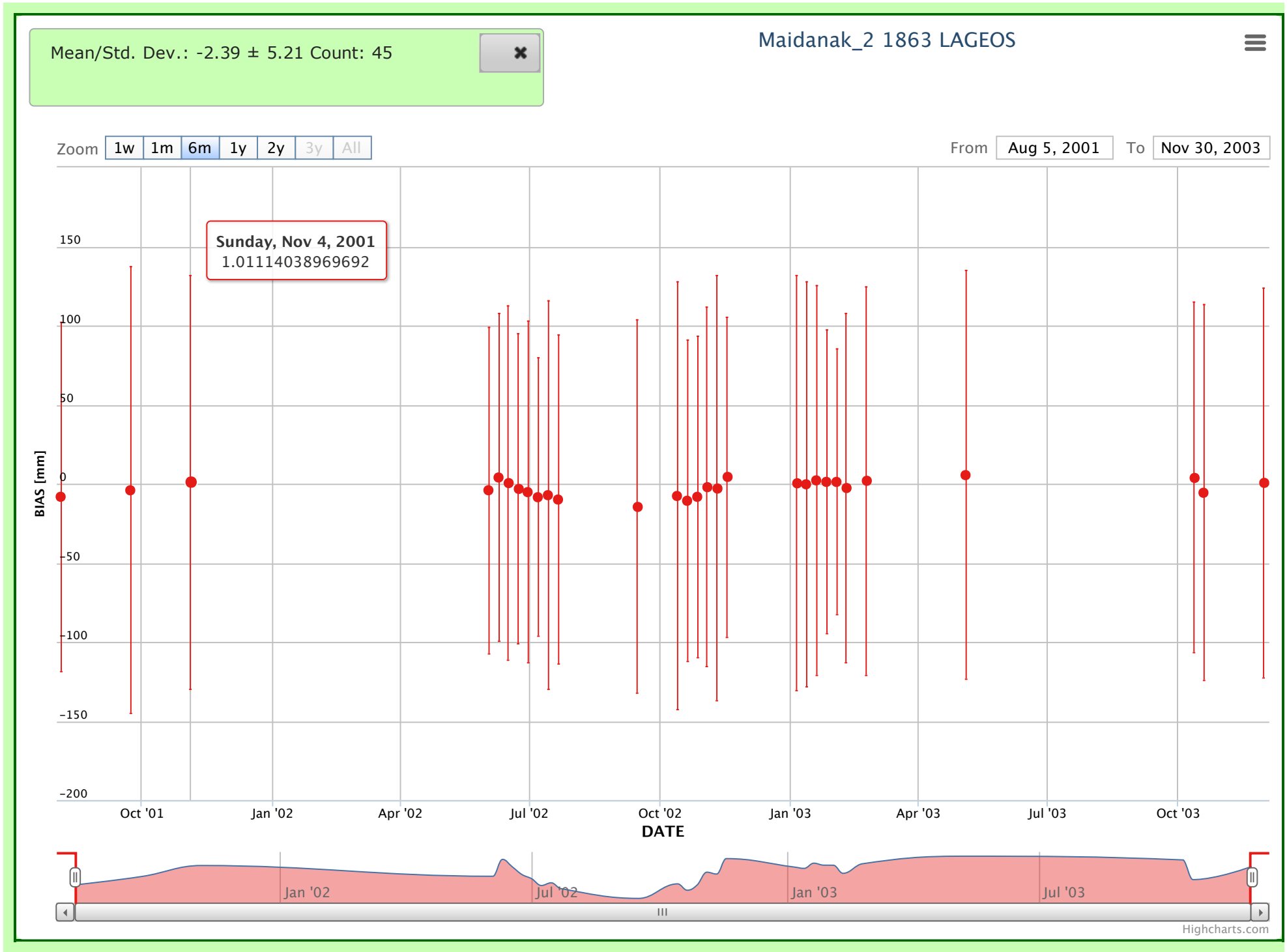
LATEST GRAVITATIONAL MODELS

Model	Year	Degree	Data	Reference	download
ULux_CHAMP2013s	2013	120	S(Champ)	Weigelt et al, 2013	♦zip♦
ITG-Goce02	2013	240	S(Goce)	Schall et al, 2013	♦zip♦
GO_CONS_GCF_2_TIM_R4	2013	250	S(Goce)	Pail et al, 2011	♦zip♦
GO_CONS_GCF_2_DIR_R4	2013	260	S(Goce,Grace,Lageos)	Bruinsma et al, 2013	♦zip♦
EIGEN-6C2	2012	1949	S(Goce,Grace,Lageos),G,A	Förste et al, 2012	♦zip♦
DGM-1S	2012	250	S(Goce,Grace)	Hashemi Farahani, et al. 2012	♦zip♦
GOCO03S	2012	250	S(Goce,Grace,...)	Mayer-Gürr, et al. 2012	♦zip♦
GO_CONS_GCF_2_DIR_R3	2011	240	S(Goce,Grace,Lageos)	Bruinsma et al, 2010	♦zip♦
GO_CONS_GCF_2_TIM_R3	2011	250	S(Goce)	Pail et al, 2011	♦zip♦
GIF48	2011	360	S(Grace),G,A	Ries te al, 2011	♦zip♦
EIGEN-6C	2011	1420	S(Goce,Grace,Lageos),G,A	Förste et al, 2011	♦zip♦
EIGEN-6S	2011	240	S(Goce,Grace,Lageos)	Förste et al, 2011	♦zip♦
GOCO02S	2011	250	S(Goce,Grace,...)	Goiginger et al, 2011	♦zip♦
AIUB-GRACE03S	2011	160	S(Grace)	Jäggi et al, 2011	♦zip♦
GO_CONS_GCF_2_DIR_R2	2011	240	S(Goce)	Bruinsma et al, 2010	♦zip♦
GO_CONS_GCF_2_TIM_R2	2011	250	S(Goce)	Pail et al, 2011	♦zip♦
GO_CONS_GCF_2_SPW_R2	2011	240	S(Goce)	Migliaccio et al, 2011	♦zip♦
GO_CONS_GCF_2_DIR_R1	2010	240	S(Goce)	Bruinsma et al, 2010	♦zip♦
GO_CONS_GCF_2_TIM_R1	2010	224	S(Goce)	Pail et al, 2010a	♦zip♦
GO_CONS_GCF_2_SPW_R1	2010	210	S(Goce)	Migliaccio et al, 2010	♦zip♦
GOCO01S	2010	224	S(Goce,Grace)	Pail et al, 2010b	♦zip♦
EIGEN-51C	2010	359	S(Grace,Champ),G,A	Bruinsma et al, 2010	♦zip♦
AIUB-CHAMP03S	2010	100	S(Champ)	Prange, 2011	♦zip♦
EIGEN-CHAMP05S	2010	150	S(Champ)	Flechtner et al, 2010	♦zip♦
ITG-Grace2010s	2010	180	S(Grace)	Mayer-Gürr et al, 2010	♦zip♦
AIUB-GRACE02S	2009	150	S(Grace)	Jäggi et al, 2009	♦zip♦
GGM03C	2009	360	S(Grace),G,A	Tapley et al, 2007	♦zip♦

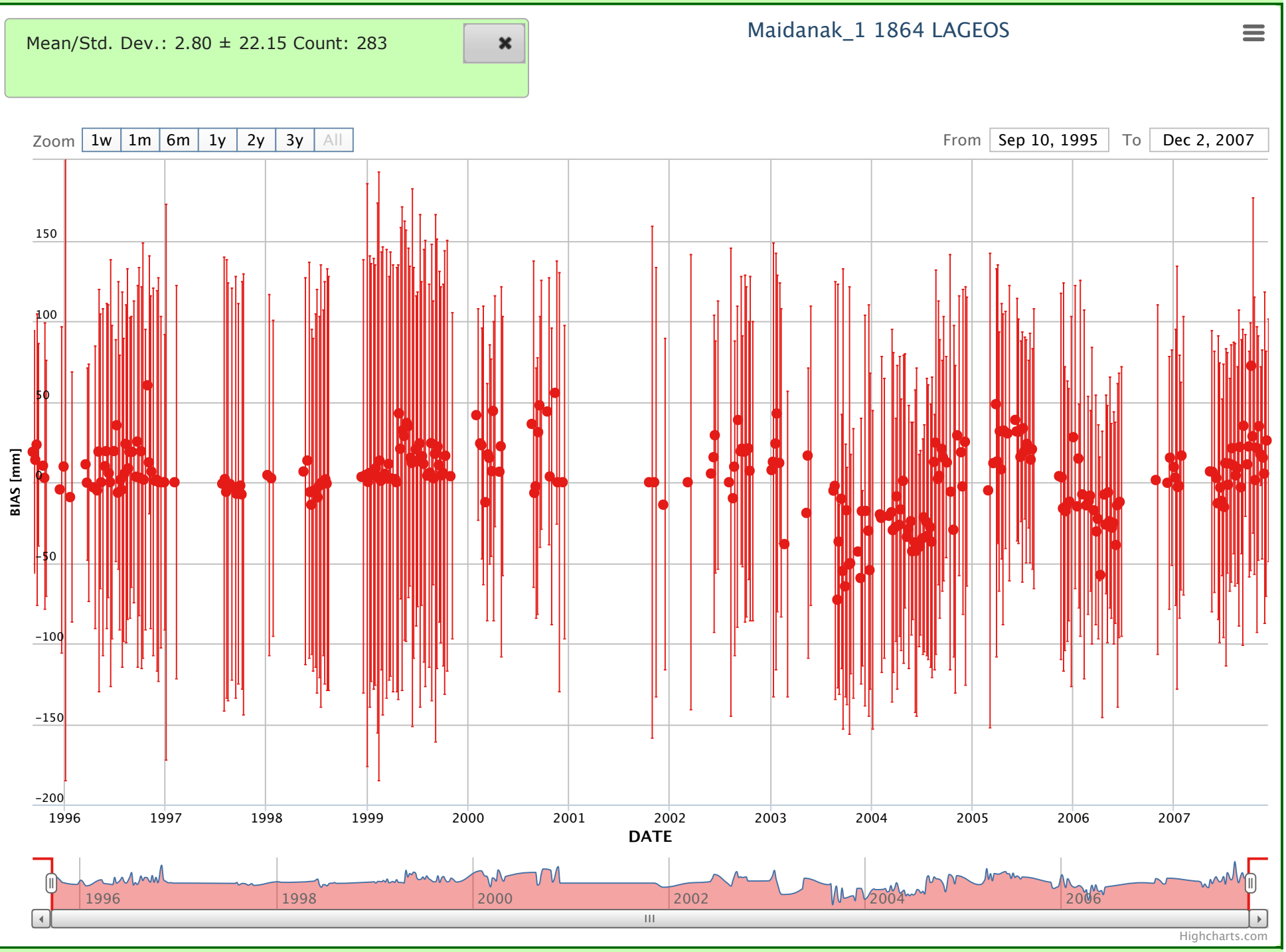
Ocean Loading for SLR Sites

- GSFC's GOT4.7 tide model used
- Preliminary file can be downloaded from:
  - http://geodesy.jcet.umbc.edu/ALL_SLR_SITES_OLOAD.iers
- Need to be checked for completeness, remove any duplicates, etc. (assembled from multiple files generated over years).
- Same info available in Geodyn format also

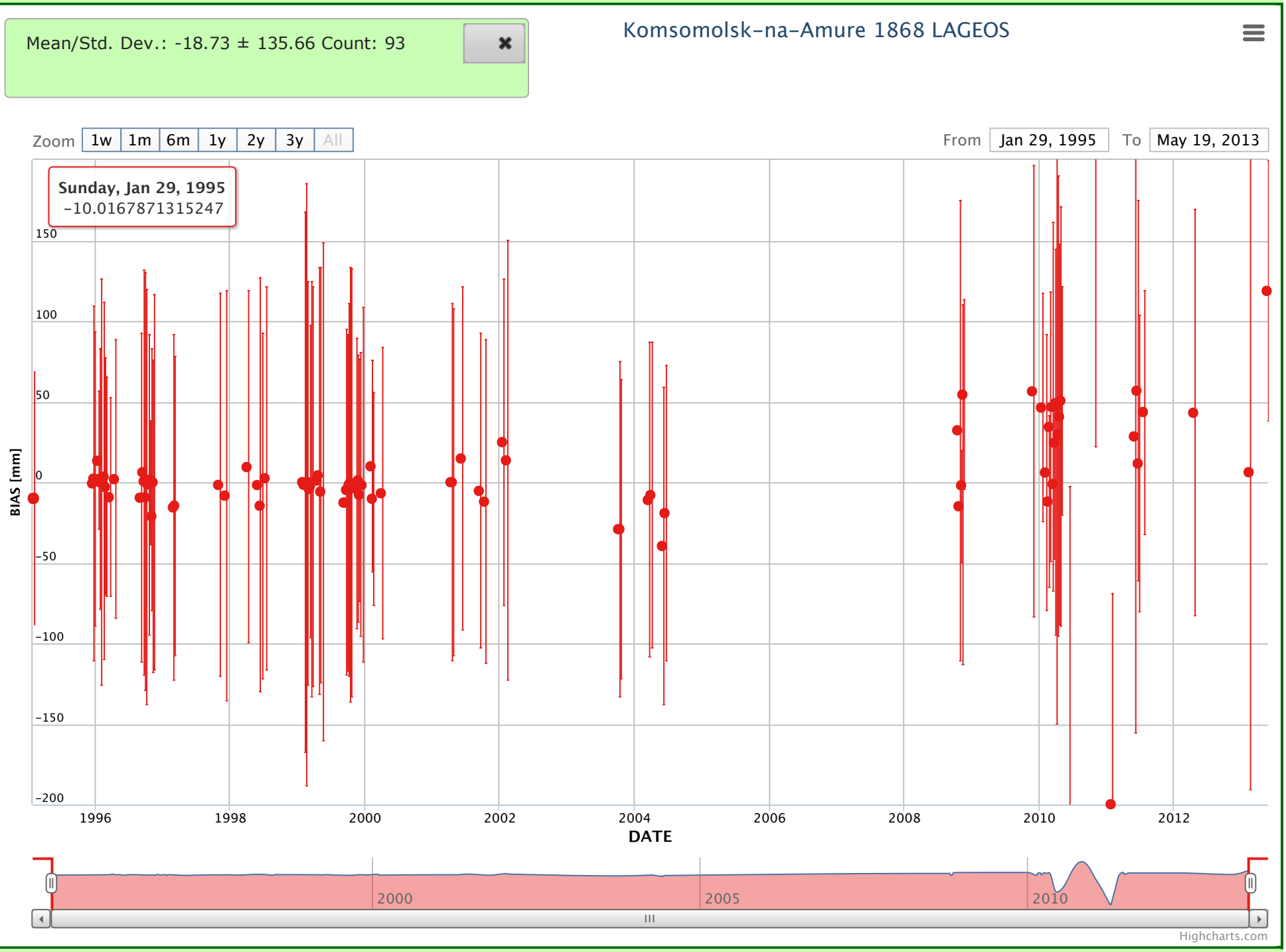

Mean/Std. Dev.: 7.29 ± 72.65 Count: 42
Lviv 1831 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jun 16, 2002 To Nov 22, 2009
150
100
50
0
-50
-100
-150
-200
BIAS [mm]
2003
2004
2005
2006
2007
2008
2009
DATE
2004
2006
2008
Highcharts.com

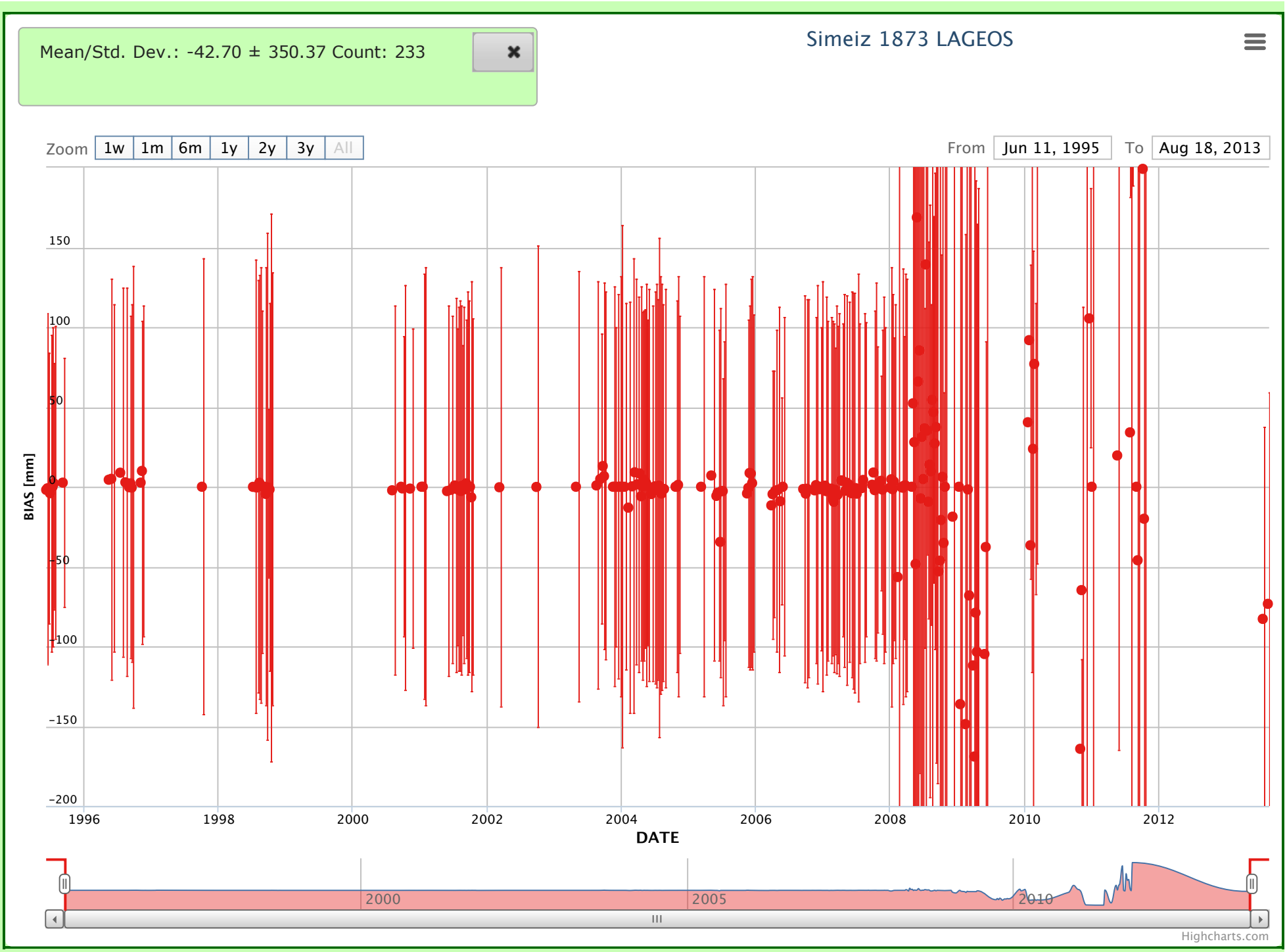

Mean/Std. Dev.: -2.39 ± 5.21 Count: 45
Maidanak_2 1863 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Aug 5, 2001 To Nov 30, 2003
Sunday, Nov 4, 2001
1.01114038969692
150
100
50
0
-50
-100
-150
-200
BIAS [mm]
Oct '01
Jan '02
Apr '02
Jul '02
Oct '02
Jan '03
Apr '03
Jul '03
Oct '03
DATE
Jan '02
Jul '02
Jan '03
Jul '03
Highcharts.com

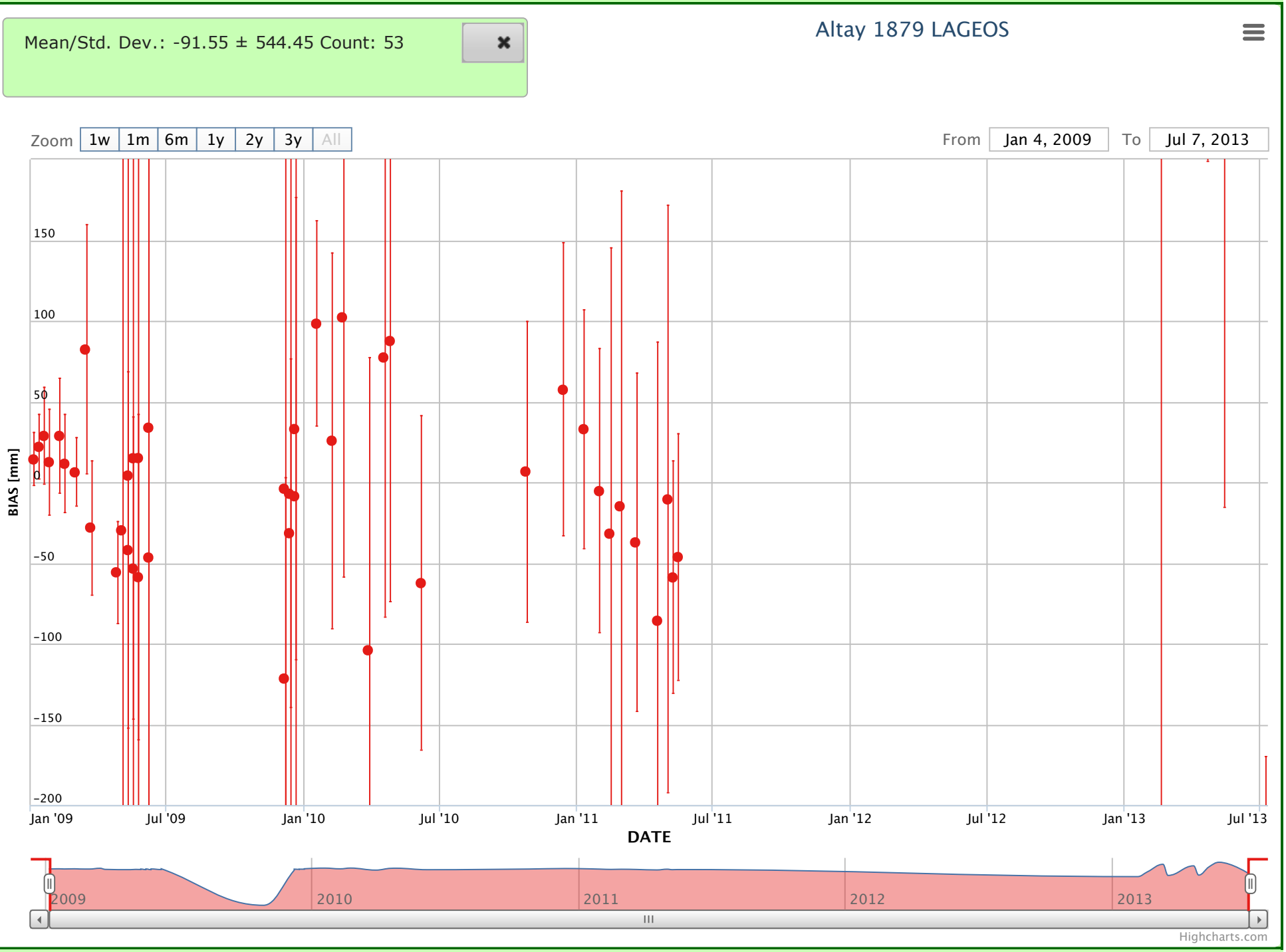
Mean/Std. Dev.: 2.80 ± 22.15 Count: 283

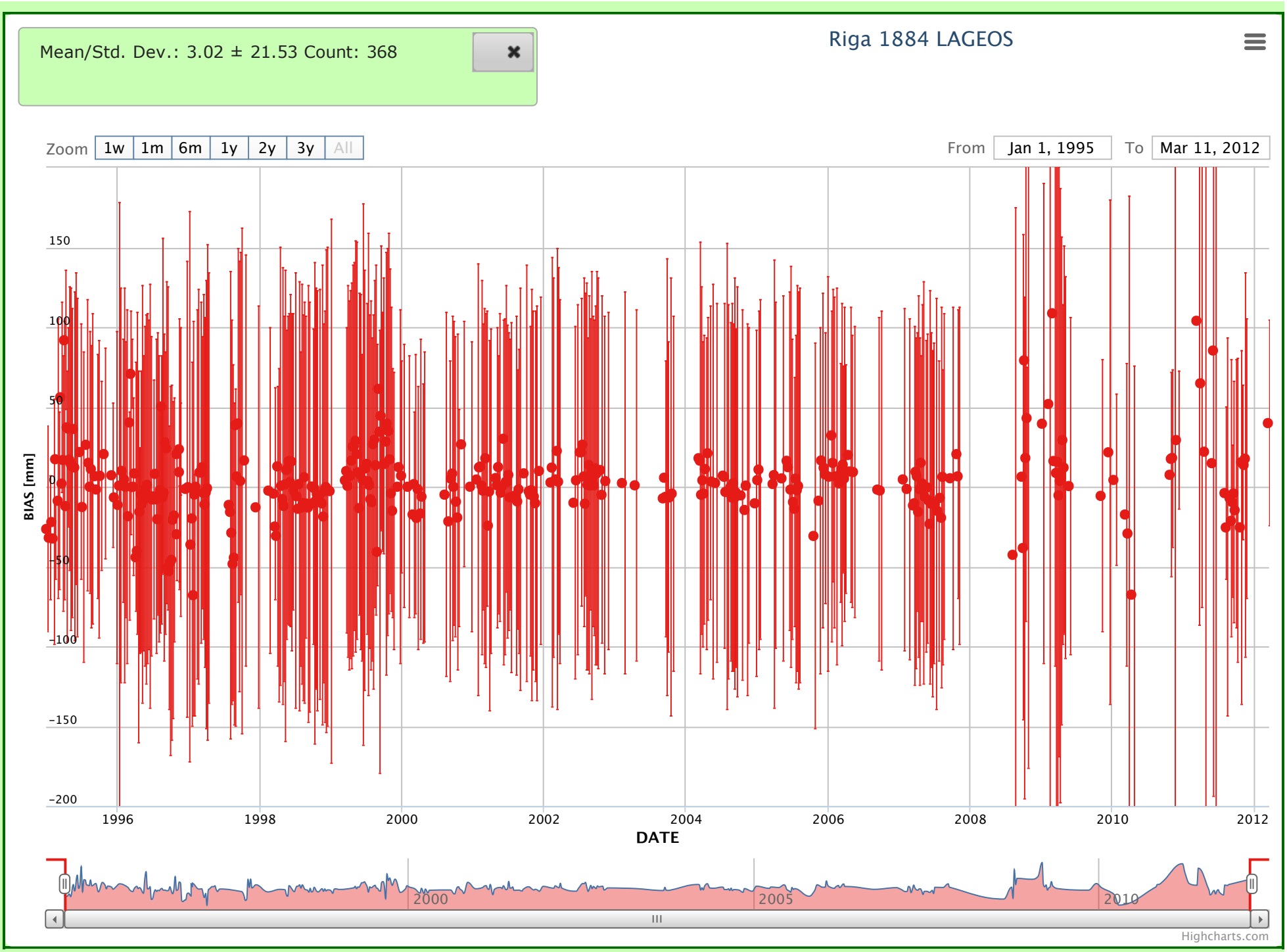


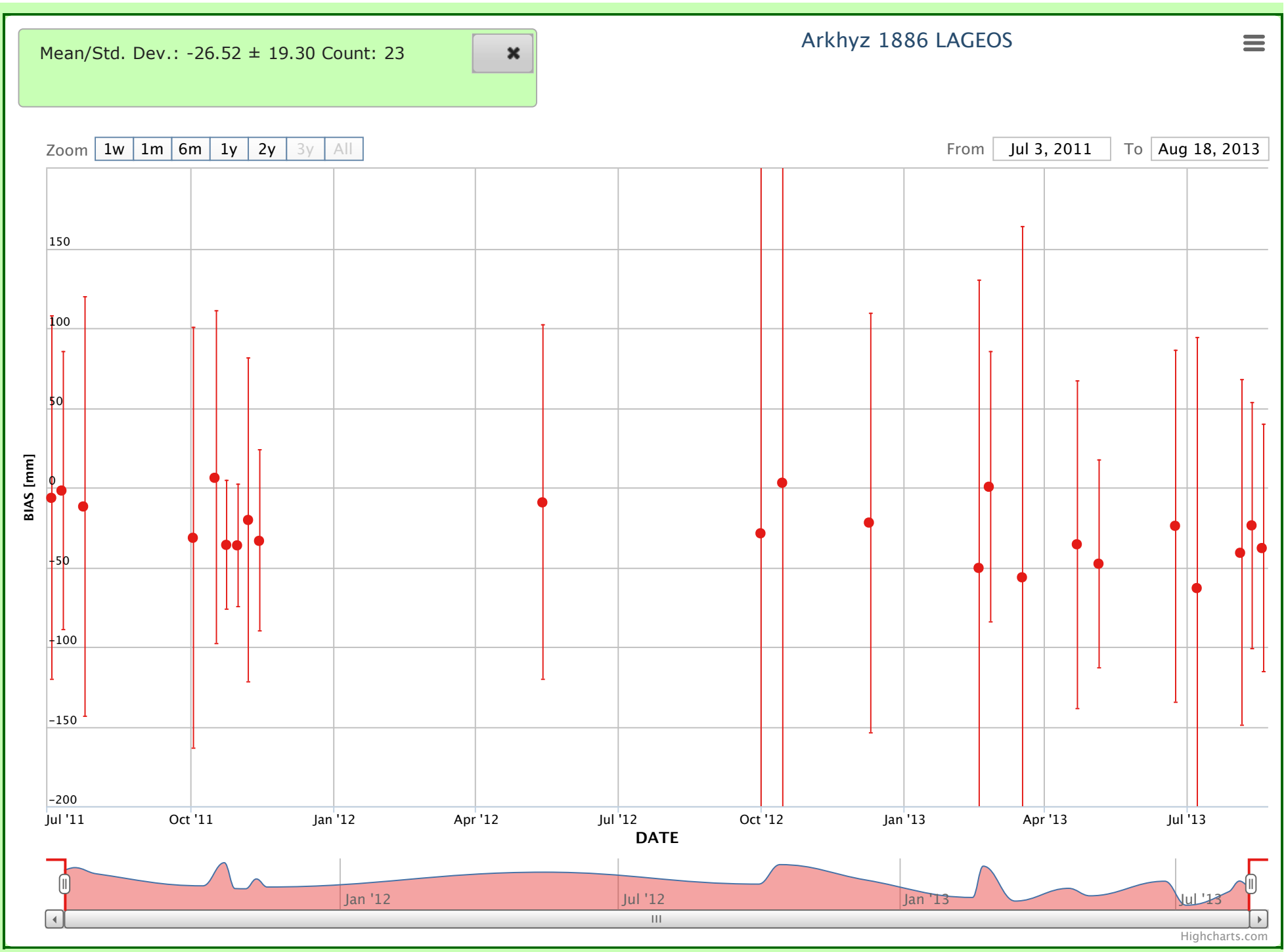
Mean/Std. Dev.: -18.73 ± 135.66 Count: 93



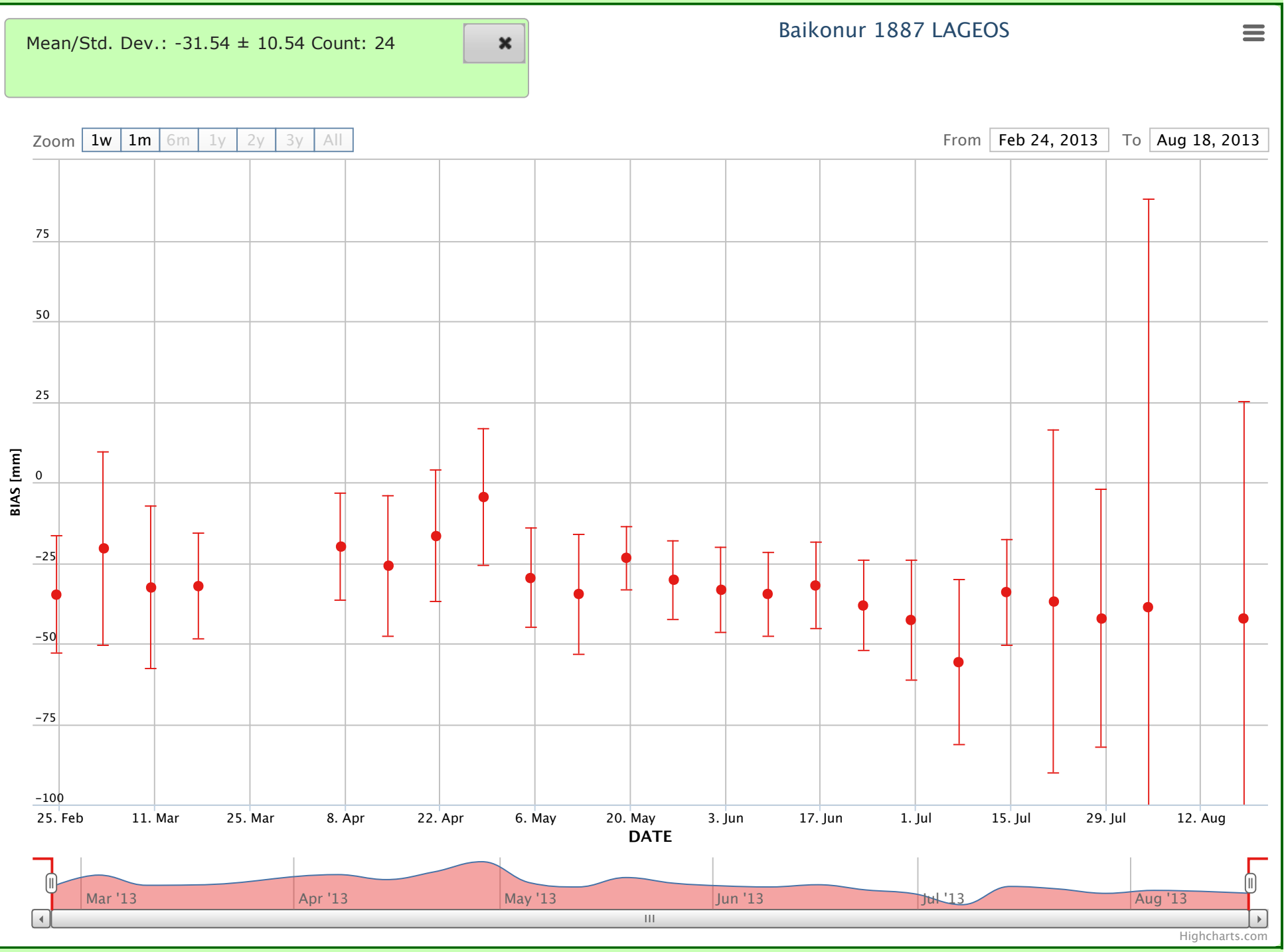

Mean/Std. Dev.: -42.70 ± 350.37 Count: 233
Simeiz 1873 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jun 11, 1995 To Aug 18, 2013
BIAS [mm]
150
100
50
0
-50
-100
-150
-200
1996
1998
2000
2002
2004
2006
2008
2010
2012
DATE
2000
2005
2010
Highcharts.com


Mean/Std. Dev.: -91.55 ± 544.45 Count: 53
Altay 1879 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jan 4, 2009 To Jul 7, 2013
BIAS [mm]
150
100
50
0
-50
-100
-150
-200
Jan '09
Jul '09
Jan '10
Jul '10
Jan '11
Jul '11
Jan '12
Jul '12
Jan '13
Jul '13
DATE
2009
2010
2011
2012
2013
Highcharts.com


Mean/Std. Dev.: 3.02 ± 21.53 Count: 368
Riga 1884 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jan 1, 1995 To Mar 11, 2012
BIAS [mm]
150
100
50
0
-50
-100
-150
-200
1996
1998
2000
2002
2004
2006
2008
2010
2012
DATE
2000
2005
2010
Highcharts.com

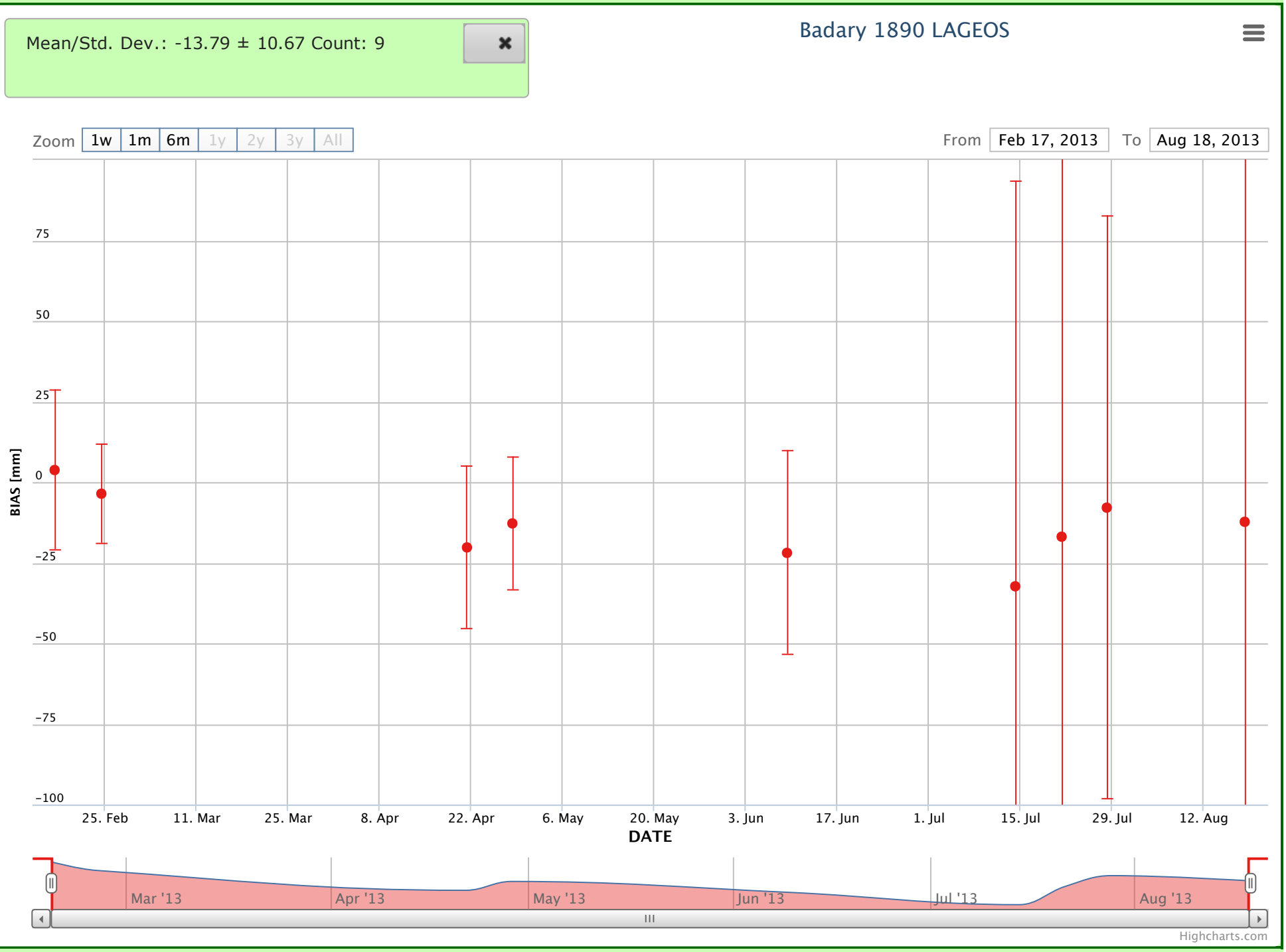

Mean/Std. Dev.: -26.52 ± 19.30 Count: 23
Arkhyz 1886 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jul 3, 2011 To Aug 18, 2013
BIAS [mm]
150
100
50
0
-50
-100
-150
-200
Jul '11
Oct '11
Jan '12
Apr '12
Jul '12
Oct '12
Jan '13
Apr '13
Jul '13
DATE
Jan '12
Jul '12
Jan '13
Jul '13
Highcharts.com

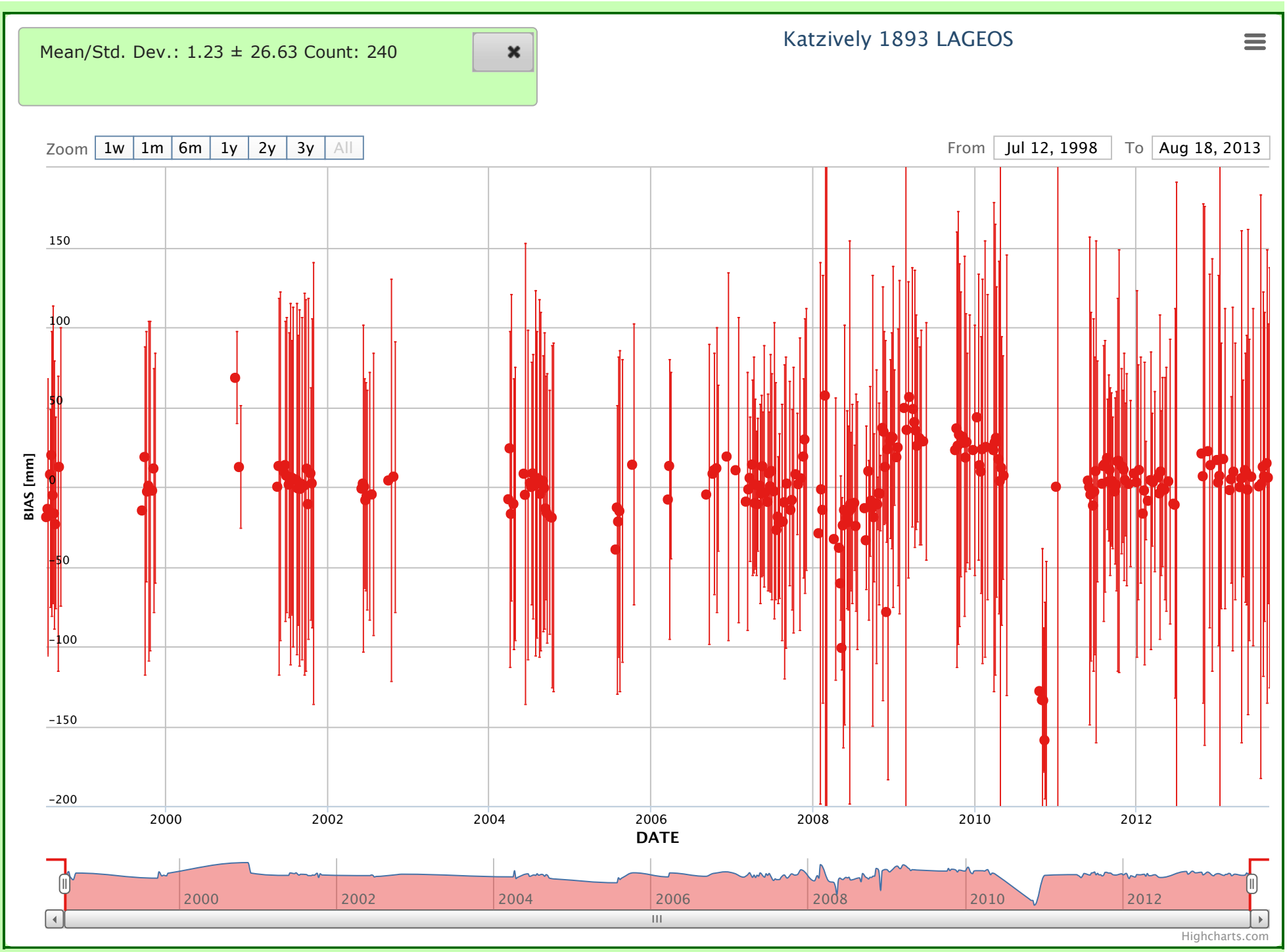
Mean/Std. Dev.: -31.54 ± 10.54 Count: 24

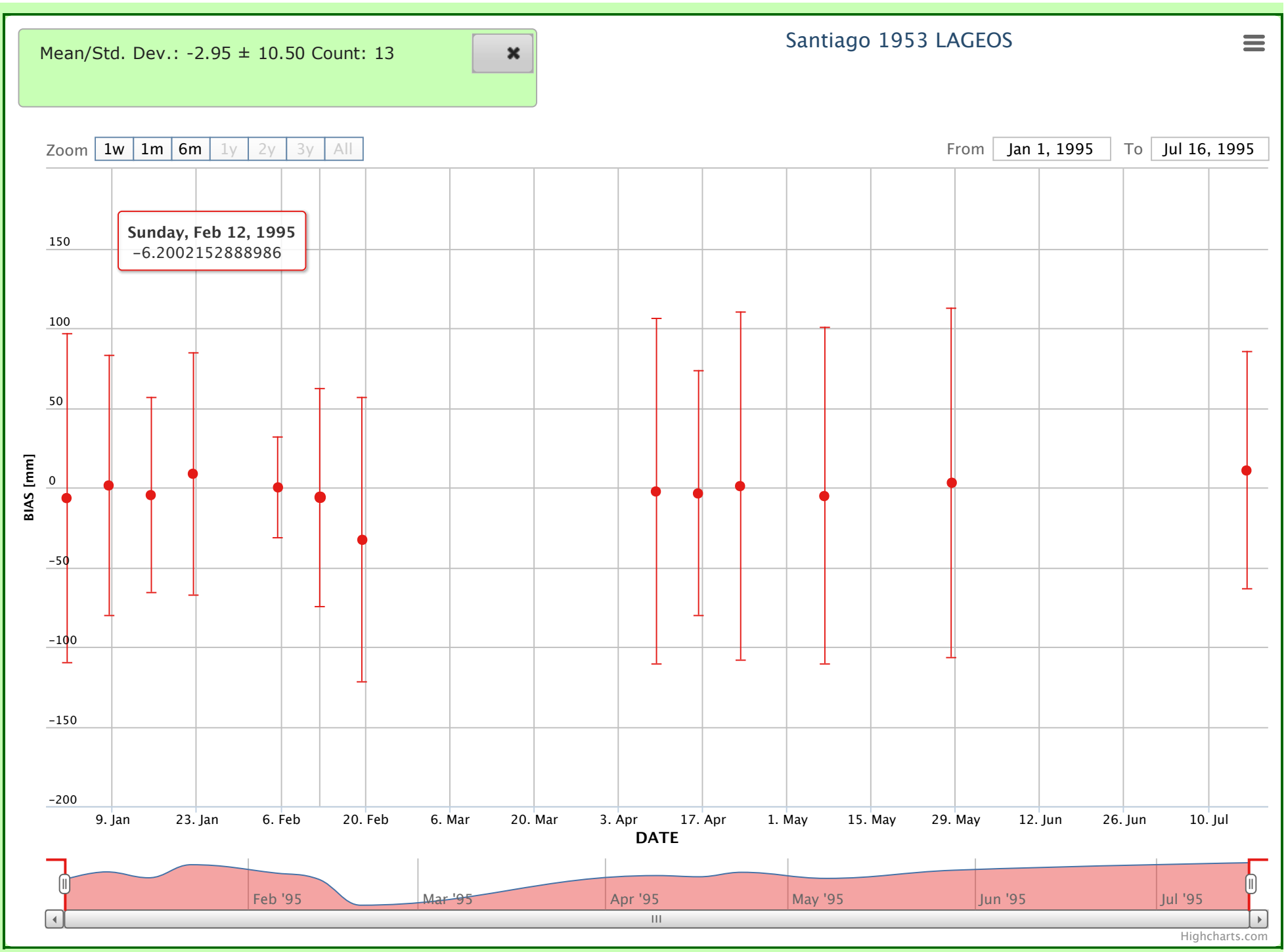



Mean/Std. Dev.: 3.13 ± 4.69 Count: 4
Zelenchukskya 1889 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Apr 21, 2013 To Aug 18, 2013
Sunday, May 26, 2013
4.90115072382296
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
29. Apr
13. May
27. May
10. Jun
24. Jun
8. Jul
22. Jul
5. Aug
19. Aug
DATE
May '13
Jun '13
Jul '13
Aug '13
Highcharts.com

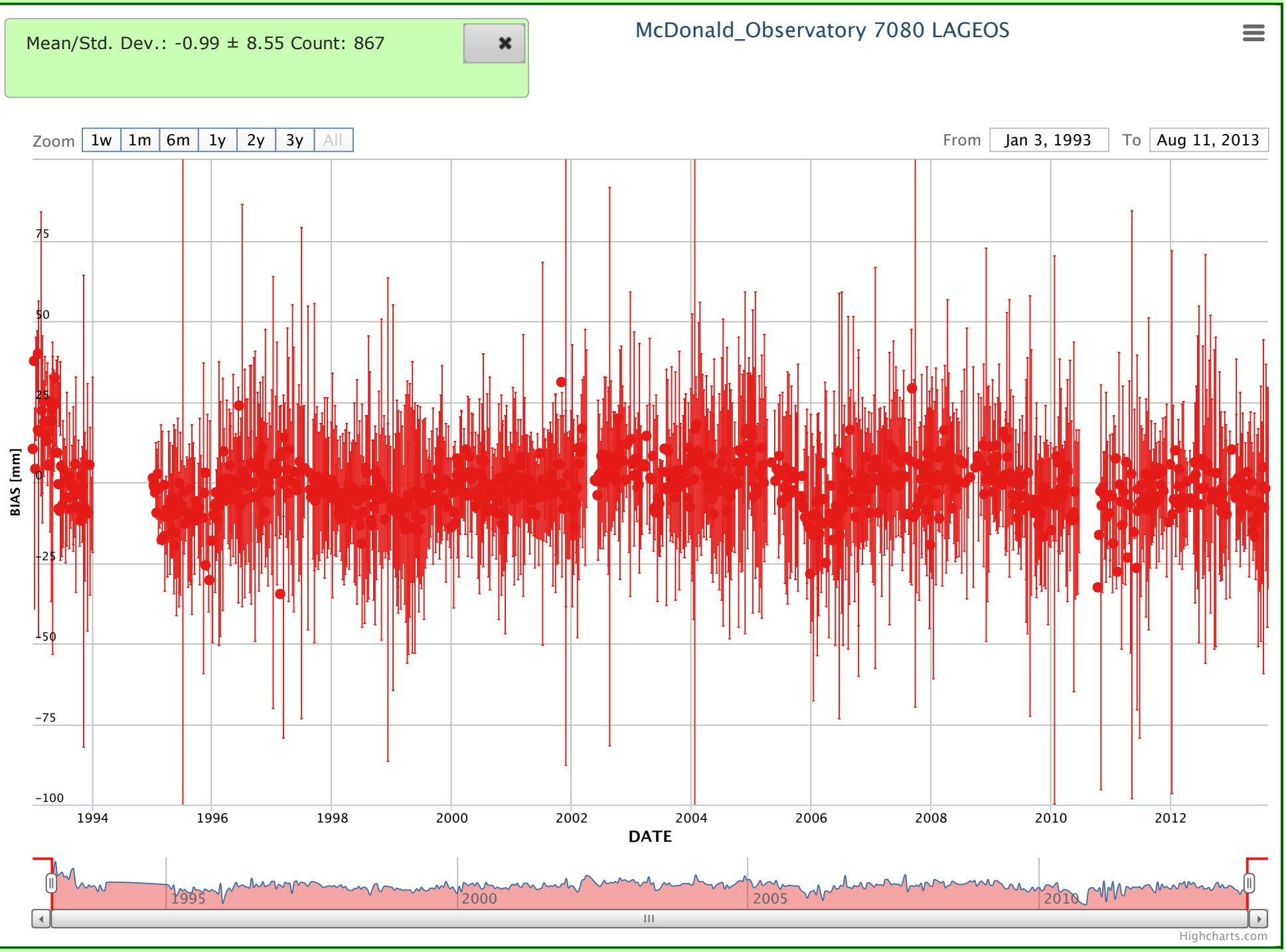
Mean/Std. Dev.: -13.79 ± 10.67 Count: 9



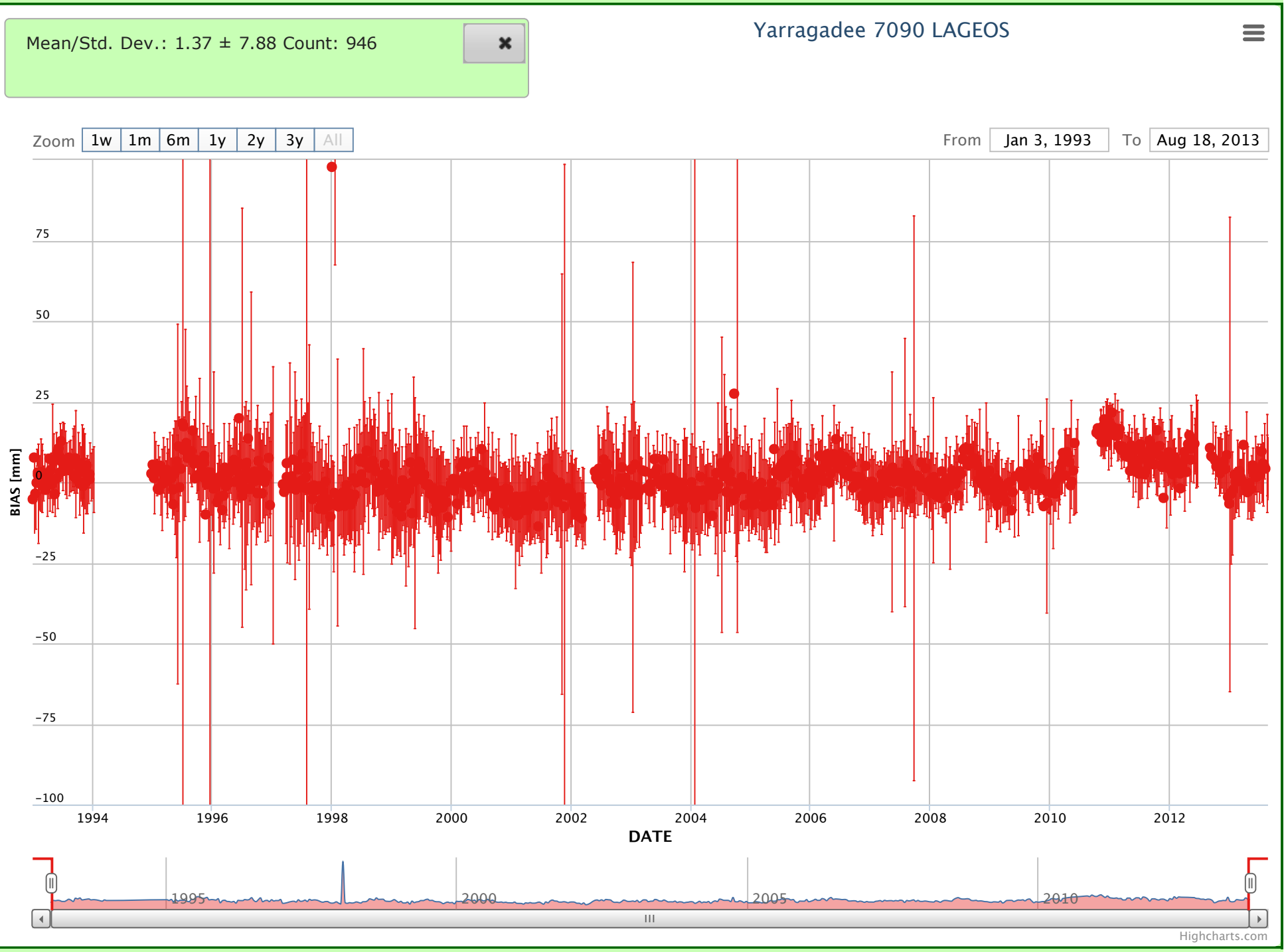

Mean/Std. Dev.: 1.23 ± 26.63 Count: 240
Katzively 1893 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jul 12, 1998 To Aug 18, 2013
150
100
50
0
-50
-100
-150
-200
BIAS [mm]
2000
2002
2004
2006
2008
2010
2012
DATE
Highcharts.com


Mean/Std. Dev.: -2.95 ± 10.50 Count: 13
Santiago 1953 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jan 1, 1995 To Jul 16, 1995
Sunday, Feb 12, 1995
-6.2002152888986
150
100
50
0
-50
-100
-150
-200
BIAS [mm]
9. Jan
23. Jan
6. Feb
20. Feb
6. Mar
20. Mar
3. Apr
17. Apr
1. May
15. May
29. May
12. Jun
26. Jun
10. Jul
DATE
Feb '95
Mar '95
Apr '95
May '95
Jun '95
Jul '95
Highcharts.com

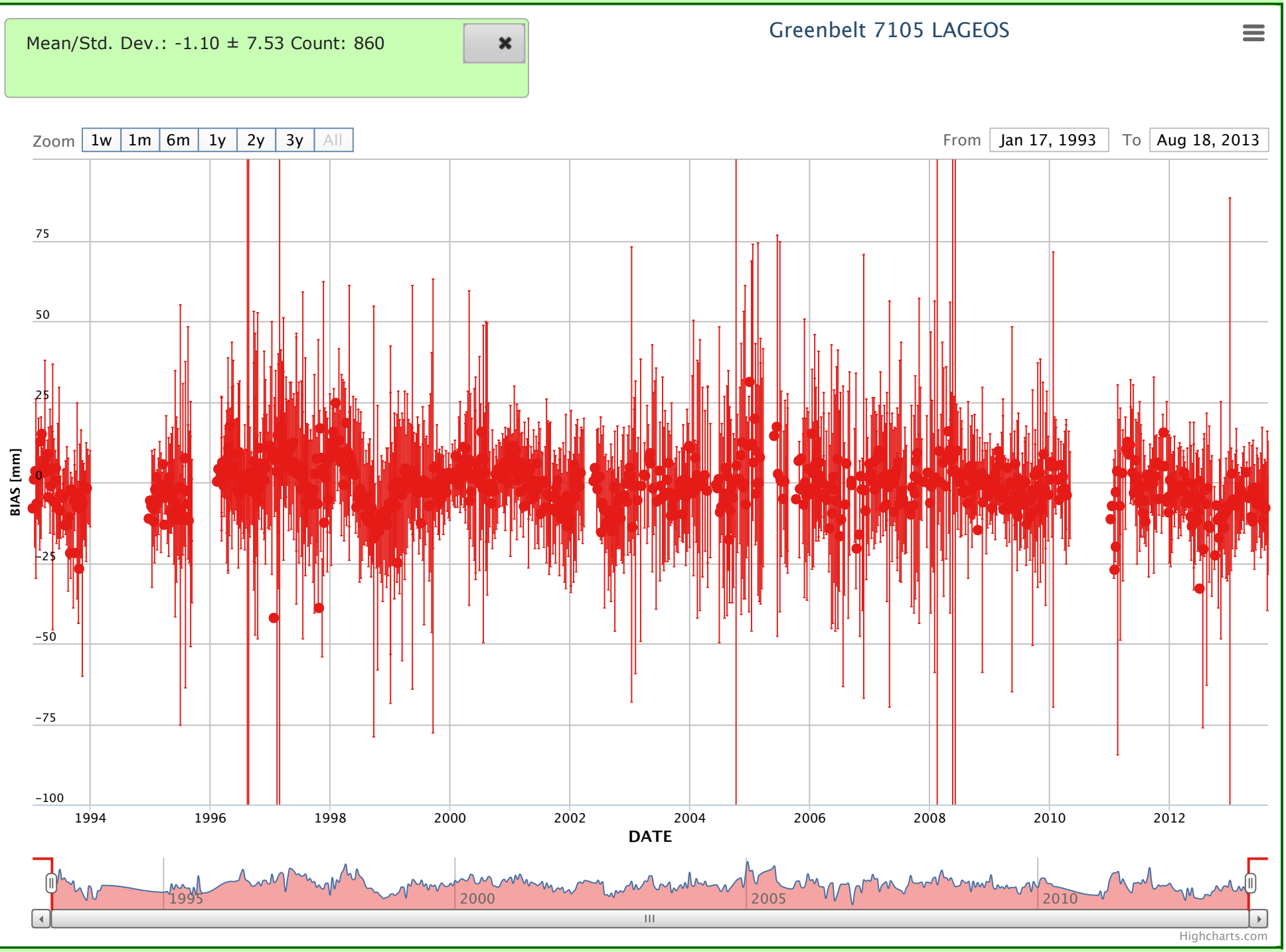
Mean/Std. Dev.: -0.99 ± 8.55 Count: 867



Mean/Std. Dev.: 1.37 ± 7.88 Count: 946

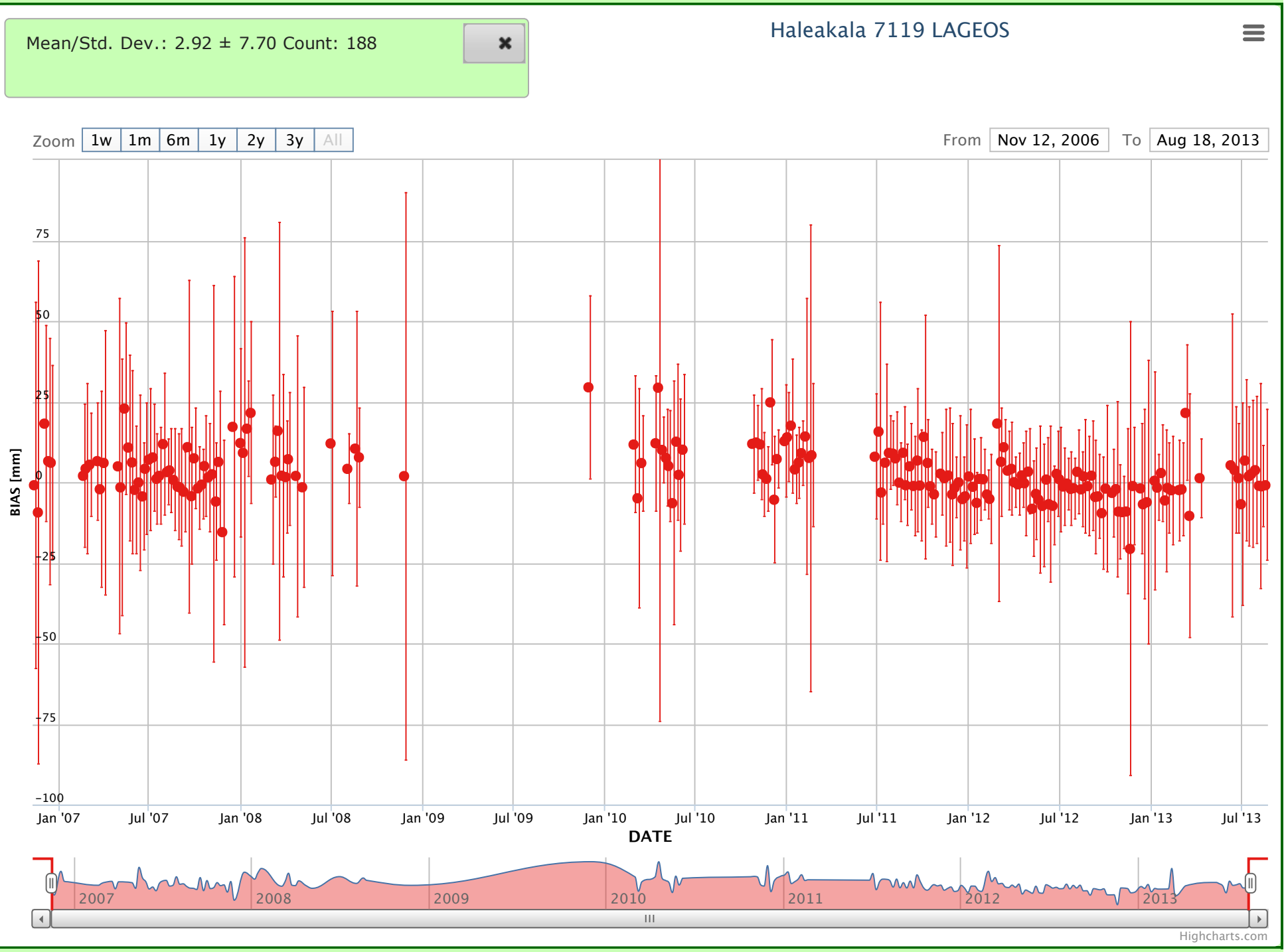


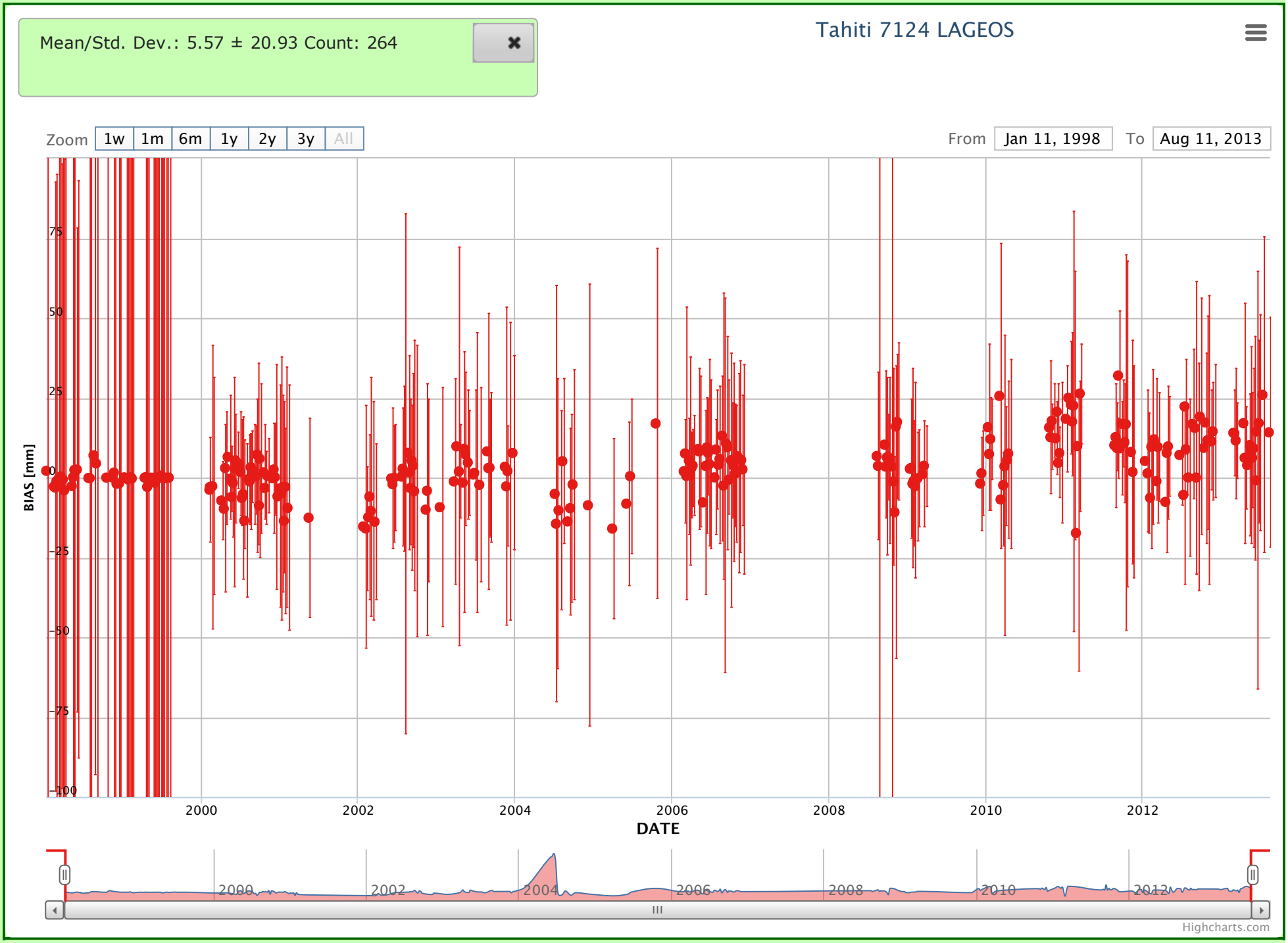
Mean/Std. Dev.: -1.10 ± 7.53 Count: 860

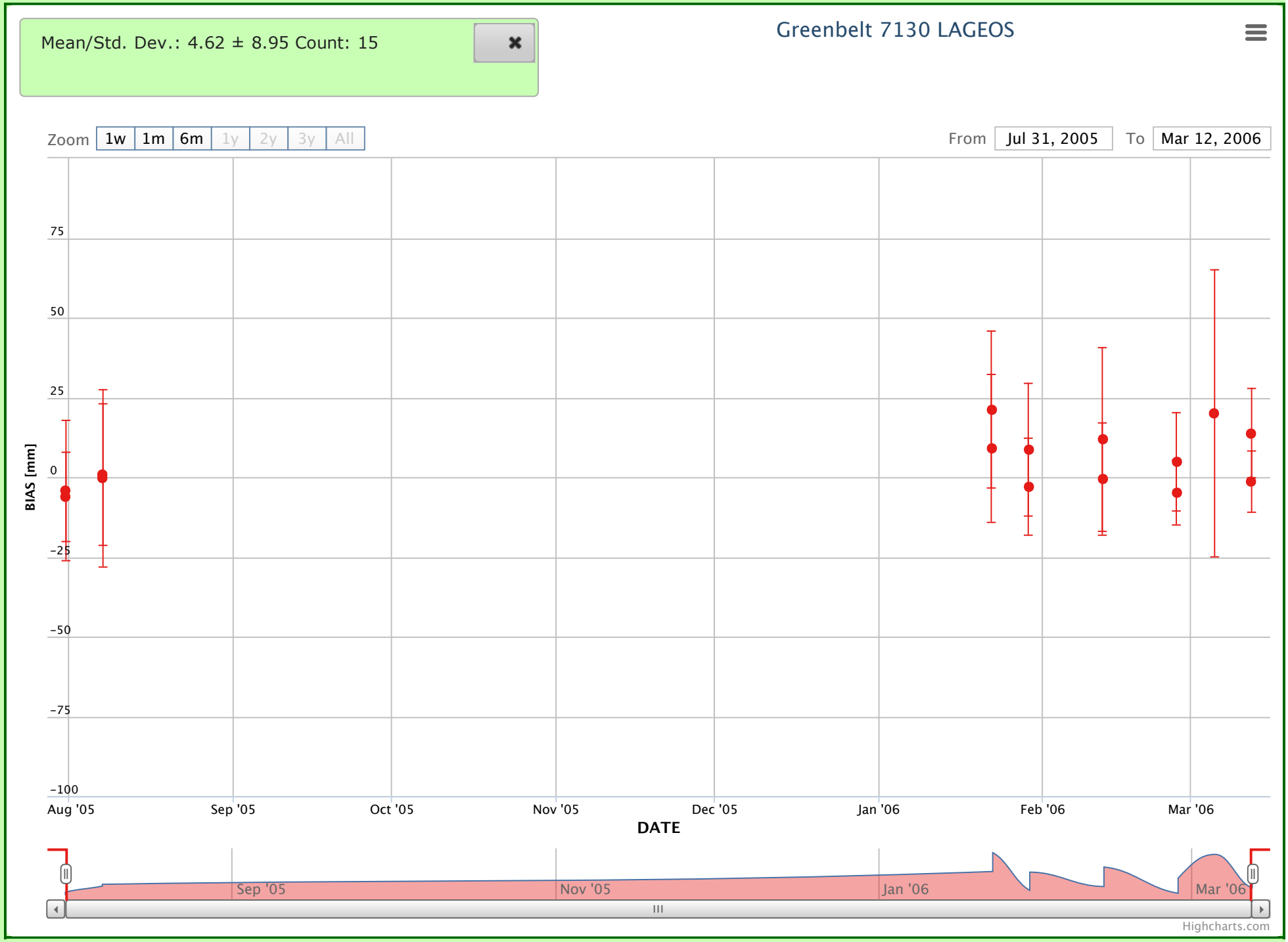



Mean/Std. Dev.: 2.07 ± 8.68 Count: 868
Monument_Peak 7110 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jan 3, 1993 To Aug 18, 2013
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
1994 1996 1998 2000 2002 2004 2006 2008 2010 2012
DATE
1995 2000 2005 2010
Highcharts.com

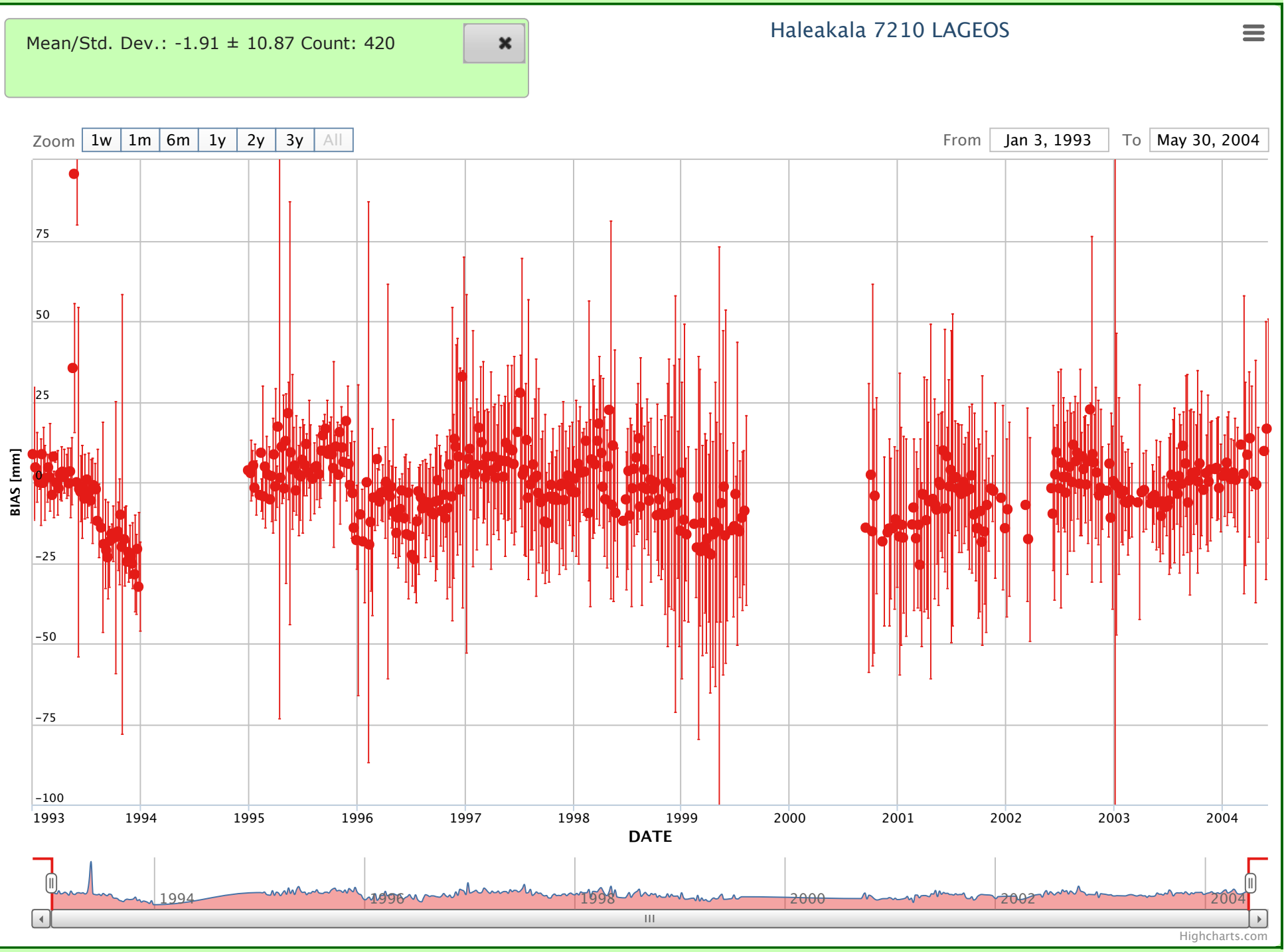
Mean/Std. Dev.: 2.92 ± 7.70 Count: 188

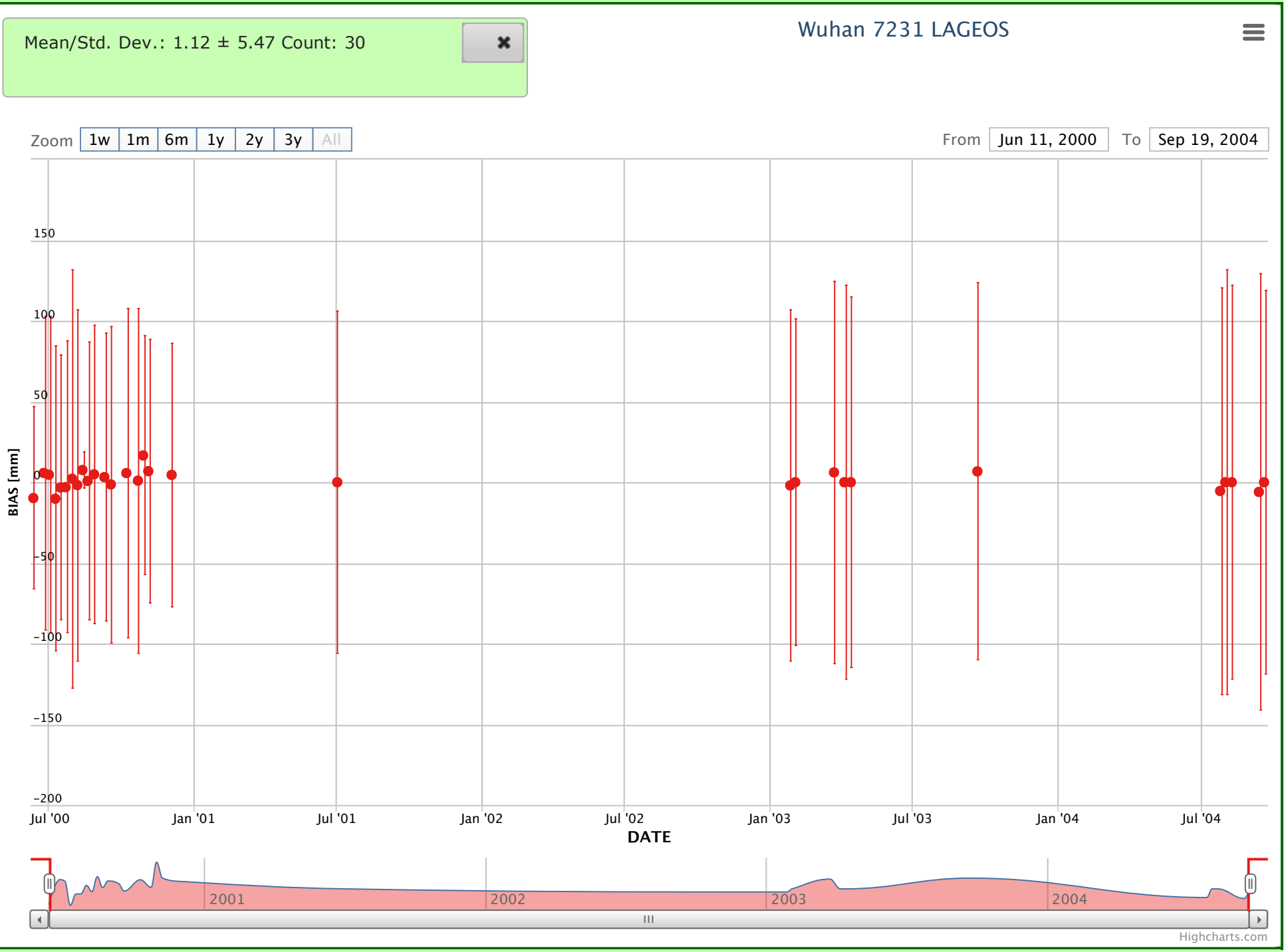


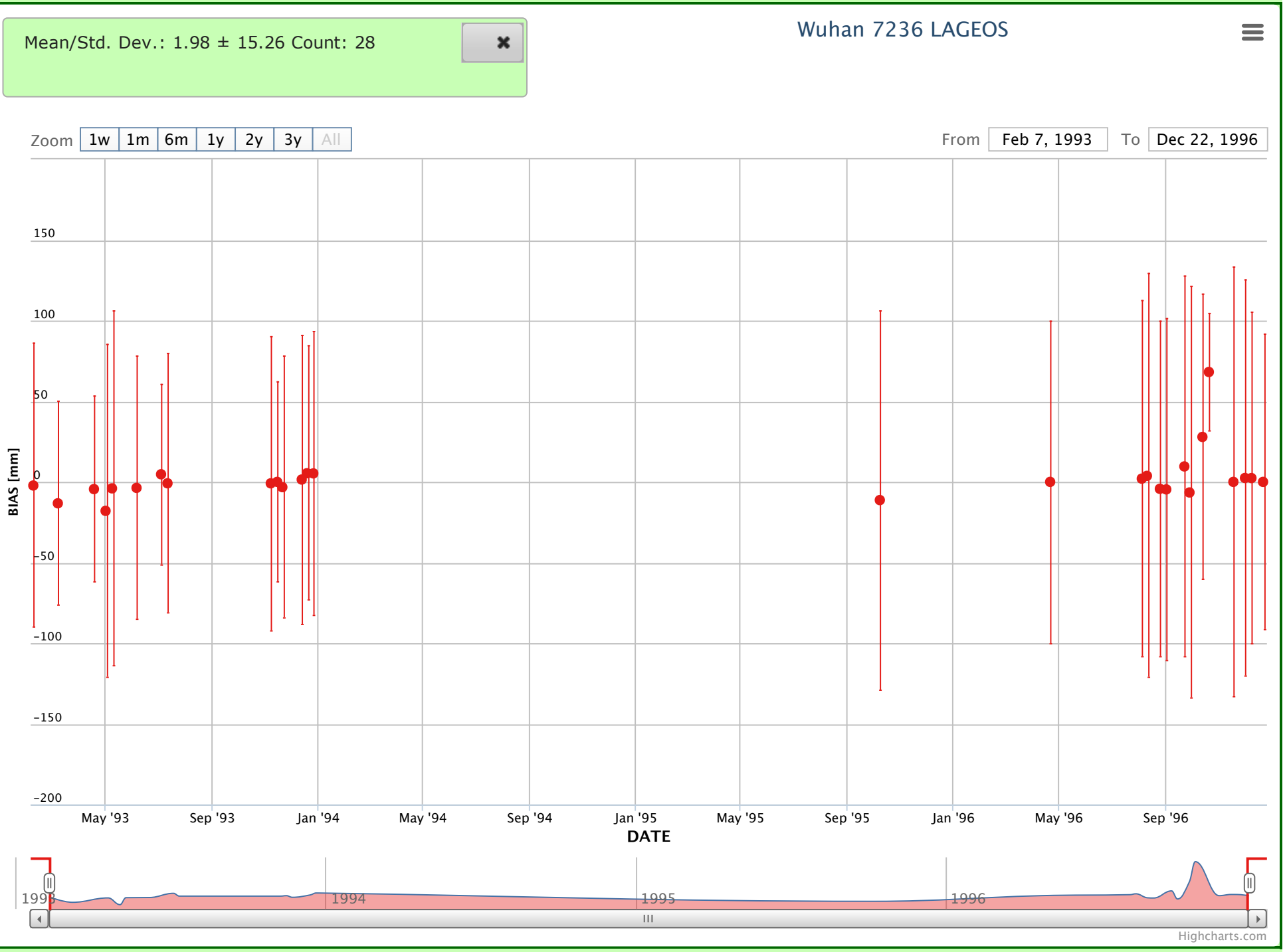

Mean/Std. Dev.: 5.57 ± 20.93 Count: 264
Tahiti 7124 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jan 11, 1998 To Aug 11, 2013
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
2000
2002
2004
2006
2008
2010
2012
DATE
Highcharts.com

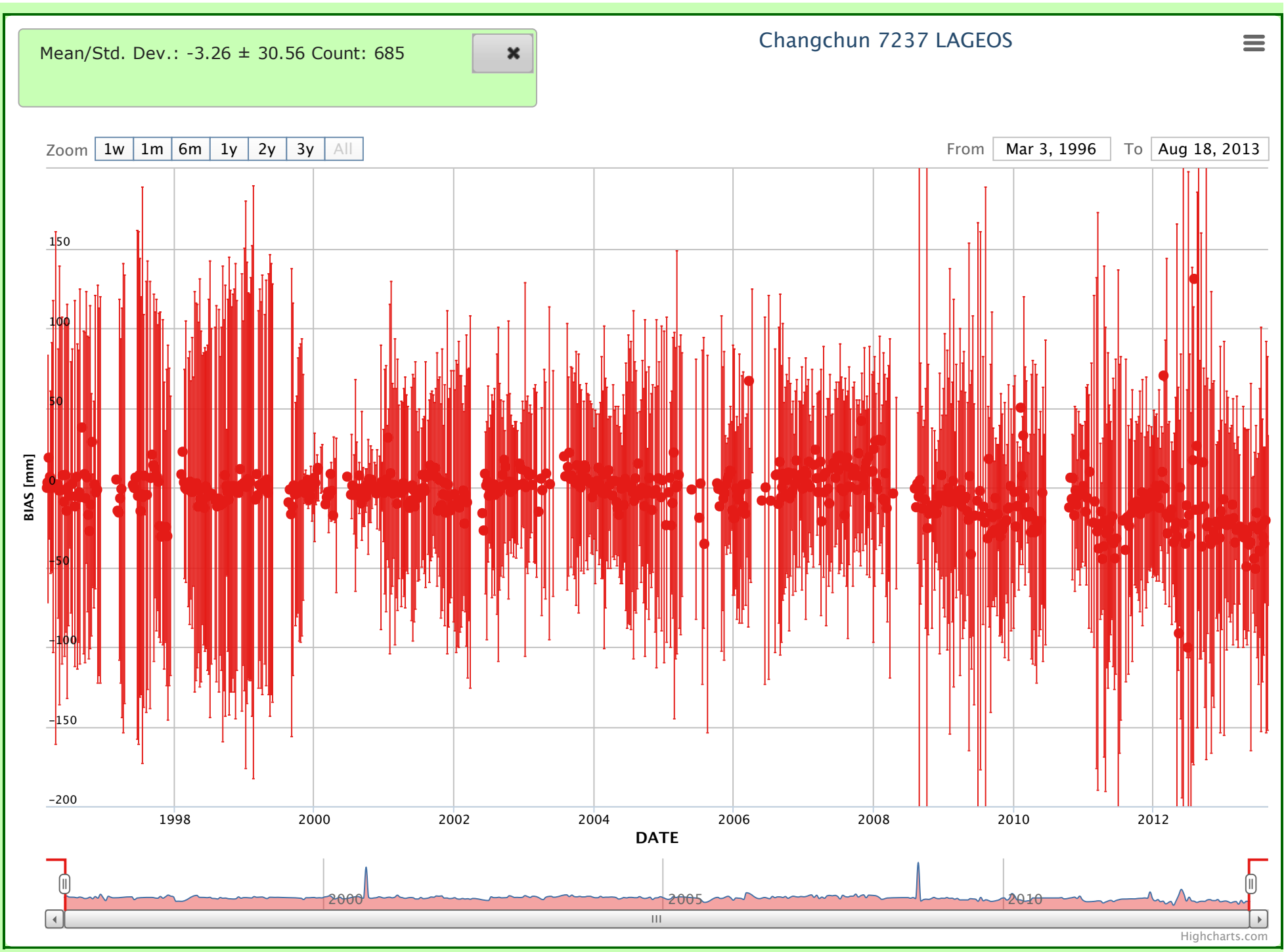

Mean/Std. Dev.: 4.62 ± 8.95 Count: 15
Greenbelt 7130 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jul 31, 2005 To Mar 12, 2006
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
Aug '05
Sep '05
Oct '05
Nov '05
Dec '05
Jan '06
Feb '06
Mar '06
DATE
Sep '05
Nov '05
Jan '06
Mar '06
Highcharts.com

Mean/Std. Dev.: -1.91 ± 10.87 Count: 420

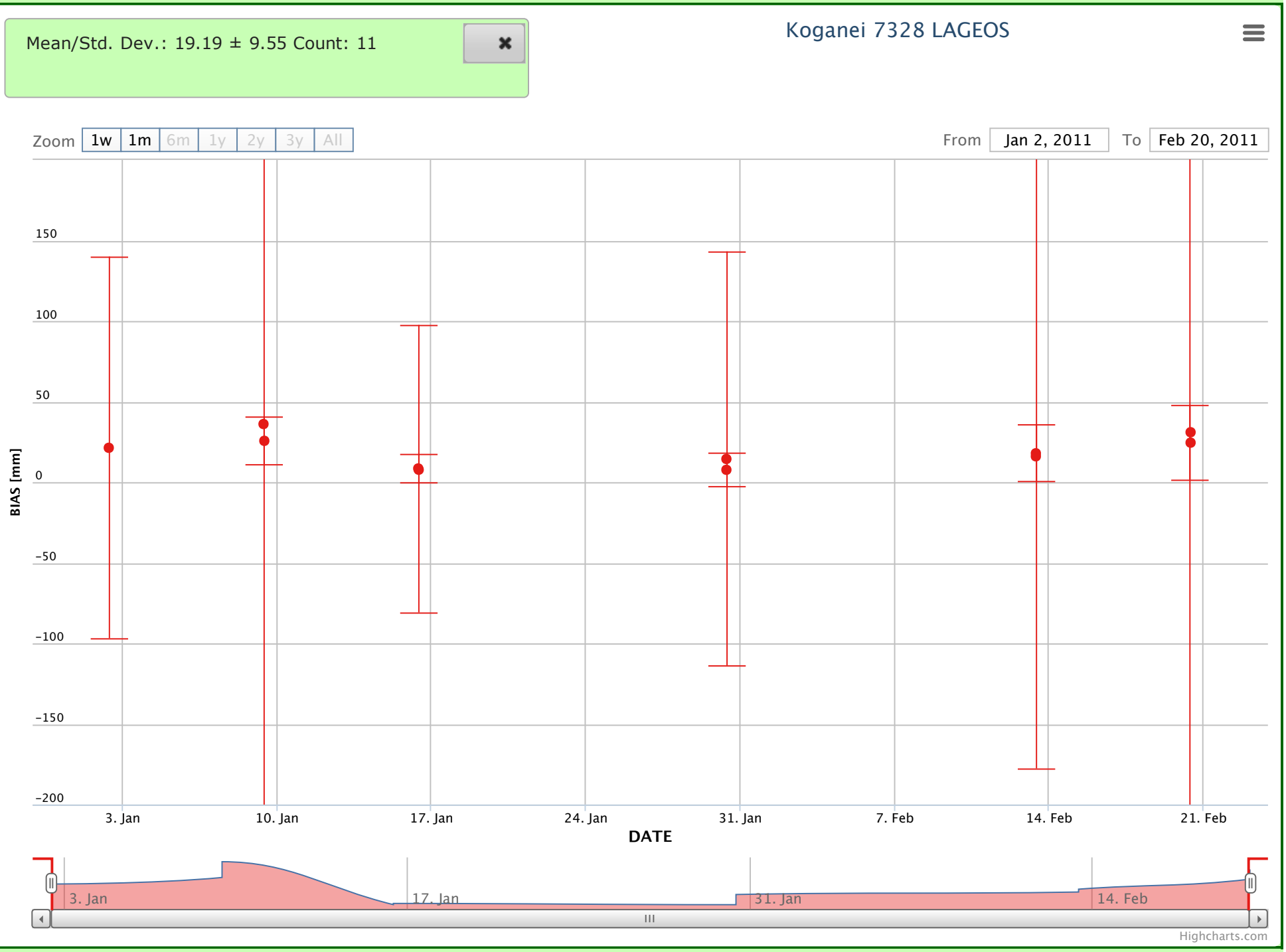



Mean/Std. Dev.: 1.12 ± 5.47 Count: 30
Wuhan 7231 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jun 11, 2000 To Sep 19, 2004
150
100
50
0
-50
-100
-150
-200
BIAS [mm]
Jul '00
Jan '01
Jul '01
Jan '02
Jul '02
Jan '03
Jul '03
Jan '04
Jul '04
DATE
2001
2002
2003
2004
Highcharts.com

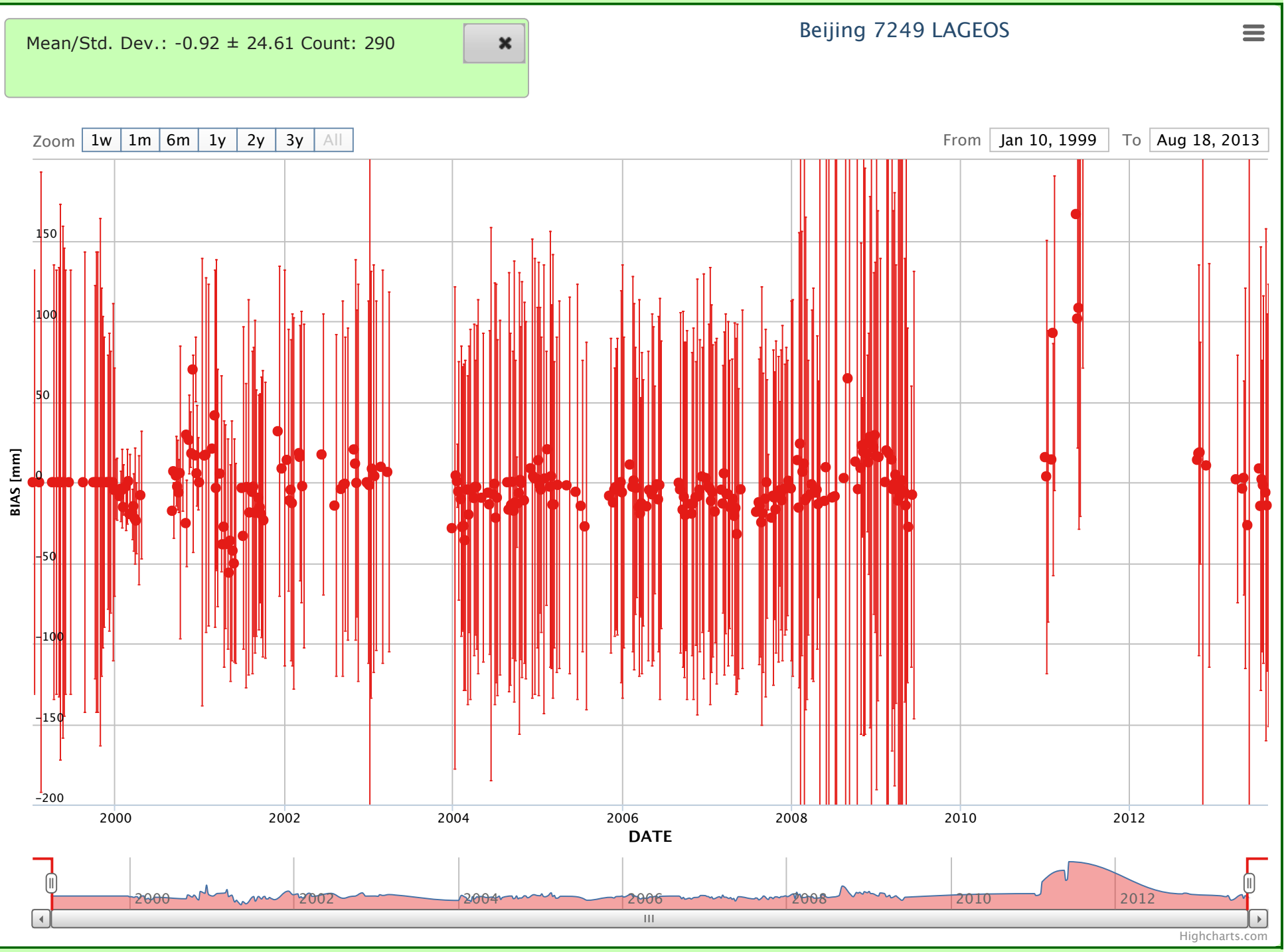

Mean/Std. Dev.: 1.98 ± 15.26 Count: 28
Wuhan 7236 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Feb 7, 1993 To Dec 22, 1996
150
100
50
0
-50
-100
-150
-200
BIAS [mm]
May '93
Sep '93
Jan '94
May '94
Sep '94
Jan '95
May '95
Sep '95
Jan '96
May '96
Sep '96
DATE
1993
1994
1995
1996
Highcharts.com

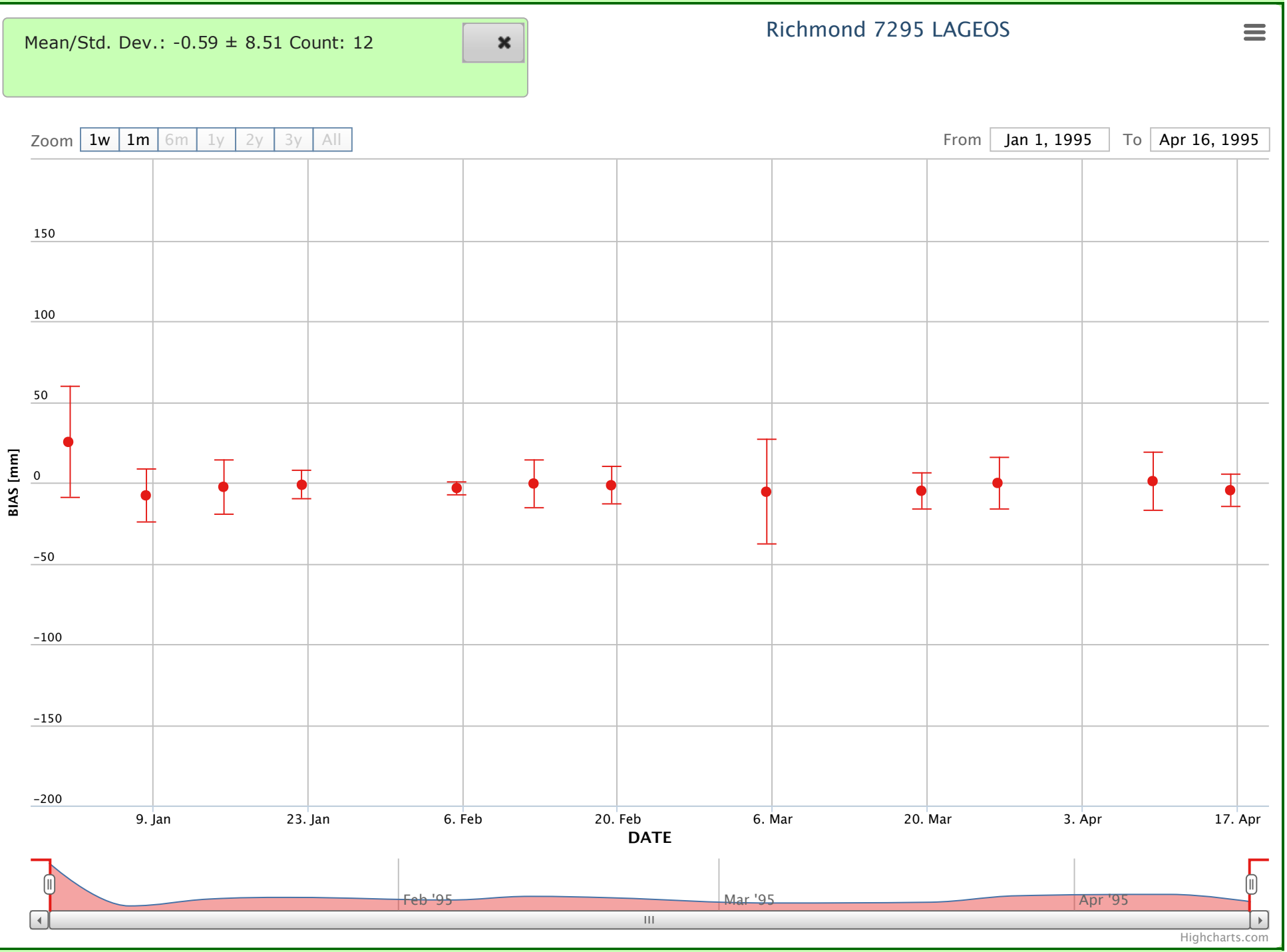

Mean/Std. Dev.: -3.26 ± 30.56 Count: 685
Changchun 7237 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Mar 3, 1996 To Aug 18, 2013
BIAS [mm]
150
100
50
0
-50
-100
-150
-200
1998
2000
2002
2004
2006
2008
2010
2012
DATE
2000
2005
2010
Highcharts.com

Mean/Std. Dev.: 19.19 ± 9.55 Count: 11

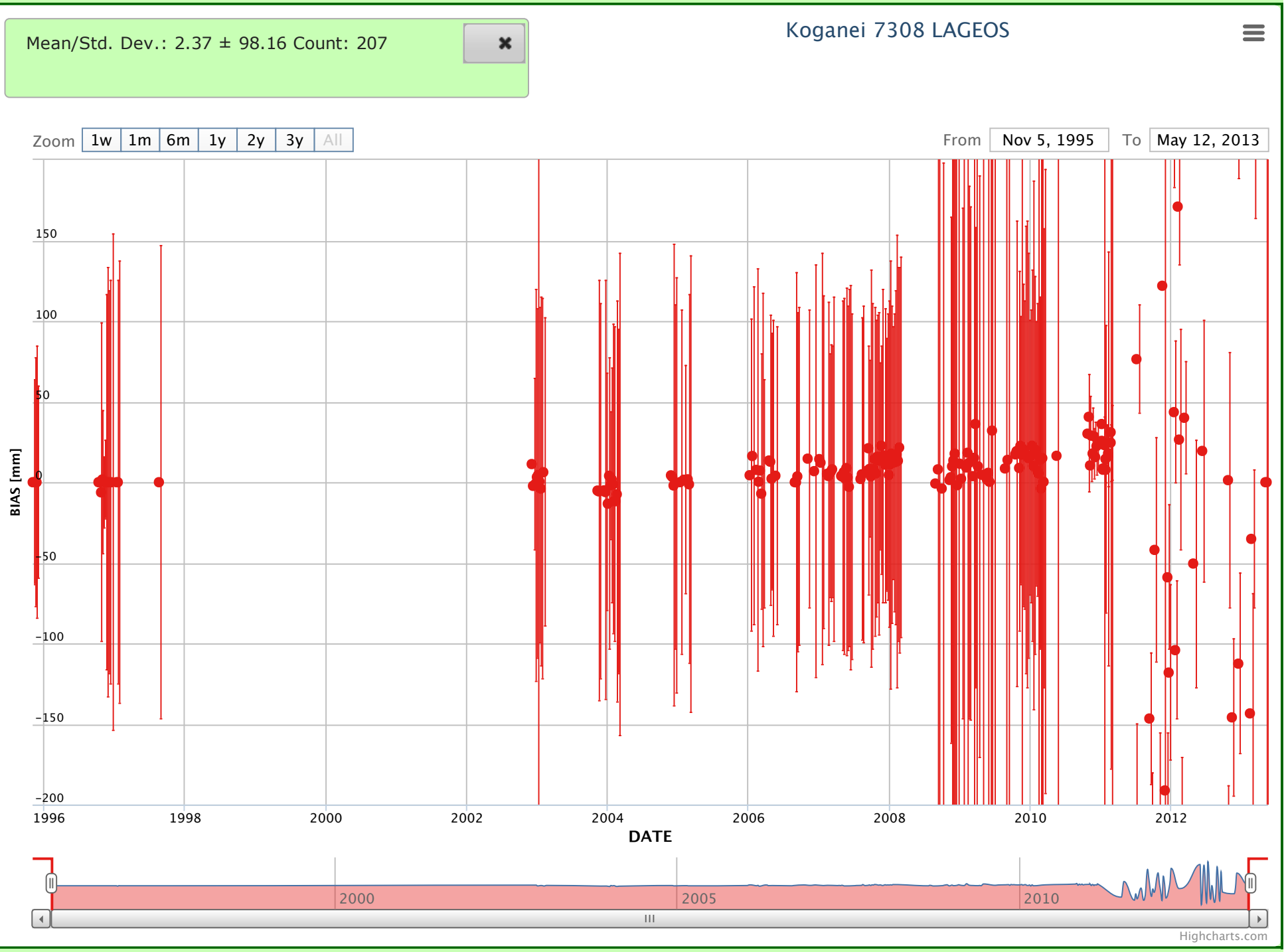


Mean/Std. Dev.: -0.92 ± 24.61 Count: 290

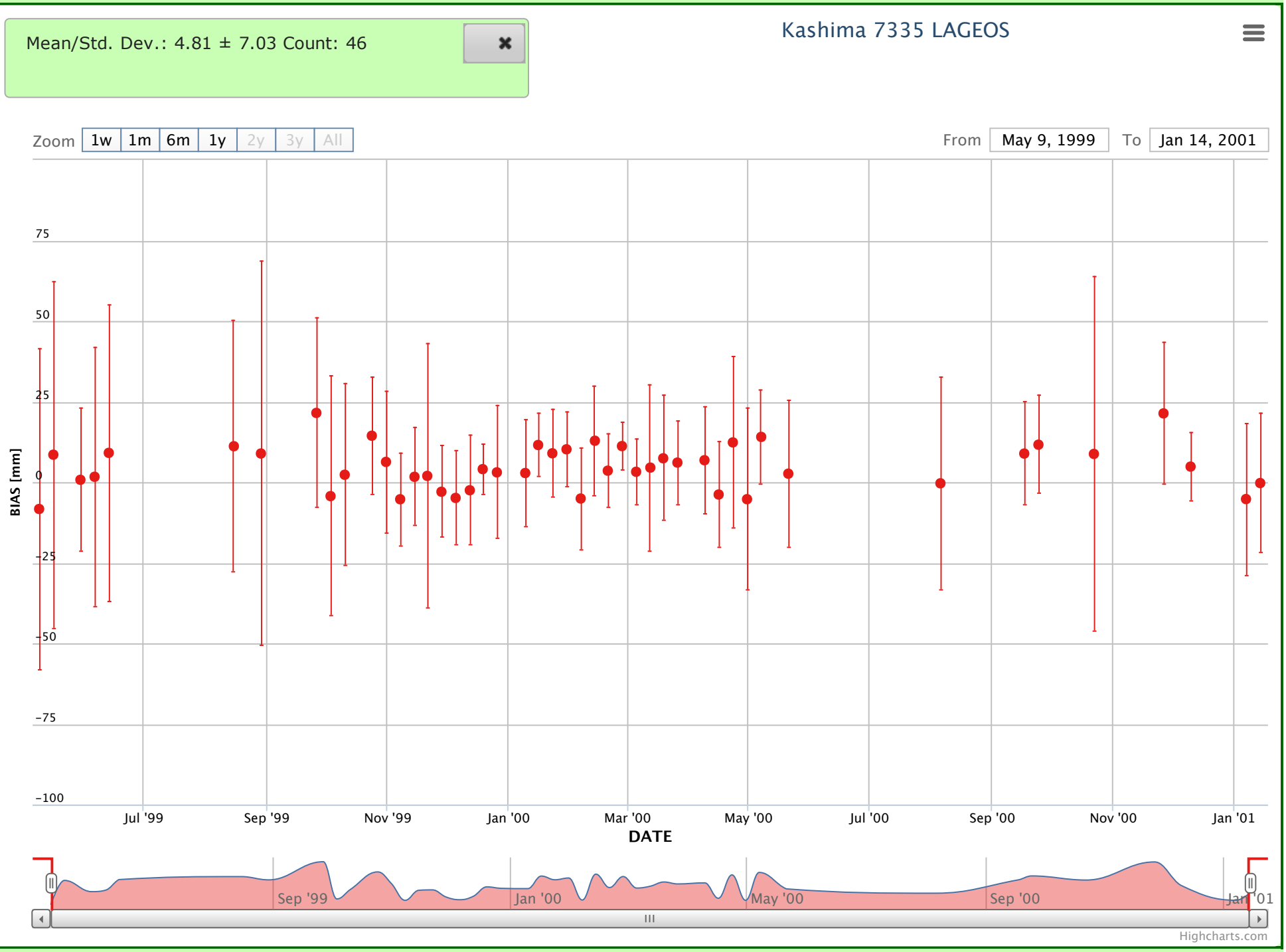


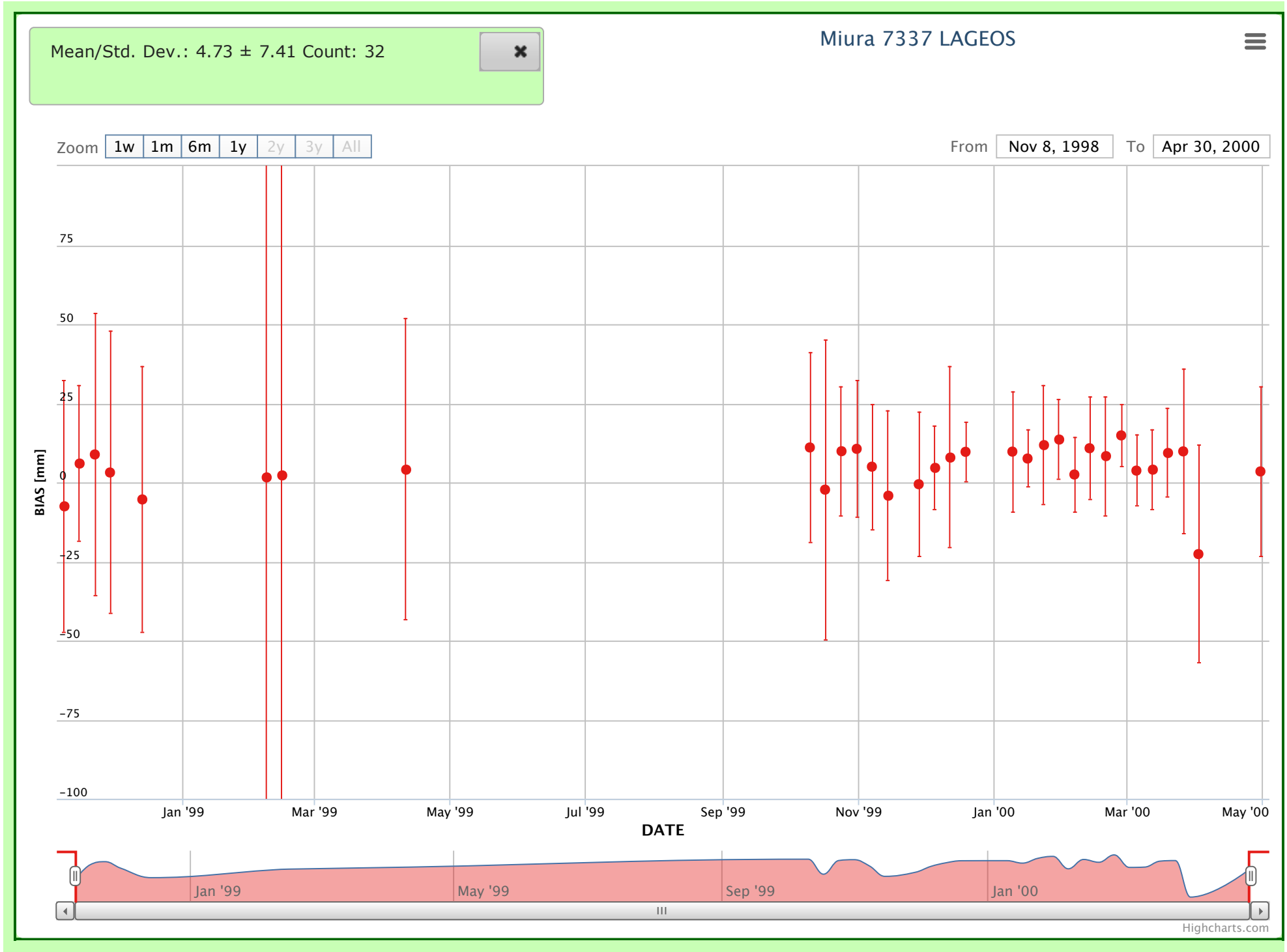

Mean/Std. Dev.: -0.59 ± 8.51 Count: 12
Richmond 7295 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jan 1, 1995 To Apr 16, 1995
150
100
50
0
-50
-100
-150
-200
BIAS [mm]
9. Jan
23. Jan
6. Feb
20. Feb
6. Mar
20. Mar
3. Apr
17. Apr
DATE
Feb '95
Mar '95
Apr '95
Highcharts.com

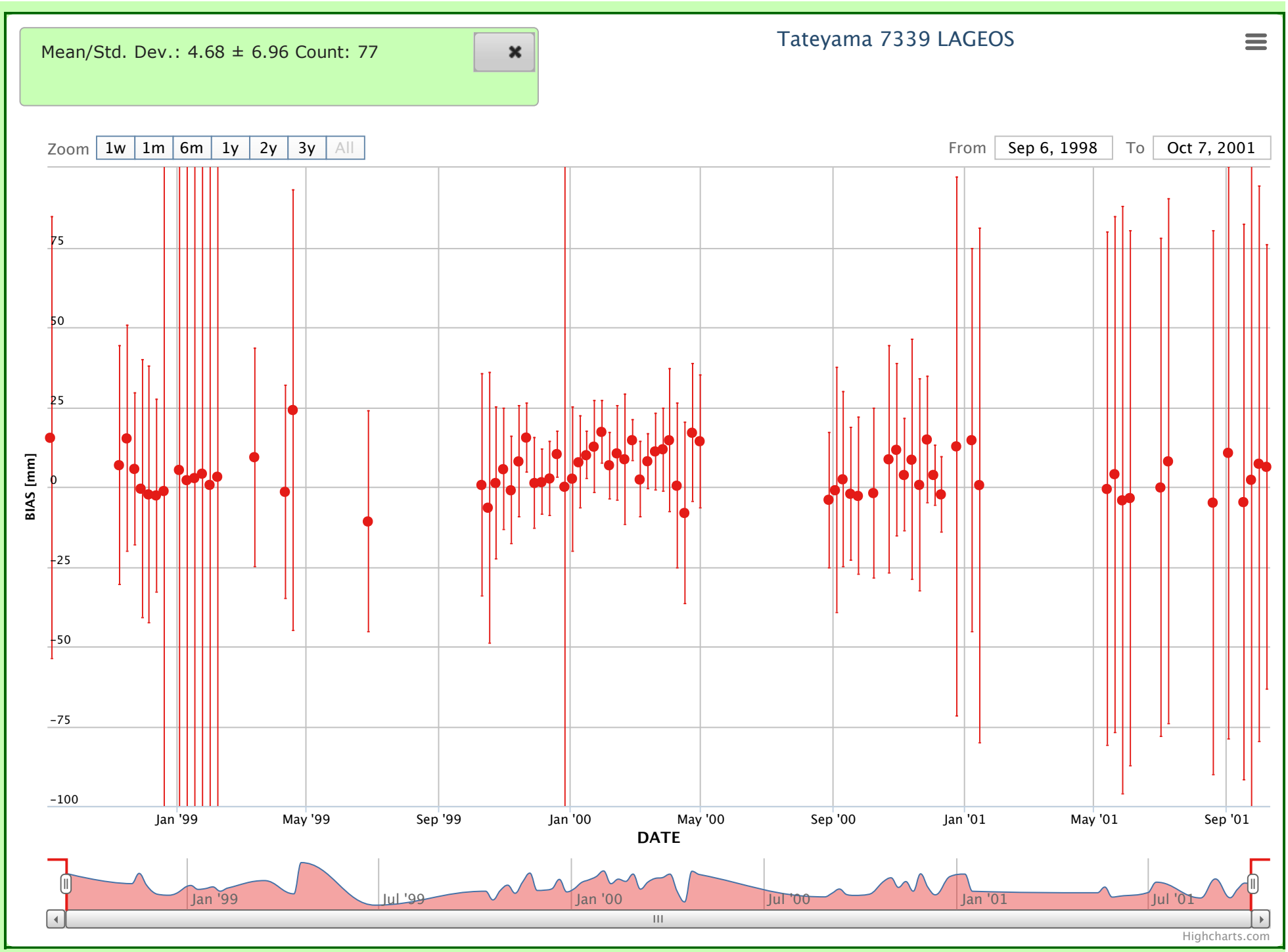
Mean/Std. Dev.: 2.37 ± 98.16 Count: 207



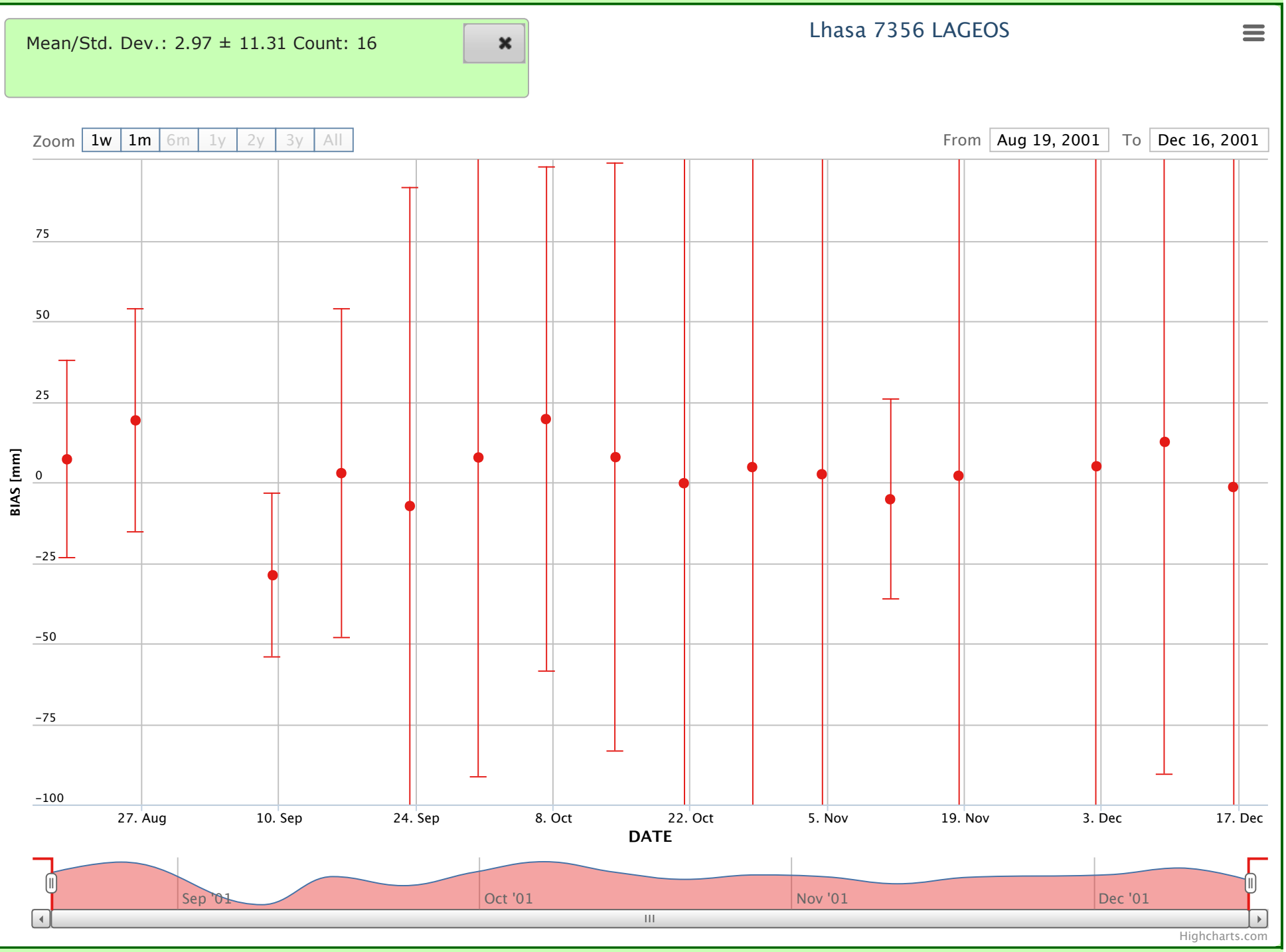
Mean/Std. Dev.: 4.81 ± 7.03 Count: 46

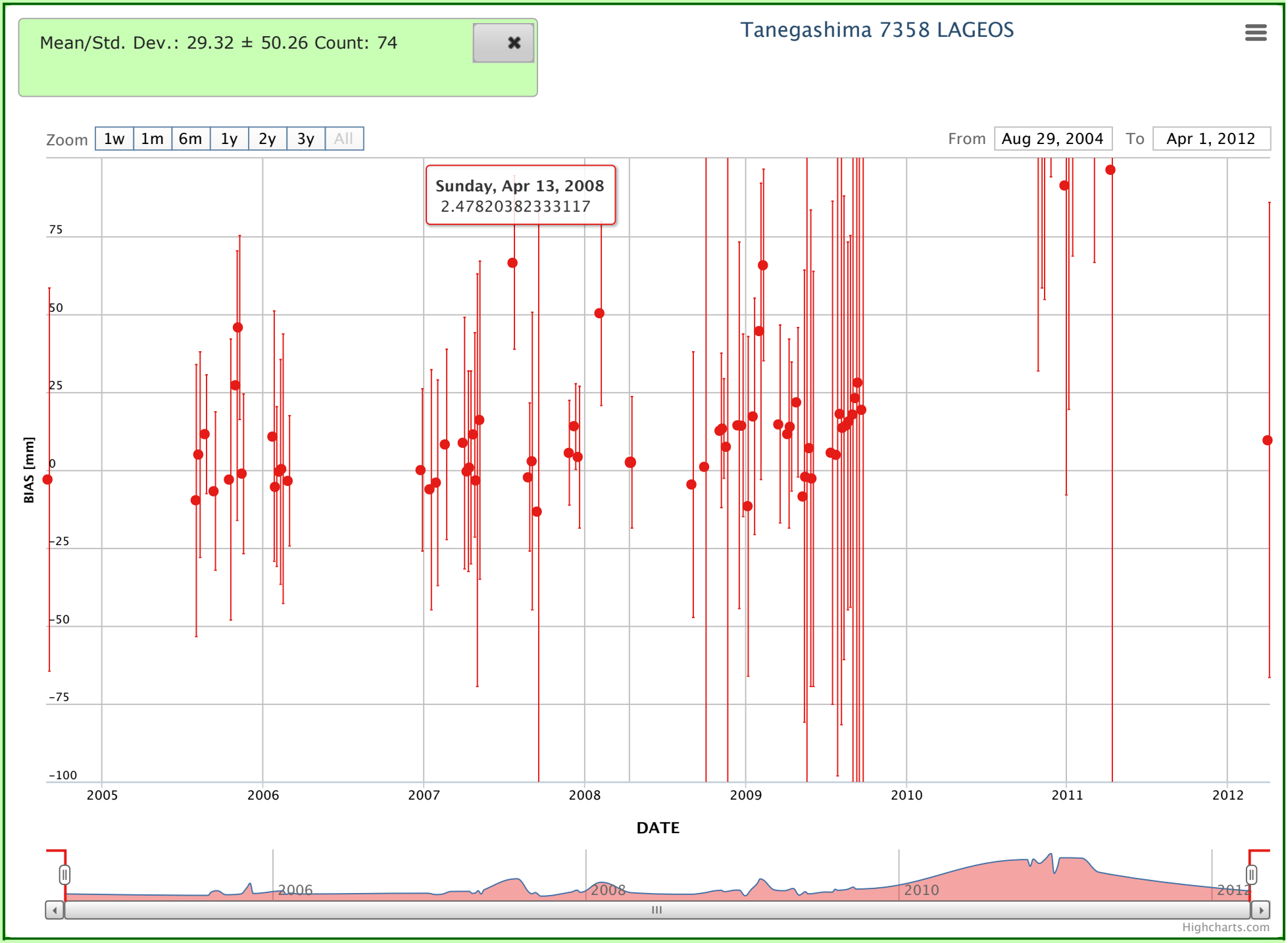



Mean/Std. Dev.: 4.73 ± 7.41 Count: 32
Miura 7337 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Nov 8, 1998 To Apr 30, 2000
75
50
25
0
-25
-50
-75
-100
BIAS [mm]
Jan '99
Mar '99
May '99
Jul '99
Sep '99
Nov '99
Jan '00
Mar '00
May '00
DATE
Jan '99
May '99
Sep '99
Jan '00
Highcharts.com

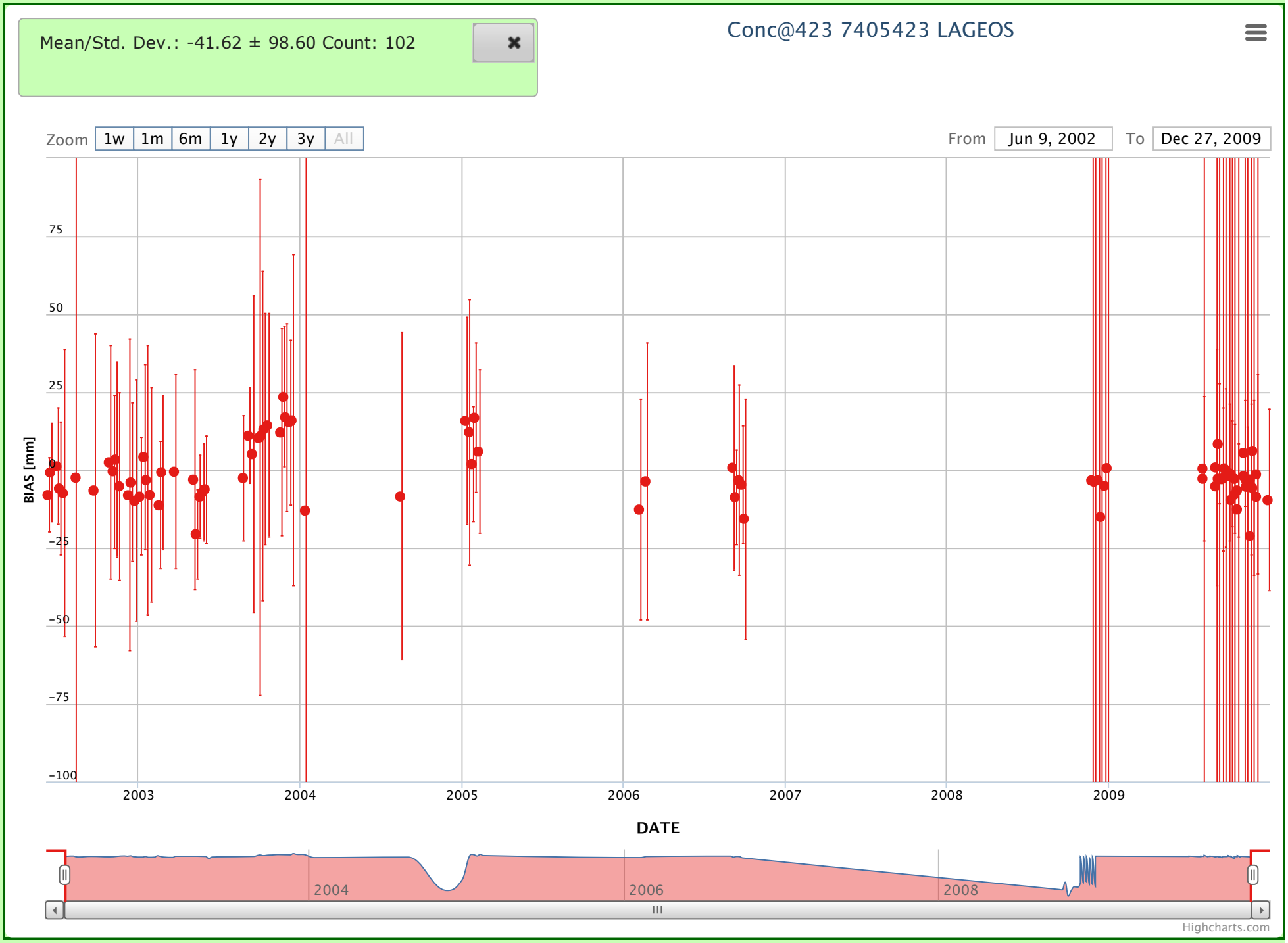

Mean/Std. Dev.: 4.68 ± 6.96 Count: 77
Tateyama 7339 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Sep 6, 1998 To Oct 7, 2001
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
Jan '99
May '99
Sep '99
Jan '00
May '00
Sep '00
Jan '01
May '01
Sep '01
DATE
Jan '99
Jul '99
Jan '00
Jul '00
Jan '01
Jul '01
Highcharts.com

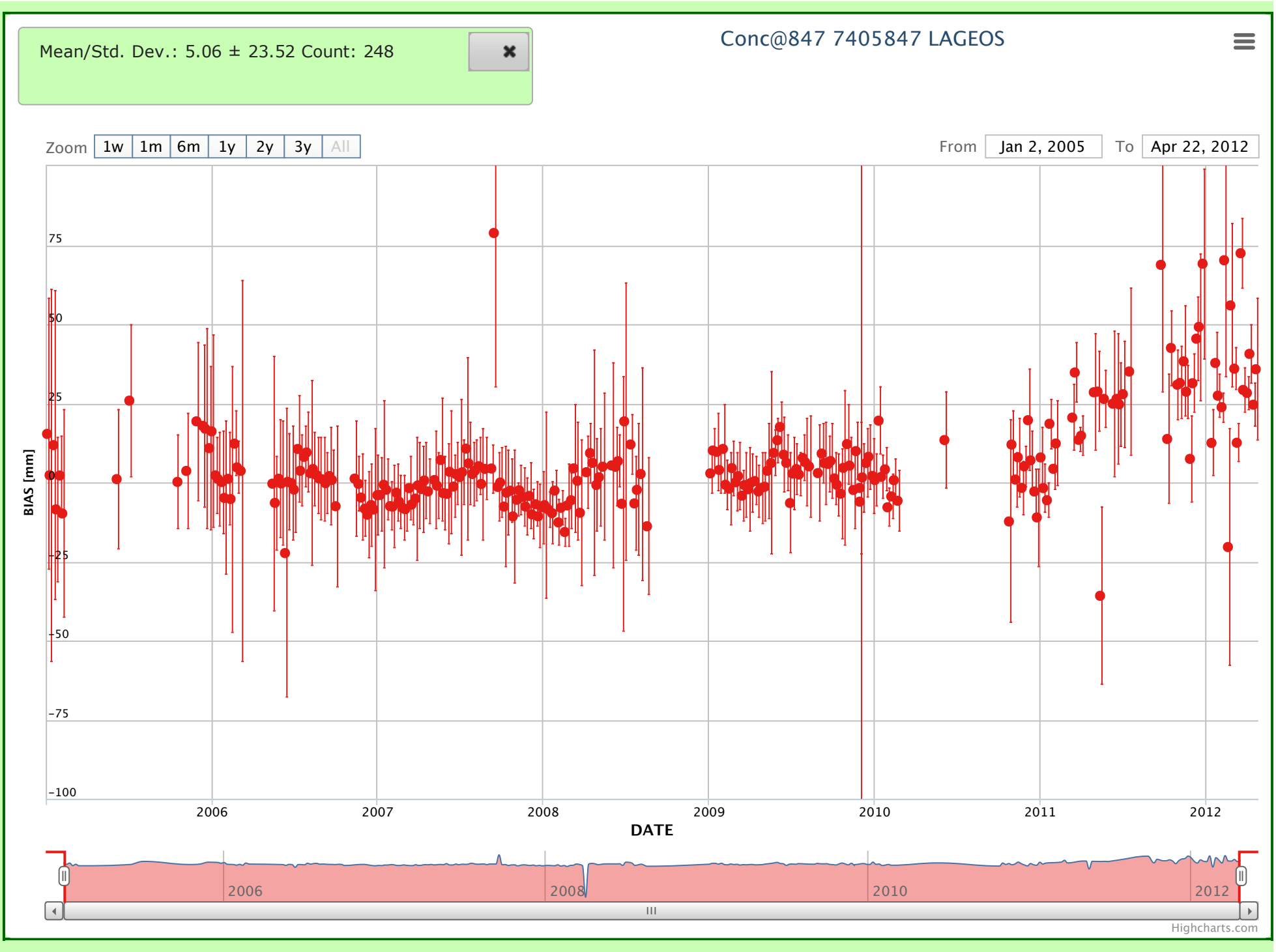
Mean/Std. Dev.: 2.97 ± 11.31 Count: 16

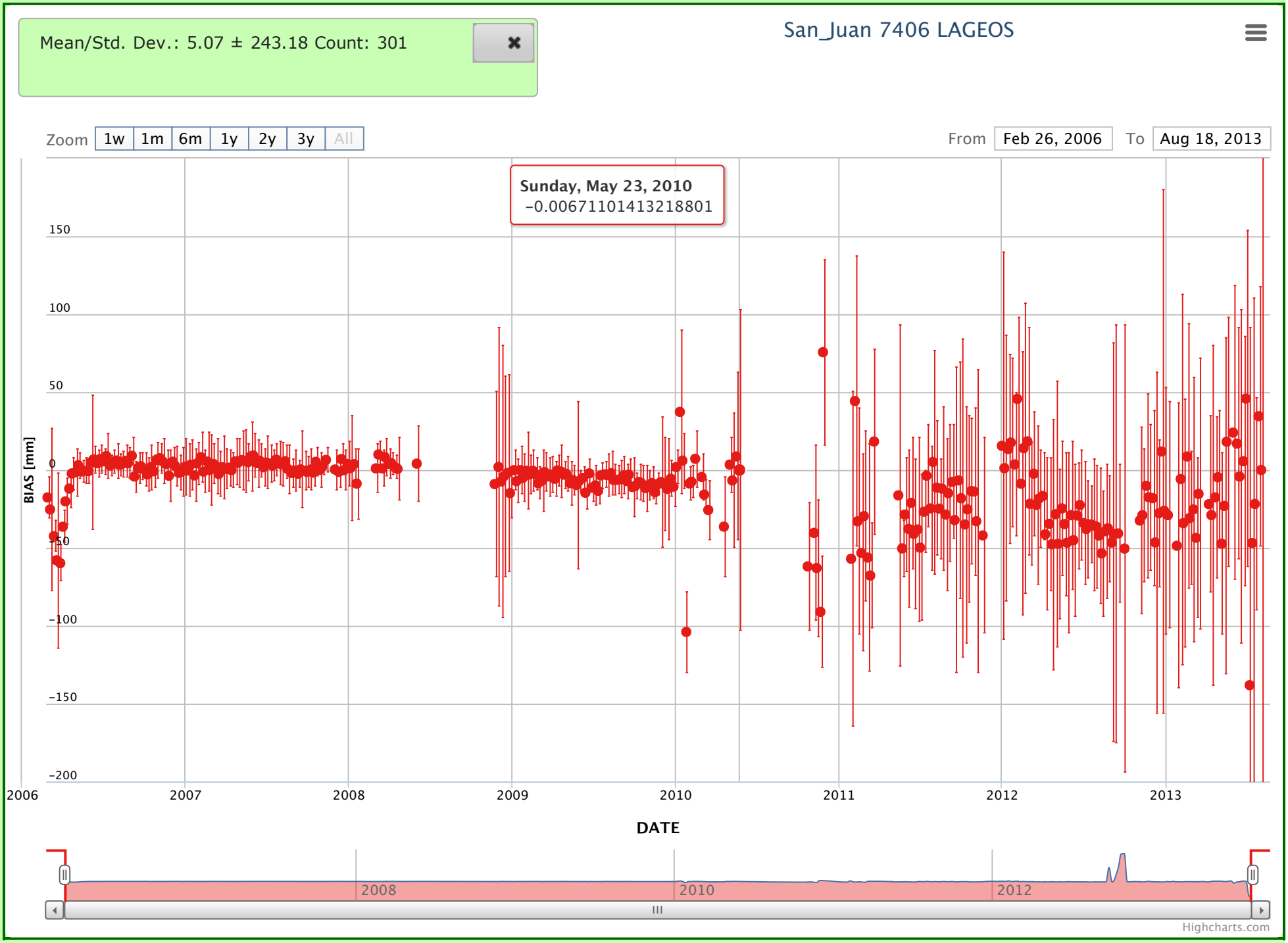



Mean/Std. Dev.: 29.32 ± 50.26 Count: 74
Tanegashima 7358 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Aug 29, 2004 To Apr 1, 2012
Sunday, Apr 13, 2008
2.47820382333117
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
2005
2006
2007
2008
2009
2010
2011
2012
DATE
Highcharts.com

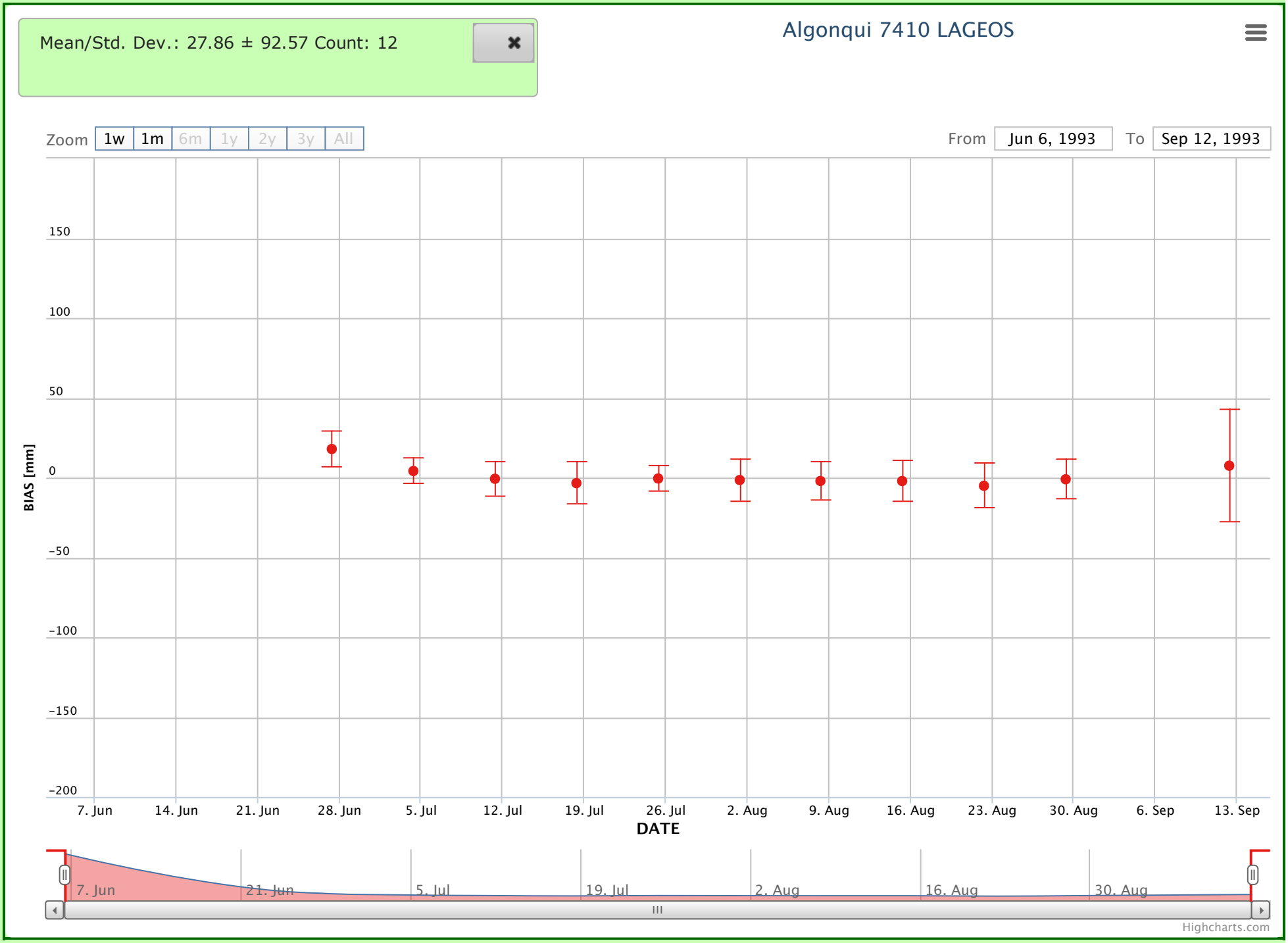

Mean/Std. Dev.: 3.13 ± 17.16 Count: 410
Arequipa 7403 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Feb 7, 1993 To Aug 18, 2013
Sunday, Feb 2, 2003
-4.30480677090875
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
DATE
1995
2000
2005
2010
Highcharts.com


Mean/Std. Dev.: -41.62 ± 98.60 Count: 102
Conc@423 7405423 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jun 9, 2002 To Dec 27, 2009
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
2003
2004
2005
2006
2007
2008
2009
DATE
2004
2006
2008
Highcharts.com

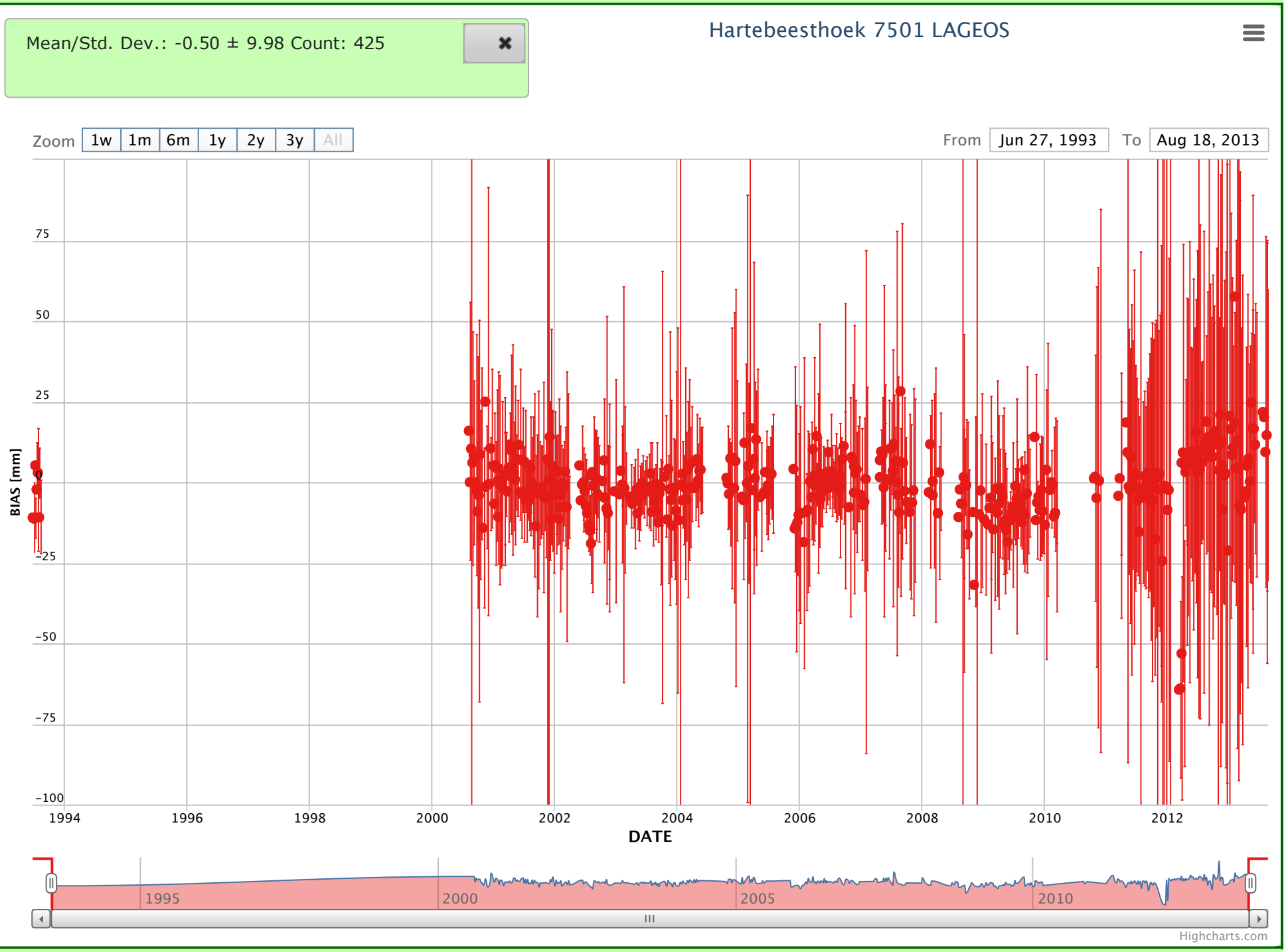

Mean/Std. Dev.: 5.06 ± 23.52 Count: 248
Conc@847 7405847 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jan 2, 2005 To Apr 22, 2012
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
2006
2007
2008
2009
2010
2011
2012
DATE
Highcharts.com

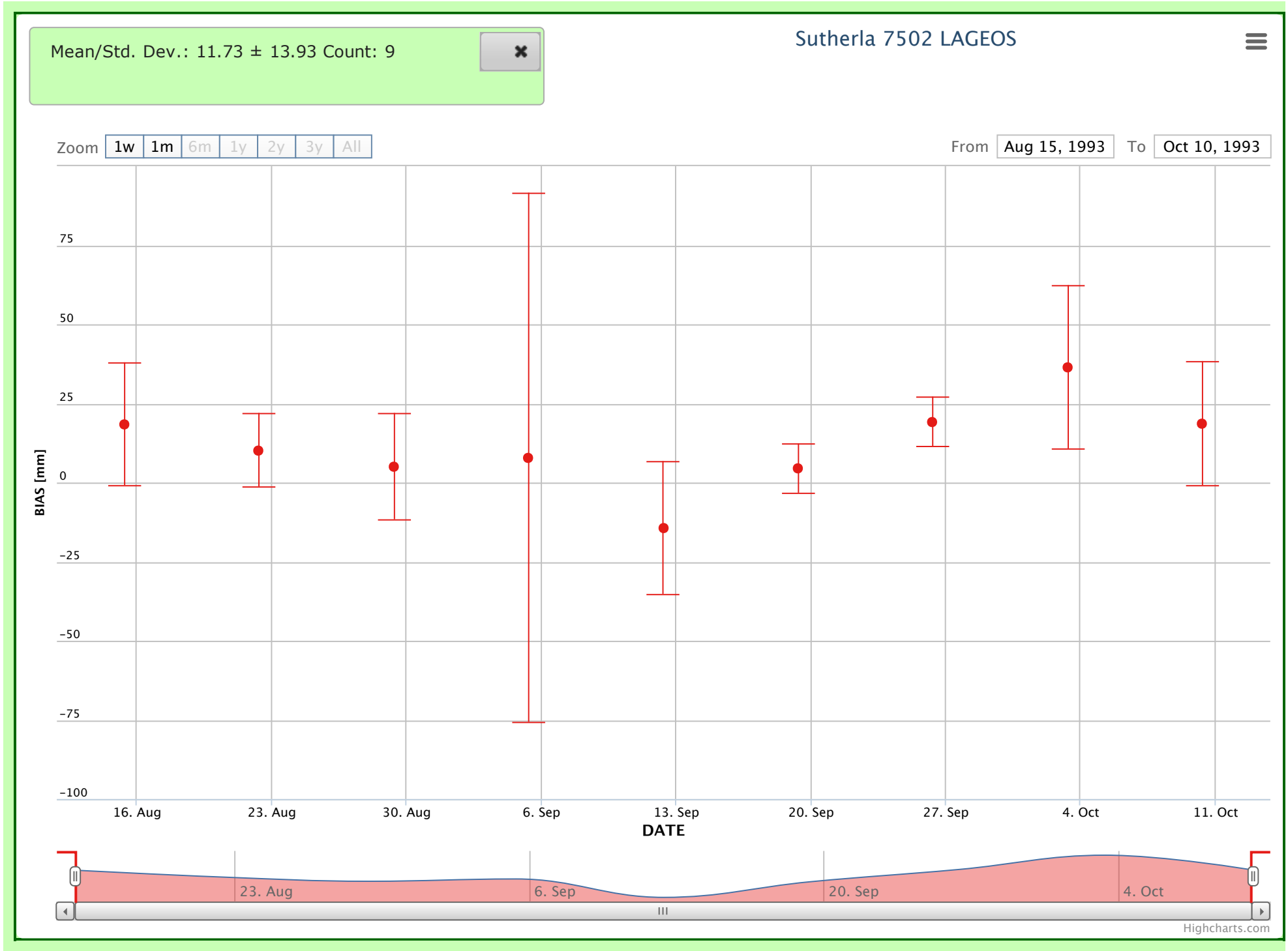

Mean/Std. Dev.: 5.07 ± 243.18 Count: 301
San_Juan 7406 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Feb 26, 2006 To Aug 18, 2013
Sunday, May 23, 2010
-0.00671101413218801
150
100
50
0
-50
-100
-150
-200
BIAS [mm]
2006
2007
2008
2009
2010
2011
2012
2013
DATE
2008
2010
2012
Highcharts.com

Mean/Std. Dev.: 27.86 ± 92.57 Count: 12

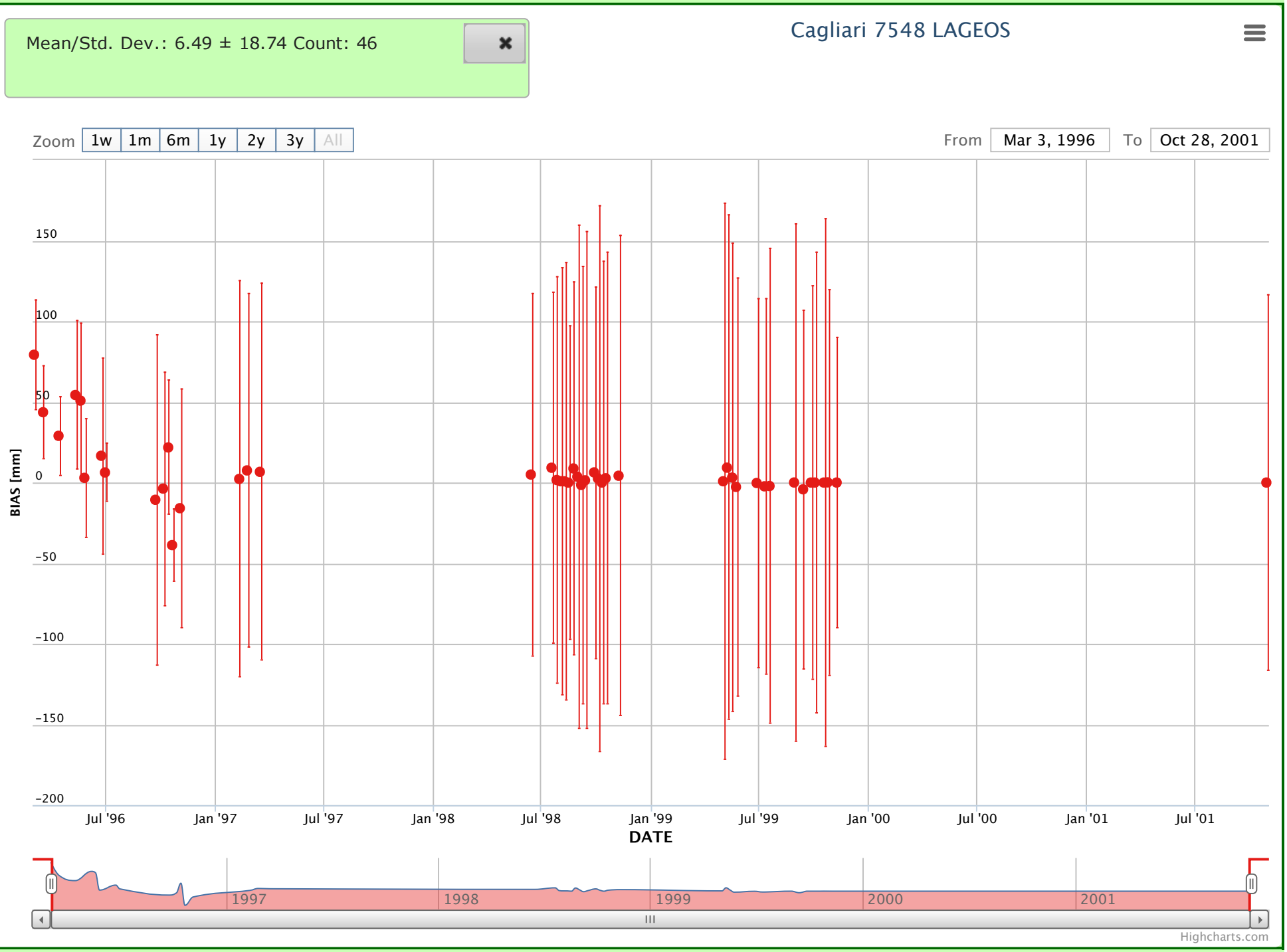


Mean/Std. Dev.: -0.50 ± 9.98 Count: 425



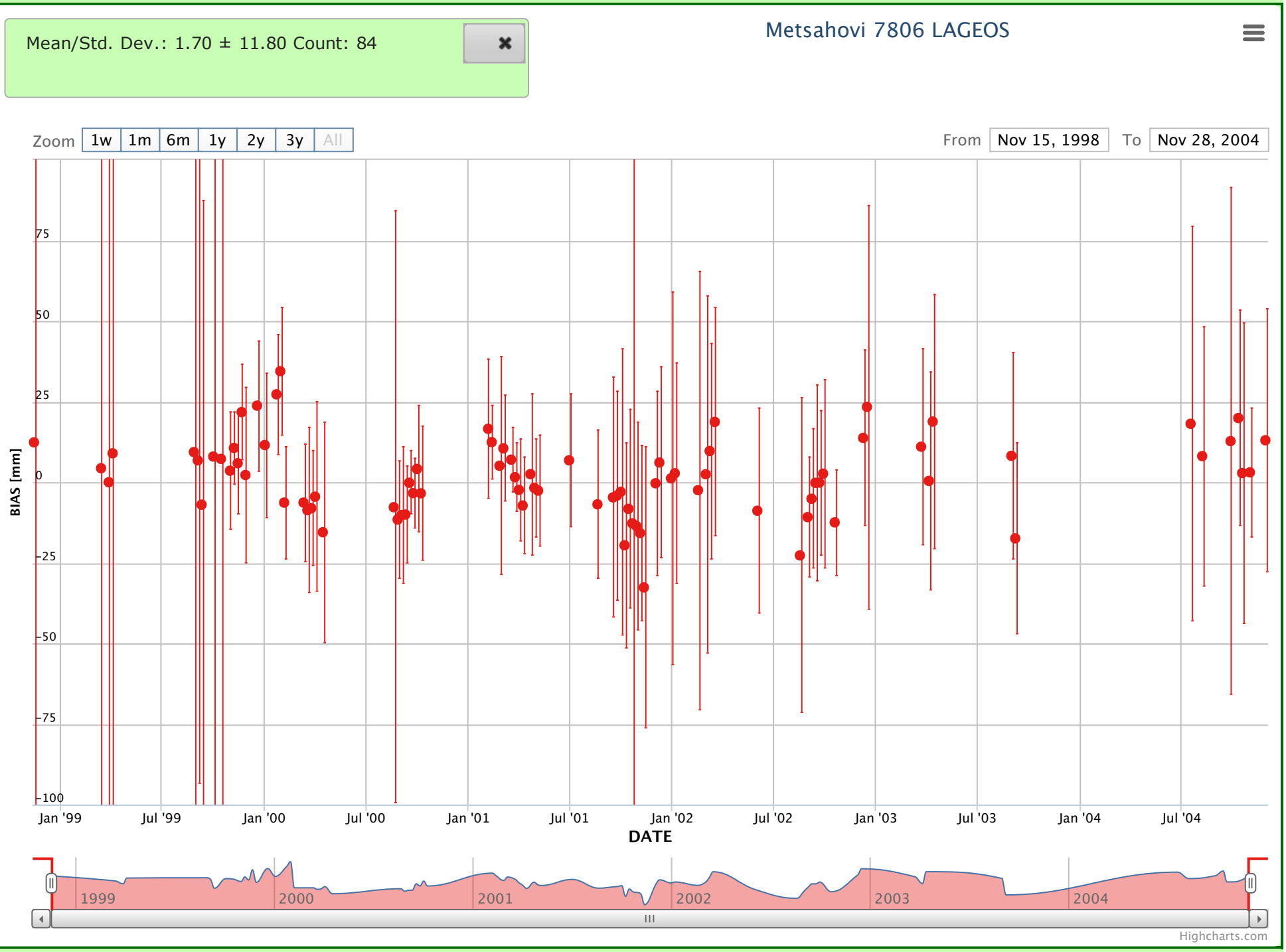

Mean/Std. Dev.: 11.73 ± 13.93 Count: 9
Sutherla 7502 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Aug 15, 1993 To Oct 10, 1993
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
16. Aug
23. Aug
30. Aug
6. Sep
13. Sep
20. Sep
27. Sep
4. Oct
11. Oct
DATE
23. Aug
6. Sep
20. Sep
4. Oct
Highcharts.com

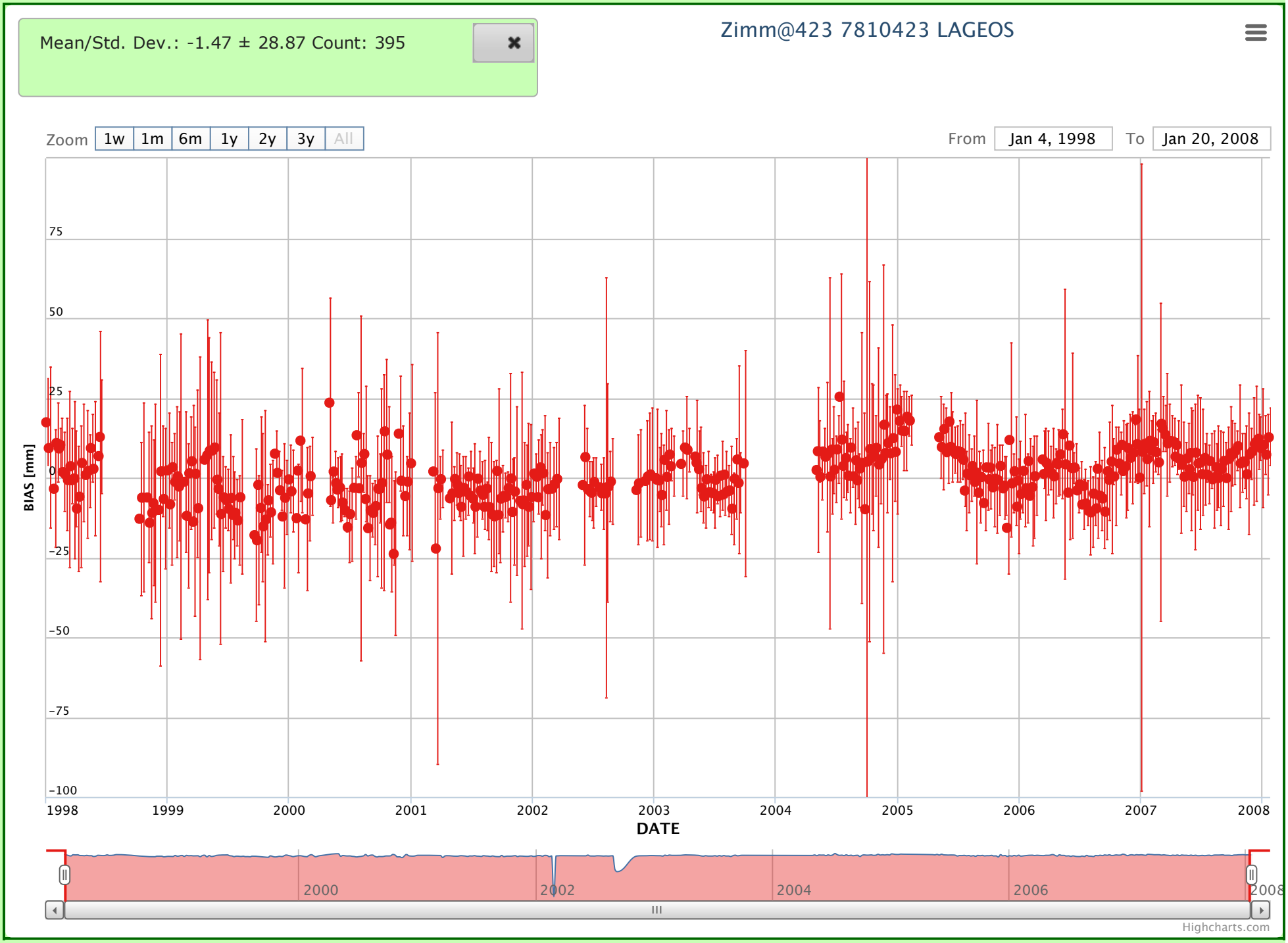
Mean/Std. Dev.: 6.49 ± 18.74 Count: 46

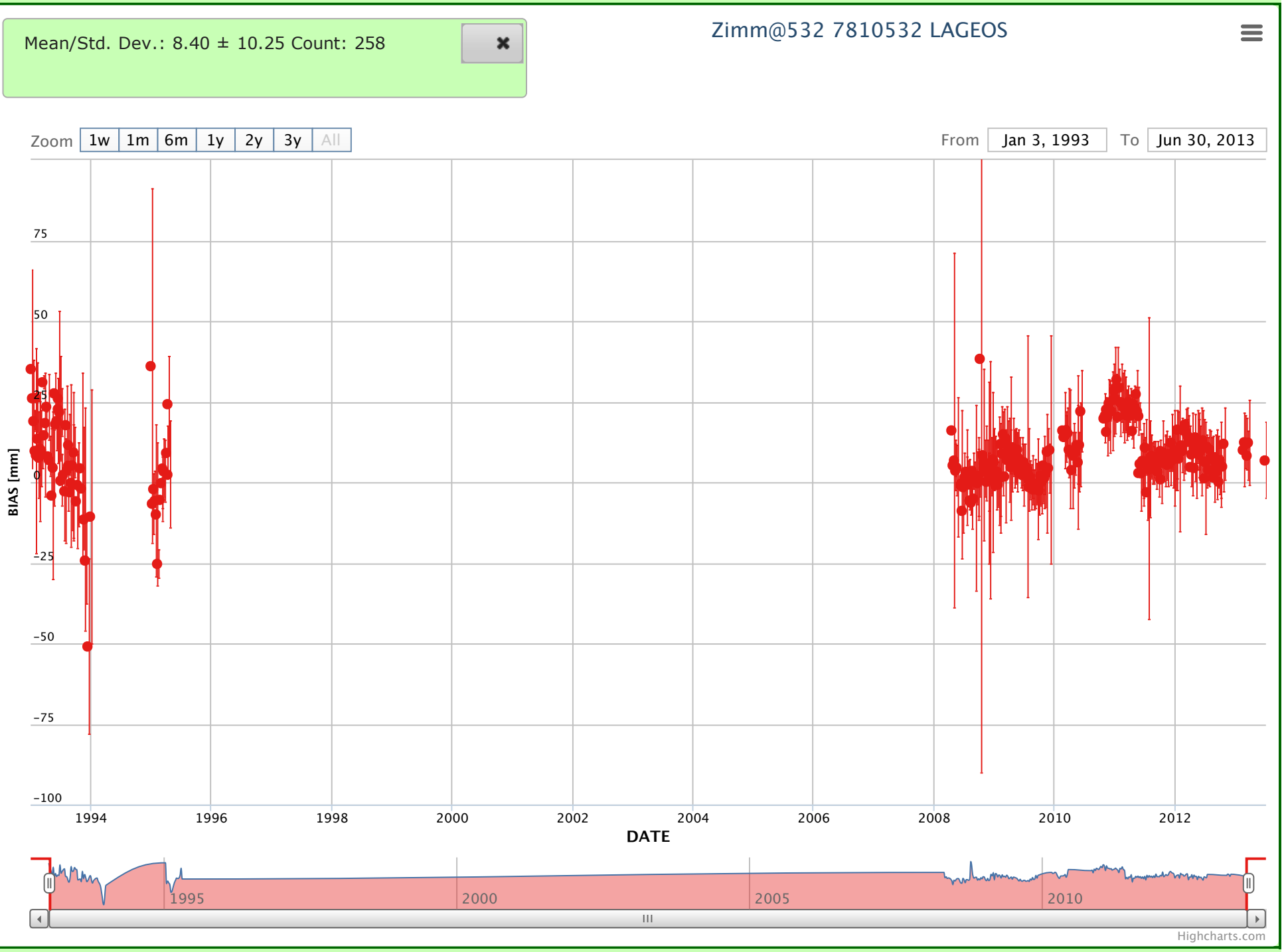


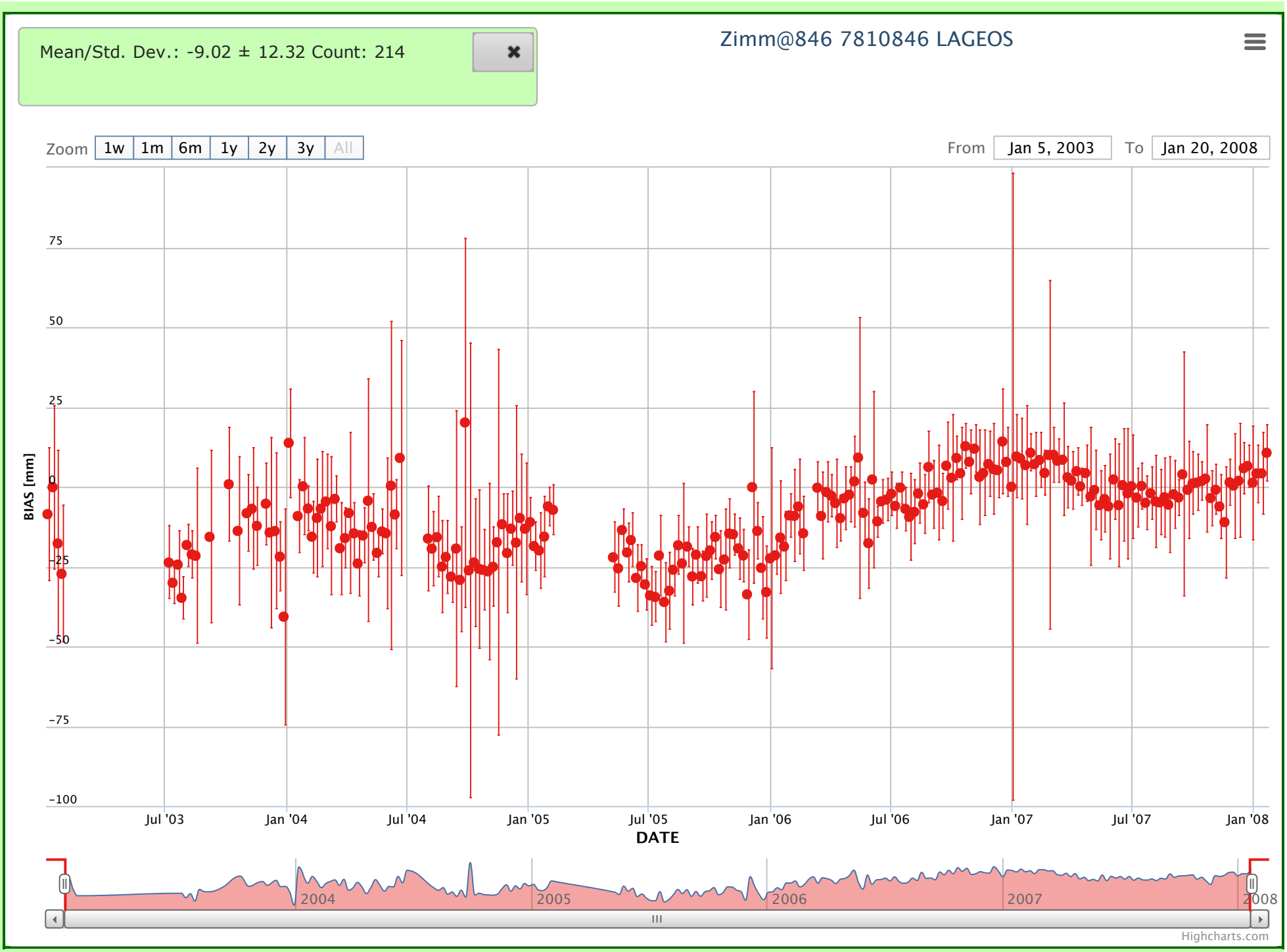
Mean/Std. Dev.: 1.50 ± 8.99 Count: 14

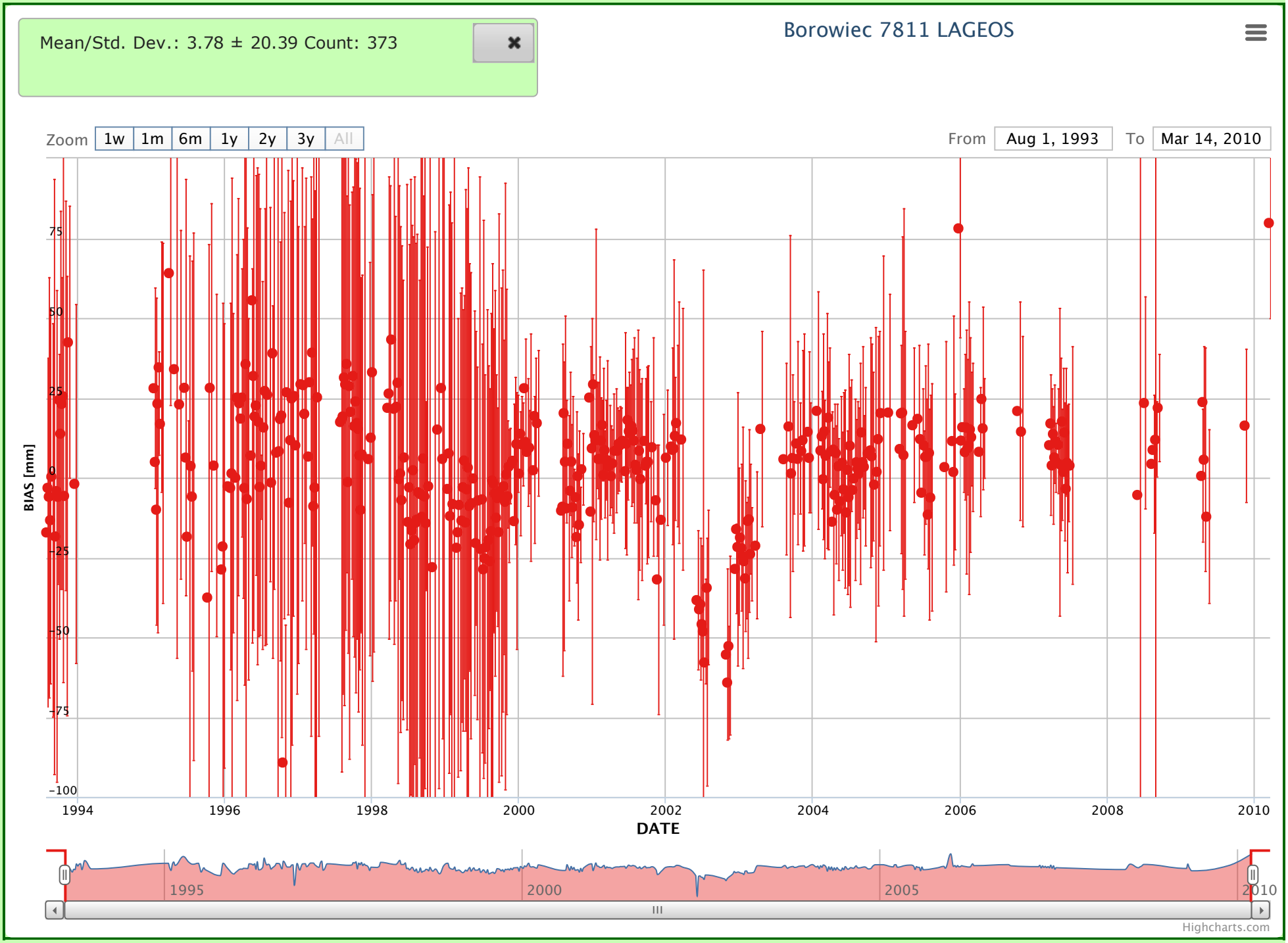
Mean/Std. Dev.: 1.70 ± 11.80 Count: 84




Mean/Std. Dev.: -1.47 ± 28.87 Count: 395
Zimm@423 7810423 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jan 4, 1998 To Jan 20, 2008
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
DATE
2000 2002 2004 2006 2008
Highcharts.com


Mean/Std. Dev.: 8.40 ± 10.25 Count: 258
Zimm@532 7810532 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jan 3, 1993 To Jun 30, 2013
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
1994 1996 1998 2000 2002 2004 2006 2008 2010 2012
DATE
1995 2000 2005 2010
Highcharts.com


Mean/Std. Dev.: -9.02 ± 12.32 Count: 214
Zimm@846 7810846 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jan 5, 2003 To Jan 20, 2008
75
50
25
0
-25
-50
-75
-100
BIAS [mm]
Jul '03
Jan '04
Jul '04
Jan '05
Jul '05
Jan '06
Jul '06
Jan '07
Jul '07
Jan '08
DATE
2004
2005
2006
2007
2008
Highcharts.com


Mean/Std. Dev.: 3.78 ± 20.39 Count: 373
Borowiec 7811 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Aug 1, 1993 To Mar 14, 2010
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
1994
1996
1998
2000
2002
2004
2006
2008
2010
DATE
1995
2000
2005
2010
Highcharts.com

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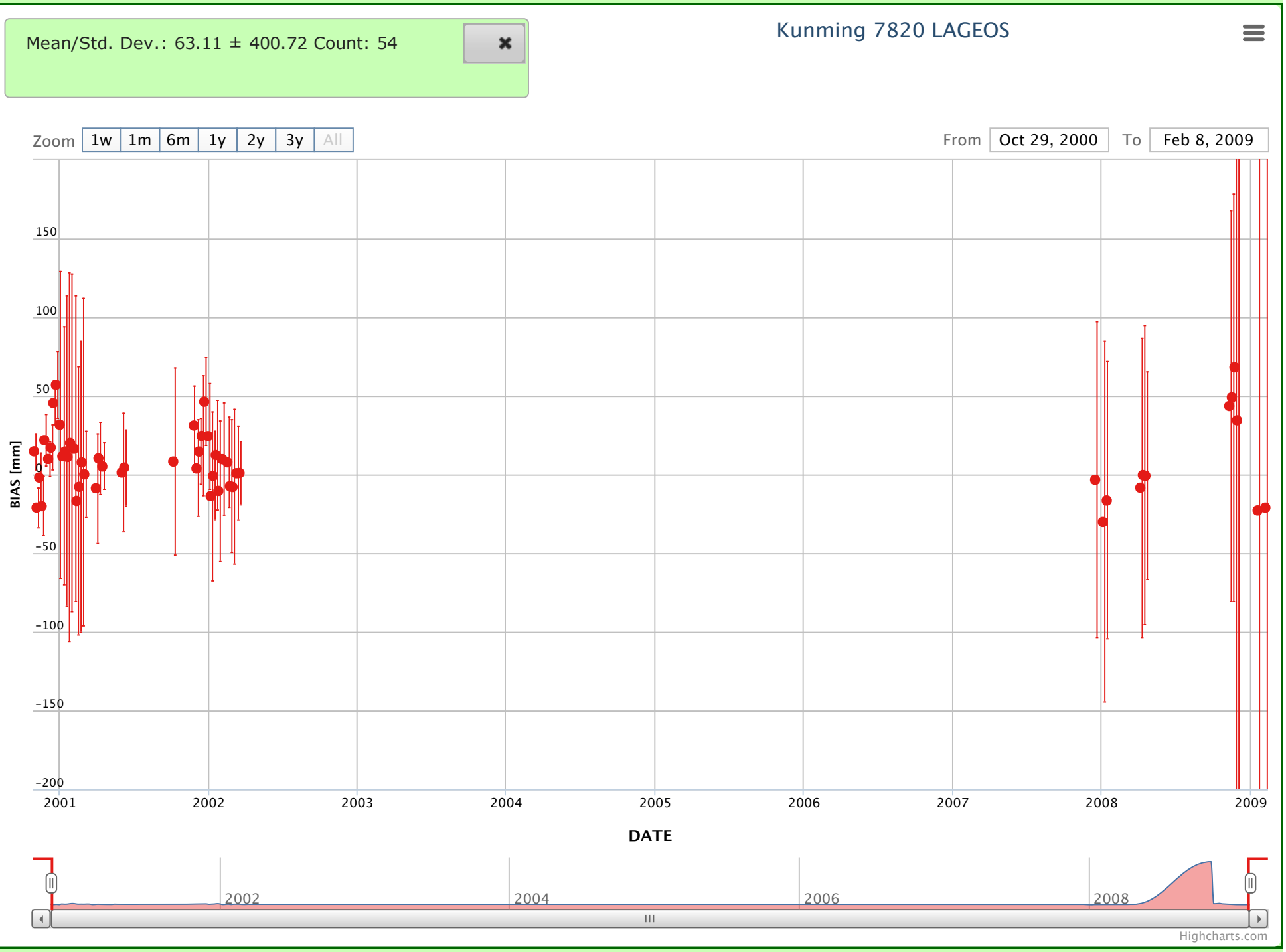
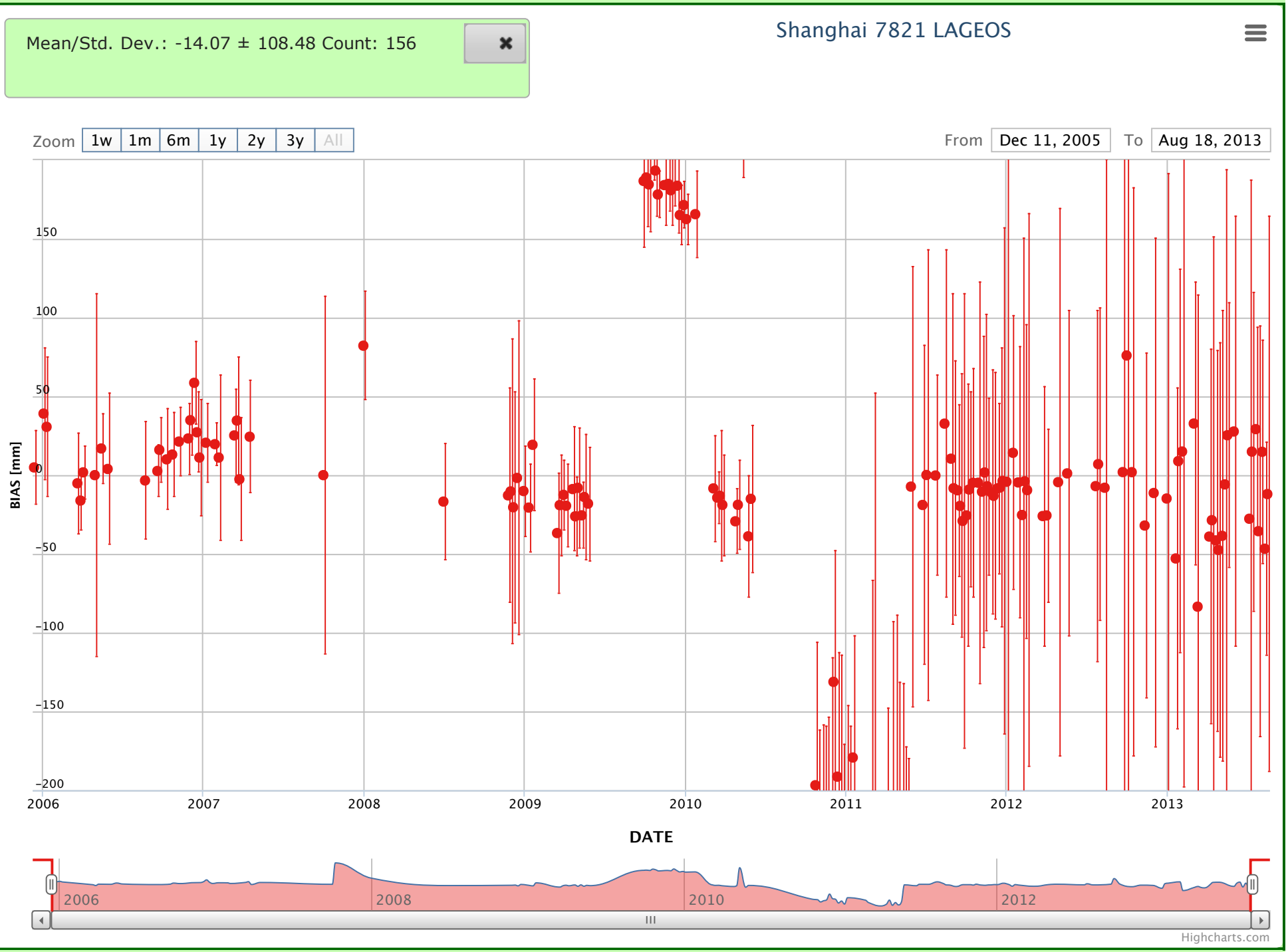
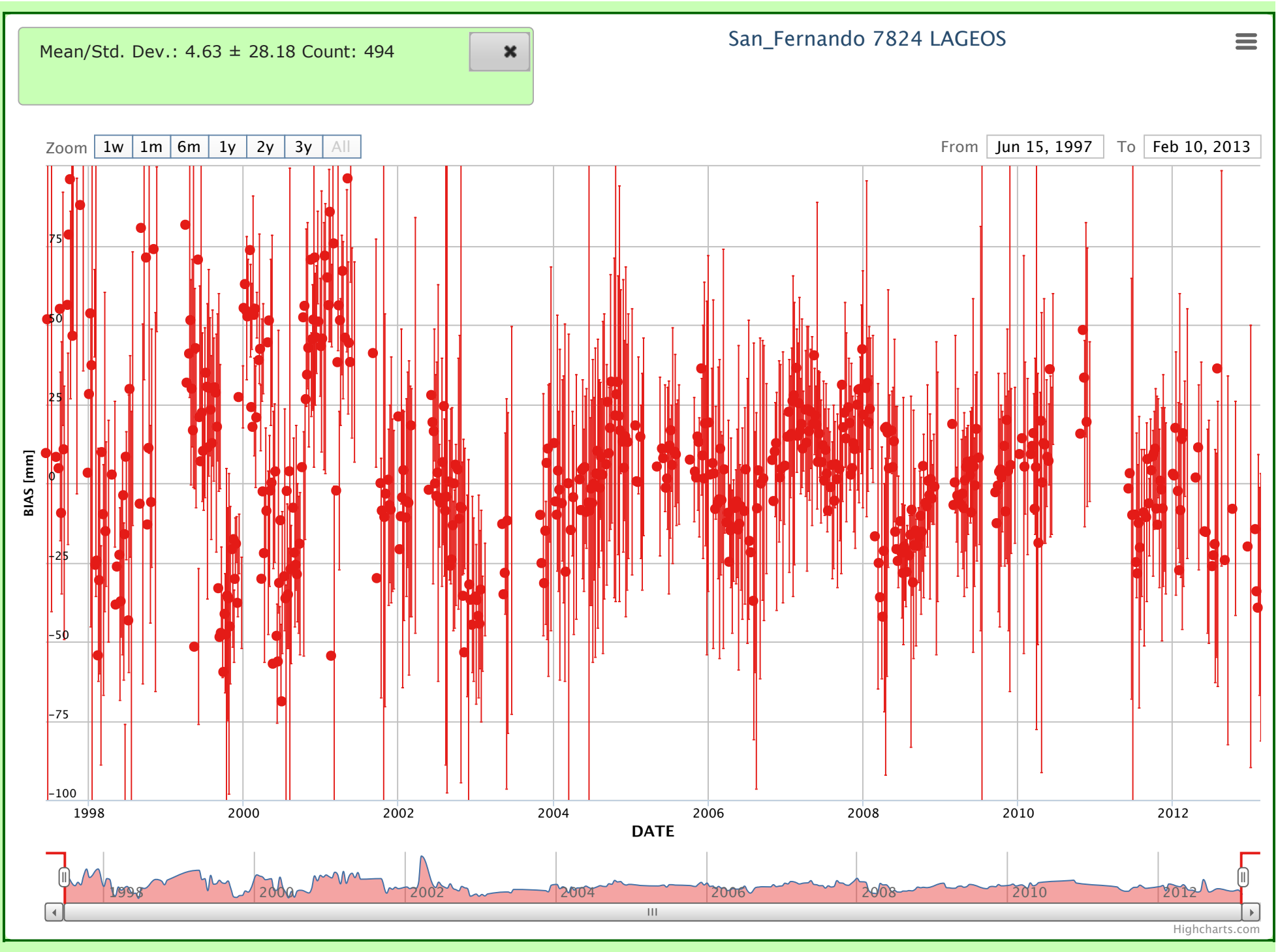
Mean/Std. Dev.: 63.11 ± 400.72 Count: 54



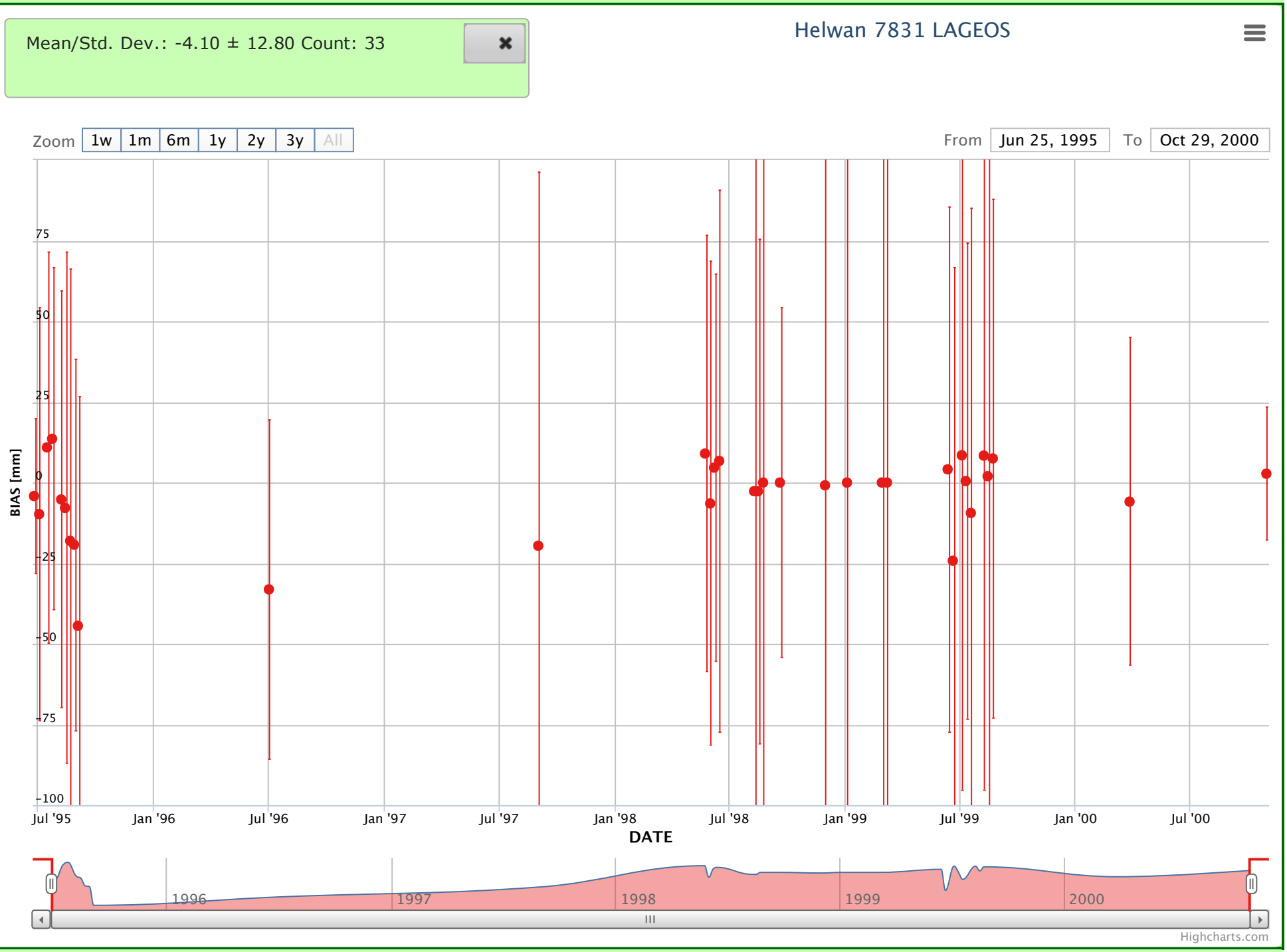
Mean/Std. Dev.: -14.07 ± 108.48 Count: 156



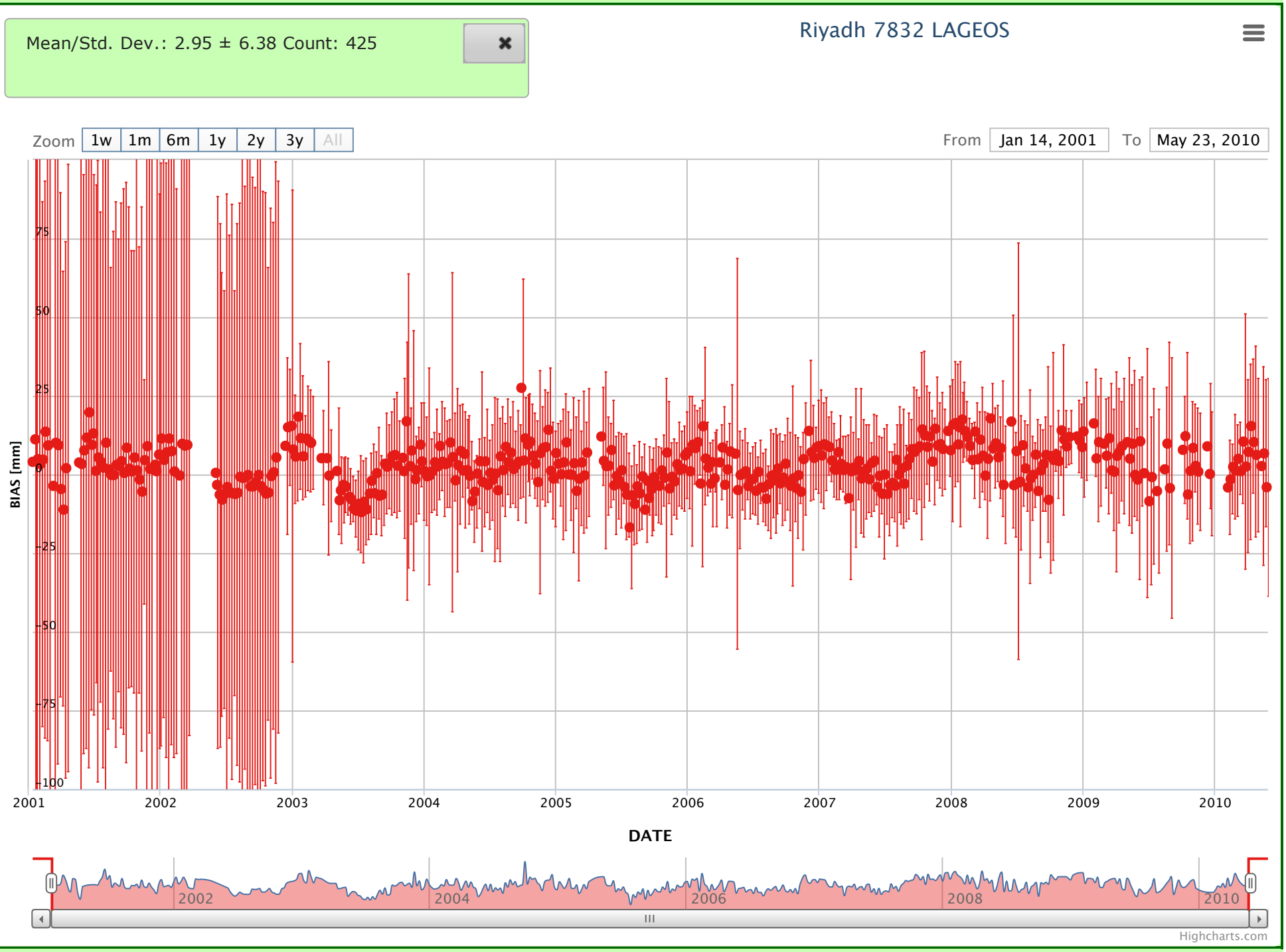

Mean/Std. Dev.: 4.63 ± 28.18 Count: 494
San_Fernando 7824 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jun 15, 1997 To Feb 10, 2013
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
1998
2000
2002
2004
2006
2008
2010
2012
DATE
Highcharts.com


Mean/Std. Dev.: 5.24 ± 8.37 Count: 434
Mt_Stromlo 7825 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Aug 1, 2004 To Aug 18, 2013
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
2005
2006
2007
2008
2009
2010
2011
2012
2013
DATE
2006
2008
2010
2012
Highcharts.com

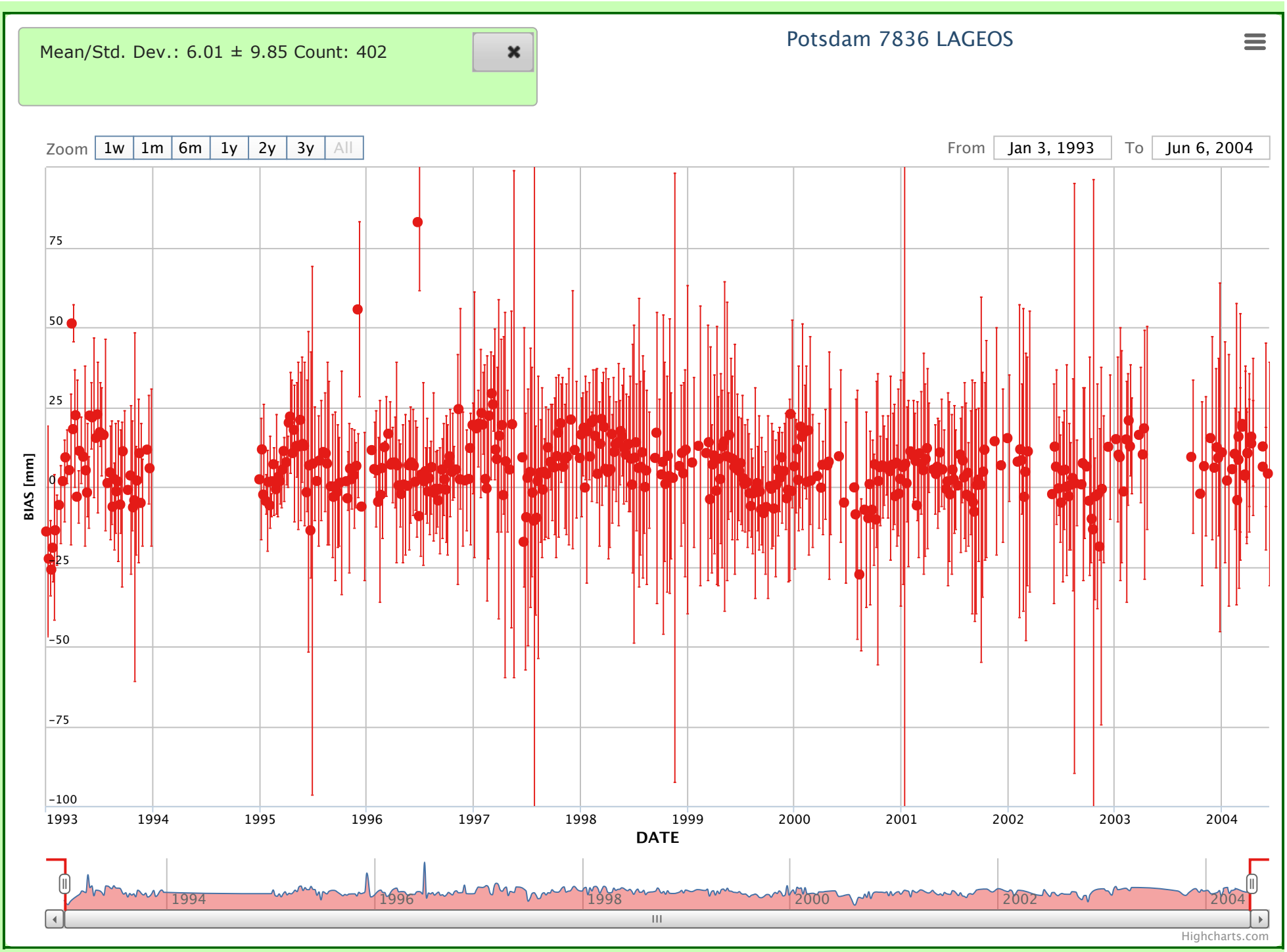
Mean/Std. Dev.: -4.10 ± 12.80 Count: 33

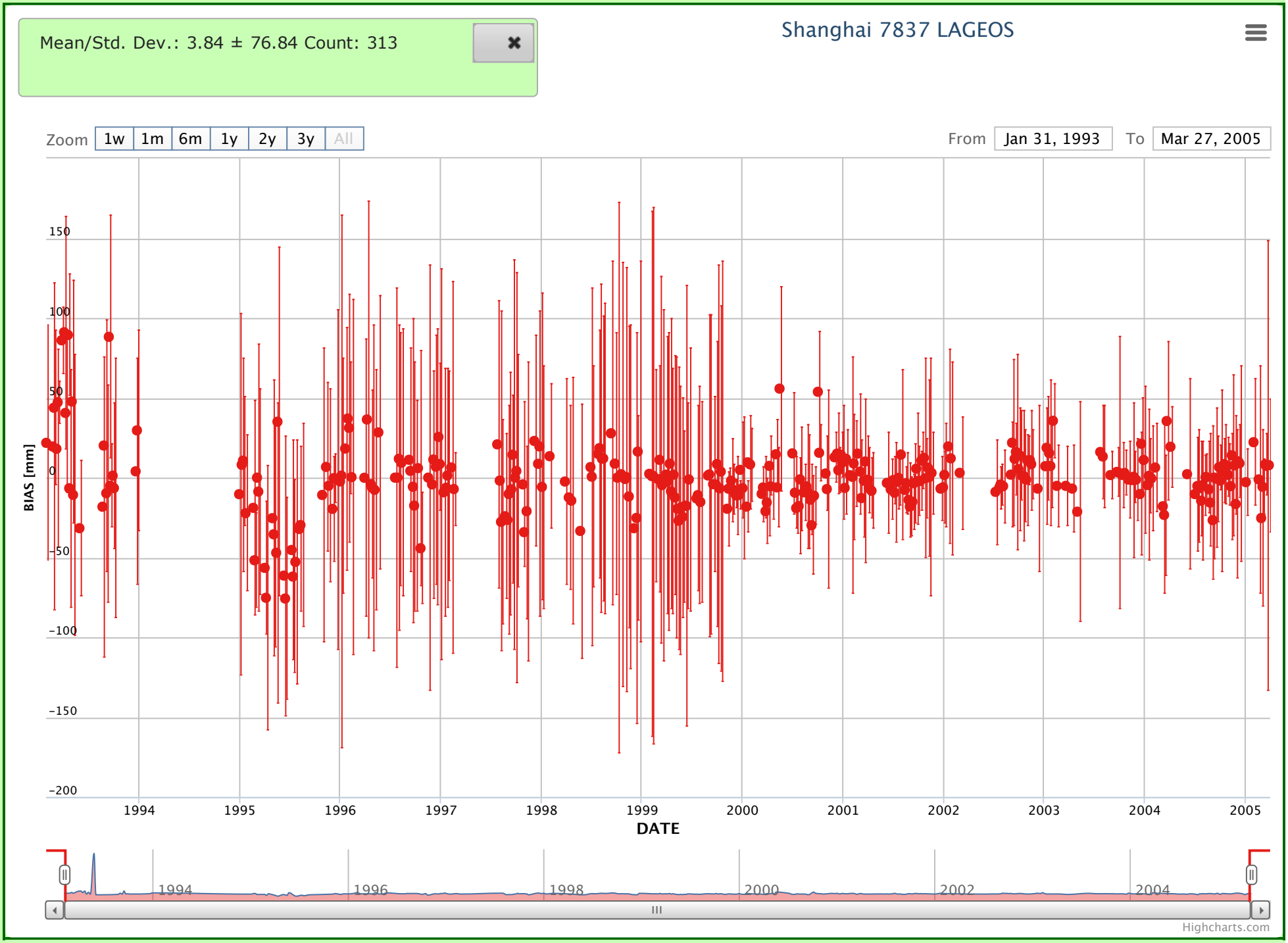


Mean/Std. Dev.: 2.95 ± 6.38 Count: 425

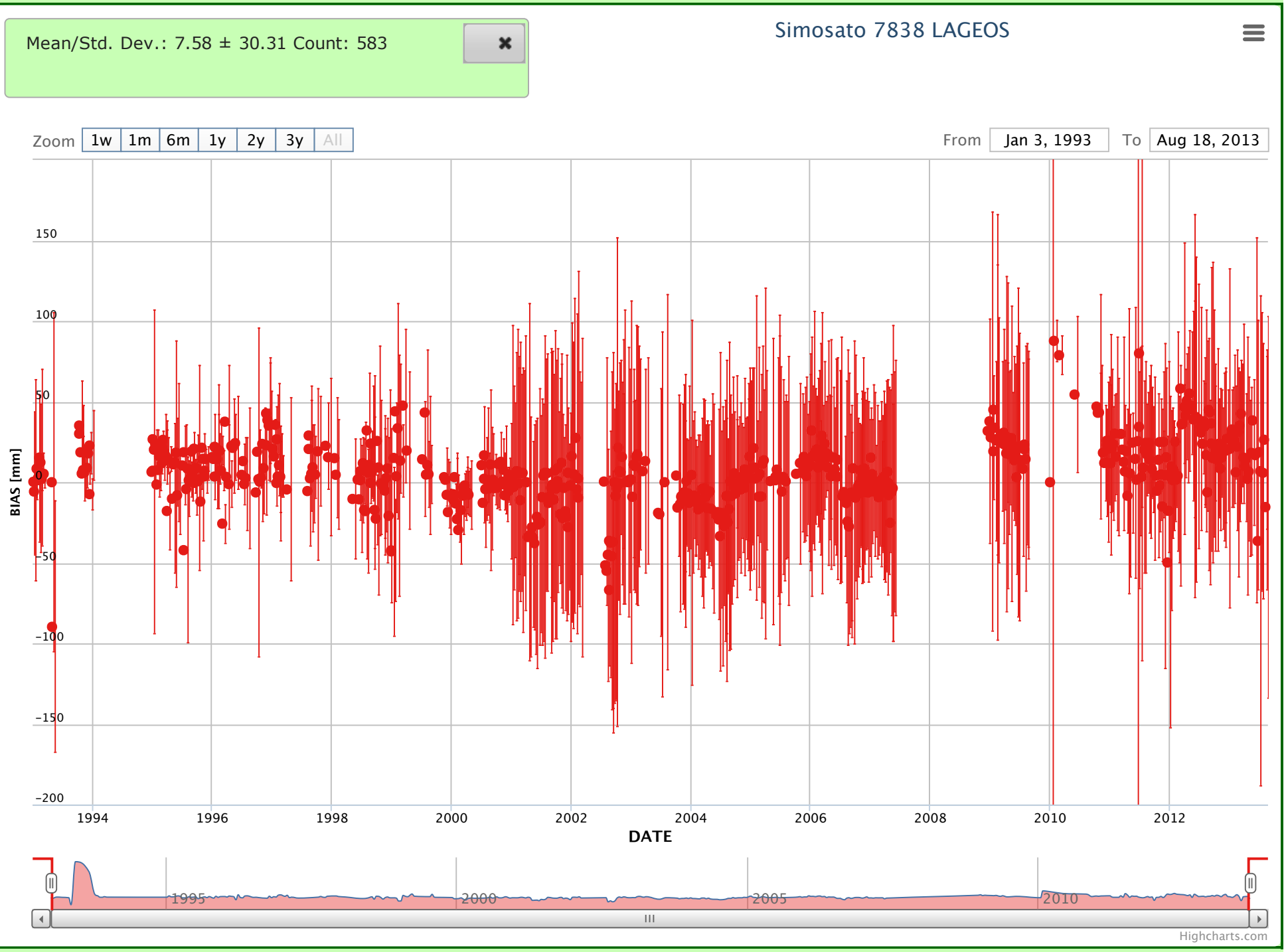



Mean/Std. Dev.: -0.26 ± 50.12 Count: 615
Grasse 7835 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jan 3, 1993 To Jul 3, 2005
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005
DATE
1994 1996 1998 2000 2002 2004
Highcharts.com

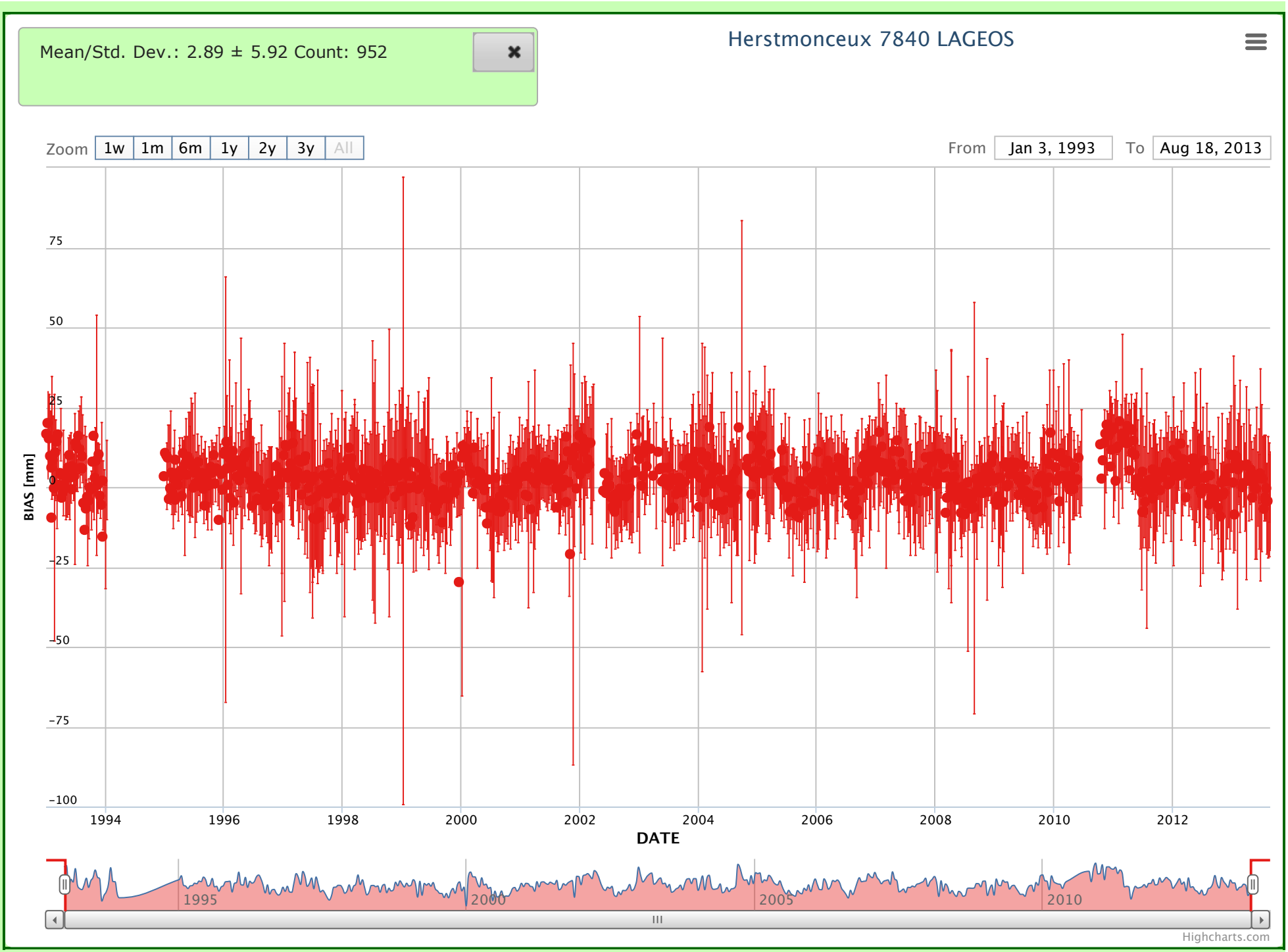

Mean/Std. Dev.: 6.01 ± 9.85 Count: 402
Potsdam 7836 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jan 3, 1993 To Jun 6, 2004
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
DATE
1994 1996 1998 2000 2002 2004
Highcharts.com


Mean/Std. Dev.: 3.84 ± 76.84 Count: 313
Shanghai 7837 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jan 31, 1993 To Mar 27, 2005
BIAS [mm]
150
100
50
0
-50
-100
-150
-200
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005
DATE
1994 1996 1998 2000 2002 2004
Highcharts.com

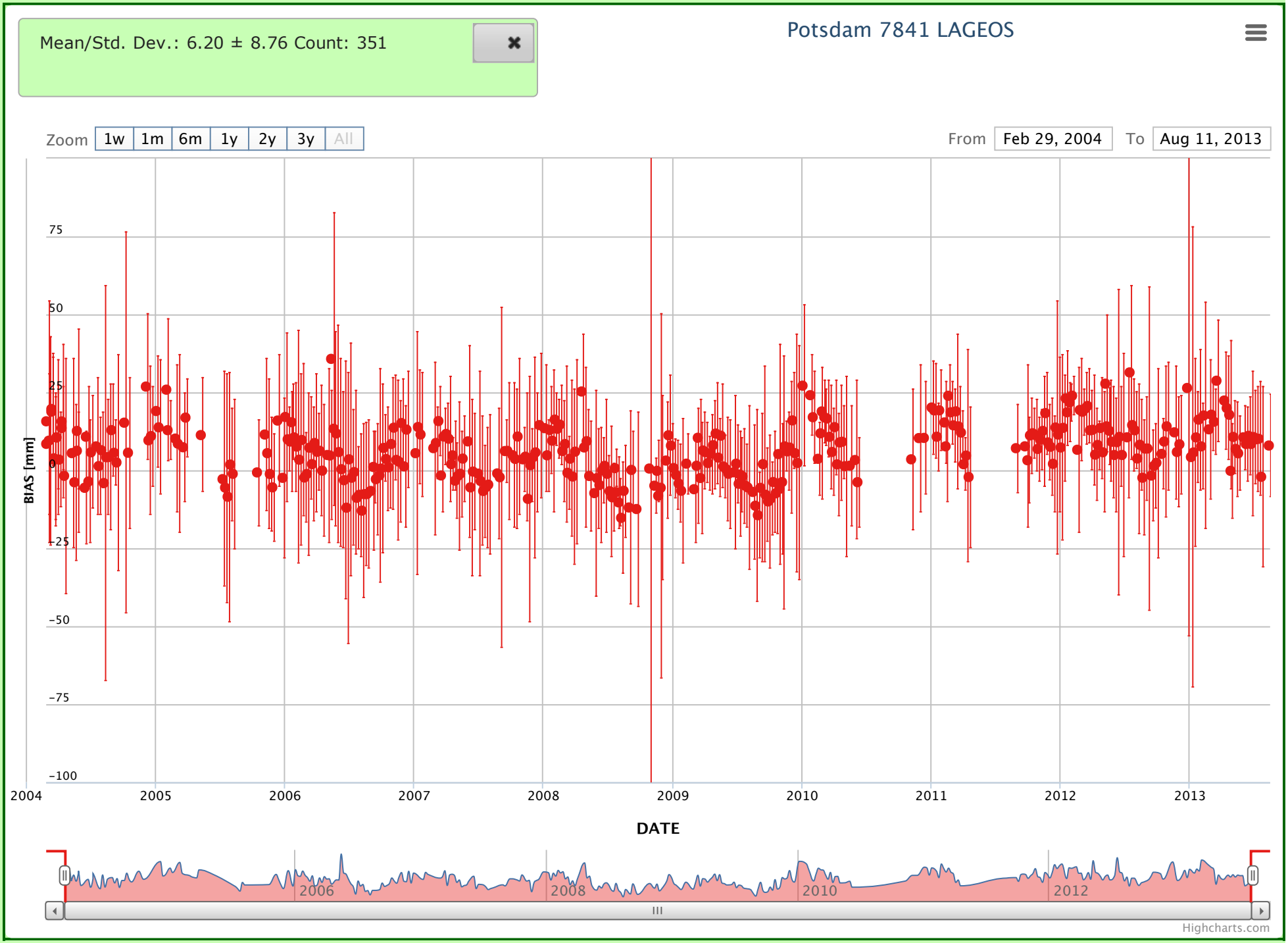
Mean/Std. Dev.: 7.58 ± 30.31 Count: 583



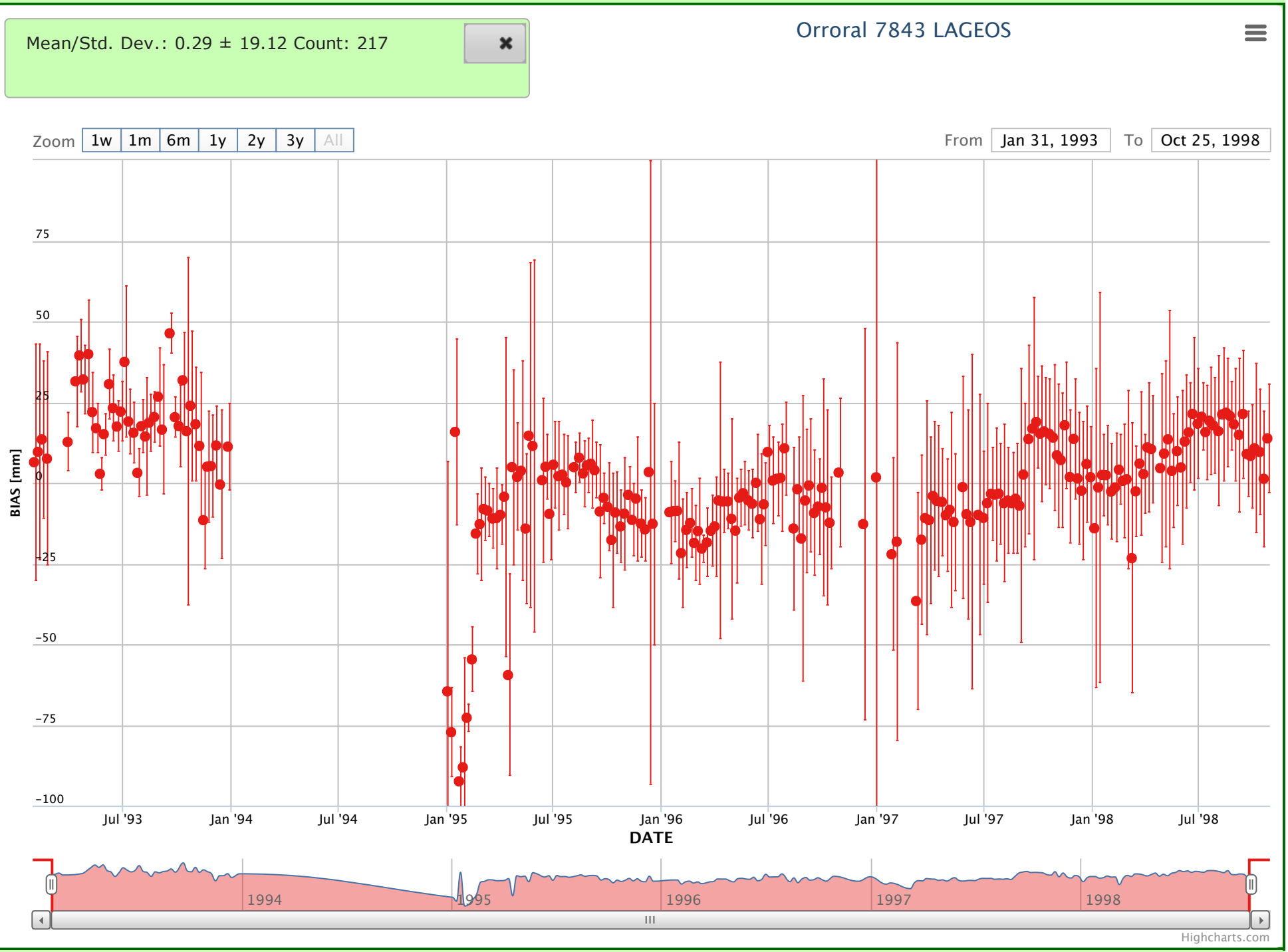
Mean/Std. Dev.: 8.06 ± 138.84 Count: 895


Mean/Std. Dev.: 2.89 ± 5.92 Count: 952
Herstmonceux 7840 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jan 3, 1993 To Aug 18, 2013
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
1994 1996 1998 2000 2002 2004 2006 2008 2010 2012
DATE
1995 2000 2005 2010
Highcharts.com

Mean/Std. Dev.: 6.20 ± 8.76 Count: 351

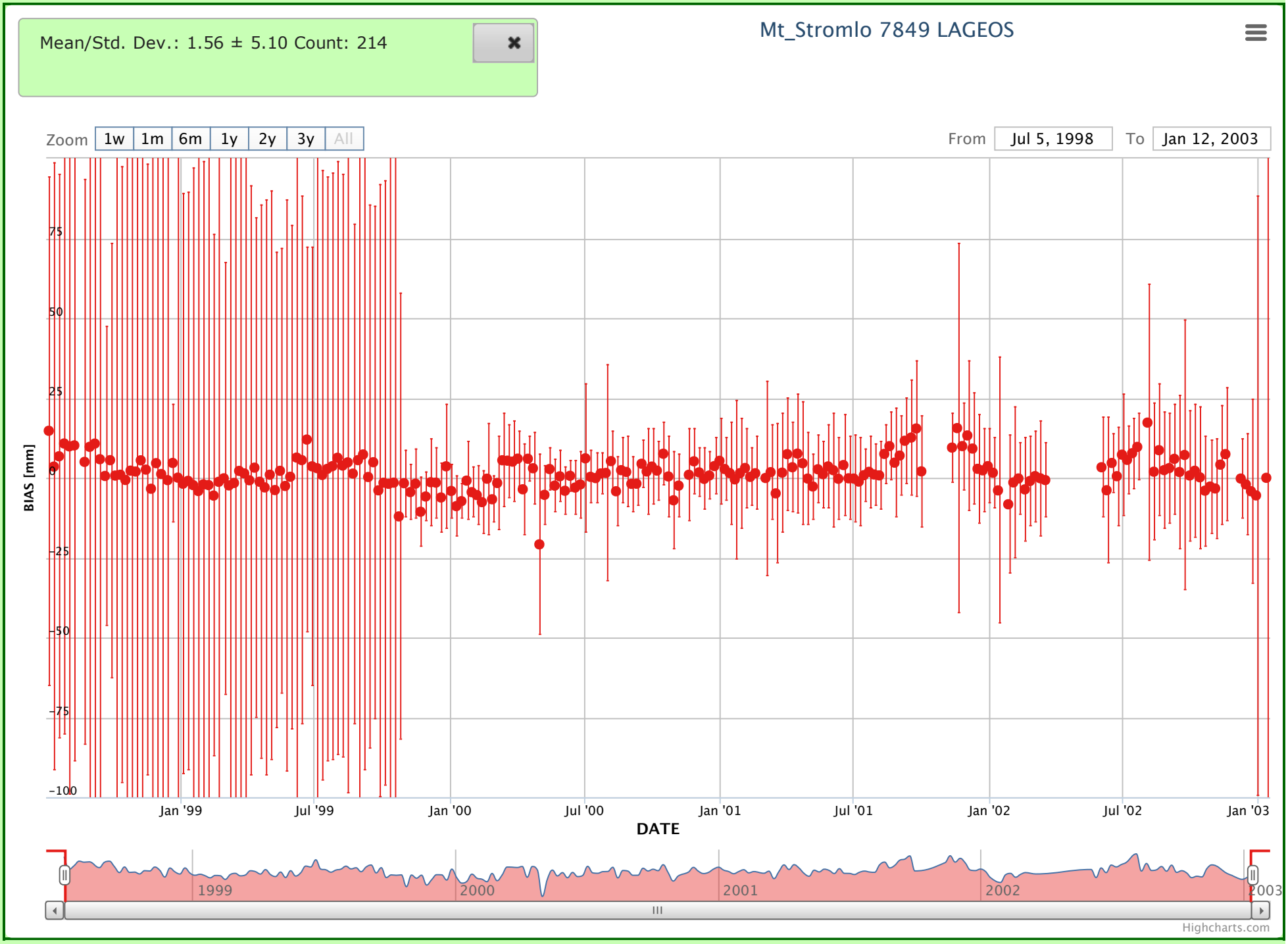


Mean/Std. Dev.: 0.29 ± 19.12 Count: 217

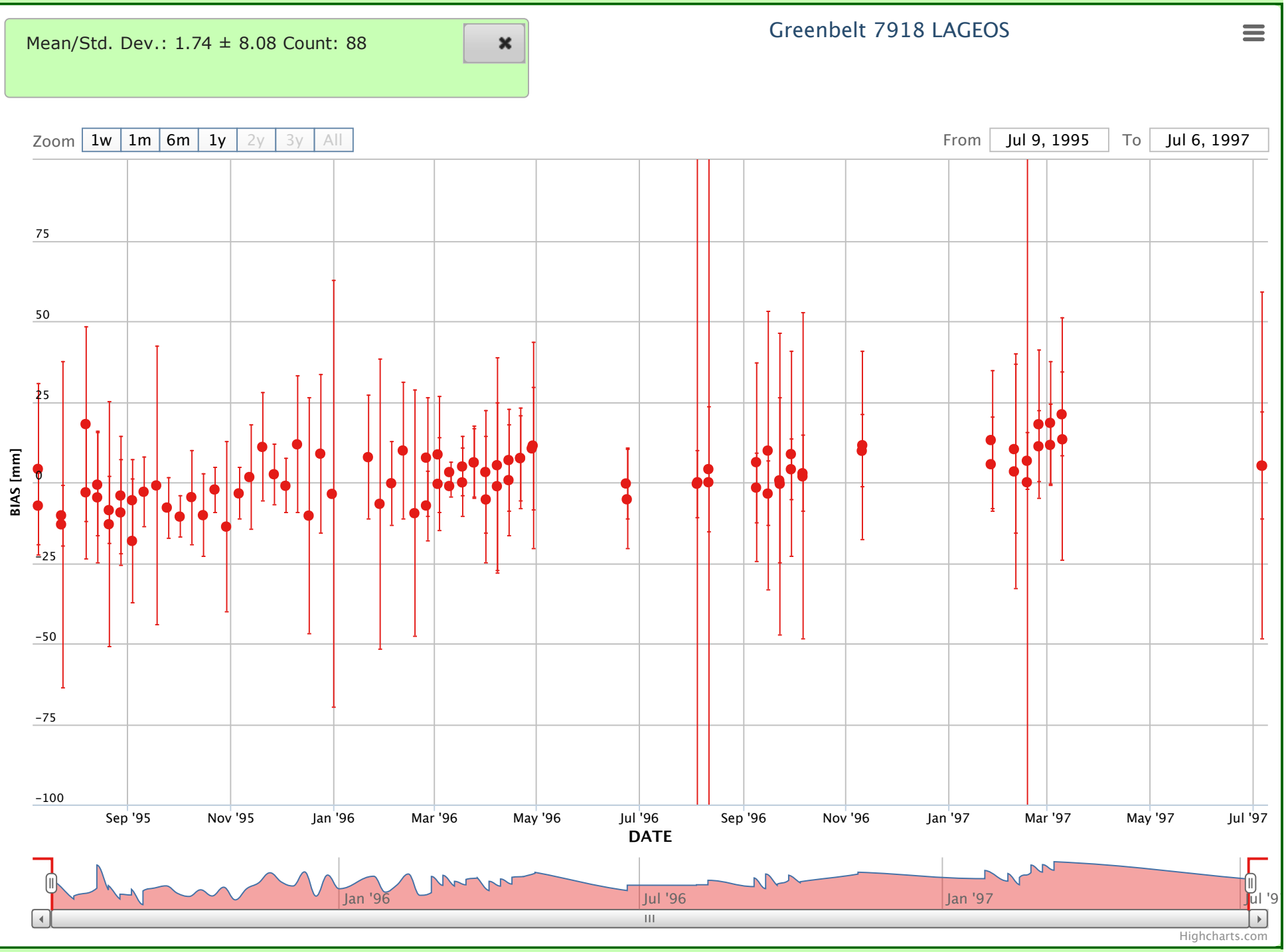


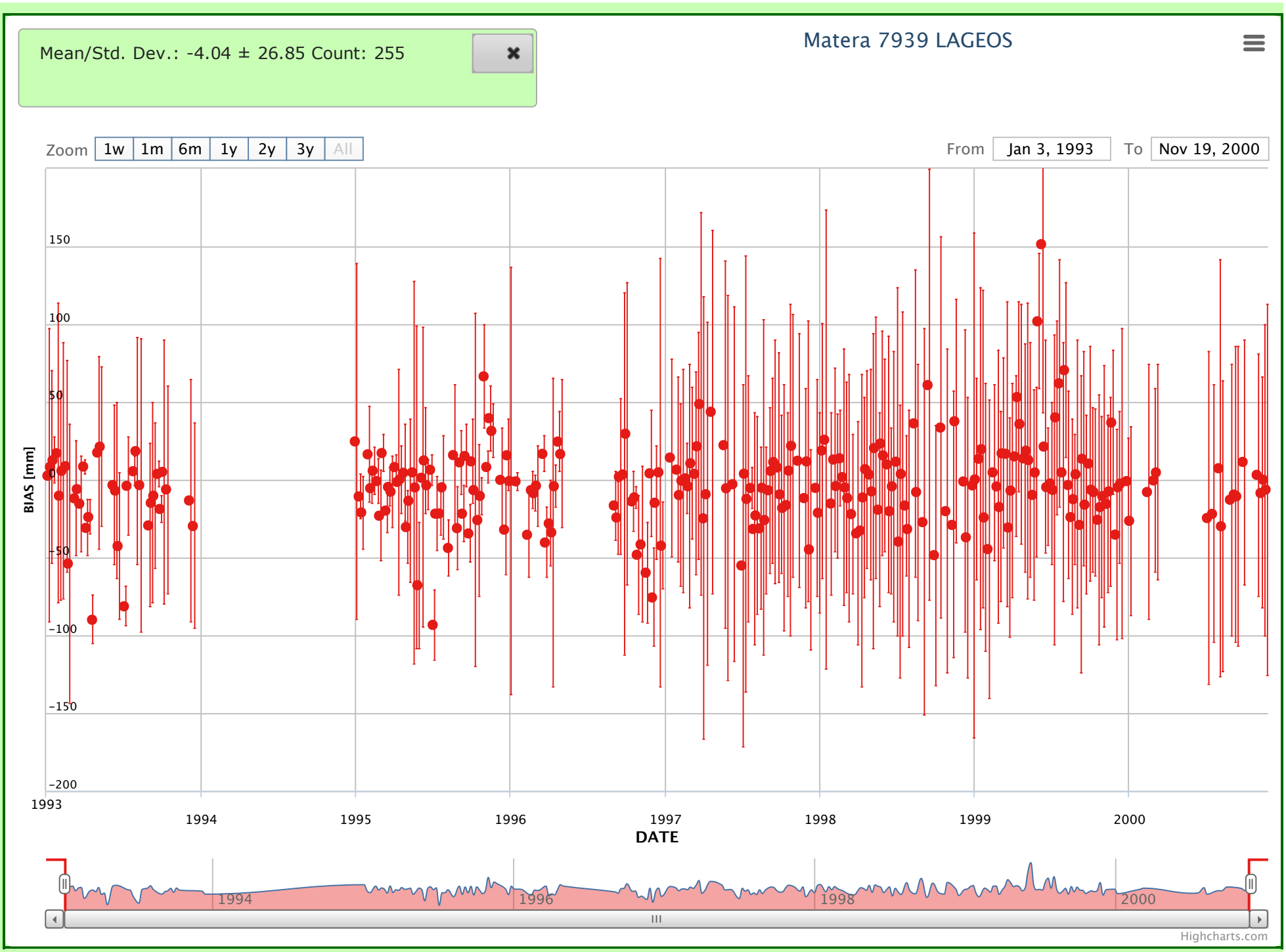

Mean/Std. Dev.: -5.01 ± 49.58 Count: 632
Grasse 7845 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jan 4, 1998 To Aug 18, 2013
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
1998
2000
2002
2004
2006
2008
2010
2012
DATE
Highcharts.com


Mean/Std. Dev.: 3.44 ± 8.04 Count: 12
Ajaccio 7848 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Feb 10, 2002 To Jul 3, 2005
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
May '02
Sep '02
Jan '03
May '03
Sep '03
Jan '04
May '04
Sep '04
Jan '05
May '05
DATE
Jul '02
Jan '03
Jul '03
Jan '04
Jul '04
Jan '05
Highcharts.com

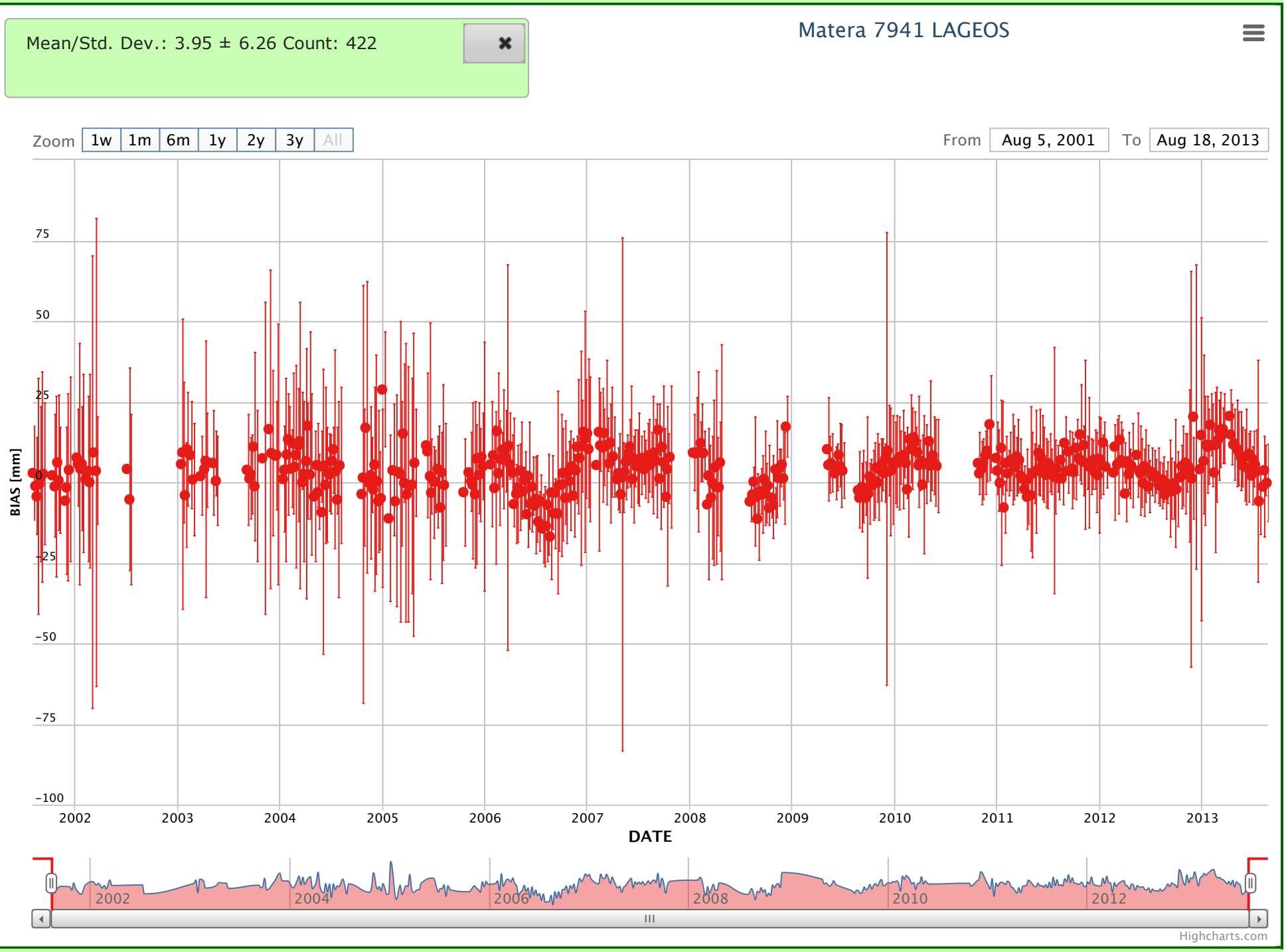

Mean/Std. Dev.: 1.56 ± 5.10 Count: 214
Mt_Stromlo 7849 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jul 5, 1998 To Jan 12, 2003
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
Jan '99
Jul '99
Jan '00
Jul '00
Jan '01
Jul '01
Jan '02
Jul '02
Jan '03
DATE
1999
2000
2001
2002
2003
Highcharts.com

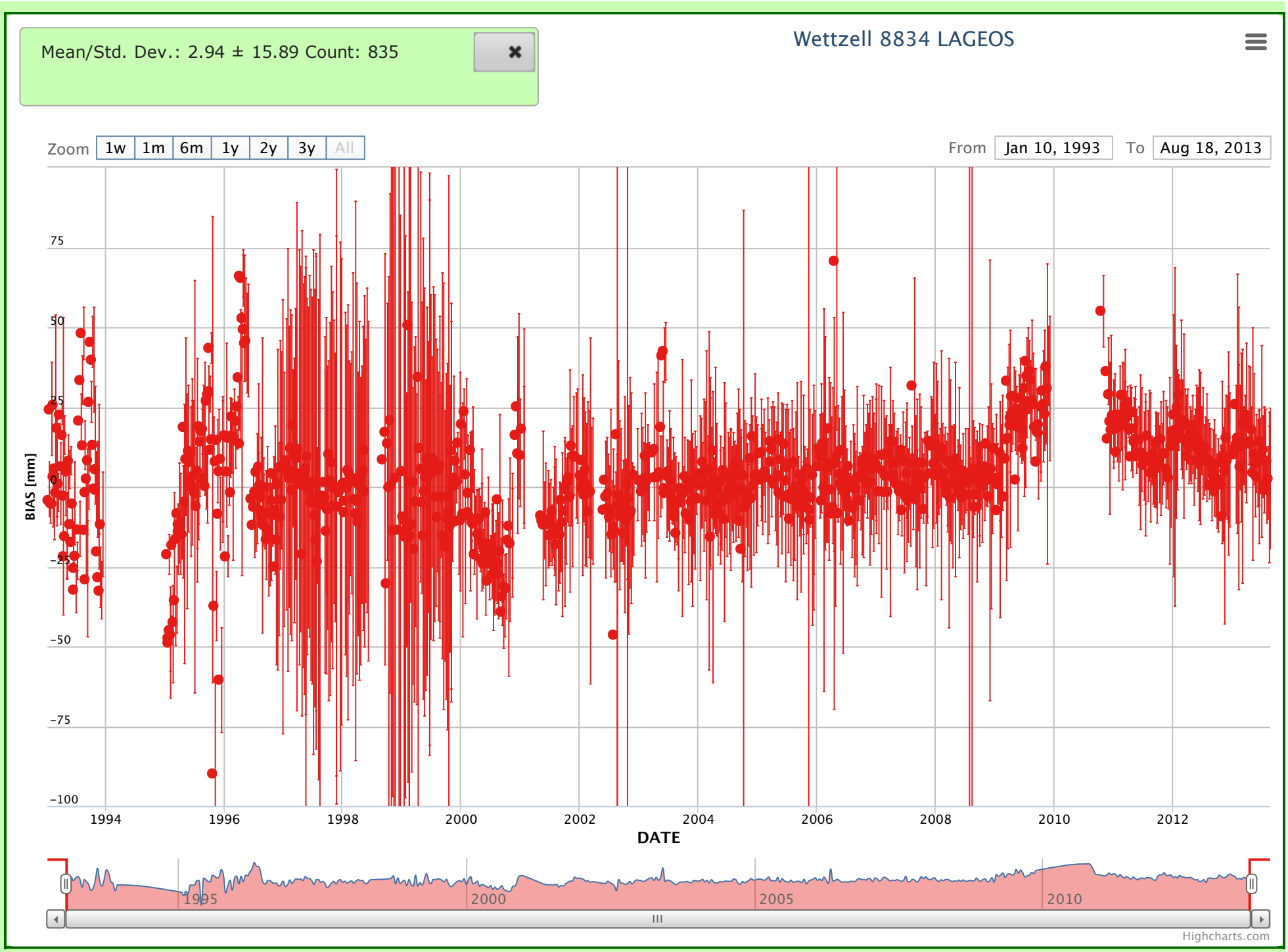
Mean/Std. Dev.: 1.74 ± 8.08 Count: 88




Mean/Std. Dev.: -4.04 ± 26.85 Count: 255
Matera 7939 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jan 3, 1993 To Nov 19, 2000
150
100
50
0
-50
-100
-150
-200
BIAS [mm]
1993
1994
1995
1996
1997
1998
1999
2000
DATE
1994
1996
1998
2000
Highcharts.com

Mean/Std. Dev.: 3.95 ± 6.26 Count: 422




Mean/Std. Dev.: 2.94 ± 15.89 Count: 835
Wettzell 8834 LAGEOS
Zoom 1w 1m 6m 1y 2y 3y All
From Jan 10, 1993 To Aug 18, 2013
BIAS [mm]
75
50
25
0
-25
-50
-75
-100
1994 1996 1998 2000 2002 2004 2006 2008 2010 2012
DATE
1995 2000 2005 2010
Highcharts.com

Systematic effects in geodetic satellite Laser Ranging observations

Graham Appleby

NERC BGS Space Geodesy Facility, Herstmonceux
aka Herstmonceux Geodetic Observatory

NATURAL ENVIRONMENT RESEARCH COUNCIL

ILRS

Outline

- The aim is to maximise the scientific value of satellite laser ranging in its role in work to realise a stable, global Terrestrial Reference Frame
- A driver is the large number of miss-closures at few to several mm in GPS-SLR site ties in ITRF2008 (Altamimi, et al, 2011)
  - Not all these can be due to local survey or GPS technique errors
- Overview of sources, magnitudes and discovery of potential errors in SLR technique
- Impact on measurement precision and accuracy of technology changes from the 1980s to the present
- Centre-of-mass issues, from measurements to models
- On-going work, in discussions with all ILRS ACs and AWG

Satellite Laser Ranging to the geodetic spheres

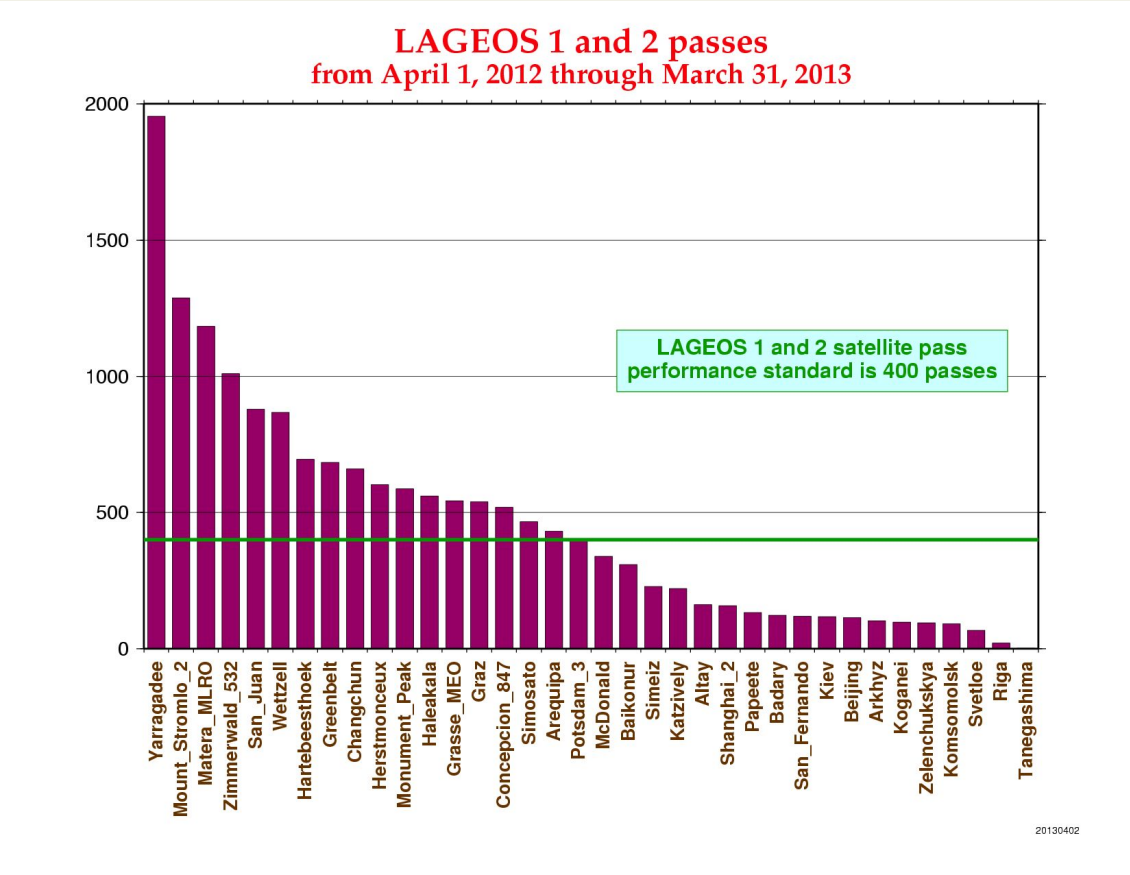
- In principle the geodetic SLR technique is straightforward
  - Ultra-short laser pulses and high-speed detectors (for single- or multi-photons)
  - Time-of-flight counters or epoch (event) timers of mm-level precision
  - Compact space segments – LAGEOS at 60cm and Etalon at 130cm diameter
    - Ground measurements and station-dependent models for phase-centre (CoM) correction now in use (Appleby and Otsubo, 2012)
- Convolution of these elements' PDFs gives single-shot precision at ~10mm and 'normal point' precision at 1mm level.
- Ground-target ranging for removal of electronic delays and as a system stability-test

ITRF2008 site-ties

- The ITRF2008 publication (Altamimi, *et al*, 2011) lists GPS-SLR tie component residuals (space geodesy – terrestrial tie)
- Some are impressively small, <1mm, the target level of agreement.
- Others are large, >10mm
- We cannot fully blame the local survey for discrepancies, nor systematics in GPS technique
- Must track down and quantify potential sources of error in SLR technique-implementation at each site

ZIMM	14001M004	1	7810	14001S001	1	0.5	-1.3	0.9	-1.6	96: 95
GRAS	10002M006	1	7845	10002S002	1	-1.1	-1.2	-0.6	-0.9	99:28
STR1	50119M002	3	7849	50119S001	1	4.1	0.1	4.0	-0.8	1:21
HERS	13212M007	5	7840	13212S001	1	-1.2	-3.1	-2.4	-0.6	8:177
YAR1	50107M004	3	7090	50107M0011		3.3	-1.9	14.4	-3.7	3:305

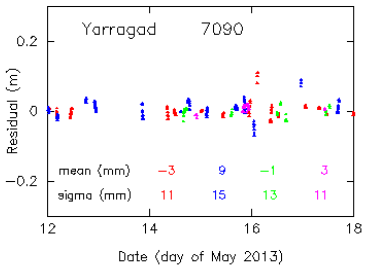
ILRS Network Productivity – from ILRS CB

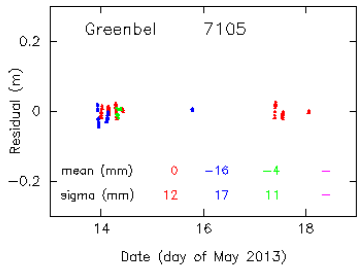


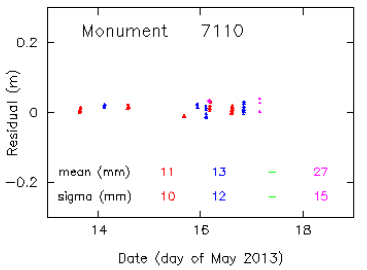
Some 20 stations are responsible for the majority of the laser range observations of the primary geodetic LAGEOS satellites.

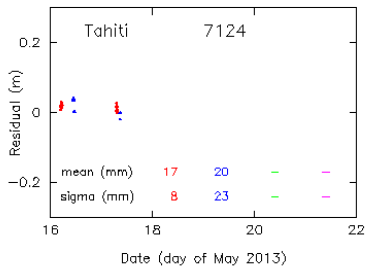
How *accurate* are these range measurements?

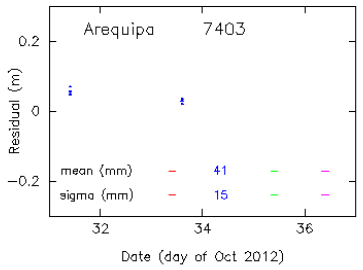
Rapid QC by ILRS Analysis Centres monitors network for ‘blunders’ at several-cm level

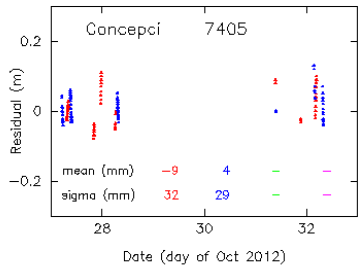


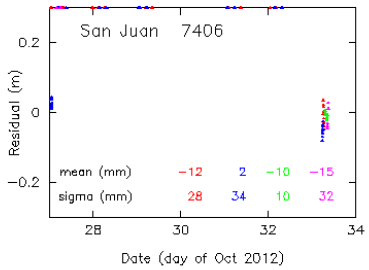


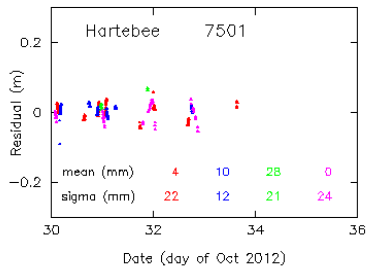




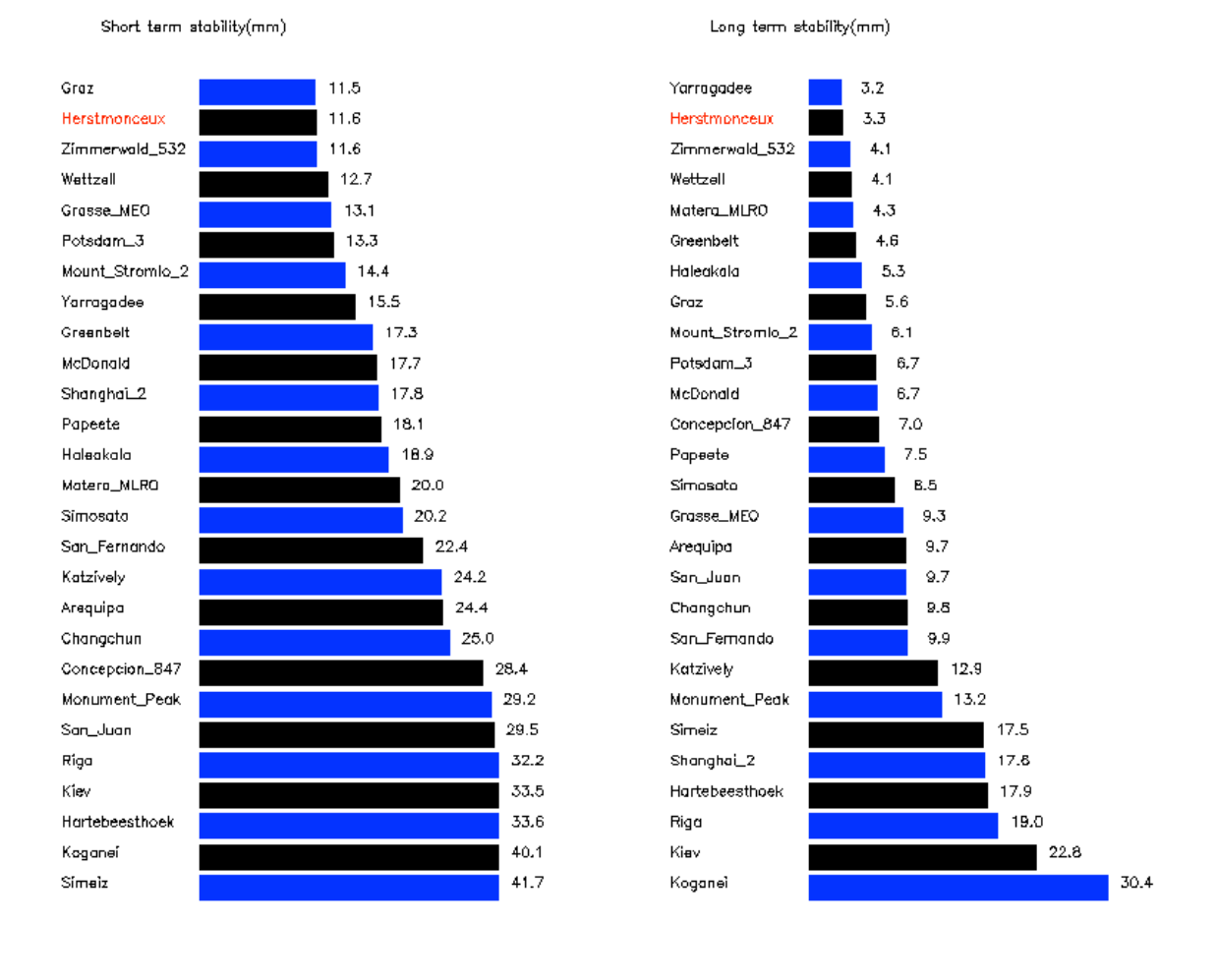








QC work leads to short- and long-term *precision* estimates



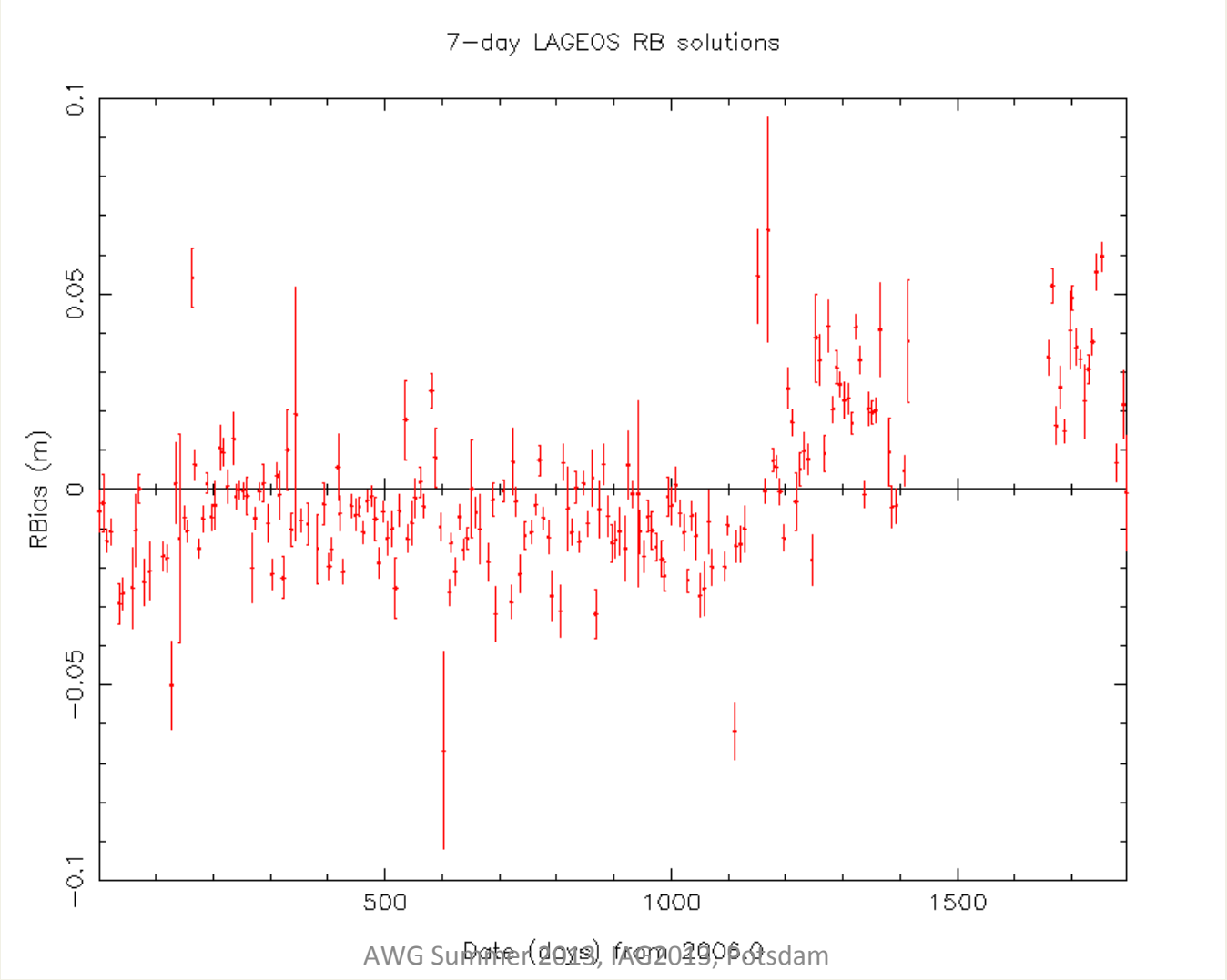
Limitations of QC

- The rapid QC procedures are capable of detecting changes leading to bias at cm-level
- But this effort will *never* address the possibility that systematic range errors exist at the few to several mm level
  - essential if the SLR technique is to improve its support for scale and origin of the ITRF
  - We must either detect hardware problem or remove by estimation during orbit determination

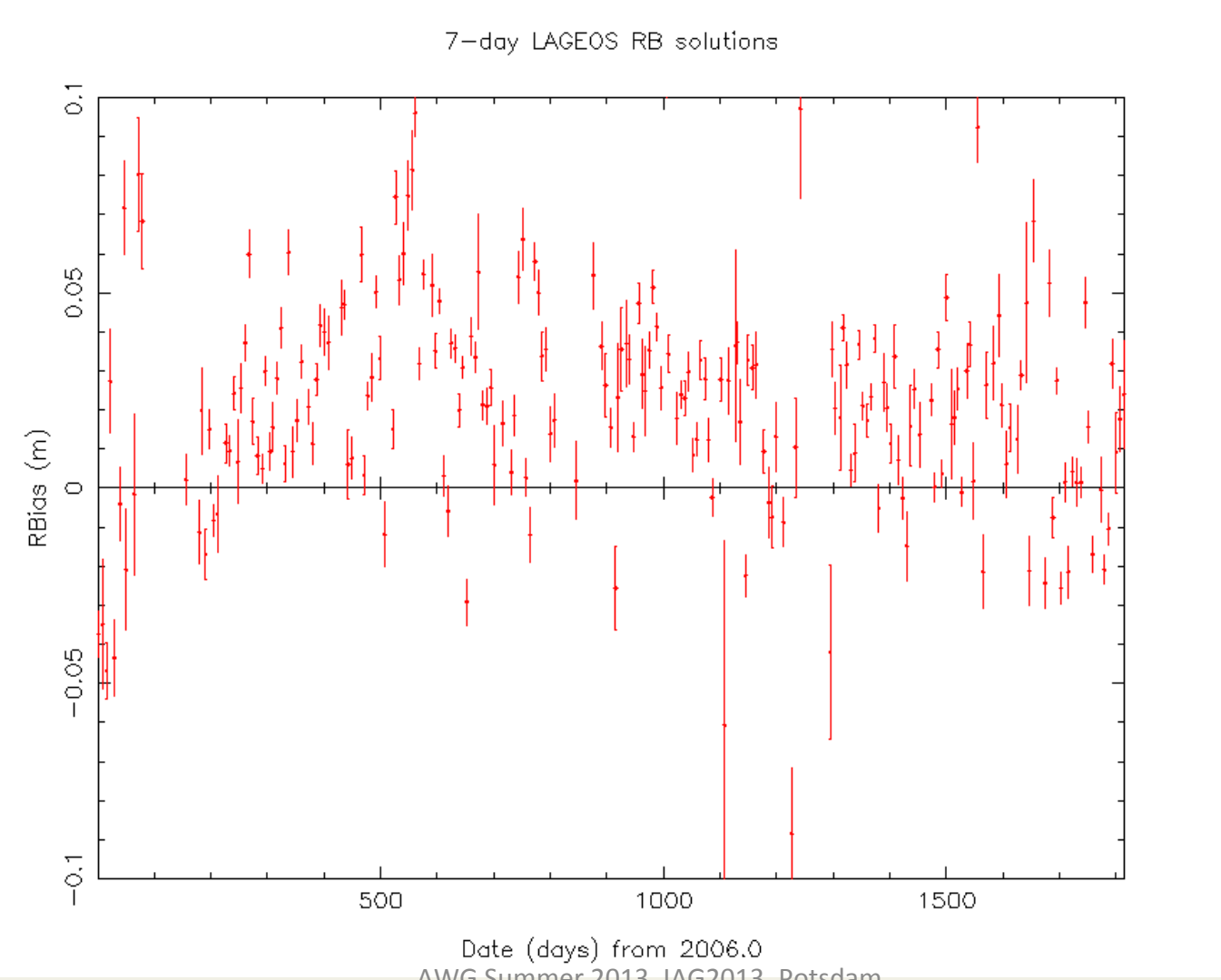
Previously

- During preparation work for ILRS input to ITRF2008, much effort by ASI AC/CC (Luceri *et al*) to resolve apparent station bias at several sites
- Result is a dynamic table of corrections maintained at EDC (Mueller)
  - To be used by all SLR analysts:
  - http://ilrs.dgfi.badw.de/data_handling/ILRS_Data_Handling_File.snx
- **Plus** AC-wide decision that for a number of stations, a range bias be estimated along with reference frame parameters – for example:

Five-year time-series of a station's LAGEOS RB values from 7-day geodetic satellite arc



Five-year time-series of a station's LAGEOS RB values from 7-day geodetic satellite arc



Major contributors to geodetic observations

- 'top twenty' stations consistently contribute most to the reference frame
- Study individual sites' technology for potential source of mm-level bias
  - Based on previous work on counters (Gibbs, Davis)
    - Stanford, HP, potential for ~5mm bias
    - Modern Event Timer sub-mm
  - and on CoM issues (Appleby, Otsubo)
    - Tables of CoM values now in use – effects at 10mm level accounted-for

Variety of hardware, especially ‘counters’ in use in ILRS network

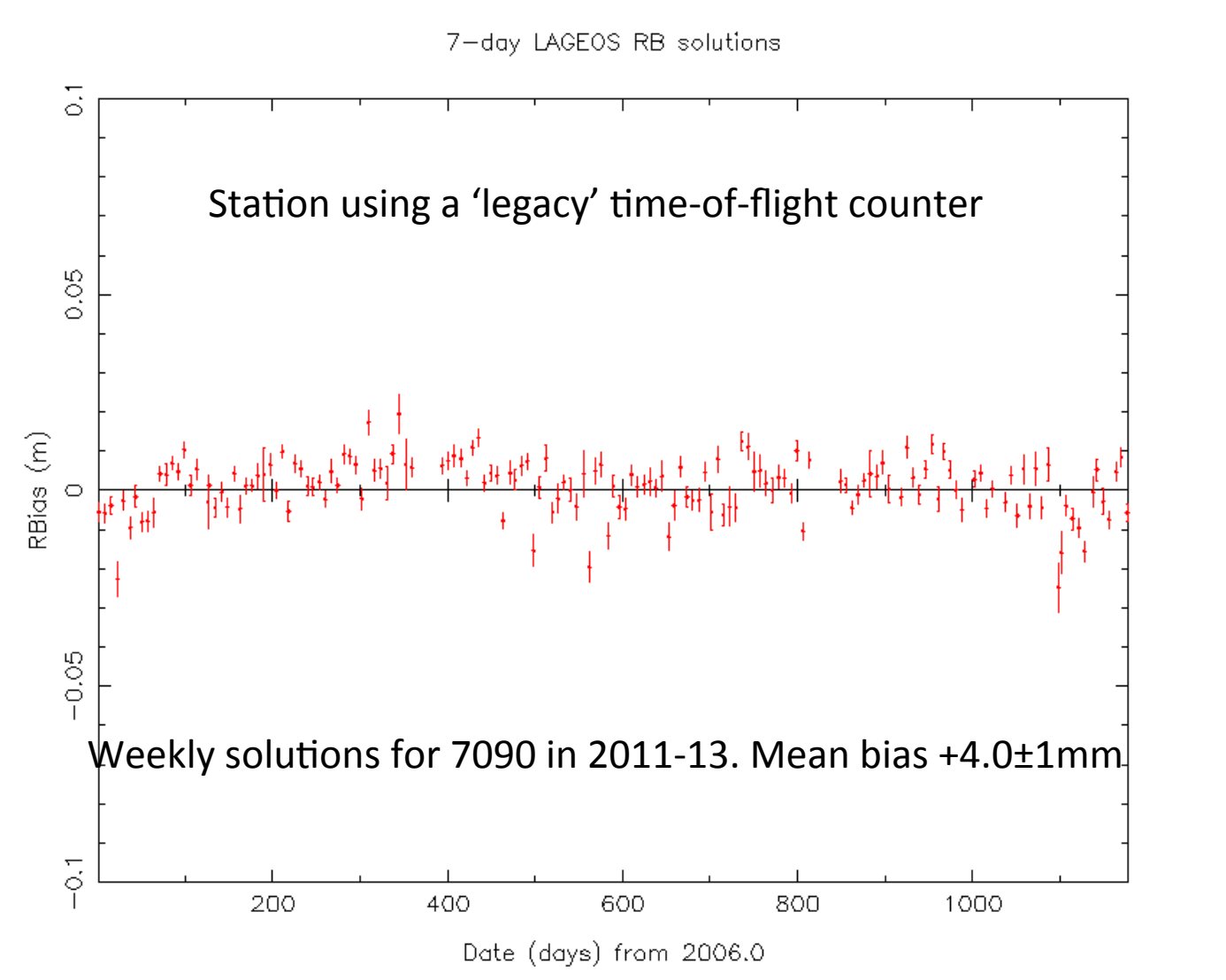
Leading station details

Staion	Counter	Station	Counter
YARR 7090	HP	MONL 7110	HP
STRL 7825	EOS ET	HALE 7119	HP
MATL 7941	HTSI ET	GRSL 7845	Thales ET
ZIML 7810	Riga ET	GRZL 7839	Thales ET
SANJ 7406	Stanford	CONC 7405	Thales ET
WETL 8834	Thales ET	SIML 7838	Riga ET
HART 7501	HP	AREL 7403	HP
GODL 7105	HP	POTS 7841	Riga ET
CHAL 7237	HP	MCDO 7080	EGG counter
HERL 7840	Thales ET	BAIK 1887	Riga ET

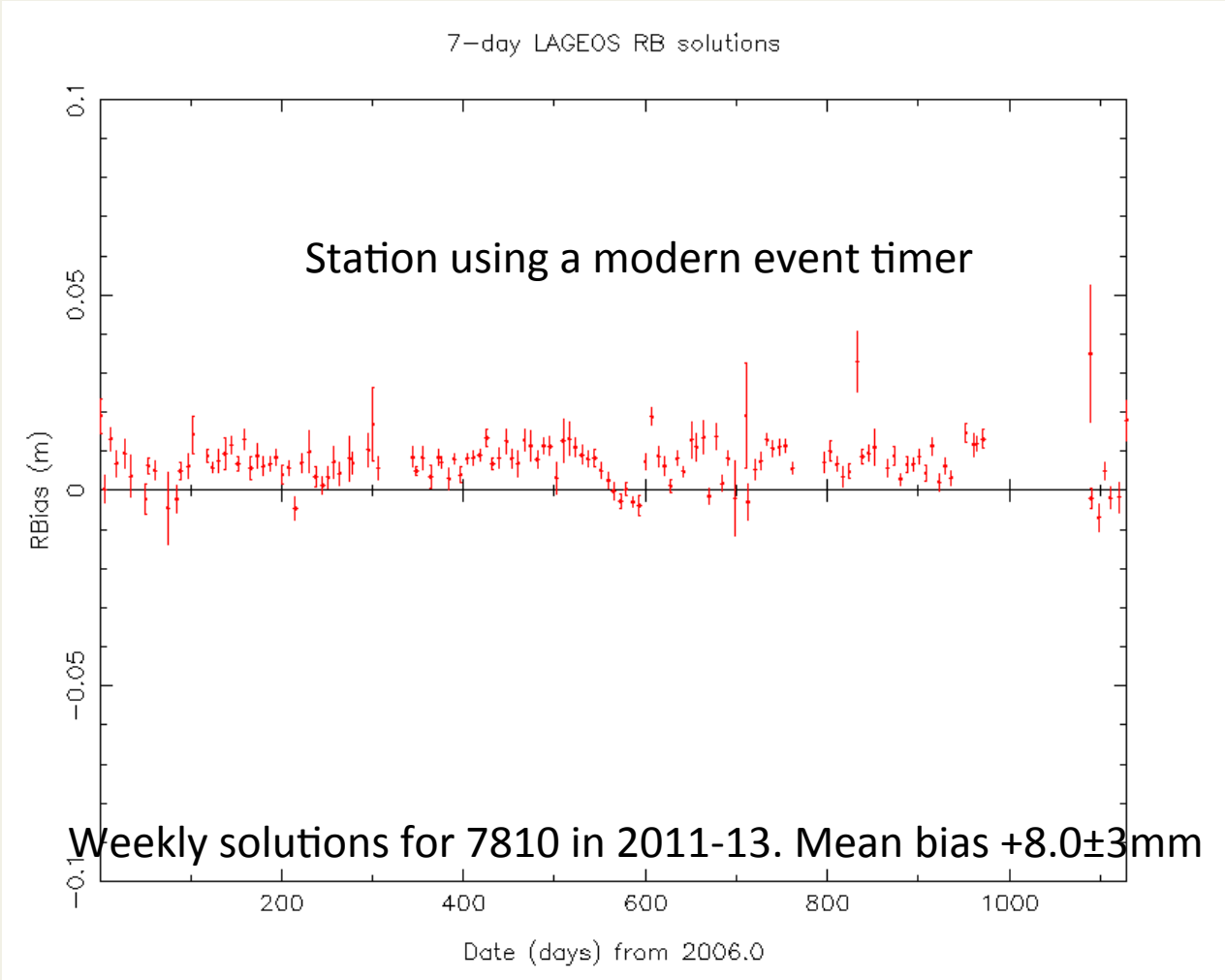
Counter error-calibration?

- Work with multiple counters (Gibbs, 2006) and the experience at Herstmonceux (Appleby *et al*, 2009) suggests:
- Possible only to ascertain the approximate upper-limit magnitude of the error for a given counter, by measurement relative to high-precision linear event timer (ps-level)
- Actual error depends upon specific in-situ electronic setup
- Thus must solve for bias even for these 'top' sites as part of weekly reference frame solutions

Recent bias solutions

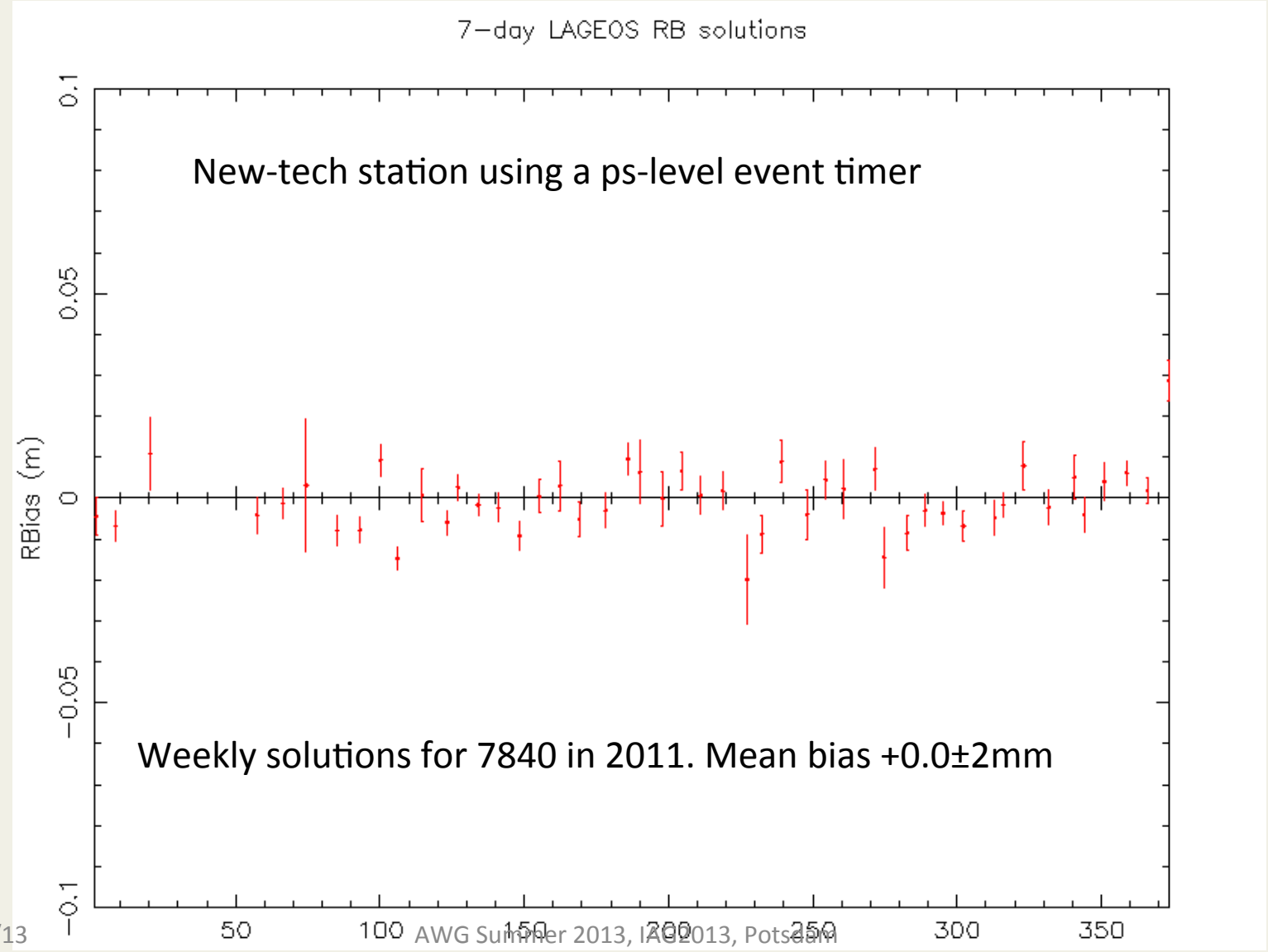


Recent bias solutions

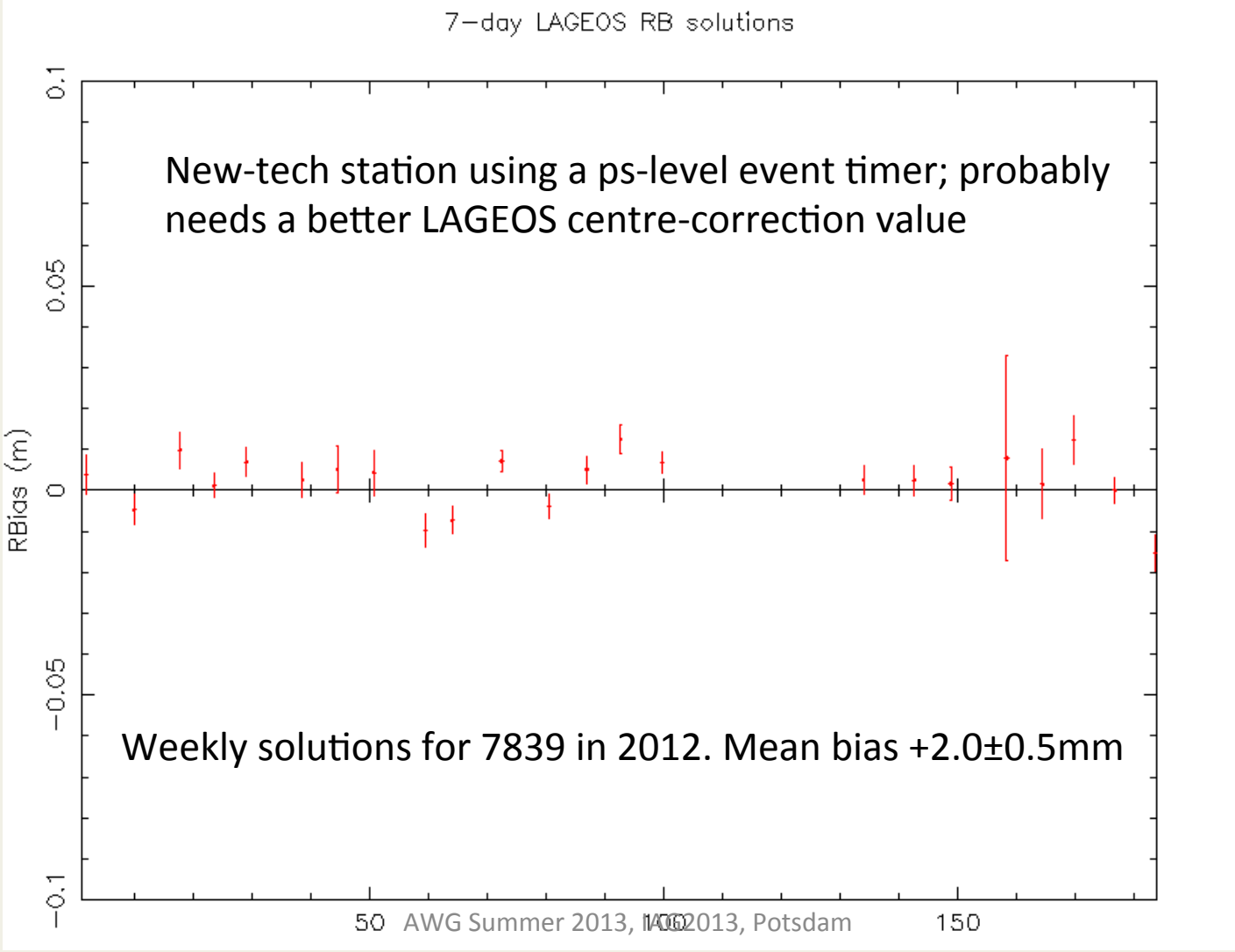


Weekly solutions for 7810 in 2011-13. Mean bias +8.0±3mm

Recent bias solutions



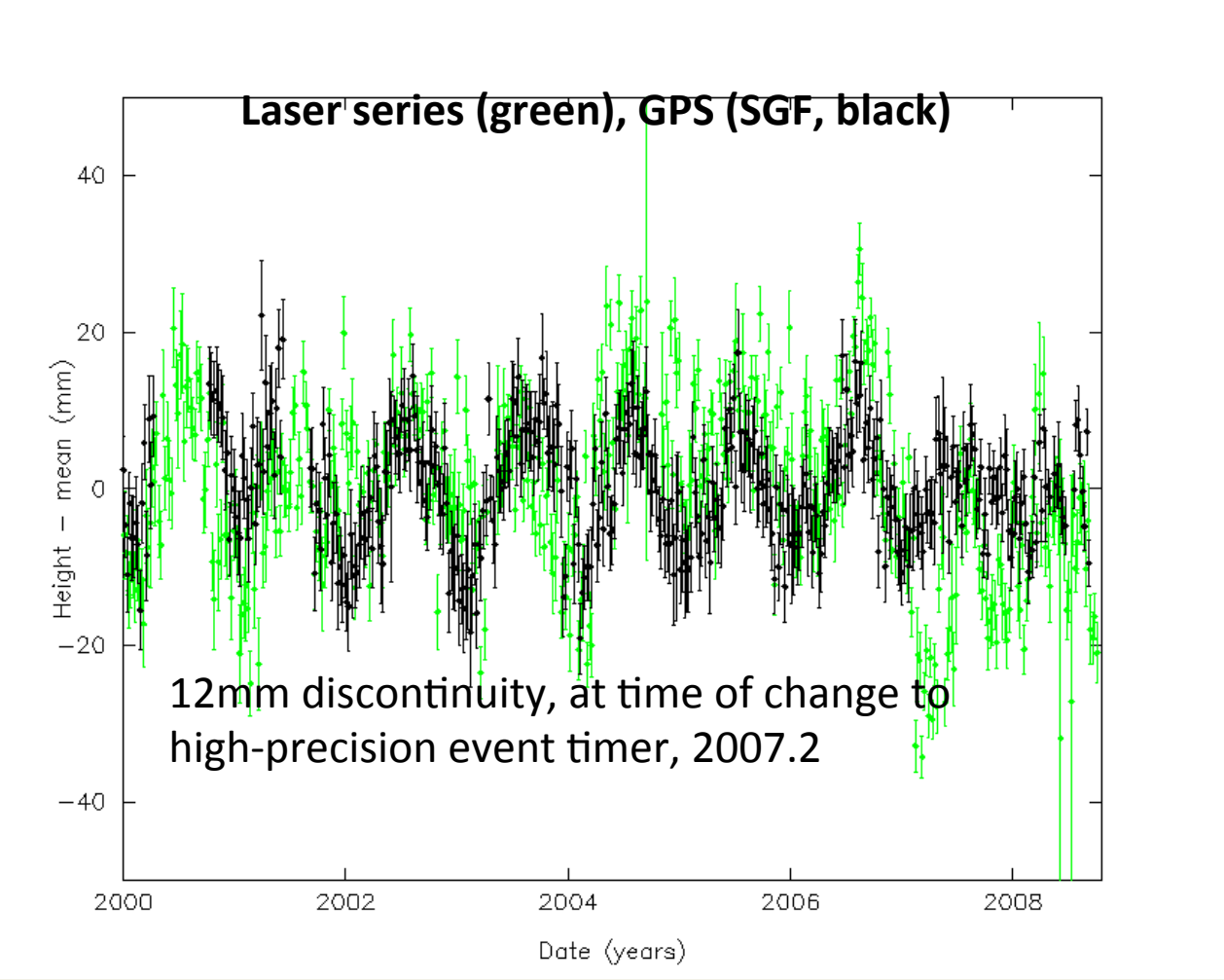
Recent bias solutions



Limitations

- However, it is not possible without introducing constraints to solve for bias for **all** stations
  - Especially so for the short 7-day arcs
  - Especially if limited quantity of low elevation ranges (lack of separation of bias from height)
- Need to choose 'perfect' stations carefully
  - The most important step
- Danger in fixing coordinates at an ITRF *then* solving for bias:

e.g. HERS coordinates wrt ITRF2005- ‘jump’ in 2007 caused by **pre**-2007 range error



To do

- We have identified the major sites that will be subject to counter-induced bias – from site-logs
- We solve for sites' range bias during the standard week-long geodetic solutions, simultaneously with reference-frame parameters and orbits
- We need a study to compare and combine all AC's results, towards appearance of the bias results in the final ILRS weekly sinex solutions and elimination from the reference frame solutions

Comments/conclusions

- The trend within ILRS is to upgrade to ranging at kHz rates
  - Six sites currently operational
- A prerequisite for high repetition rate is modern ps-level event timers
  - They exhibit none of the non-linear features discussed here:
- Expect that single-mm site-tie residuals are possible, provided that calibration target distances are accurately surveyed and monitored along with the inter-technique vectors