The WGS 84 Terrestrial Reference Frame in 2016

Stephen Malys, Robert Wong, Scott A. True

8 November 2016

Presented at ICG-11, Sochi Russia

Outline

- NGA Contributes to and Benefits from the IGS
- WGS 84 (G1762) vs. ITRF2008
  - The 7-Parameter Transformation
    - Based on GPS Monitor Stations
    - Based on GPS Orbit Comparisons
- Conclusions

NGA GPS Tracking Data at the IGS

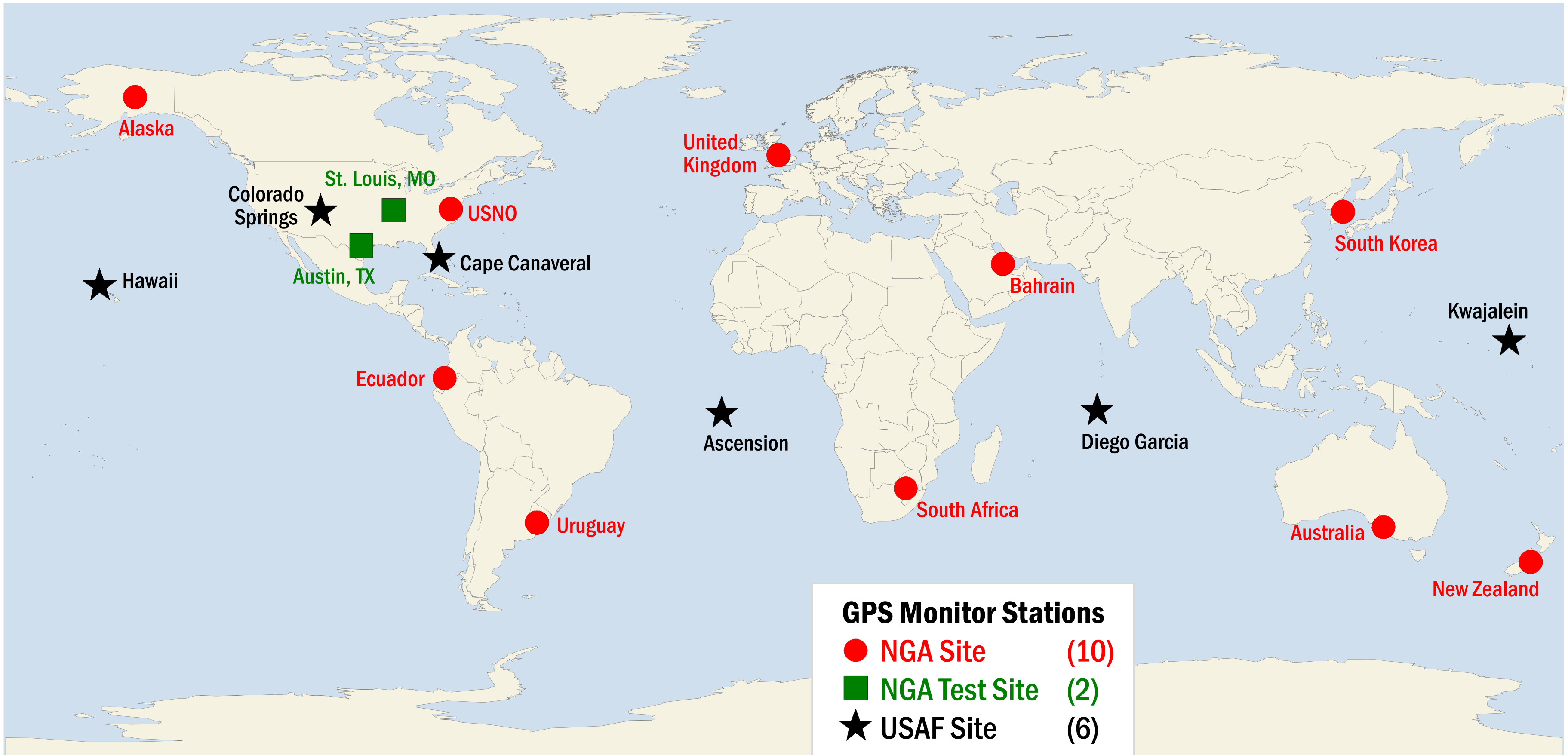
- Since November 2015, NGA has been providing the International GNSS Service (IGS) with it's GPS tracking data in the form of daily 30 second RINEX files.

- Since 1 January 2016, these data are combined with the rest of the IGS data for daily position estimates within the International Terrestrial Reference Frame 2008 (ITRF08).
  - ITRF2014 became available in January 2016 but is not yet implemented at IGS Analysis Centers

- Results of the coordinate adjustments are published in the IGS SINEX files available at

ftp://cddis.gsfc.nasa.gov/pub/gps/products/

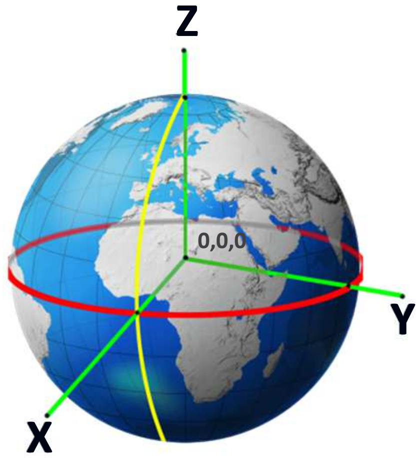
The USAF and NGA GPS Monitor Station Network

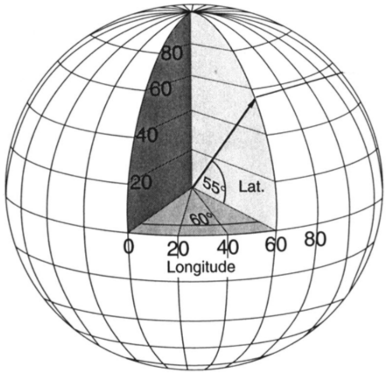


USAF and NGA have separate, but complementary, missions in GPS

NGA

World Geodetic System 1984 (WGS 84)





NGA Predecessor Agencies – Developed the First (1958) Global Reference Frame and Geophysical Models for Modern Geospatial Information including WGS 60, 66, 72

Origin for ALL modern Geospatial Data is at Earth's Center of Mass

Known in 3-D with uncertainty smaller than the size of a postage Stamp

Recent WGS 84 Frame Realizations

Realization	Absolute Accuracy	Date
Original (TRANSIT)	1-2 m	Jan 1987
G730	10 cm	Jun 1994
G873	5 cm	Jun 1997
G1150	2 cm	Jan 2002
G1674	1 cm	Feb 2012
G1762	1 cm	Oct 2013

NGA GPS Station Updates

Last Full WGS 84 Network Update Performed in 2012:

Ref: Wong, R.F., C.M. Rollins, and C.F. Minter (2012), Recent Updates to the WGS 84 Reference Frame, Proceedings of the 25th International Technical Meeting of the Satellite Division of the Institution of Navigation (ION GNSS 2012), pp. 1164–1172.

Reference Frame Realization: WGS 84 (G1762)

Since then, NGA station moves and antenna swaps required individual station position updates

Resulting Reference Frame Realization: **WGS 84 (G1762')**

NGA ID	Date Moved
URUGM	Nov 2014
ENGLM	May 2013
BAHRM	Apr 2015
ECUADM	May 2015
USNOM	Aug 2014
ALASKM	June 2015
NEWZM	Sept 2012
SOAFRM	Feb 2015
OSANM	Sept 2014

NGA

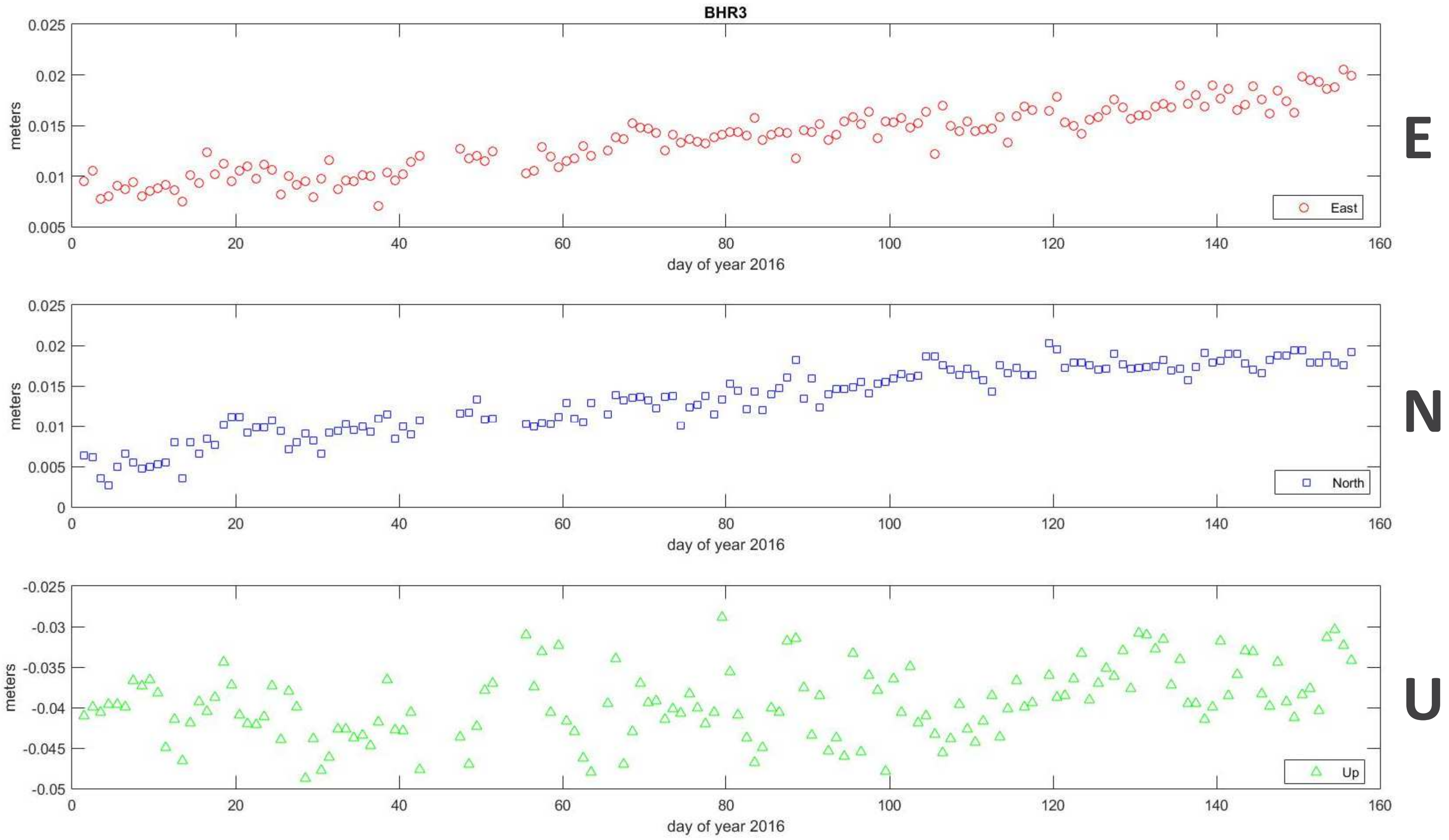
Station Coordinate Comparisons

- IGS solutions for the NGA stations are pulled from .snx files resulting in time series of X, Y, and Z for each site.

- A weighted linear fit of each series gives an estimate of the 2016.00 positions and velocities.

- The IGS coordinates (ITRF2008) of the nine NGA stations are compared to NGA's own coordinates (WGS 84 G1762') at the 2016.00 epoch
  - Comparison of Cartesian ECEF X,Y,Z components
  - Comparison of East, North, Up components
  - Comparison in a best-fit 7-parameter transformation

Sample of Daily IGS Position Estimates – NGA Station BAHRM



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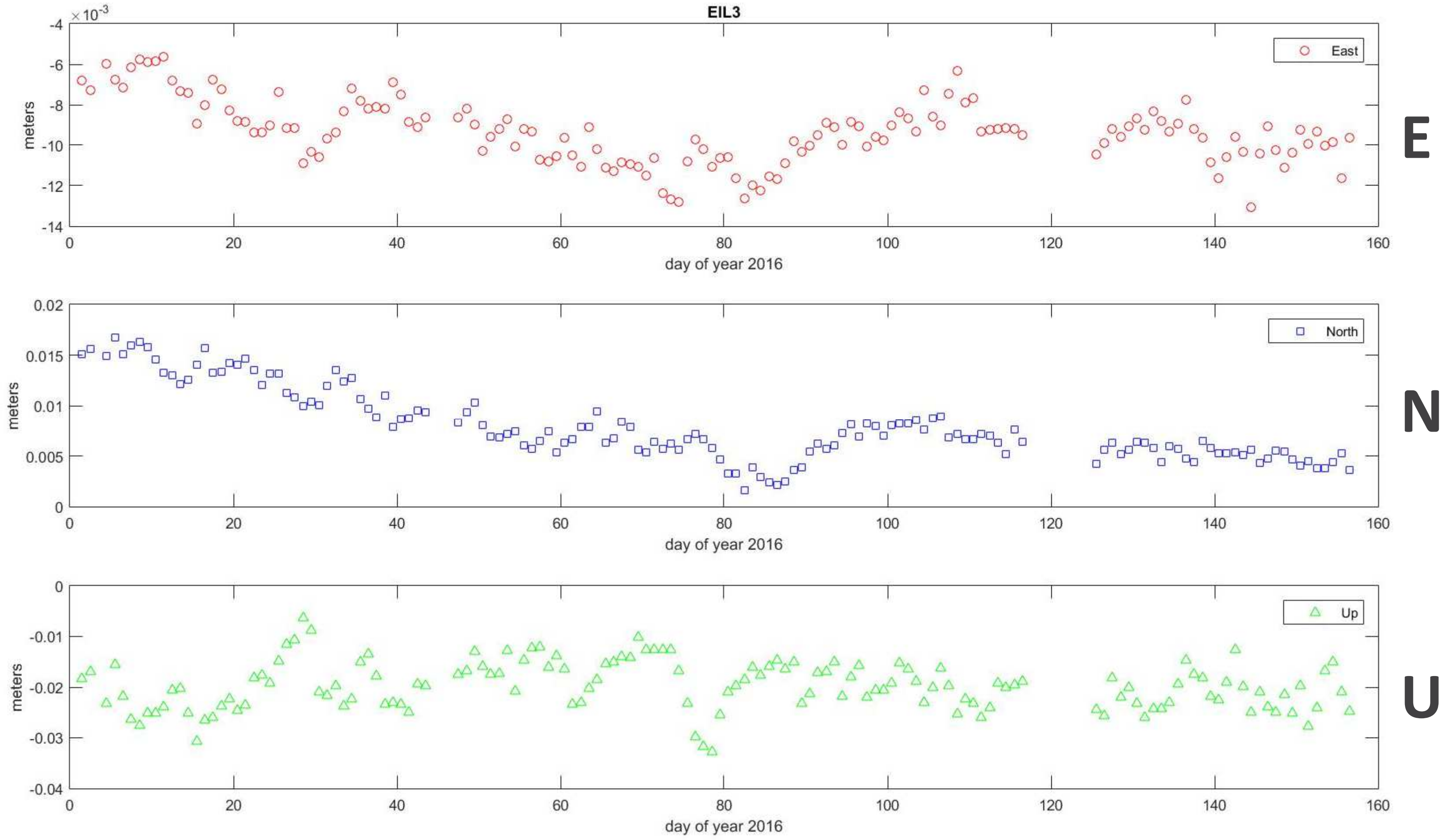
Sample of Daily IGS Position Estimates – NGA Station ALASKM



NGA (WGS 84 G1762') and IGS (ITRF2008) coordinates at Antenna Reference Point

		NGA Coordinates (EPOCH 2016.00)			SINEX Coordinates (EPOCH 2016.00)		
NGA ID	IGS ID	X(m)	Y(m)	Z(m)	X(m)	Y(m)	Z(m)
URUGM	MTV1	2914537.027	-4349790.374	-3630033.371	2914537.018	-4349790.359	-3630033.356
ENGLM	OAK2	4011440.750	-63375.554	4941877.195	4011440.734	-63375.559	4941877.183
BAHRM	BHR3	3633910.304	4425277.865	2799863.204	3633910.271	4425277.838	2799863.192
ECUADM	QUI3	1275746.599	-6252216.765	-15441.003	1275746.630	-6252216.750	-15440.995
USNOM	WDC5	1112158.703	-4842855.615	3985496.972	1112158.688	-4842855.604	3985496.967
ALASKM	EIL3	-2296304.327	-1484805.973	5743078.281	-2296304.315	-1484805.956	5743078.269
NEWZM	MRL2	-4749991.193	520984.626	-4210603.878	-4749991.190	520984.634	-4210603.861
SOAFRM	PRE3	5066223.476	2719223.183	-2754406.358	5066223.459	2719223.166	-2754406.330
OSANM	OSN3	-3068341.099	4066863.881	3824756.903	-3068341.098	4066863.868	3824756.907

* NGA Data from Australia Station is not accepted by the IGS due to non-standard multipath mitigation technique used here

NGA

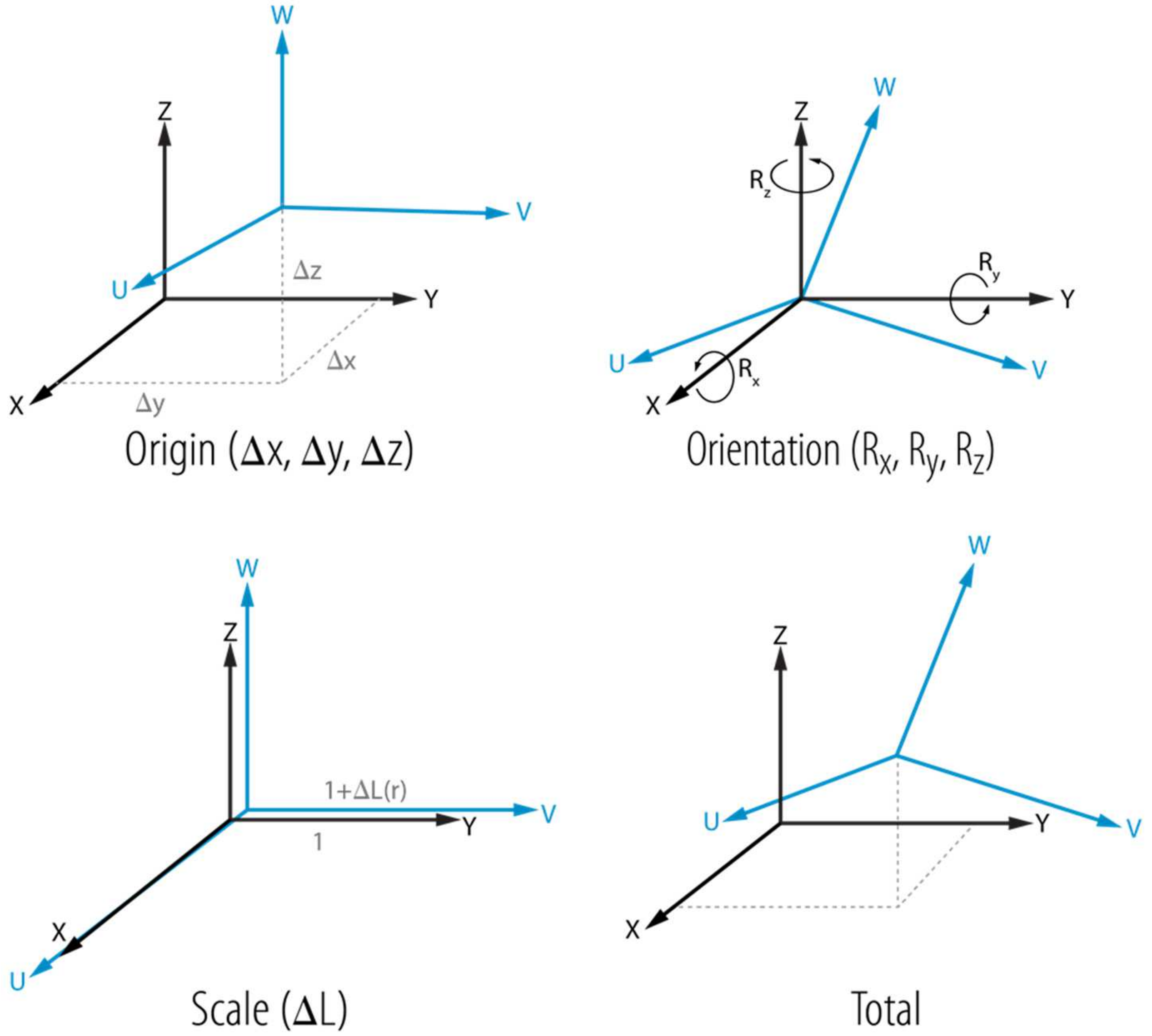
ΔXYZ

		ΔXYZ (NGA-to-SINEX)		
NGA ID	IGS ID	ΔX(cm)	ΔY(cm)	ΔZ(cm)
URUGM	MTV1	0.9	-1.5	-1.5
ENGLM	OAK2	1.6	0.5	1.2
BAHRM	BHR3	3.3	2.7	1.2
ECUADM	QUI3	-3.1	-1.5	-0.8
USNOM	WDC5	1.5	-1.1	0.5
ALASKM	EIL3	-1.2	-1.7	1.2
NEWZM	MRL2	-0.3	-0.8	-1.7
SOAFRM	PRE3	1.7	1.7	-2.8
OSANM	OSN3	-0.1	1.3	-0.4
		ΔX(cm)	ΔY(cm)	ΔZ(cm)
	Mean	0.5	0.0	-0.3
	σ	1.9	1.6	1.5

ΔENU

		ΔENU (NGA-to-SINEX)		
NGA ID	IGS ID	ΔE(cm)	ΔN(cm)	ΔU(cm)
URUGM	MTV1	0.2	0.1	-2.3
ENGLM	OAK2	0.5	-0.5	-1.9
BAHRM	BHR3	0.8	0.8	-4.3
ECUADM	QUI3	0.8	3.3	-0.9
USNOM	WDC5	0.5	-1.2	-1.4
ALASKM	EIL3	1.2	-0.8	-1.9
NEWZM	MRL2	1.1	-0.9	-1.3
SOAFRM	PRE3	1.5	-0.7	-3.3
OSANM	OSN3	1.0	0.7	-0.6
		ΔE(cm)	ΔN(cm)	ΔU(cm)
	Mean	0.9	0.1	-2.0
	σ	0.4	1.4	1.2

7 Parameter Transformation



Using Antenna Reference Point at 9 Monitor Stations

7 Parameter Transformation (NGA-to-SINEX)		
Δx	-0.2 σ= 0.4	cm
Δy	-0.2 σ= 0.4	cm
Δz	0.7 σ= 0.4	cm
R_x	-0.009 σ= 0.037	milli-arcseconds
R_y	0.009 σ= 0.039	milli-arcseconds
R_z	-0.030 σ= 0.039	milli-arcseconds
scale	-3.317 σ= 0.644	ppb

At mean Earth Radius, -3.317 ppb = -2.1 cm
σ = 0.644 ppb = 0.4 cm

NGA

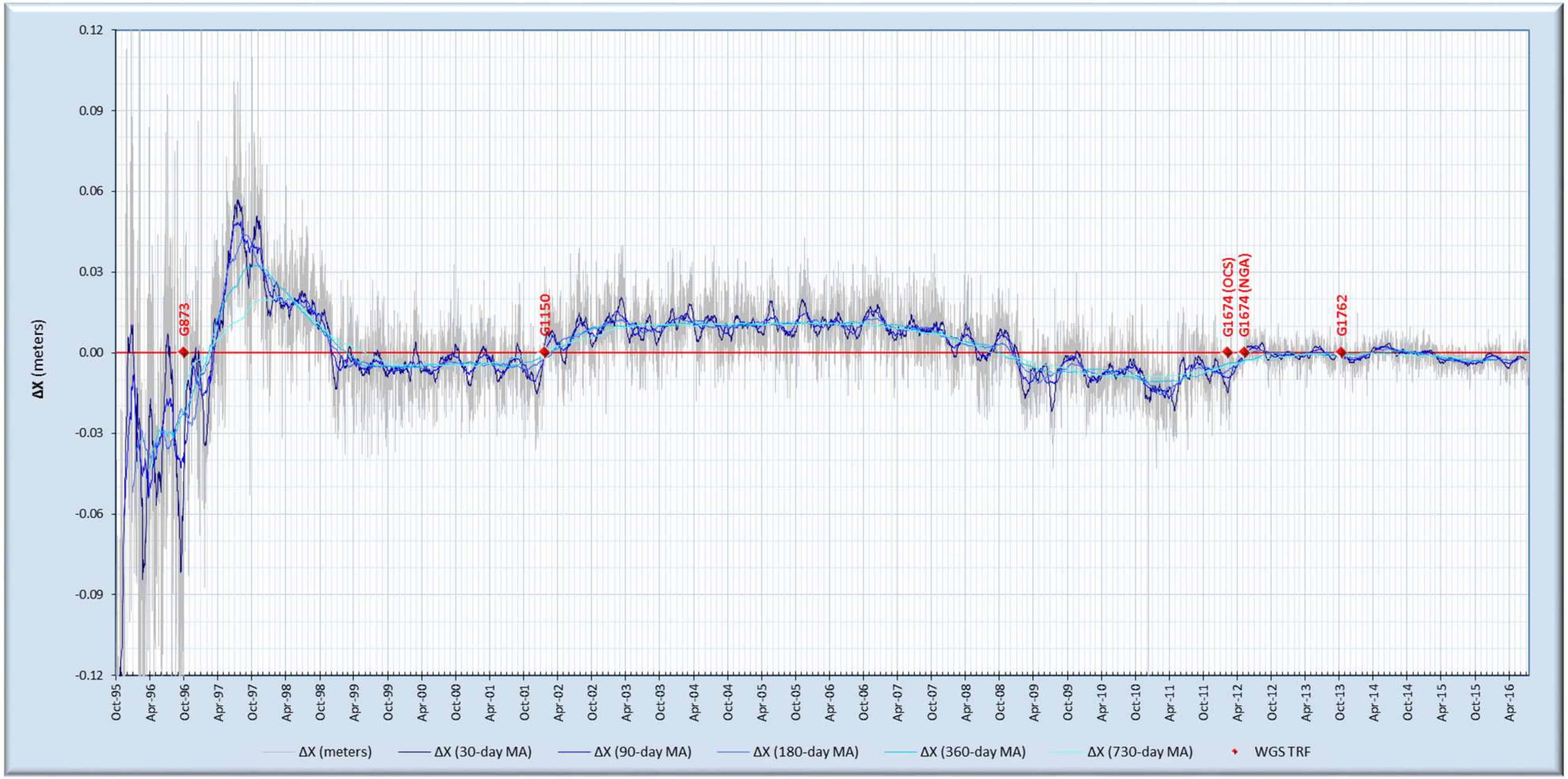
NGA-IGS GPS Orbit Comparisons

- NGA GPS precise ephemerides are referenced to the WGS 84 Terrestrial Reference Frame (G1762')
- IGS GPS precise ephemerides are referenced to the International Terrestrial Reference Frame (ITRF 2008)
- 7-Parameter Transformations between NGA and IGS precise ephemerides are calculated daily by NGA along with various orbit statistics – **Since 1995**
- The following slides provide graphs of these parameters that illustrate the long-term and short-term trends
- The graphs include the daily values along with 30-, 90-, 180-, 360-, and 730-day moving averages

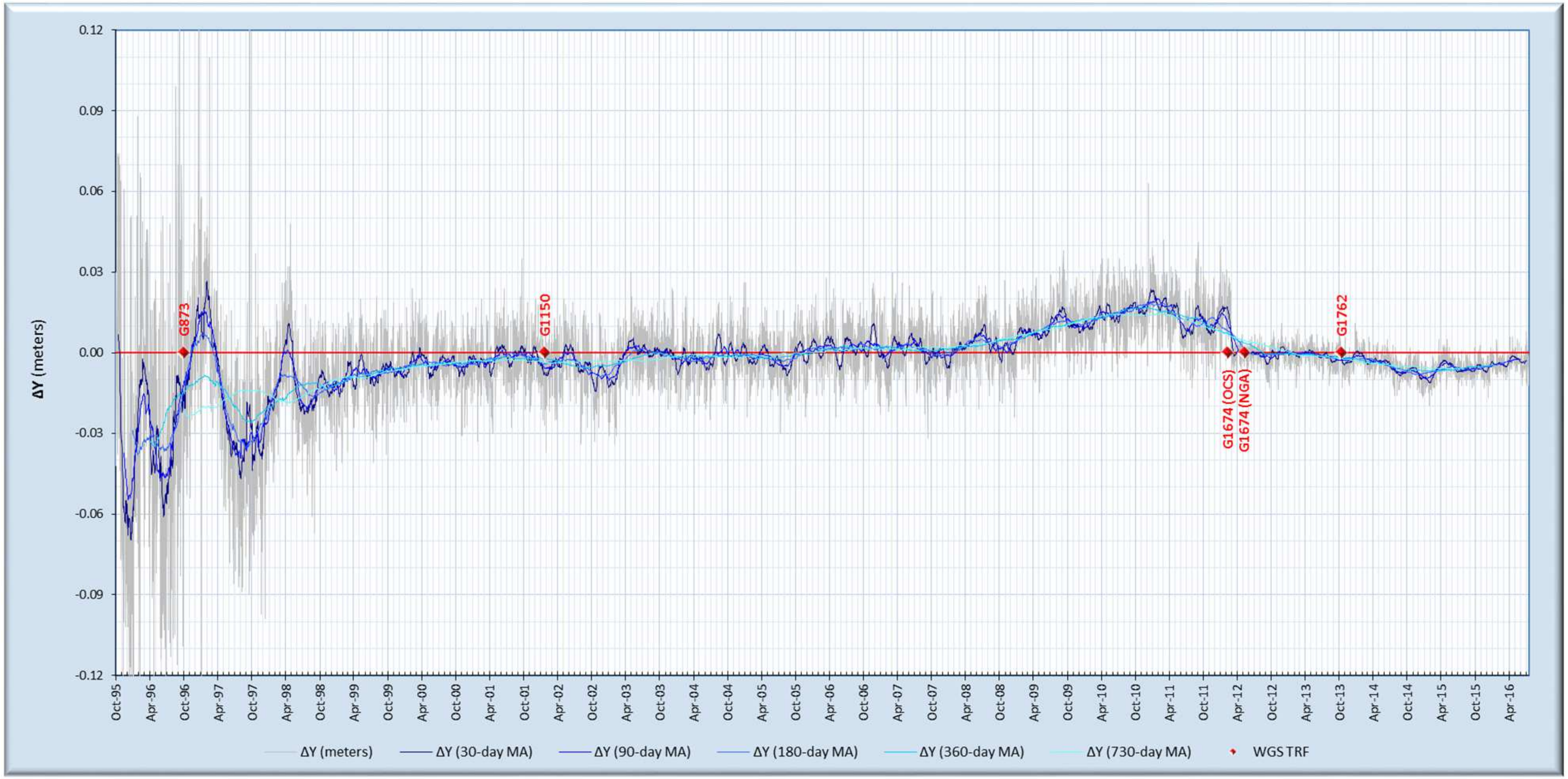
Long-Term Trends

October 1995 to Present

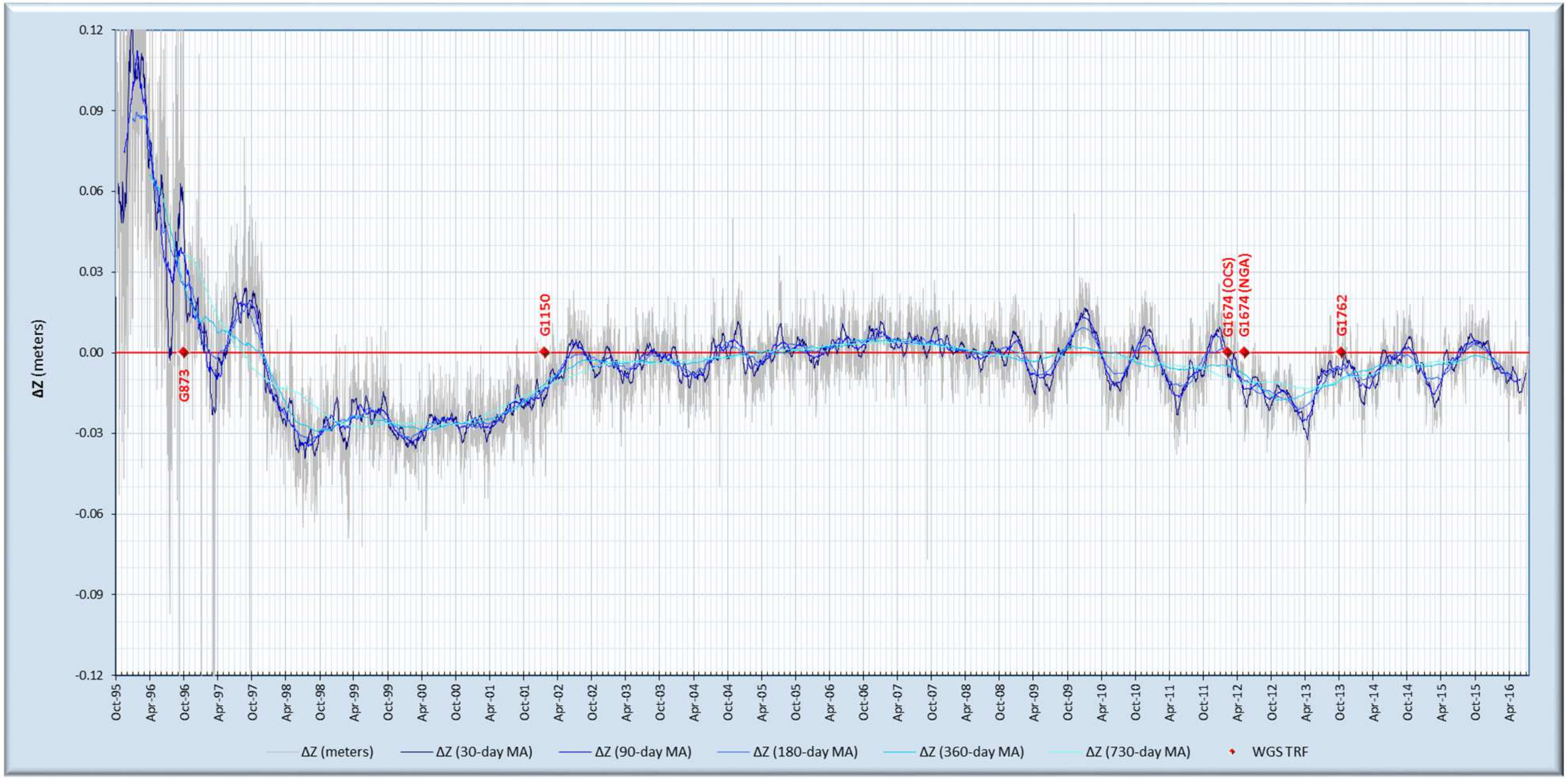
X-Translation



Y-Translation



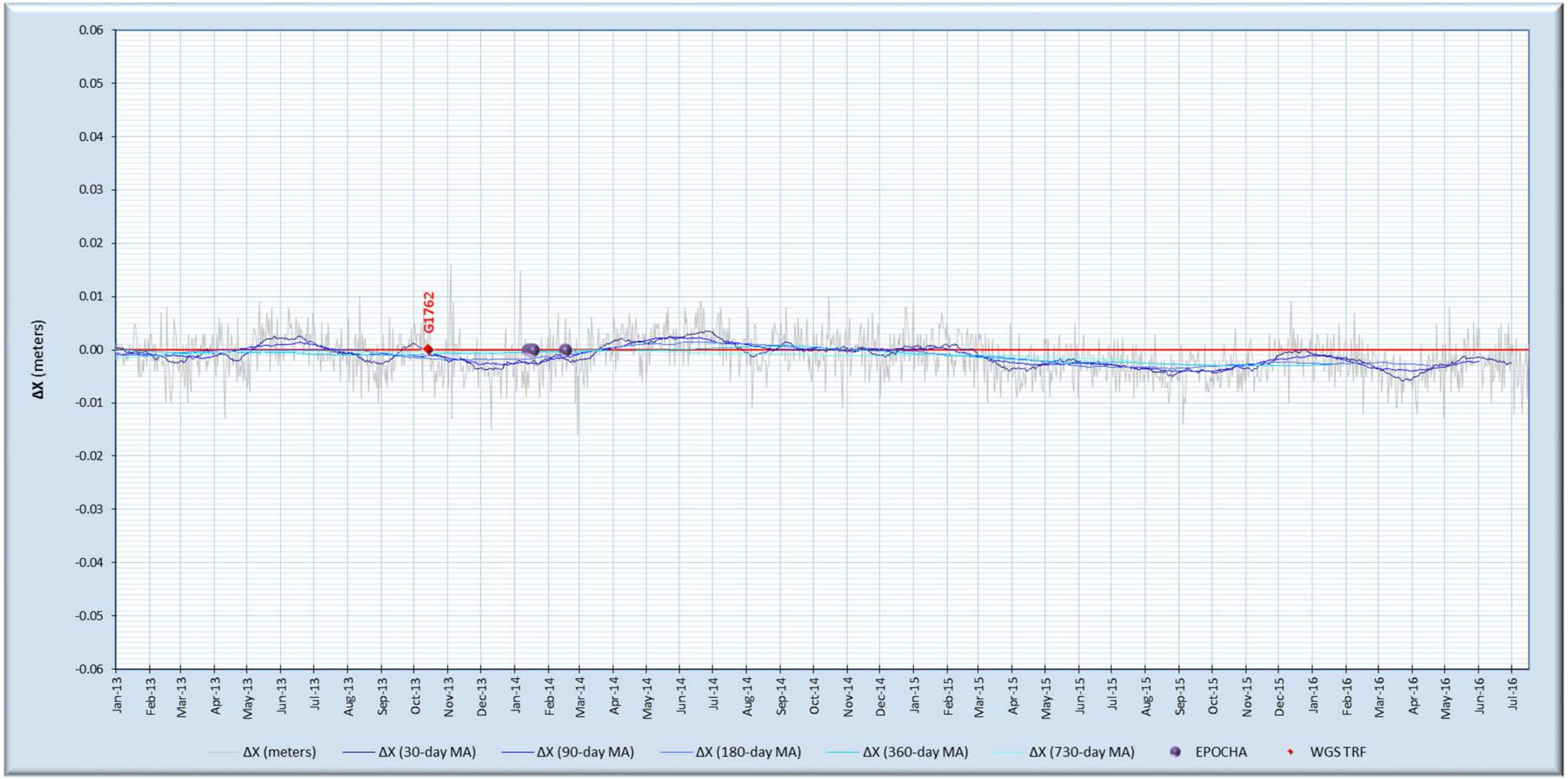
Z-Translation



Short-Term Trends

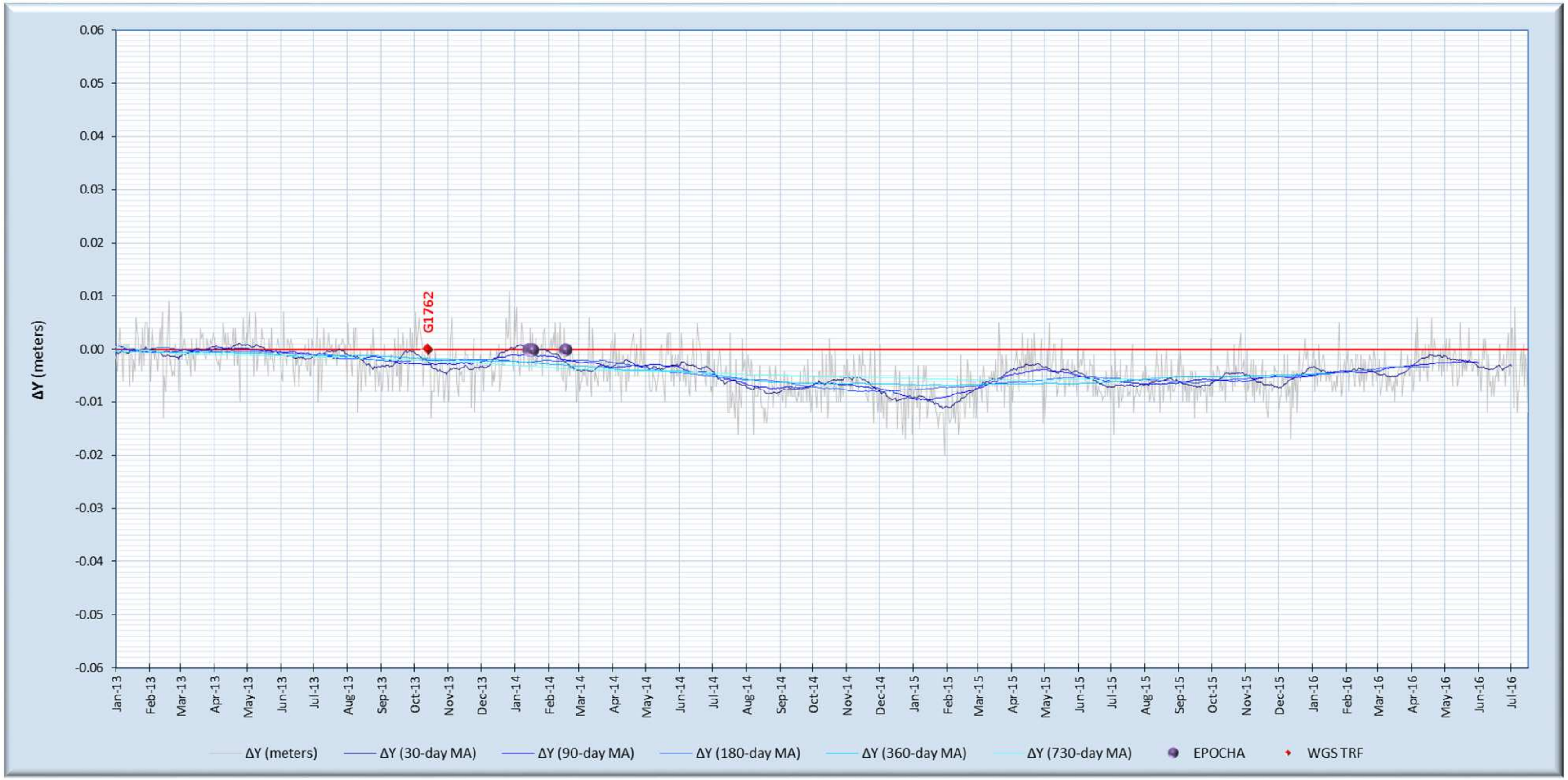
January 2013 to Present

X-Translation



NGA

Y-Translation



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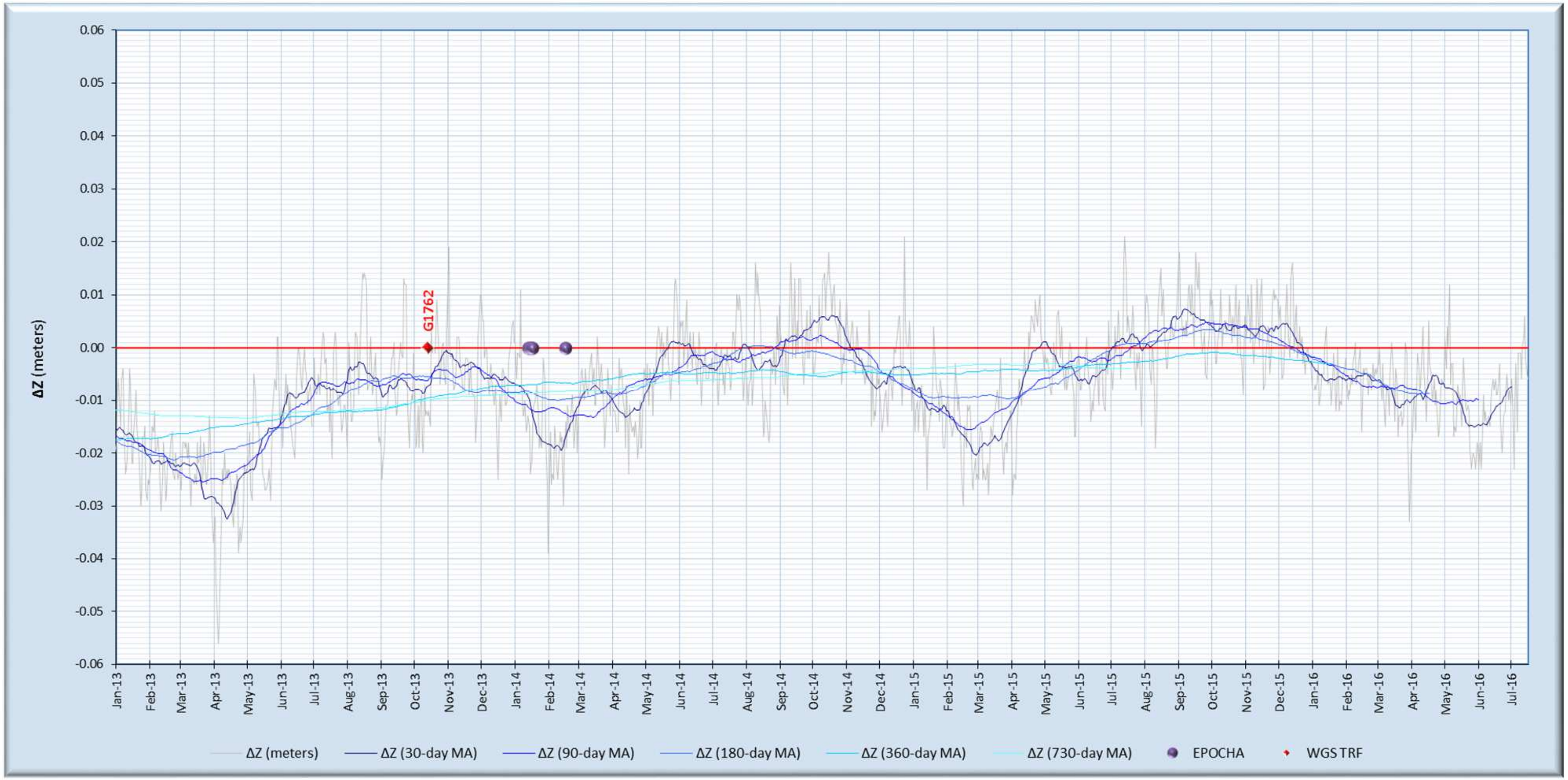
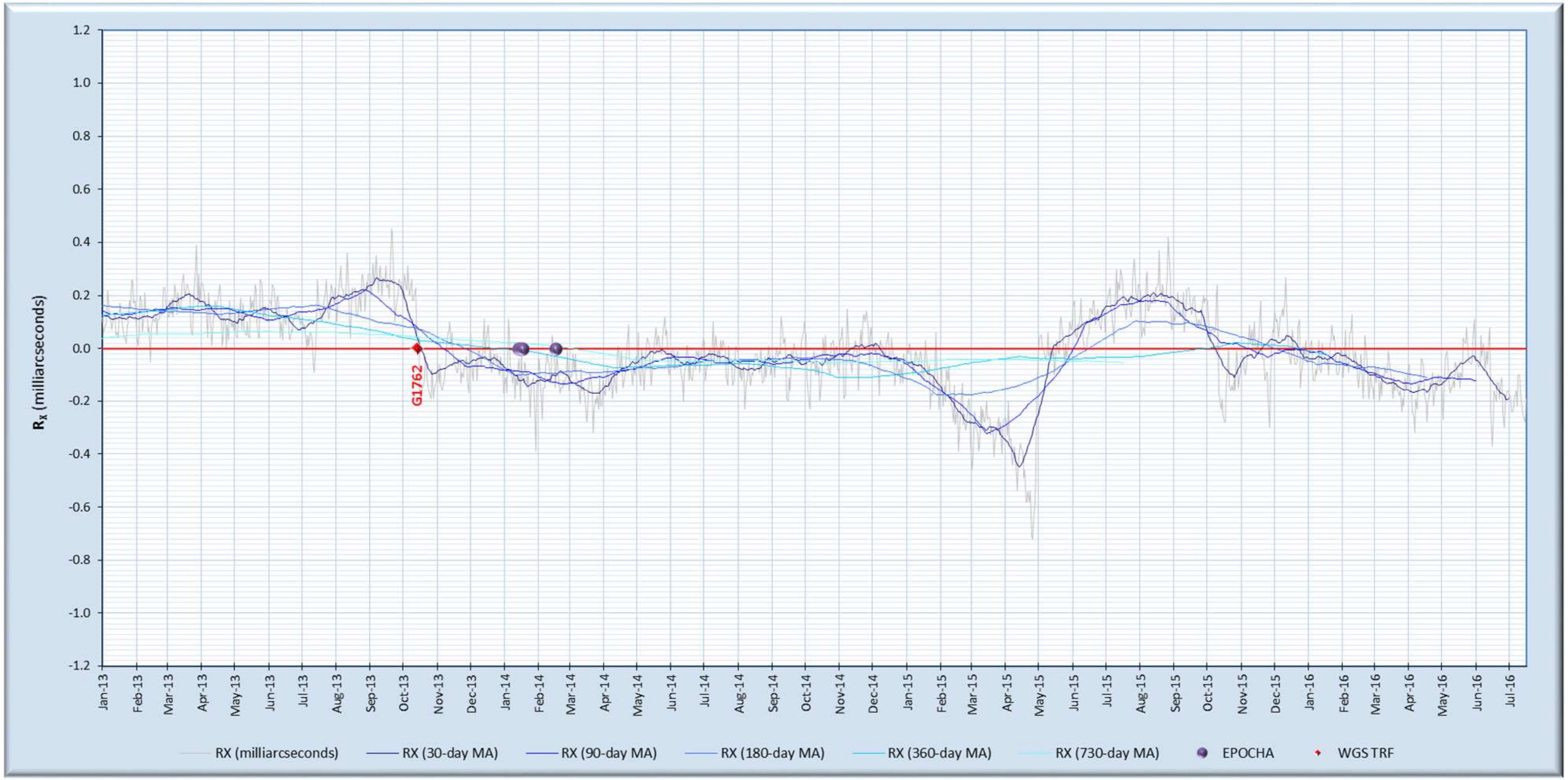
Z-Translation



X-Rotation



1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
Rx (milliarcseconds)
G1762
Jan-13
Feb-13
Mar-13
Apr-13
May-13
Jun-13
Jul-13
Aug-13
Sep-13
Oct-13
Nov-13
Dec-13
Jan-14
Feb-14
Mar-14
Apr-14
May-14
Jun-14
Jul-14
Aug-14
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Jan-15
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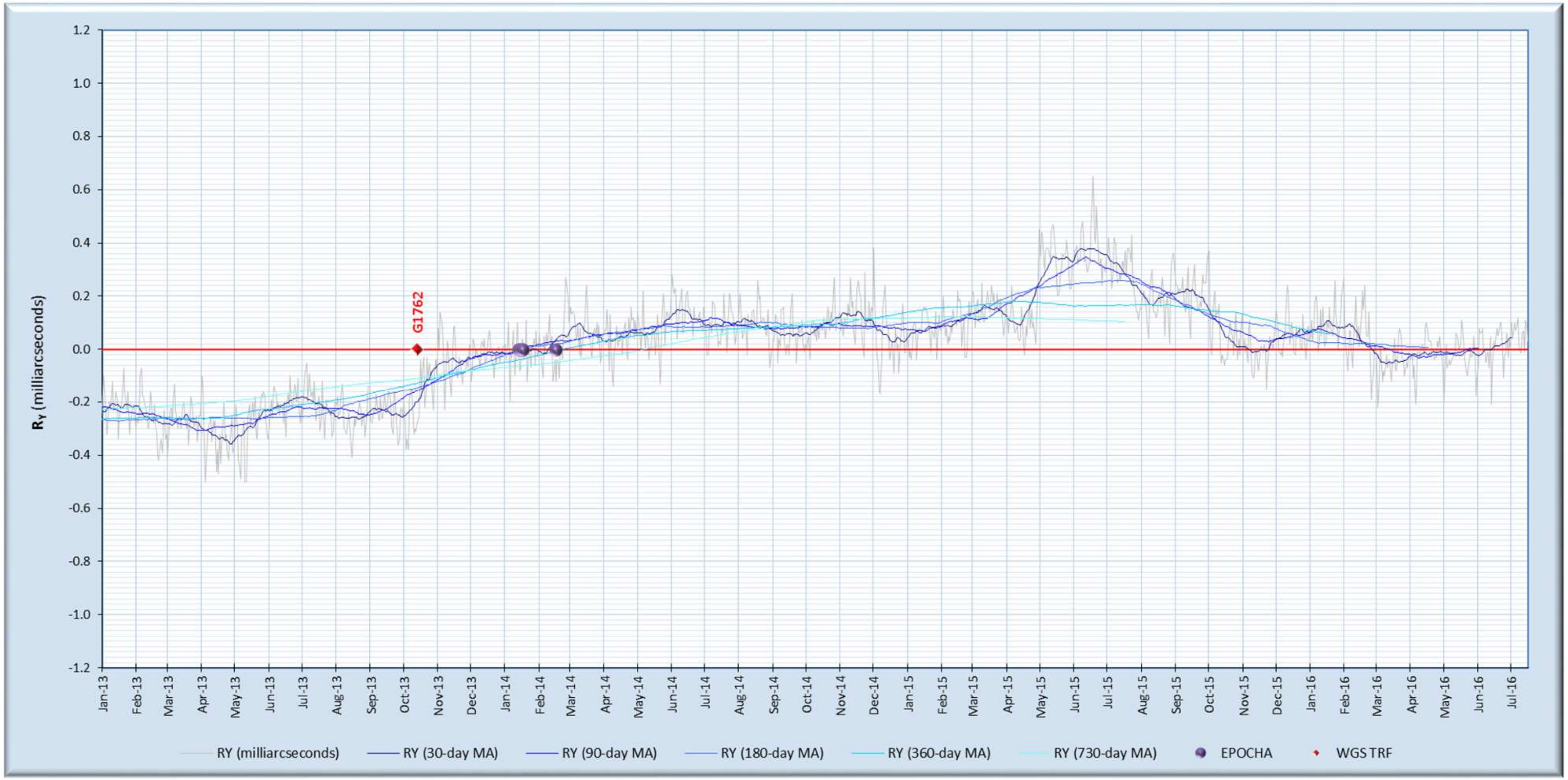
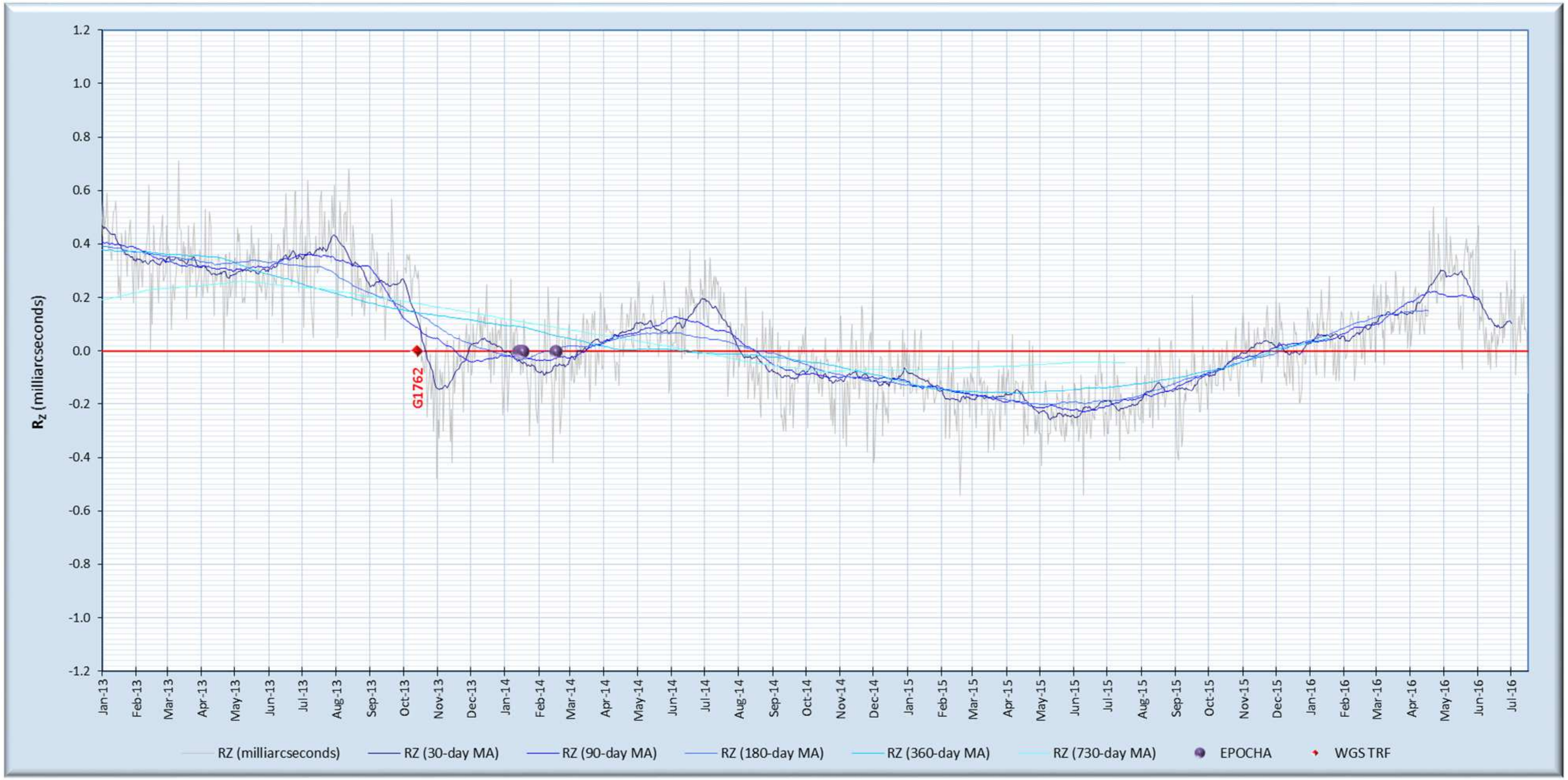
Jun-15
Jul-15
Aug-15
Sep-15
Oct-15
Nov-15
Dec-15
Jan-16
Feb-16
Mar-16
Apr-16
May-16
Jun-16
Jul-16
RX (milliarcseconds)
RX (30-day MA)
RX (90-day MA)
RX (180-day MA)
RX (360-day MA)
RX (730-day MA)
EPOCHA
WGS TRF

Y-Rotation



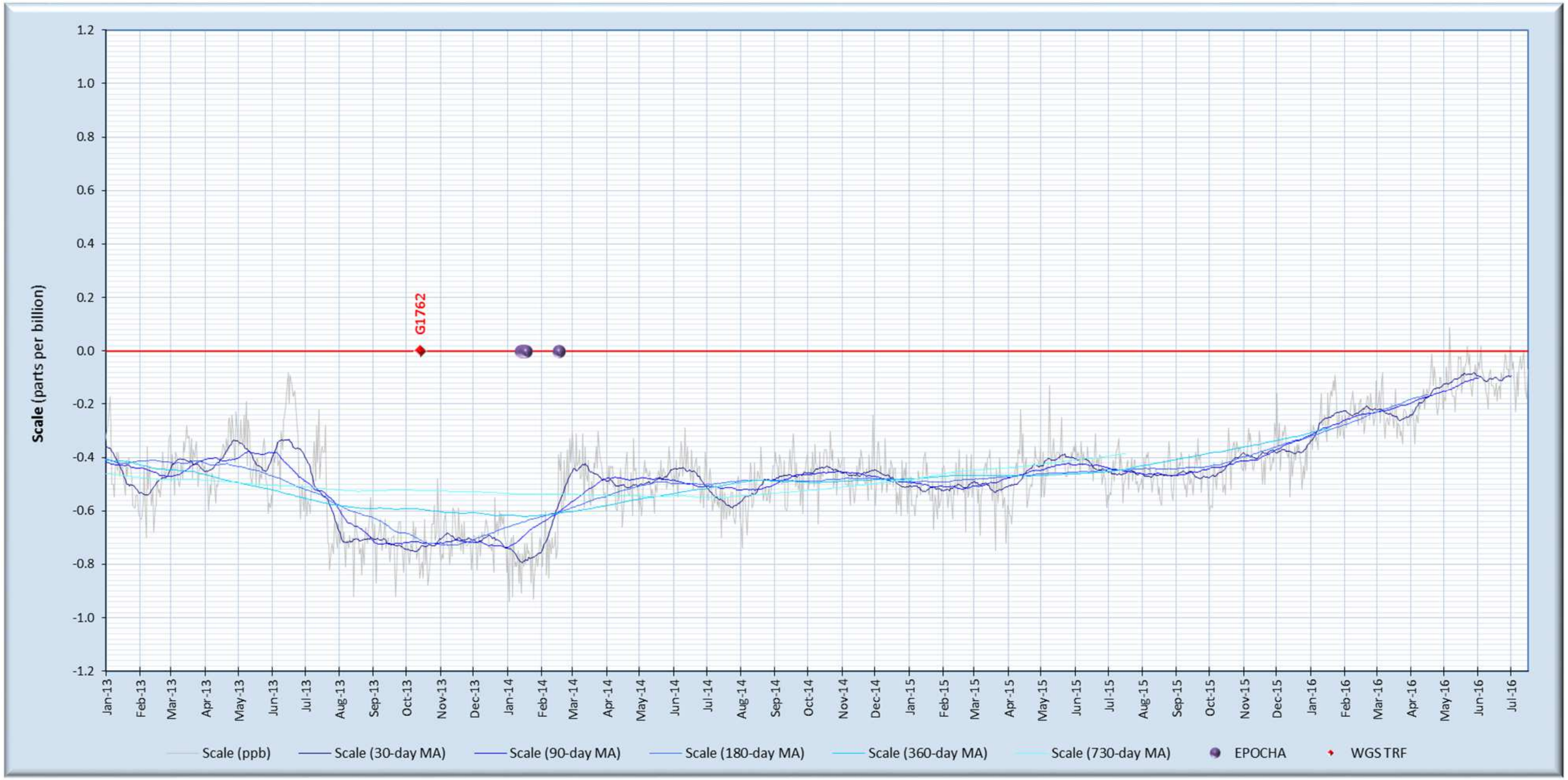
G1762
R_Y (milliarcseconds)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
Jan-13 Feb-13 Mar-13 Apr-13 May-13 Jun-13 Jul-13 Aug-13 Sep-13 Oct-13 Nov-13 Dec-13 Jan-14 Feb-14 Mar-14 Apr-14 May-14 Jun-14 Jul-14 Aug-14 Sep-14 Oct-14 Nov-14 Dec-14 Jan-15 Feb-15 Mar-15 Apr-15 May-15 Jun-15 Jul-15 Aug-15 Sep-15 Oct-15 Nov-15 Dec-15 Jan-16 Feb-16 Mar-16 Apr-16 May-16 Jun-16 Jul-16
RY (milliarcseconds)
RY (30-day MA)
RY (90-day MA)
RY (180-day MA)
RY (360-day MA)
RY (730-day MA)
EPOCHA
WGS TRF

Z-Rotation



1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
R_Z (milliarcseconds)
G1762
Jan-13 Feb-13 Mar-13 Apr-13 May-13 Jun-13 Jul-13 Aug-13 Sep-13 Oct-13 Nov-13 Dec-13 Jan-14 Feb-14 Mar-14 Apr-14 May-14 Jun-14 Jul-14 Aug-14 Sep-14 Oct-14 Nov-14 Dec-14 Jan-15 Feb-15 Mar-15 Apr-15 May-15 Jun-15 Jul-15 Aug-15 Sep-15 Oct-15 Nov-15 Dec-15 Jan-16 Feb-16 Mar-16 Apr-16 May-16 Jun-16 Jul-16
RZ (milliarcseconds)
RZ (30-day MA)
RZ (90-day MA)
RZ (180-day MA)
RZ (360-day MA)
RZ (730-day MA)
EPOCHA
WGS TRF

Scale



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7 Parameter Transformation Using Orbits 2016 NGA (WGS 84) vs. IGS (ITRF2008)

Mean of Daily Constellation-wide values from **first 198 Days of 2016**

7 Parameter Transformation (WGS84 (1762') to ITRF2008)		
Δx	-0.3 σ= 0.4	cm
Δy	-0.3 σ= 0.4	cm
Δz	-0.8 σ= 0.6	cm
R_x	-0.104 σ= 0.090	milli-arcseconds
R_y	0.014 σ=0.088	milli-arcseconds
R_z	-0.142 σ= 0.135	milli-arcseconds
scale	-0.176 σ= 0.093	ppb

Rotations and scale < 1cm at/near Earth surface

NGA

Notable Results: WGS 84 (G1762') vs ITRF 2008

Station Comparisons

- Small Number of Stations used (9) (Small Sample Size)
- 6 of 7 Transformation parameter values <1cm
- 2 cm (σ=0.4) Scale difference at mean Earth Radius
- 2 cm (σ=1.2) Vertical offset seen in ENU Comparisons

Orbit Comparisons

- Very Large Sample size over many years using full GPS constellation
- For 2016: All values <1 cm at or near Earth
- R_z Rotation can amount to 1.8 cm at GPS Altitude

Overall Conclusion

- Origin and Orientation difference all < 1cm
- Small (2 cm) scale difference in WGS 84 (G1762') Station Coordinates
- Contributing factors include
  - Knowledge of Satellite and Station phase center locations
  - Proper handling of phase center variations
  - Compensating Satellite and Station Clock offset estimates

NGA

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X-Rotation

R_X (milliarcseconds)
4
3
2
1
0
-1
-2
-3
-4
G873
G1159
G1674 (OCS)
G1674 (NGA)
G1762
Oct-95 Apr-96 Oct-96 Apr-97 Oct-97 Apr-98 Oct-98 Apr-99 Oct-99 Apr-00 Oct-00 Apr-01 Oct-01 Apr-02 Oct-02 Apr-03 Oct-03 Apr-04 Oct-04 Apr-05 Oct-05 Apr-06 Oct-06 Apr-07 Oct-07 Apr-08 Oct-08 Apr-09 Oct-09 Apr-10 Oct-10 Apr-11 Oct-11 Apr-12 Oct-12 Apr-13 Oct-13 Apr-14 Oct-14 Apr-15 Oct-15 Apr-16
RX (milliarcseconds)
RX (30-day MA)
RX (90-day MA)
RX (180-day MA)
RX (360-day MA)
RX (730-day MA)
WGS TRF

Y-Rotation

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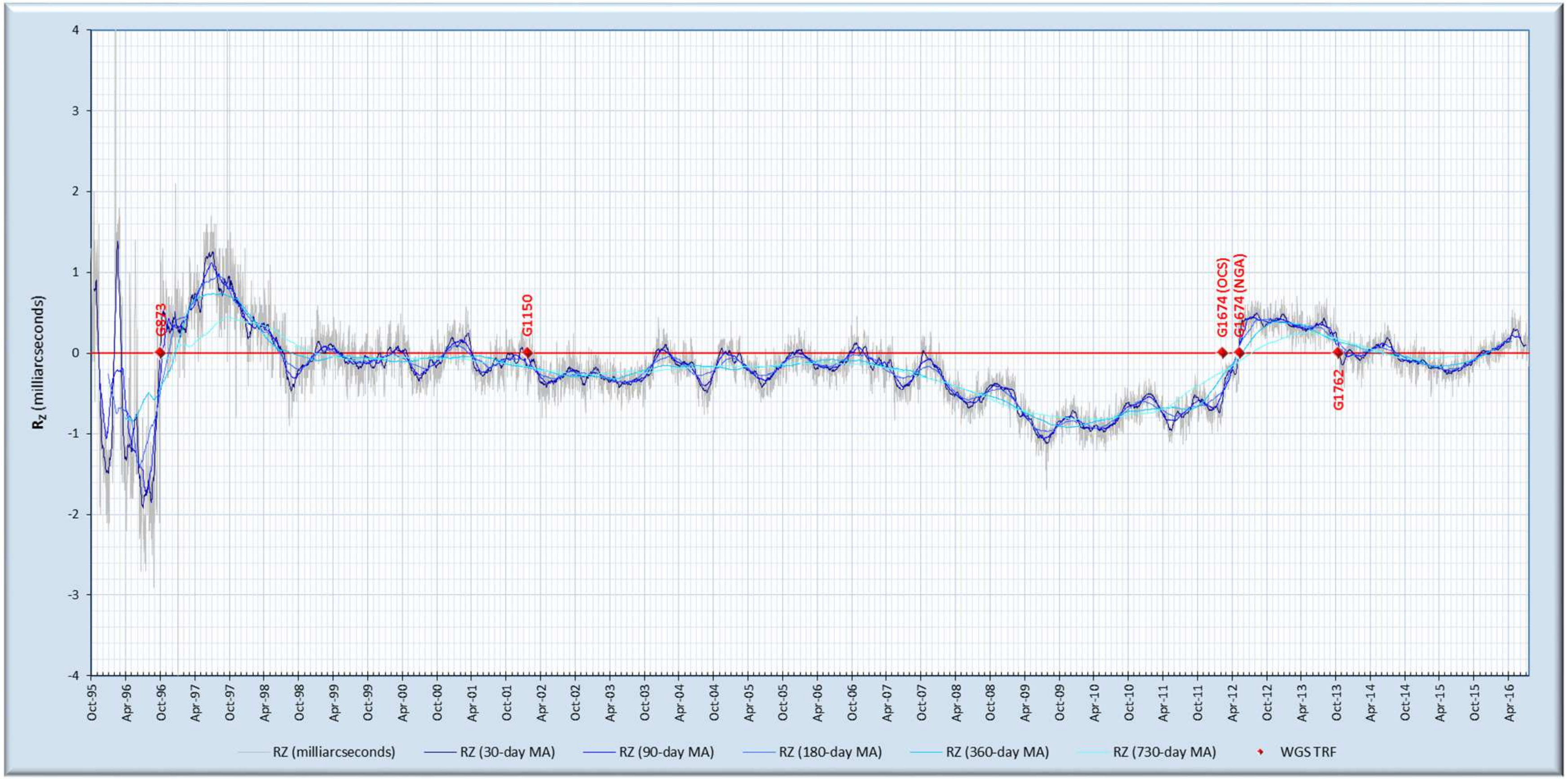
Z-Rotation



R_Z (milliarcseconds)
4
3
2
1
0
-1
-2
-3
-4
G873
G1150
G1674 (OCS)
G1674 (NGA)
G1762
Oct-95
Apr-96
Oct-96
Apr-97
Oct-97
Apr-98
Oct-98
Apr-99
Oct-99
Apr-00
Oct-00
Apr-01
Oct-01
Apr-02
Oct-02
Apr-03
Oct-03
Apr-04
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Apr-05
Oct-05
Apr-06
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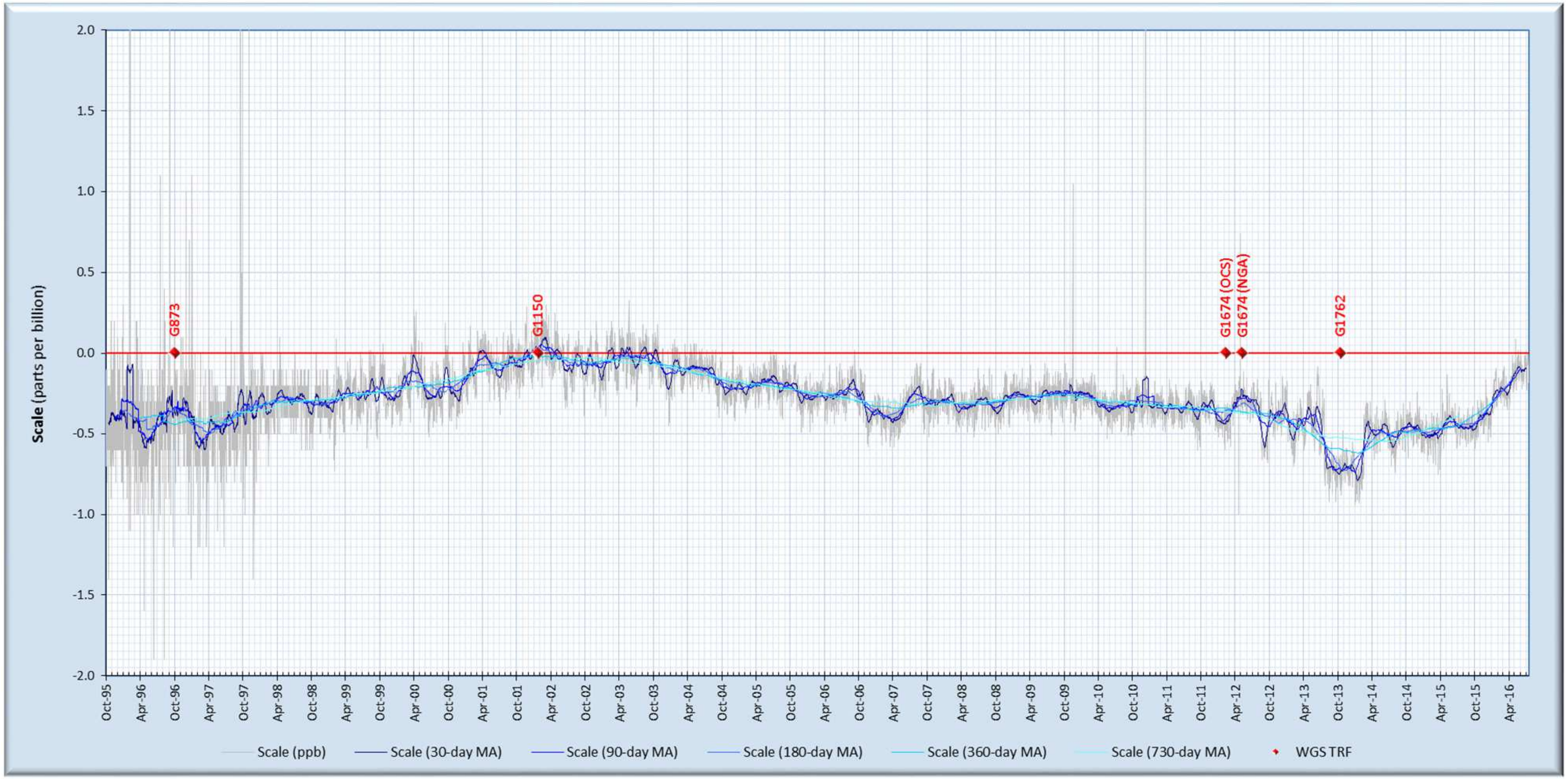
Apr-10
Oct-10
Apr-11
Oct-11
Apr-12
Oct-12
Apr-13
Oct-13
Apr-14
Oct-14
Apr-15
Oct-15
Apr-16
RZ (milliarcseconds)
RZ (30-day MA)
RZ (90-day MA)
RZ (180-day MA)
RZ (360-day MA)
RZ (730-day MA)
WGS TRF

Scale


Scale (parts per billion)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
G873
G1150
G1674 (OCS)
G1674 (NGA)
G1762
Oct-95 Apr-96 Oct-96 Apr-97 Oct-97 Apr-98 Oct-98 Apr-99 Oct-99 Apr-00 Oct-00 Apr-01 Oct-01 Apr-02 Oct-02 Apr-03 Oct-03 Apr-04 Oct-04 Apr-05 Oct-05 Apr-06 Oct-06 Apr-07 Oct-07 Apr-08 Oct-08 Apr-09 Oct-09 Apr-10 Oct-10 Apr-11 Oct-11 Apr-12 Oct-12 Apr-13 Oct-13 Apr-14 Oct-14 Apr-15 Oct-15 Apr-16
Scale (ppb)
Scale (30-day MA)
Scale (90-day MA)
Scale (180-day MA)
Scale (360-day MA)
Scale (730-day MA)
WGS TRF