ILRSA contribution to ITRF2014: the V61 solution

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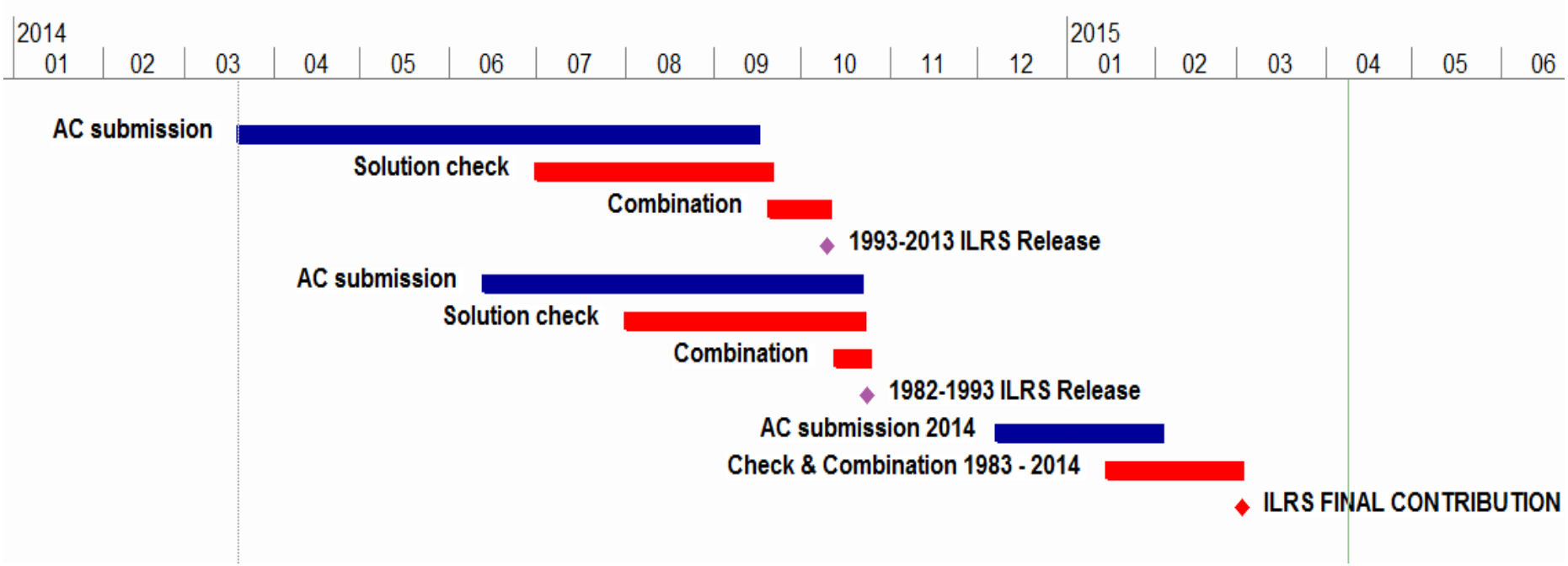
Outline

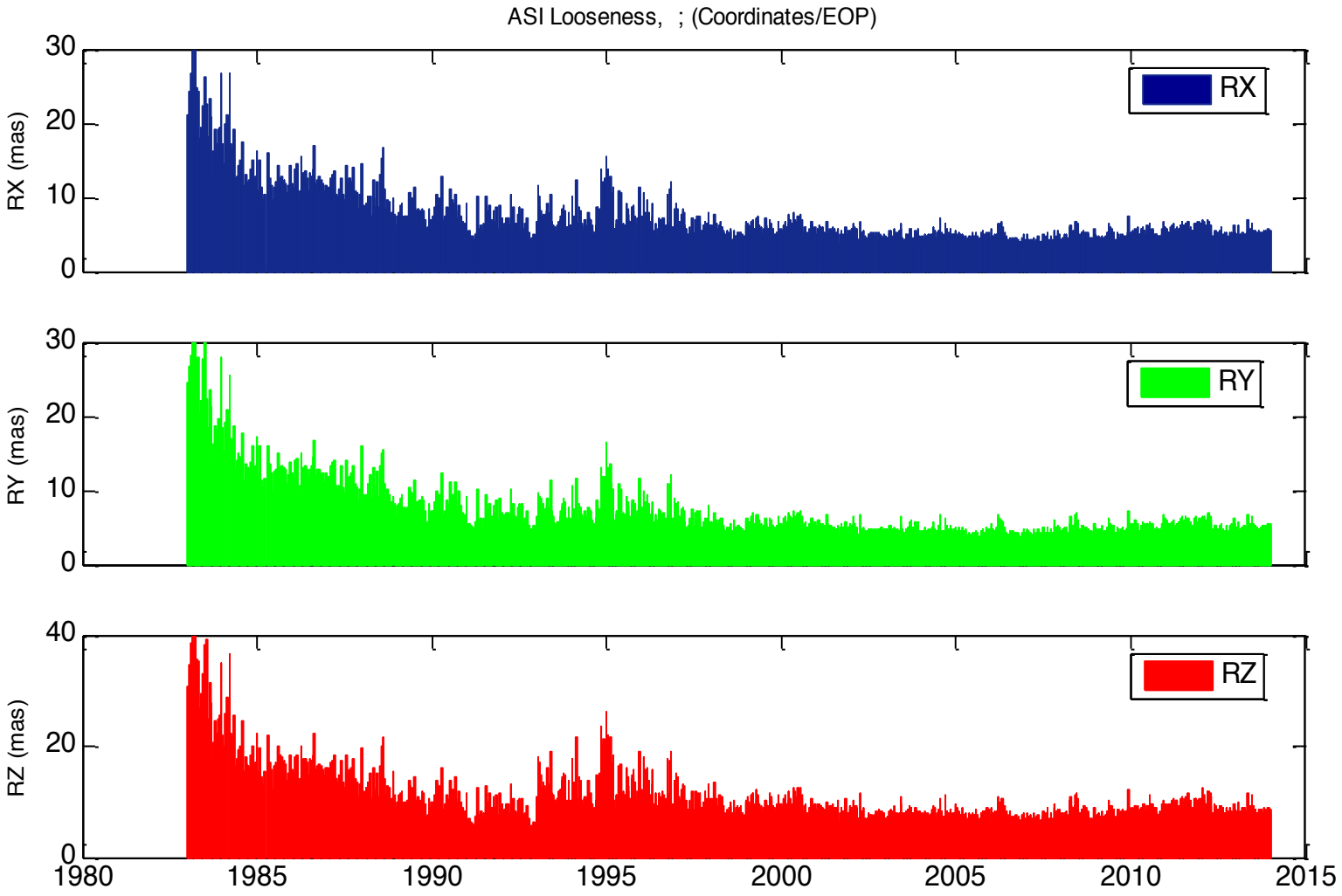
- AC/CC solution verification
  - Looseness
  - AC Bias application and editing
  - AC Scale factor
  - SSC residuals
  - EOP residuals
  - Translations & scale

ILRSA timeline

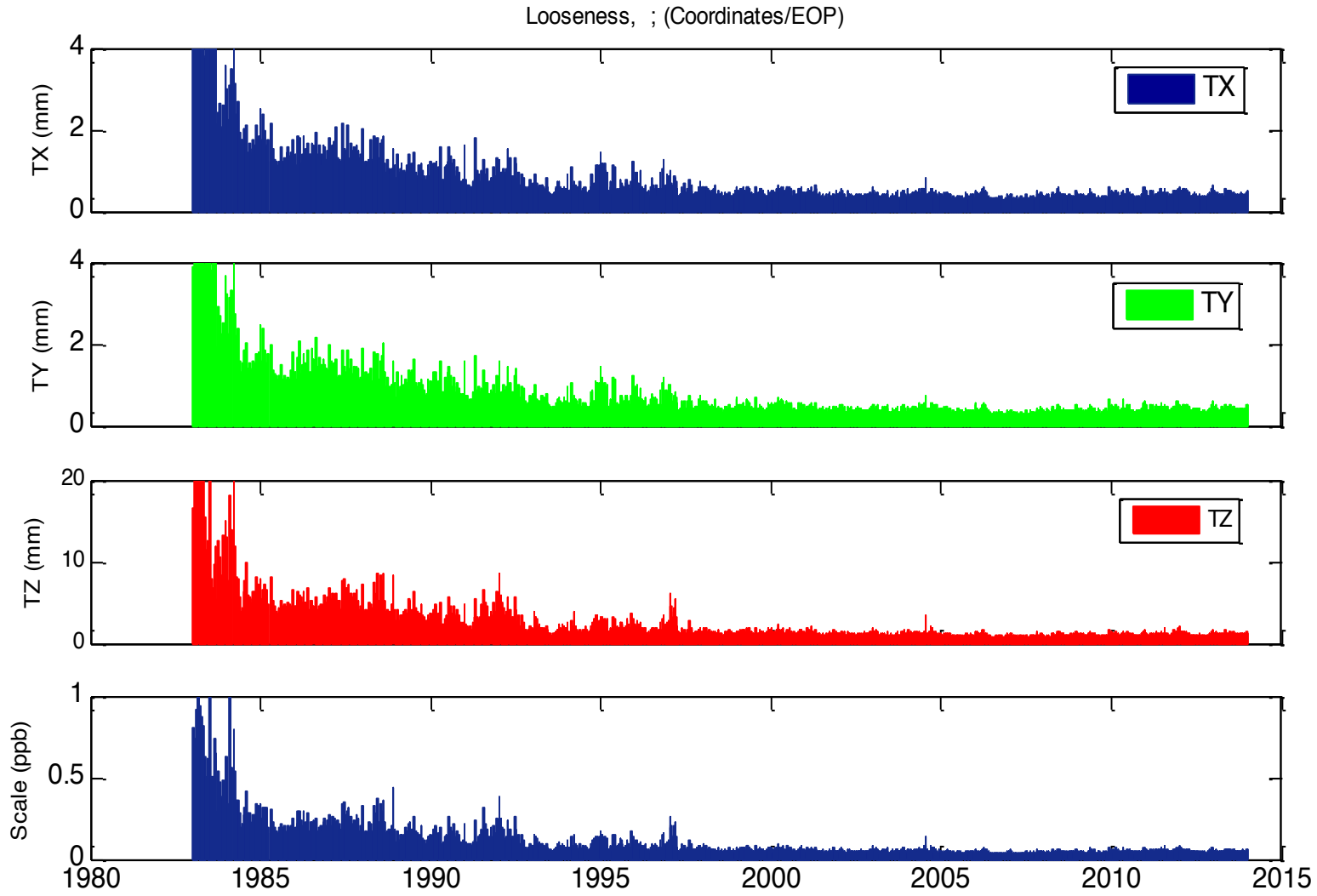


- Multiple AC submissions mainly due to erroneous bias application
- Along with the 2014 extension, 3 ACs (DGFI, ESA, JCET) resubmitted the full series 1993-2014
- ILRSA v61 is the official ILRS contribution

Looseness: typical values



Looseness: typical values

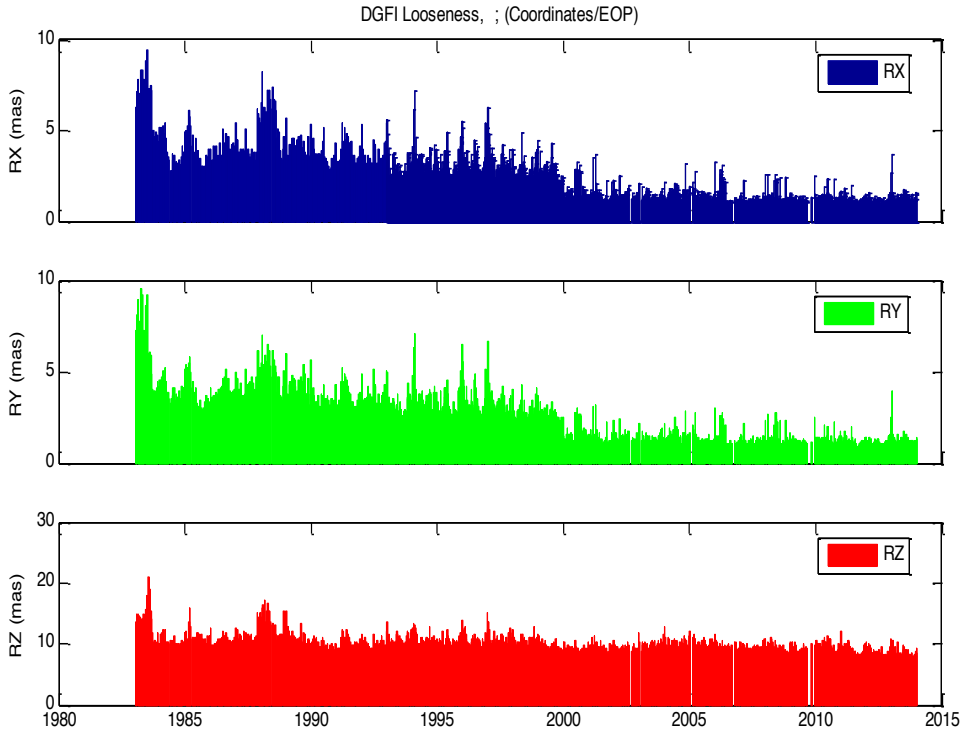


Looseness

	1983-1992								
	ASI	BKG	DGFI	ESA	GFZ	GRGS	JCET	NSGF	ILRSA
RX (mas)	11.32		4.88	10.02	5.36	9.73	4.44	20.60	5.94
RY (mas)	11.64		4.73	10.33	5.43	10.40	4.44	21.07	6.04
RZ (mas)	15.23		12.03	13.00	11.70	13.06	26.02	27.06	10.07
TX (mm)	1.71		0.79	1.07	1.44	1.69	1.60	1.50	0.93
TY (mm)	1.58		0.78	1.08	1.38	1.62	1.50	1.47	0.93
TZ (mm)	6.12		3.24	4.09	5.20	5.78	5.72	5.74	3.36
Scale (mm	1.66		1.01	1.19	1.92	1.71	1.56	1.60	0.97

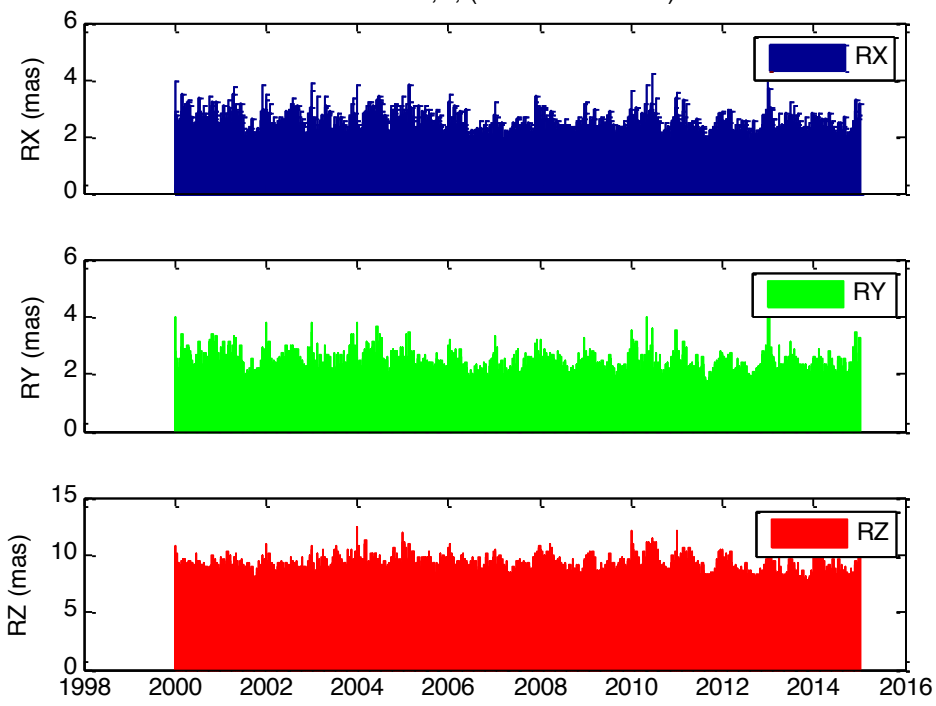
	1993-2013								
	ASI	BKG	DGFI	ESA	GFZ	GRGS	JCET	NSGF	ILRSA
RX (mas)	5.46	8.17	1.98	5.97	4.10	6.57	5.13	7.33	5.15
RY (mas)	5.29	7.91	1.94	5.80	3.97	6.29	4.96	7.28	5.17
RZ (mas)	9.04	11.10	9.73	8.05	10.80	8.53	9.47	11.79	9.27
TX (mm)	0.46	0.50	0.33	0.42	0.55	0.72	0.41	0.64	0.47
TY (mm)	0.45	0.50	0.33	0.41	0.55	0.69	0.40	0.63	0.47
TZ (mm)	1.33	1.49	0.99	1.27	1.63	2.51	1.21	1.94	1.38
Scale (mm	0.38	0.44	0.28	0.37	0.66	0.71	0.35	0.55	0.41

Looseness: DGFI



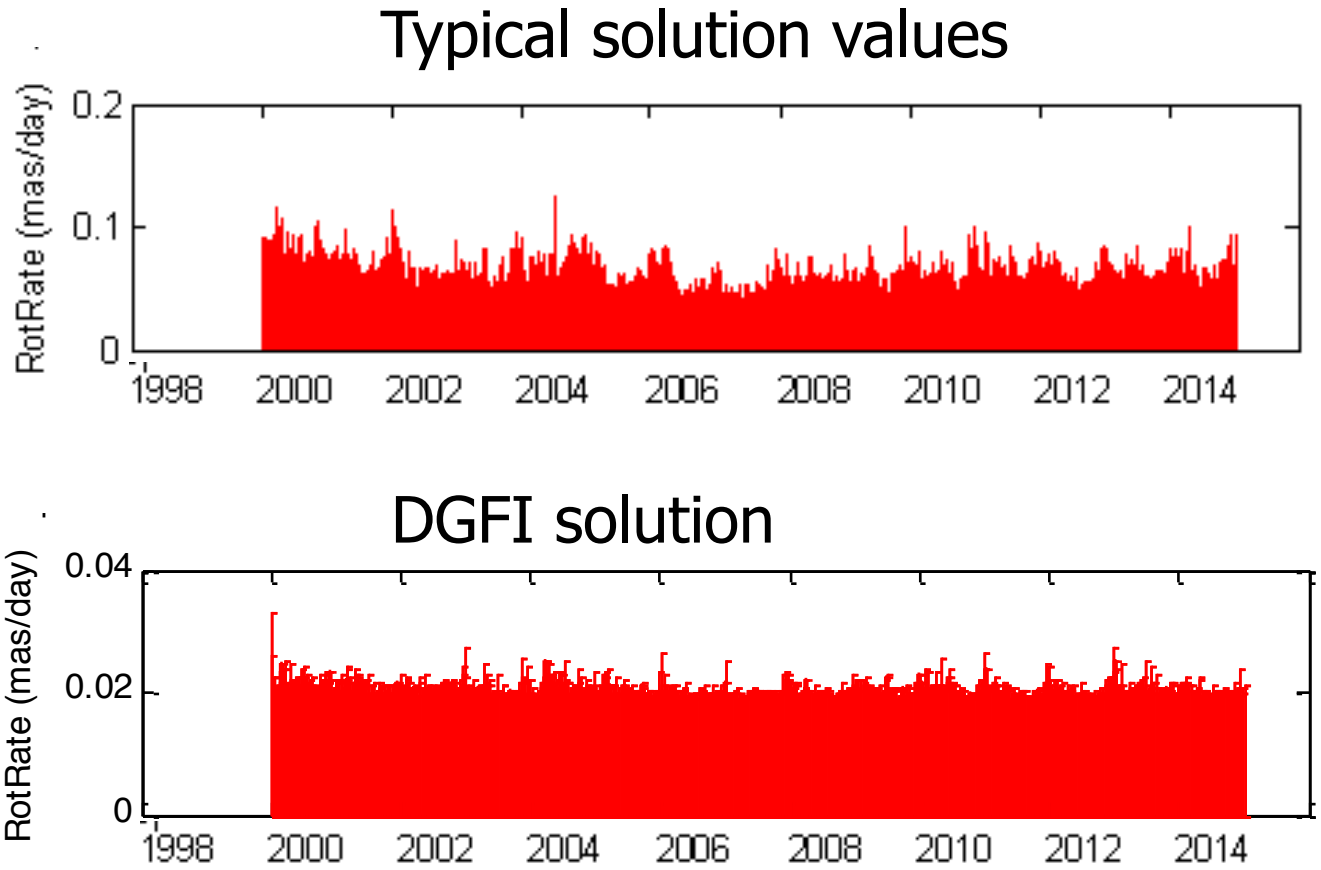
v60 submission

v61 submission



- No loosening in rotation was applied

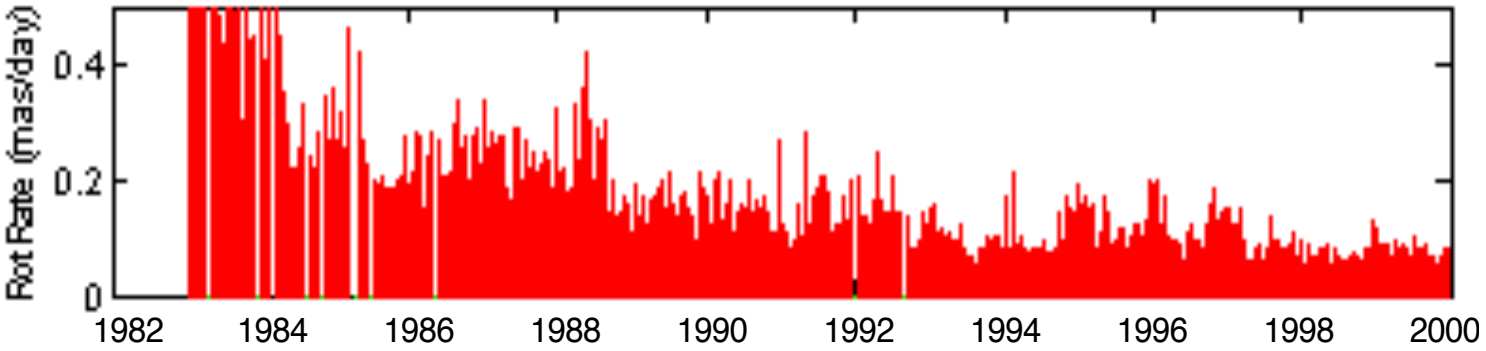
Looseness: rotation rate 2000-2014



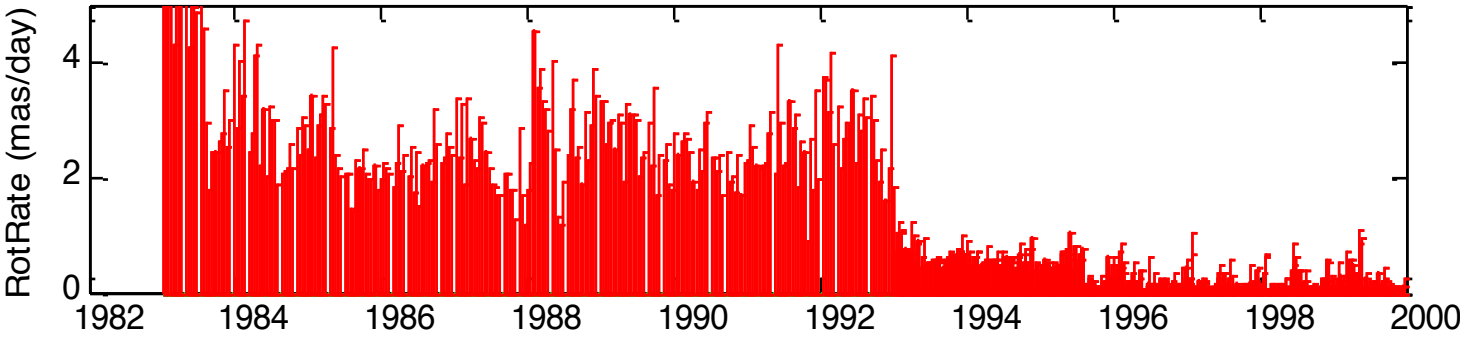
- Loosening applied in rotation rate for DGFI

Looseness: rotation rate 1983-1999

Typical solution values



ESA solution



Data & bias

BKG
% 7810 since 96:336 to 08:001 : bias estimated when not requested
% 1873 since 11:182 to 12:153: data to be deleted as specified in the data handling file
% 7080 since 96:026 to 96:130: -30/40 mm UP offset

DGFI
% 1824 since 03:001 to 06:001 :a few points (<20) with large offsets
% 1884 since 94:001 to 98:001: large UP negative offset
% 7080 since 96:026 to 96:130 : -30/40 mm UP offset in the UP component
% 7821 since 09:146 to 10:069: : -200 mm UP offset

JCET
% 1824 since 03:001 to 06:001: a few points (<20) with large offsets
% 7308 since 11:152 to 13:001: -100 mm offset in the UP component
% 7821 since 09:146 to 10:069: -200 mm offset in the UP component

ESA
% 7080 since 96:026 to 96:130 : -30/40 mm offset in the UP component
% 7907 since 83:001 to 87:001 : large UP scatter and offset

GFZ
% 1884 since 94:001 to 98:001 : large UP negative offset

NSGF
% 7907 since 83:001 to87:001 : large UP scatter and offset

Data editing

GRGS solutions non considered in the combination because the coordinate epochs are shifted by 4 days

000115
000624
000902
990403
990417
991009
980808
980815
971122
971129
971206
971220
971227
930109

Data editing

JCET solutions wit arcs longer than 7 days

jcet.pos+eop.030607.v61.snx , arc length is	7.96103009259241	days
jcet.pos+eop.030705.v61.snx , arc length is	7.97640046296146	days
jcet.pos+eop.030712.v61.snx , arc length is	7.99826388889051	days
jcet.pos+eop.030719.v61.snx , arc length is	7.46351851851796	days
jcet.pos+eop.030726.v61.snx , arc length is	7.66459490740817	days
jcet.pos+eop.030802.v61.snx , arc length is	7.29902777777897	days
jcet.pos+eop.030809.v61.snx , arc length is	7.39968750000116	days
jcet.pos+eop.030816.v61.snx , arc length is	7.86534722222132	days

DGFI solutions wit arcs longer than 15 days

dgfi.pos+eop.840204.v61.snx , arc length is	15.3824421296304	days
dgfi.pos+eop.840916.v61.snx , arc length is	16	days
dgfi.pos+eop.850213.v61.snx , arc length is	16	days
dgfi.pos+eop.850613.v61.snx , arc length is	16	days
dgfi.pos+eop.870305.v61.snx , arc length is	16	days
dgfi.pos+eop.870519.v61.snx , arc length is	16	days
dgfi.pos+eop.881010.v61.snx , arc length is	16	days
dgfi.pos+eop.881025.v61.snx , arc length is	16	days
dgfi.pos+eop.881224.v61.snx , arc length is	16	days

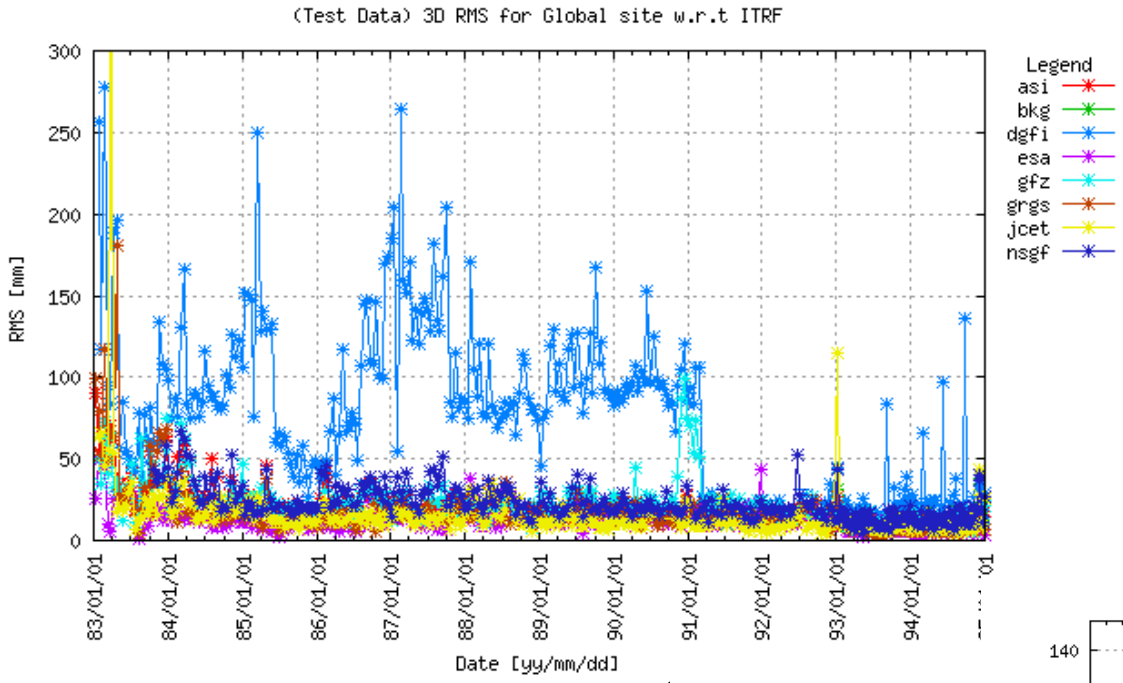
Solution Epochs

- Dates outside the arc limits (NSGF, BKG in the header only)
- Nominal dates in the SOLUTION/EPOCHS block (ESA, BKG in the header only)
- Stations in SITE ID without corresponding epoch in the SOLUTION/EPOCHS block

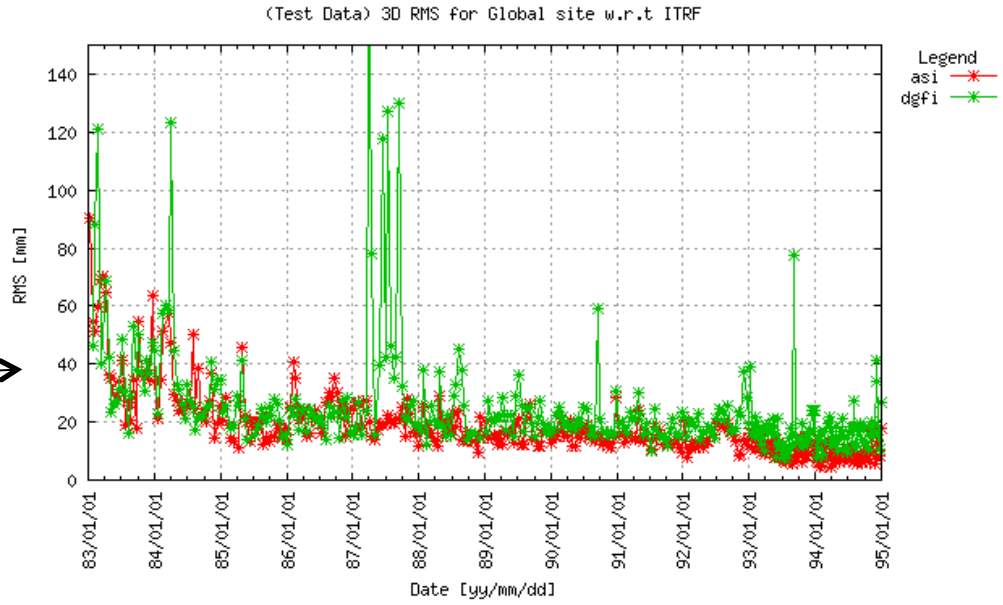
An example: the 070707 arc

```
-FILE/REFERENCE
+INPUT/HISTORY
 +SNX 2.00 ASI 14:106:10859 ASI 07:182:00063 07:188:86347 L 00083 2 E S
 +SNX 2.01 BKG 14:255:85129 BKG 07:181:86399 07:189:00000 L 00083 1 S E
 +SNX 2.00 DGF 14:233:58791 DGF 07:182:47370 07:188:40717 L 00090 2 S E
 +SNX 2.02 ESA 14:237:64322 ESA 07:182:00000 07:189:00000 L 00079 2 S E
 +SNX 2.01 GFZ 14:151:39600 GFZ 07:182:04167 07:188:84627 L 00084 2 S E
 +SNX 2.01 GRG 14:243:46568 GRG 07:182:00163 07:188:86347 L 00088 2 E S
 +SNX 2.00 JCT 14:202:76473 JCT 07:182:00063 07:188:86347 L 00092 2 E S
 +SNX 2.00 ner 14:209:59396 ner 07:182:00792 07:189:00162 L 00077 2 S E
 =SNX 2.00 ASI 14:260:62192 ASI 07:182:00000 07:189:00000 L 00087 2 E S
-INPUT/HISTORY
```

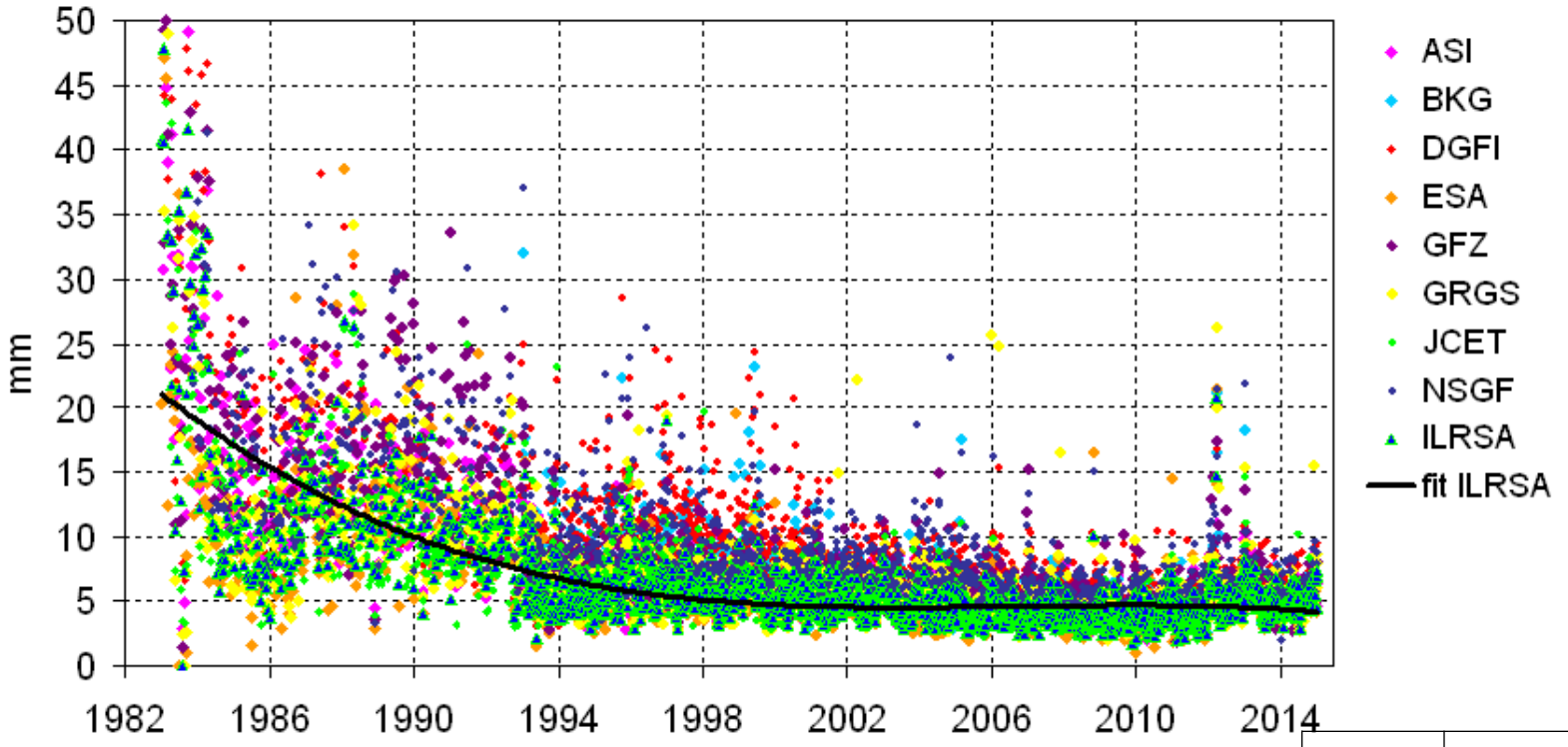
AC historic submissions



DGFI submissions V60 and V61

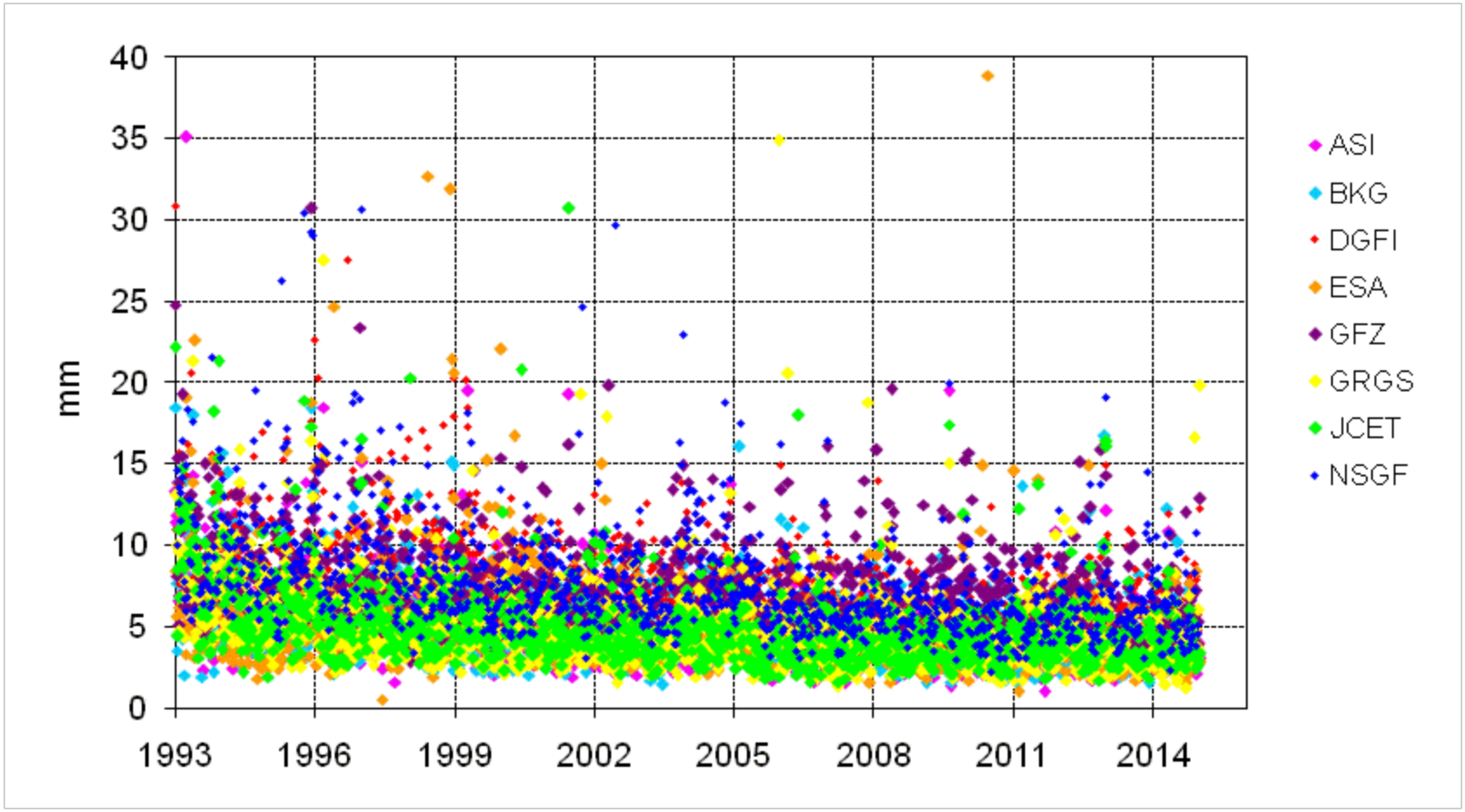


SSC Core Sites – 3D WRMS of residuals wrt SLRF2008

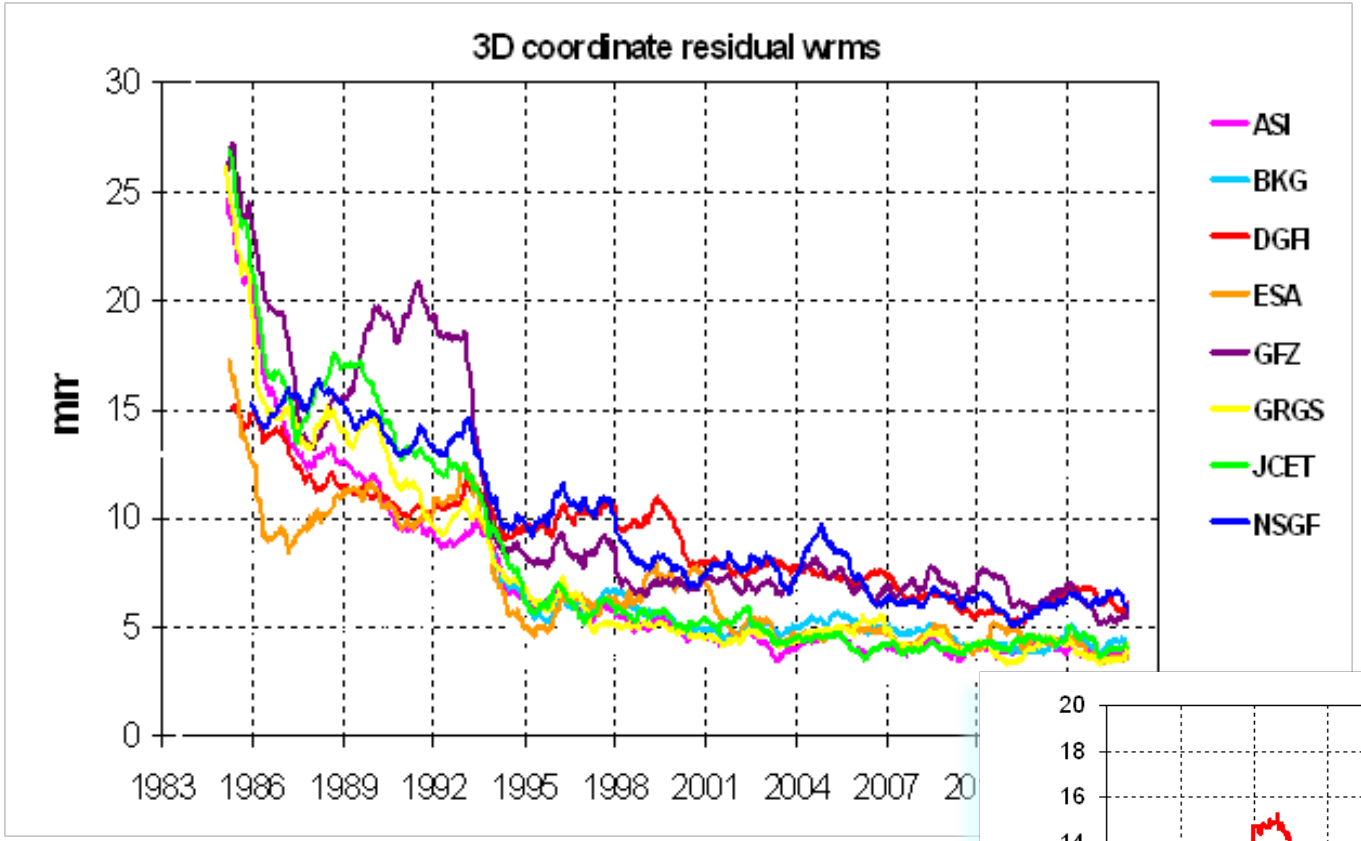


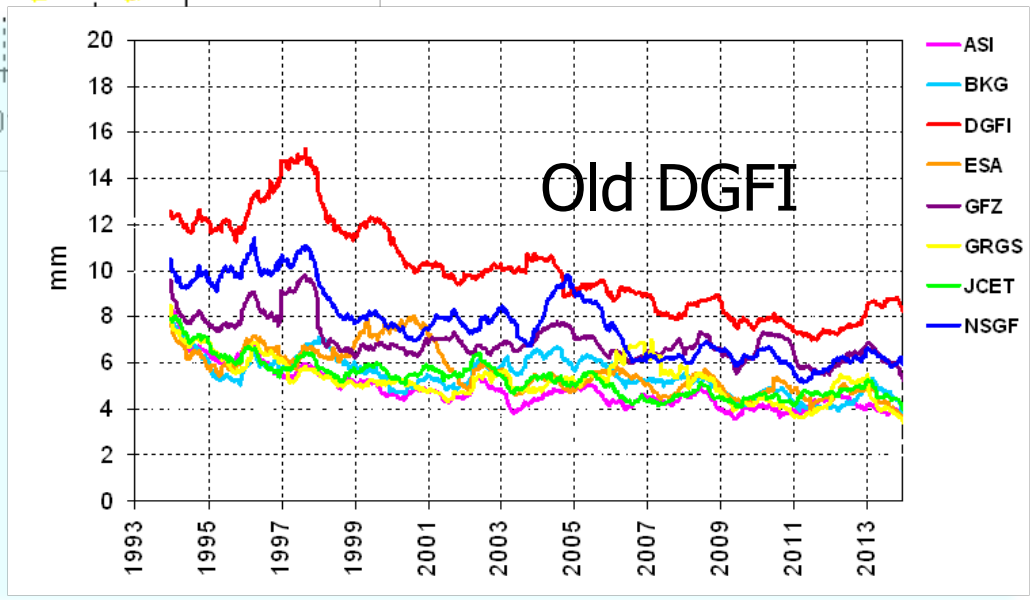
	1984-1992		1993-2014	
	mean	std	mean	std
ASI	13.6	5.5	5.6	1.8
BKG	---------	---------	6.1	2.7
DGFI	16.2	6.8	8.0	3.6
ESA	10.8	5.5	5.1	1.8
GFZ	17.8	8.5	6.2	2.0
GRGS	12.6	6.7	5.5	2.3
JCET	11.0	4.7	5.4	2.1
NSGF	15.6	6.0	7.2	2.9
ILRSA	**11.4**	**5.0**	**4.9**	**1.7**

Intra-technique consistency

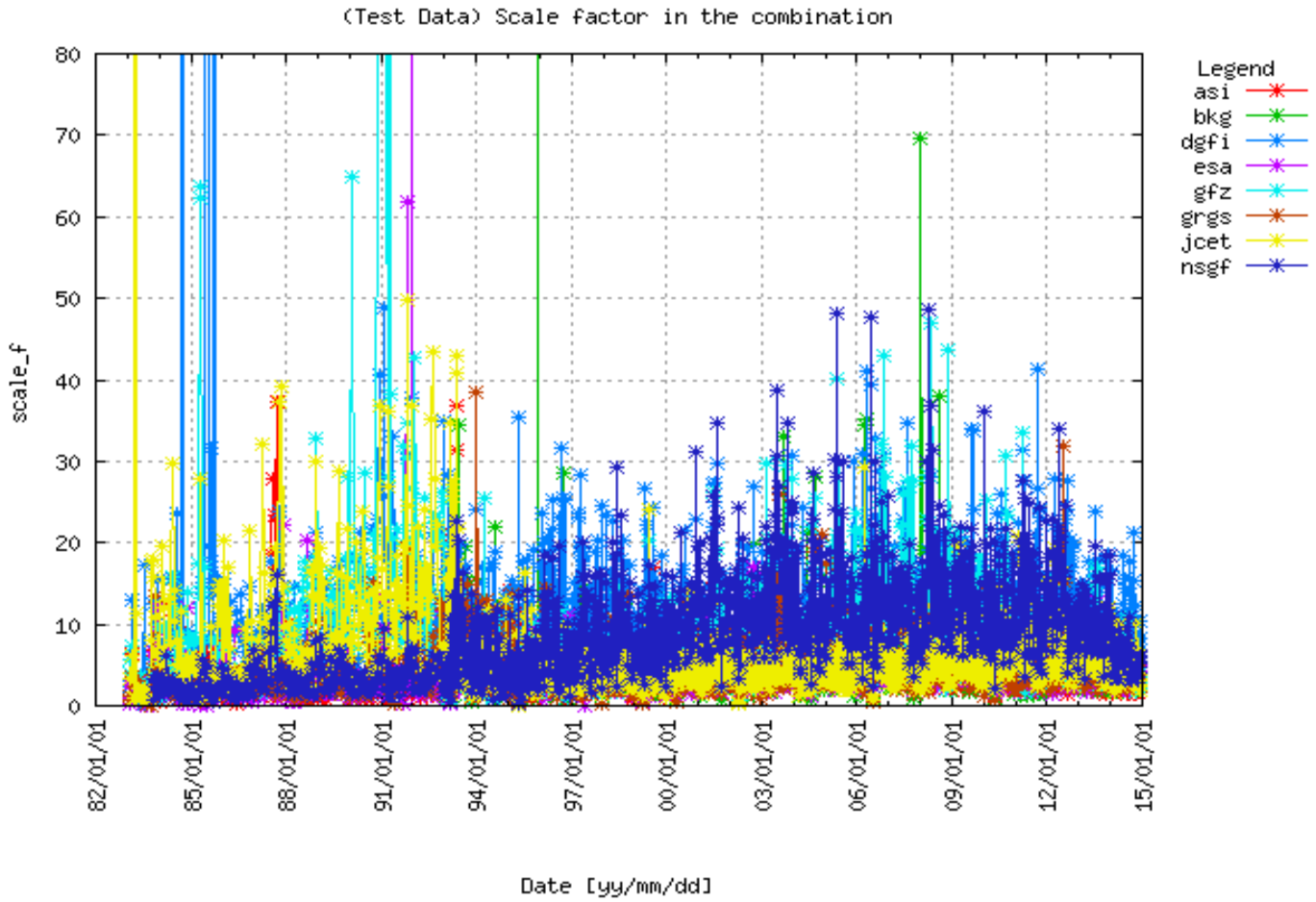


Intra-technique consistency

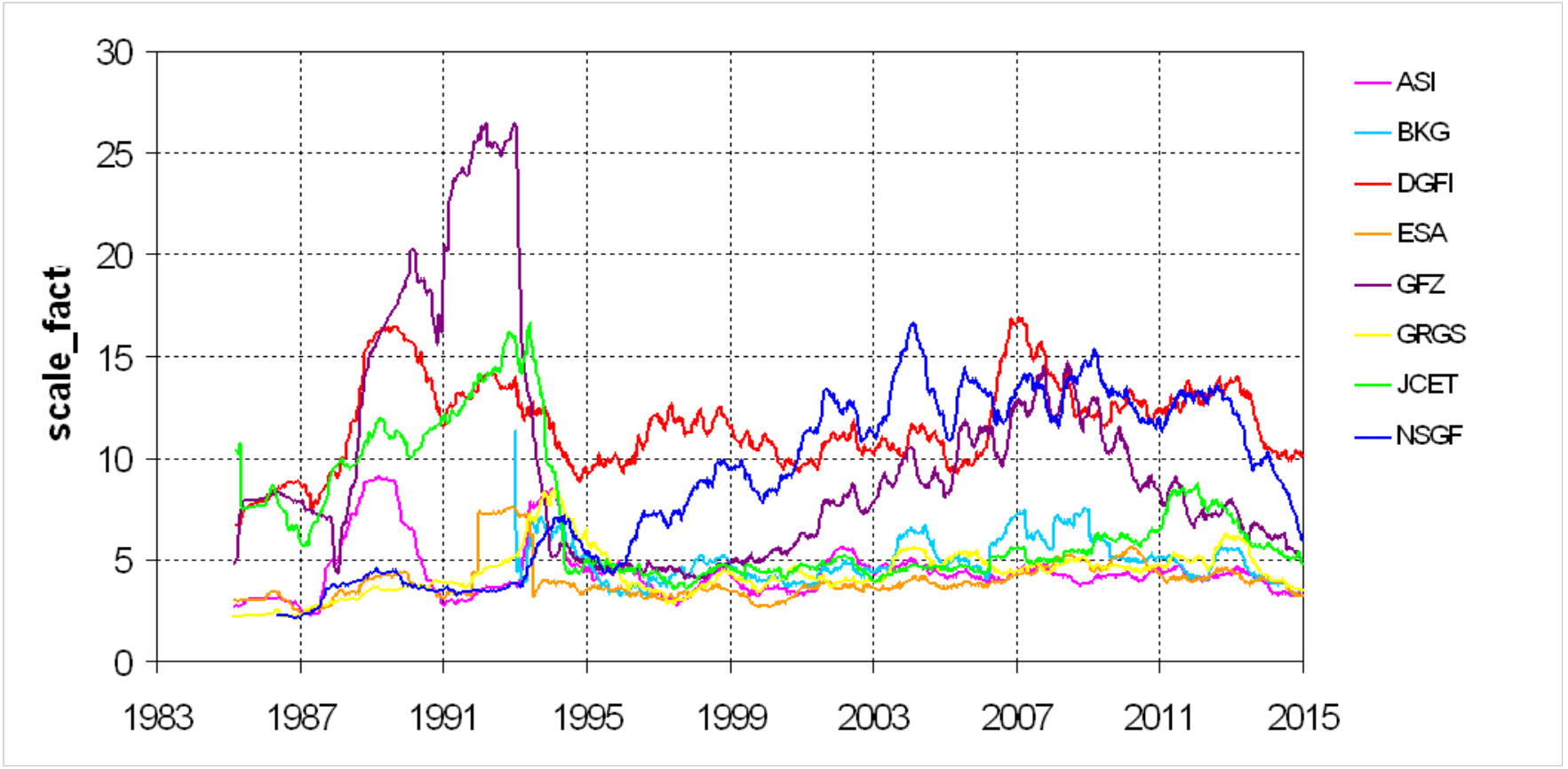




AC weight scaling factors

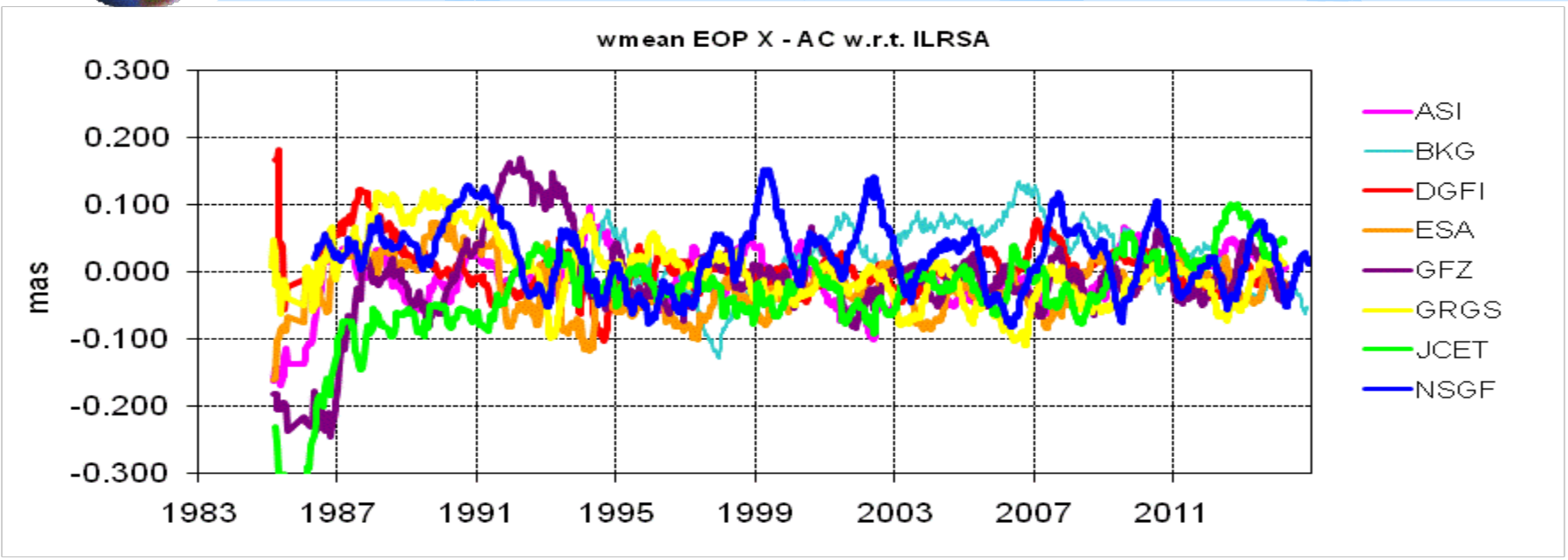


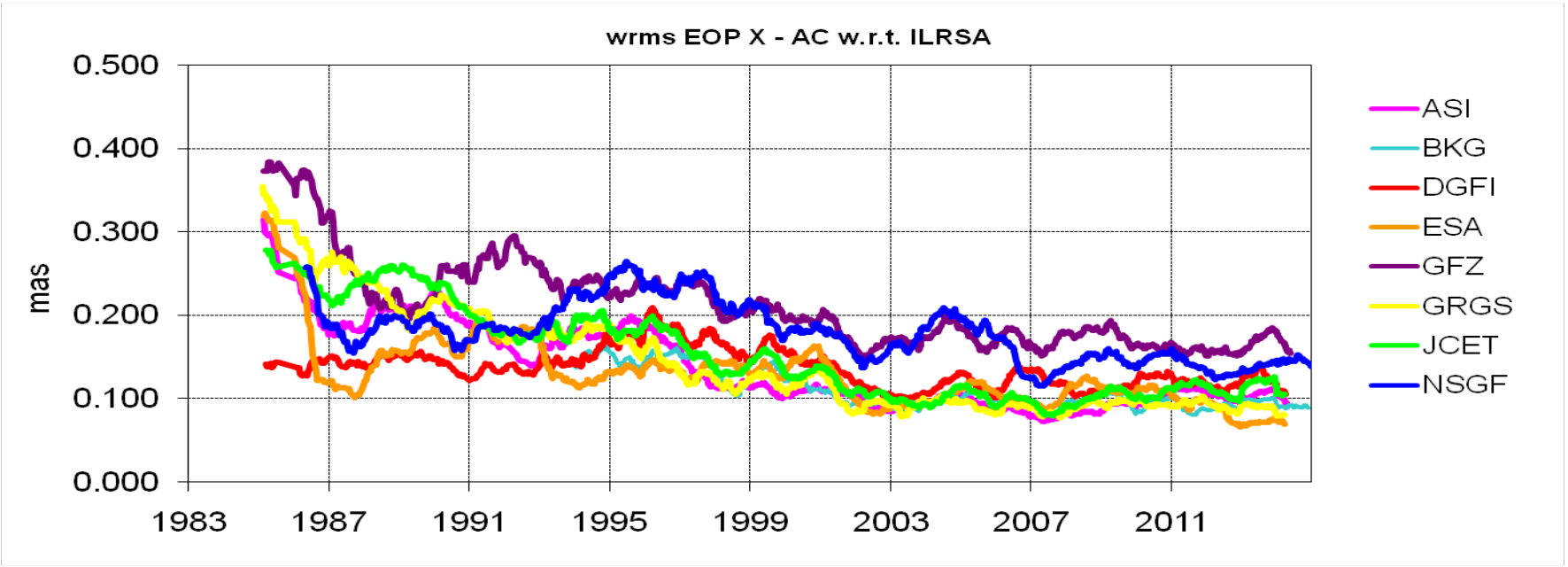
AC weight scaling factors



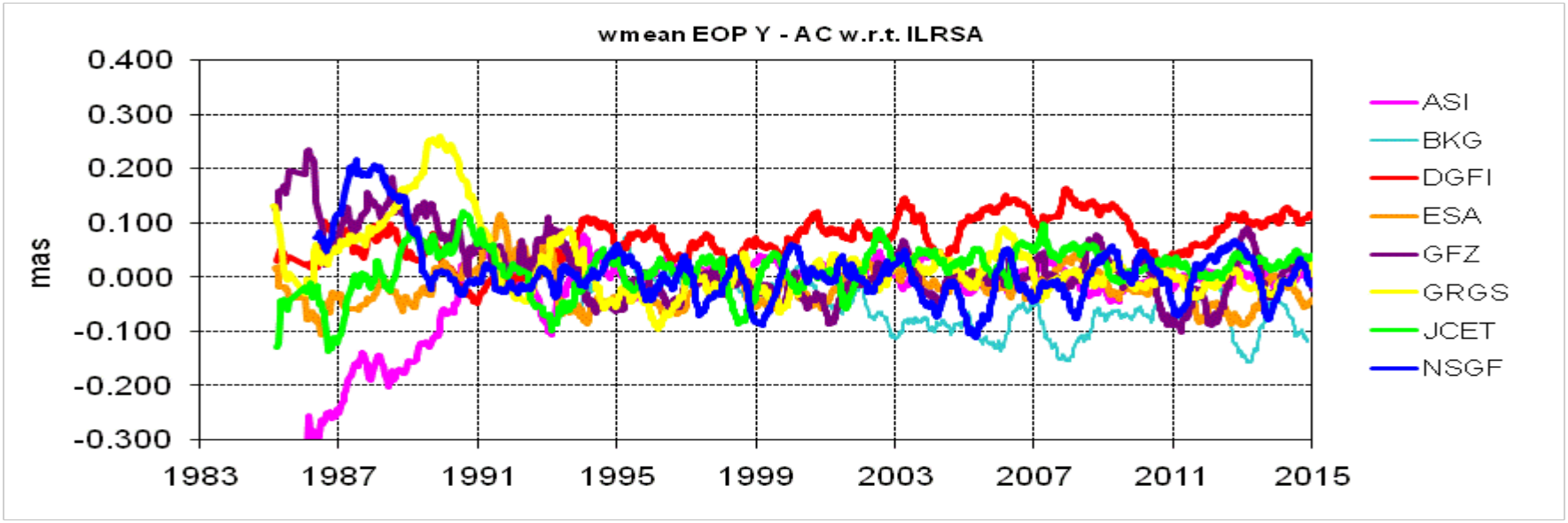
1993-2014	ASI	BKG	DGFI	ESA	GFZ	GRGS	JCET	NSGF
mean	4.3	4.9	11.6	3.9	7.6	4.7	5.4	10.6
st. dev	2.7	4.1	5.5	1.7	5.4	2.9	3.5	6.0

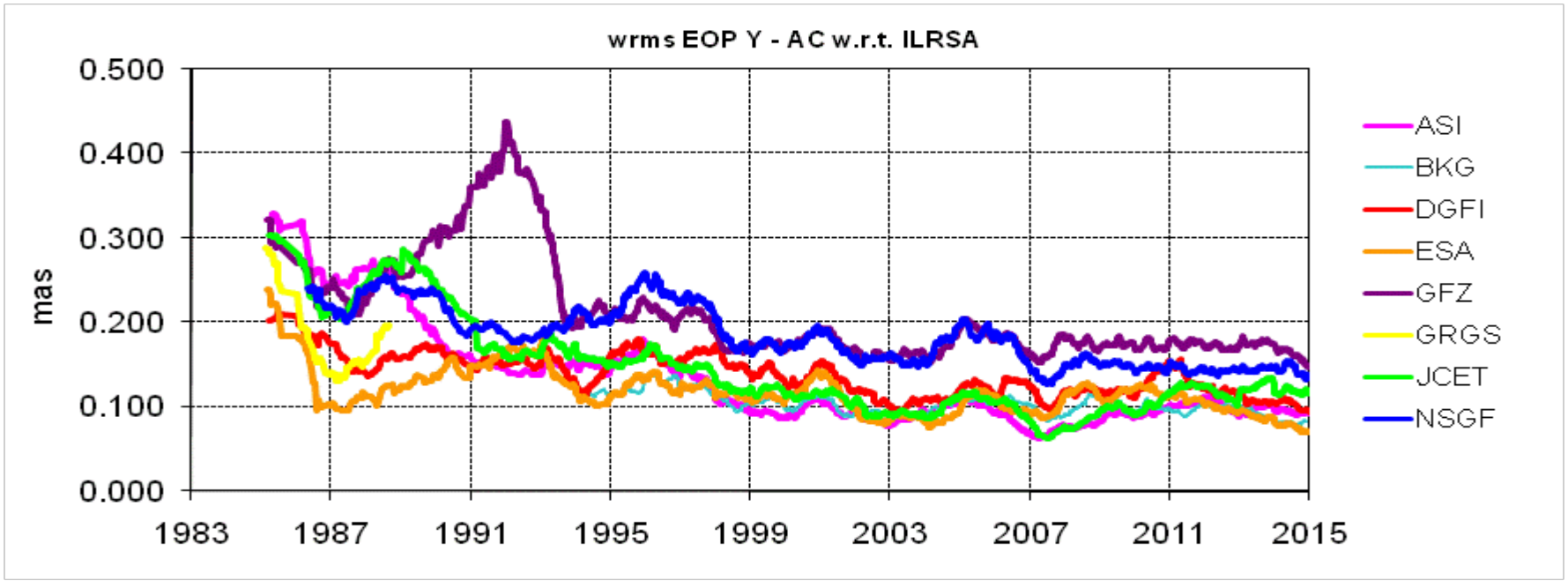
EOP X - Weekly residuals wrt ILRSA



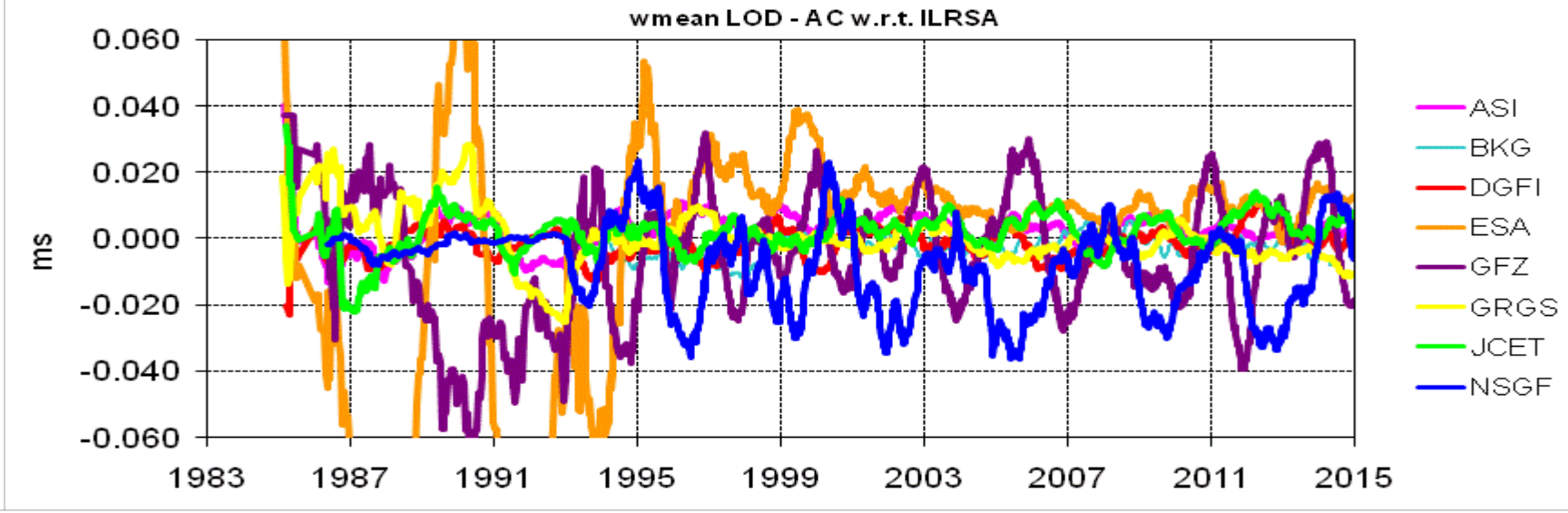


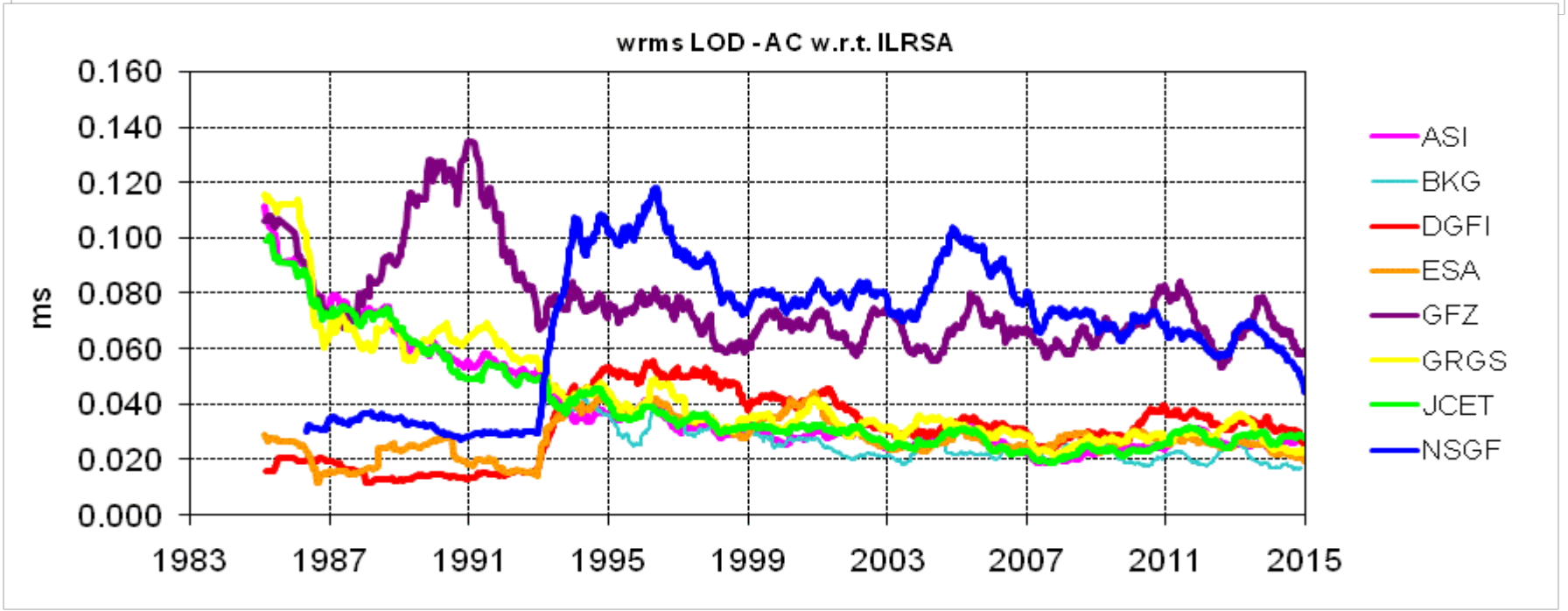
EOP Y - Weekly residuals wrt ILRSA



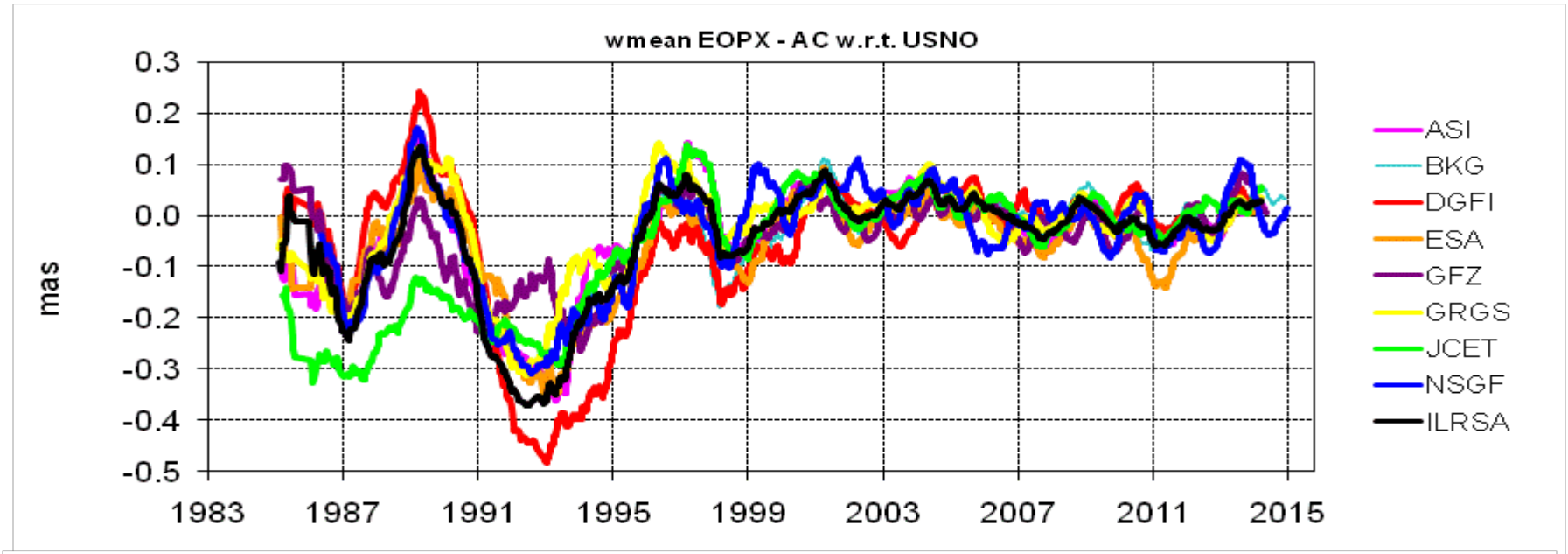


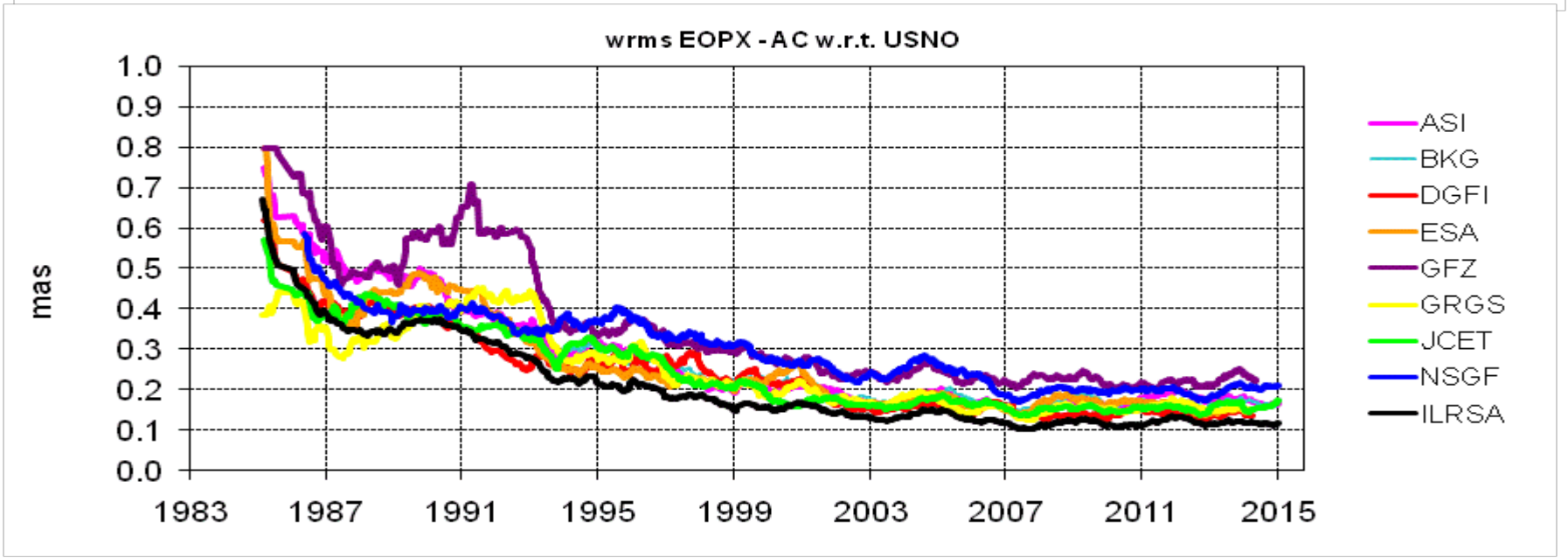
LOD - Weekly residuals wrt ILRSA



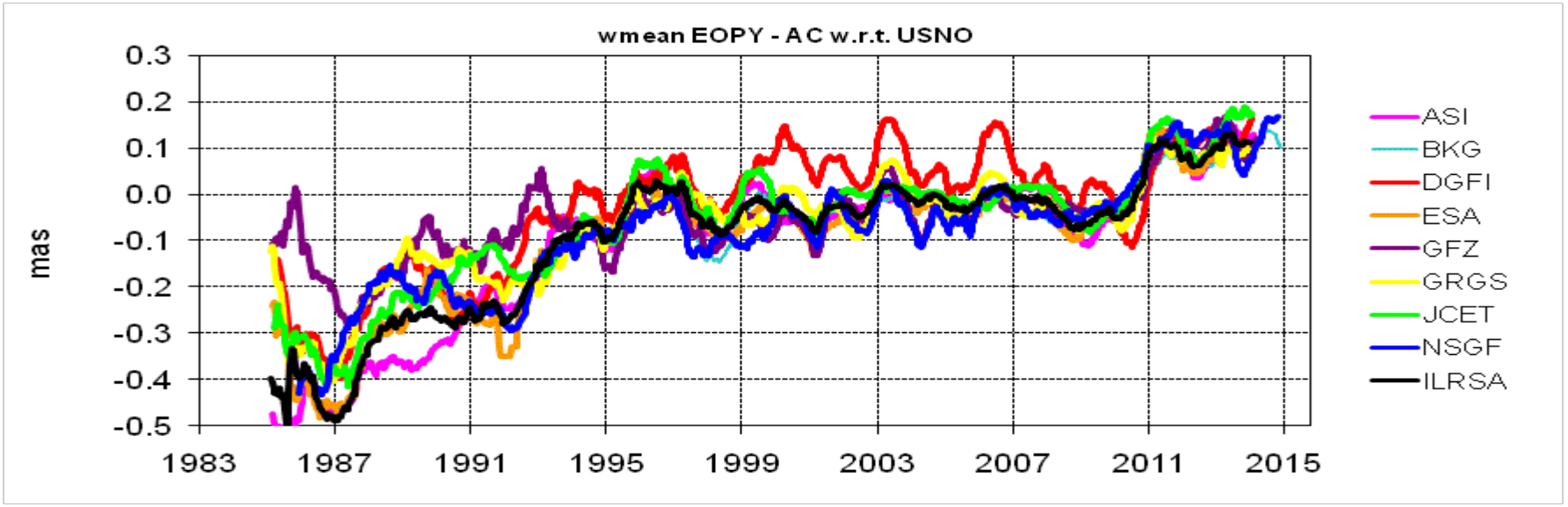


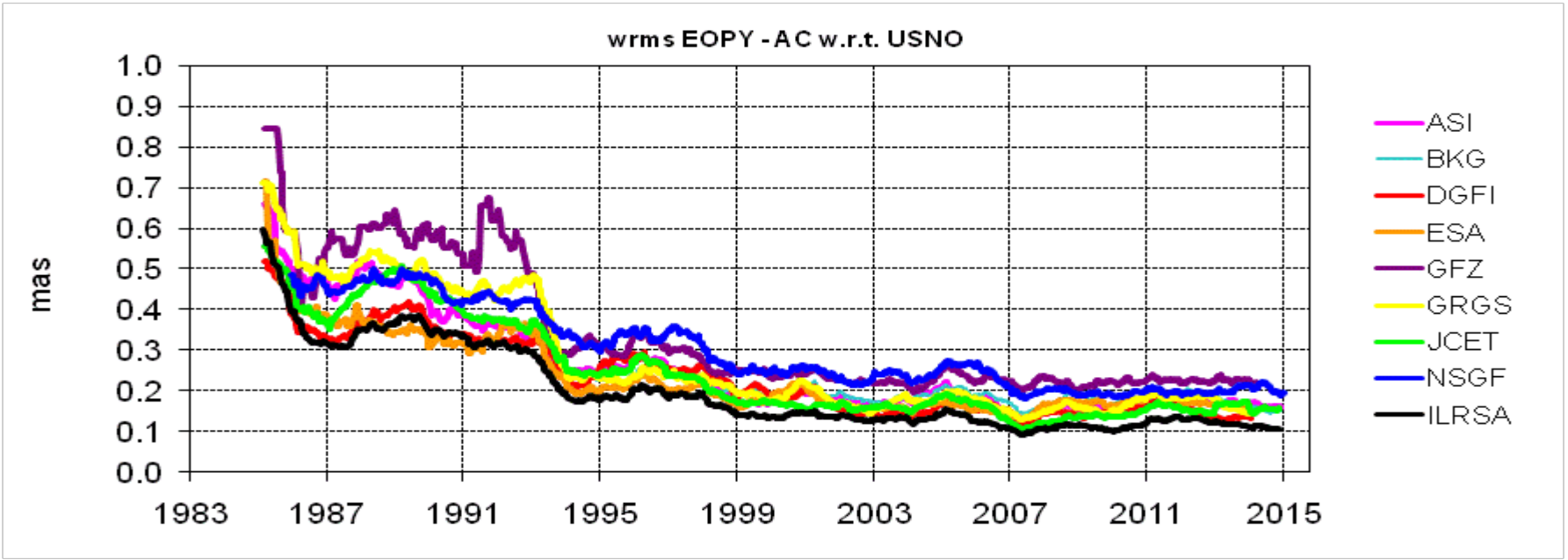
EOPX - Weekly residuals wrt USNO



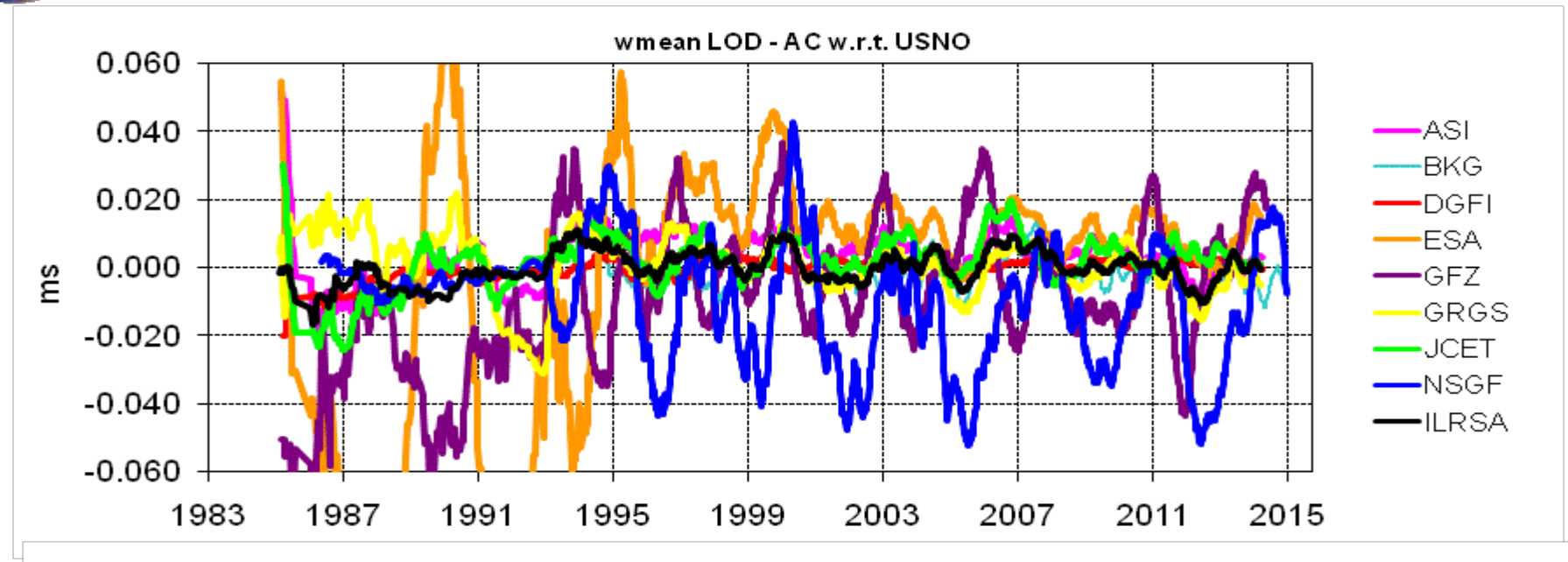


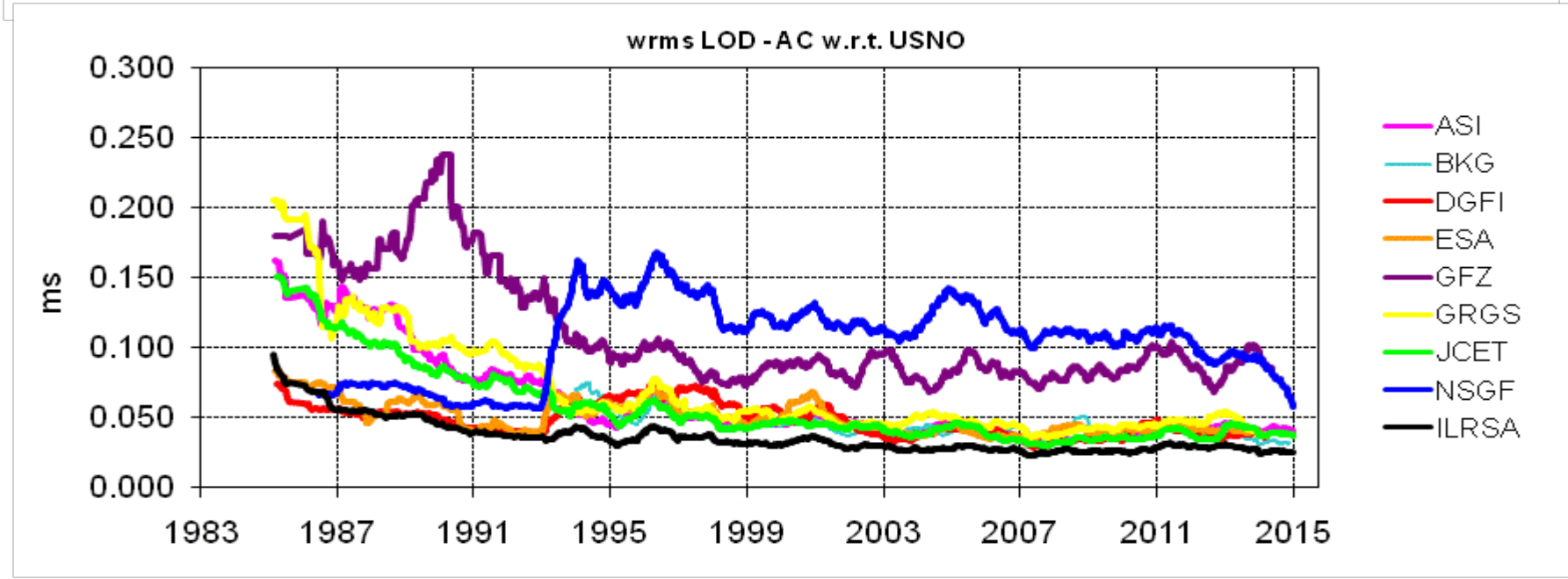
EOPY - Weekly residuals wrt USNO



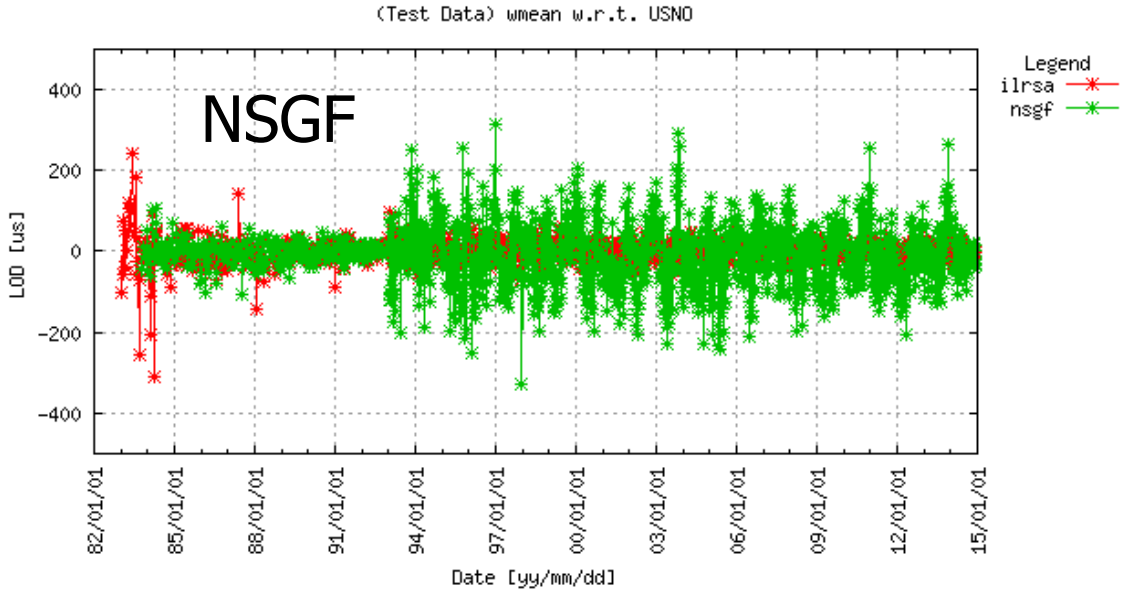


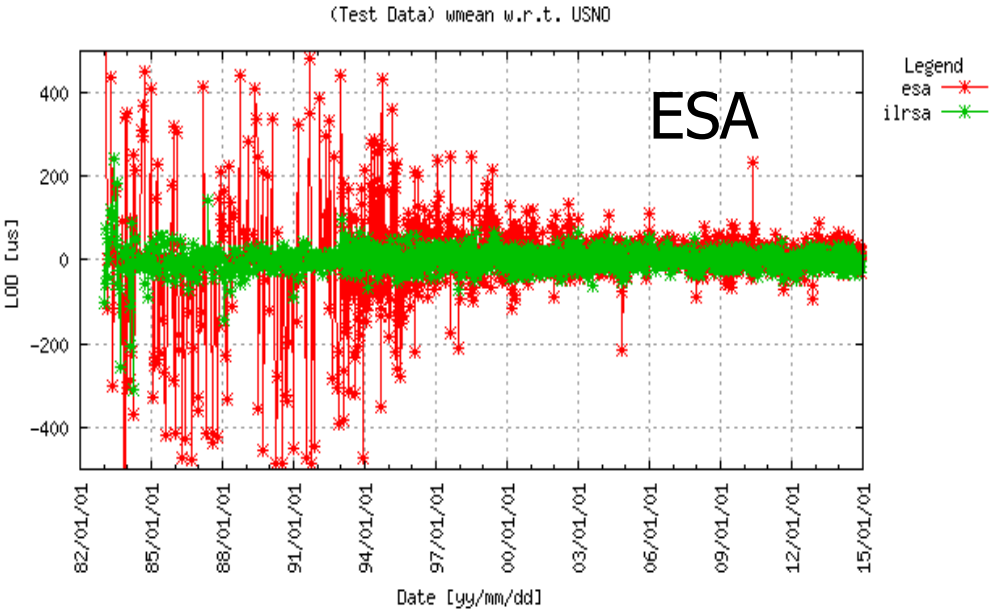
LOD - Weekly residuals wrt USNO

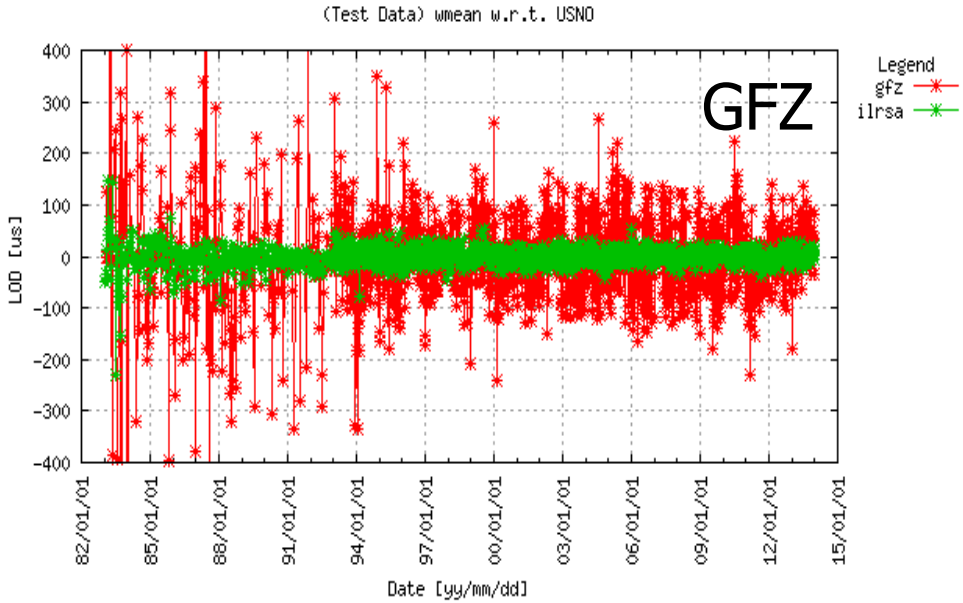




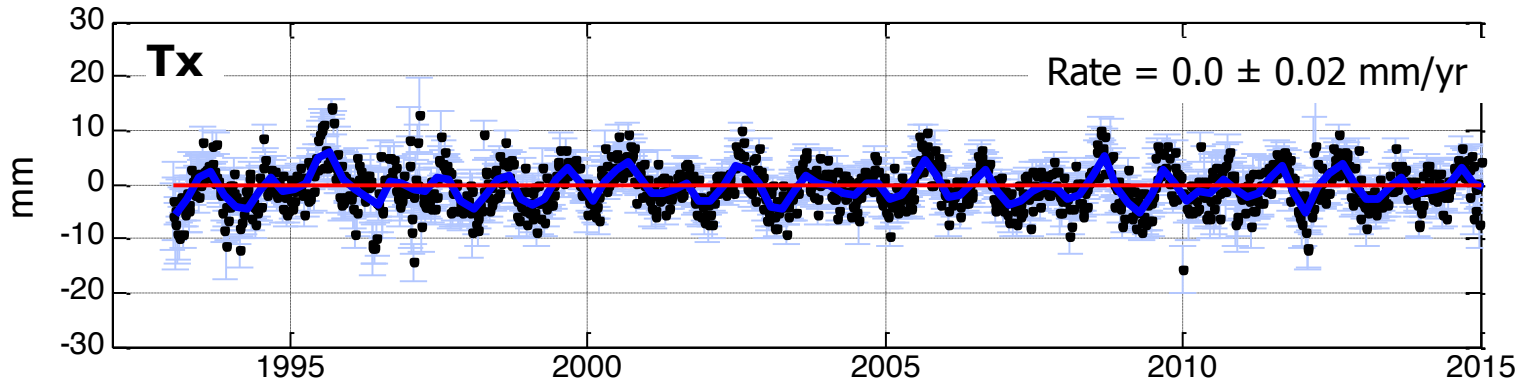
LOD: NSGF, ESA and GFZ w.r.t. USNO

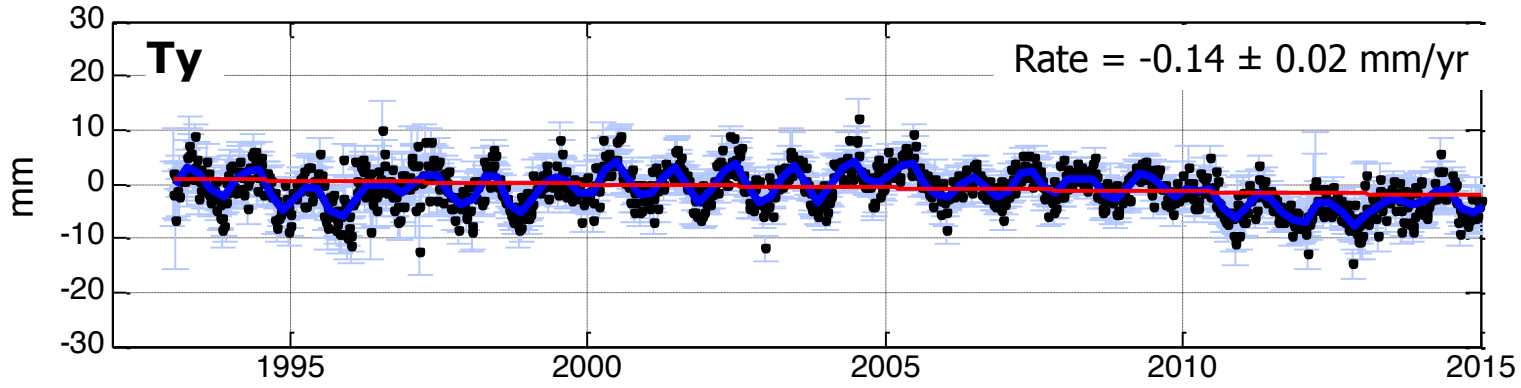


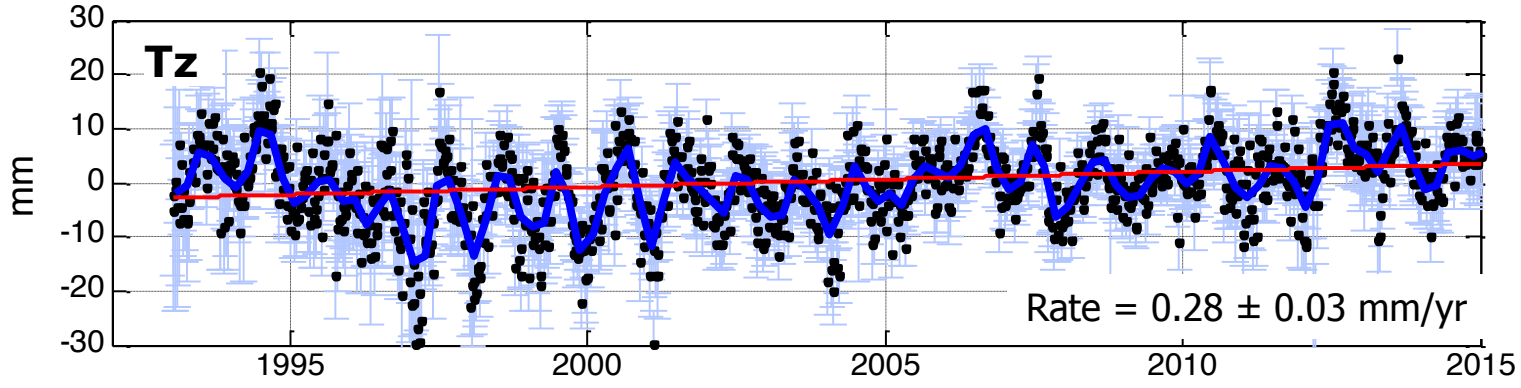




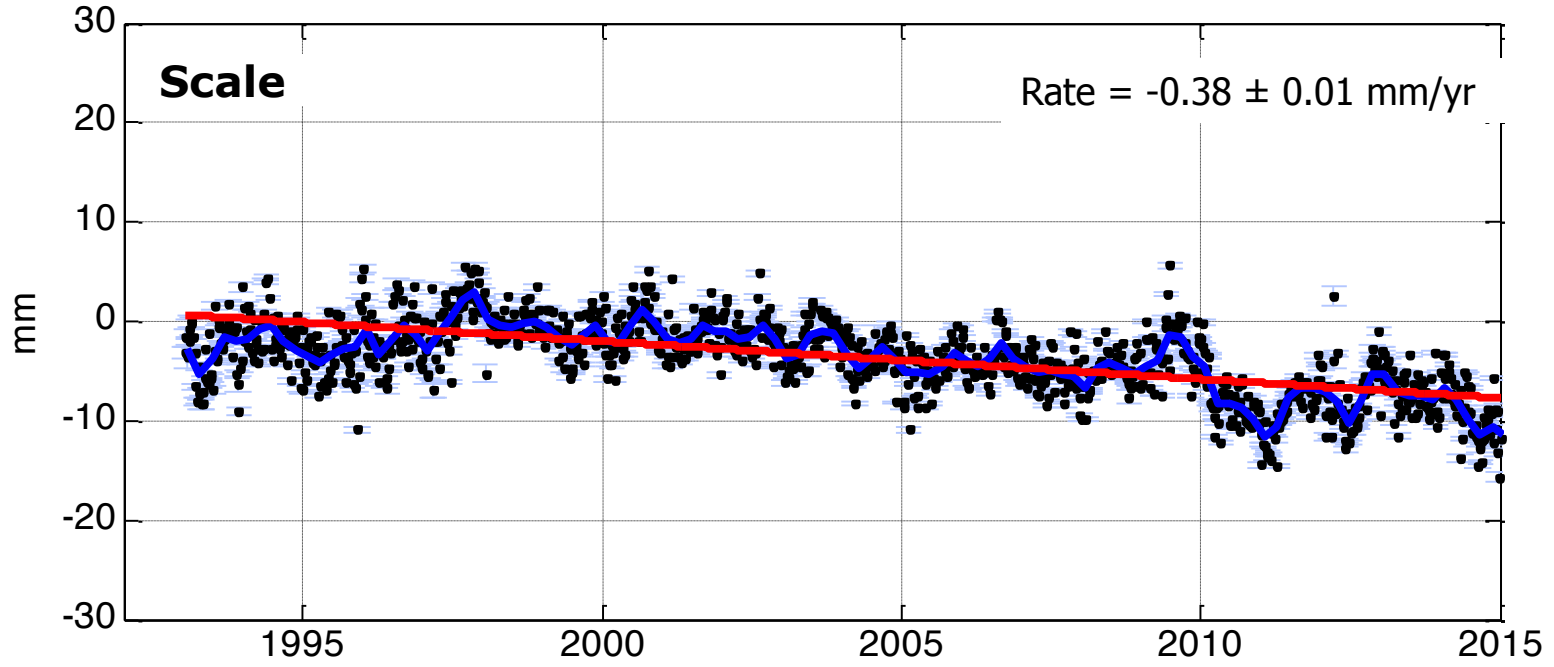
Helmert parameters – ILRSA Translations



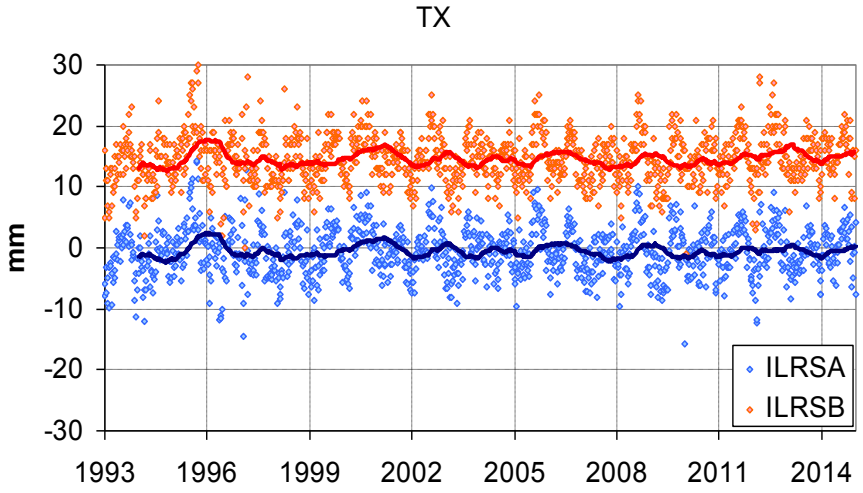


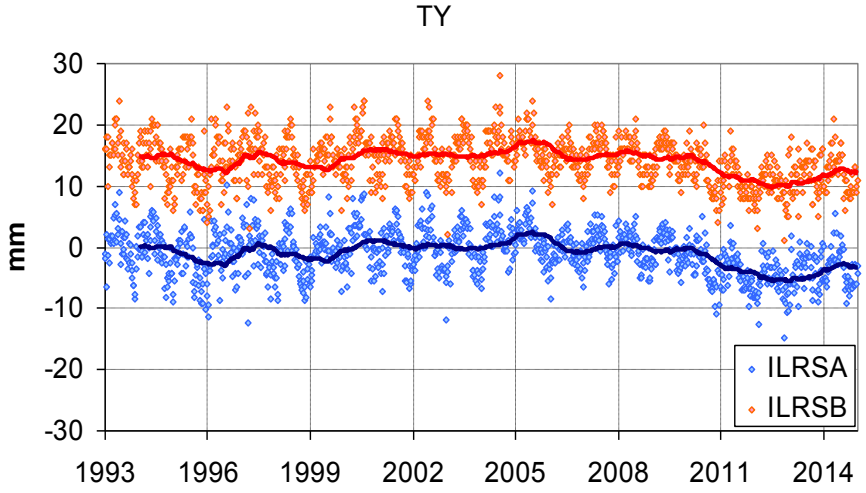


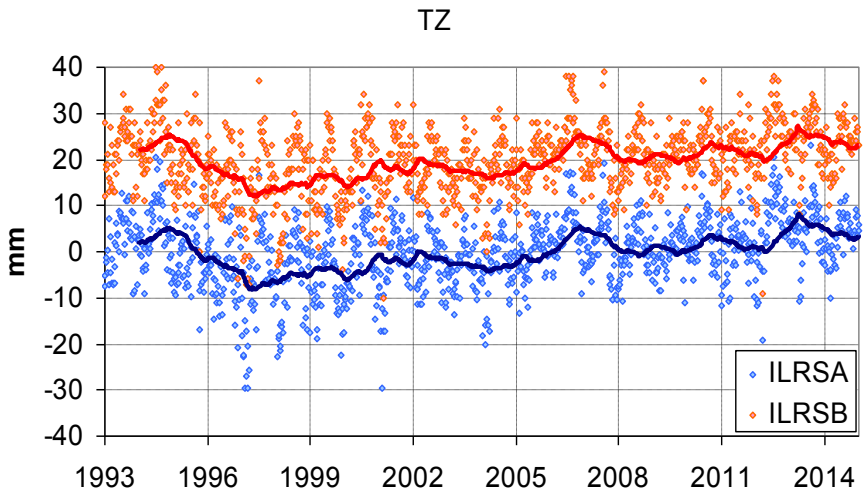
Helmert parameters – ILRSA Scale

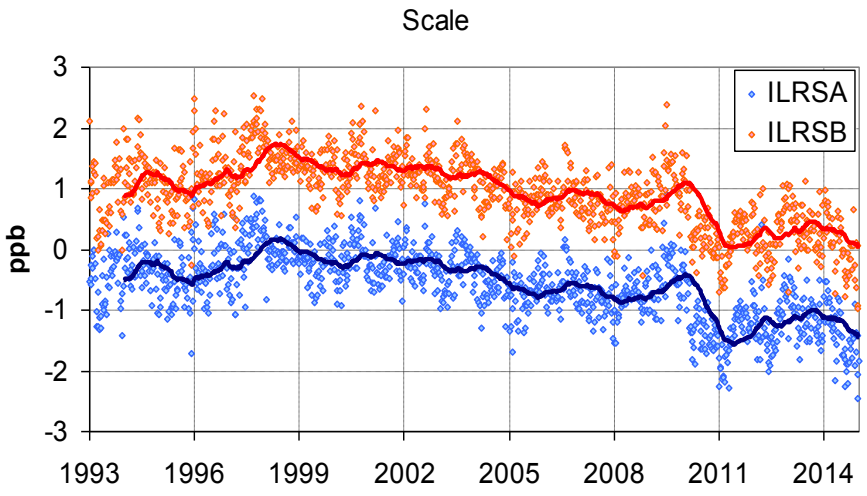


Origin & Scale from ILRSA and ILRSB

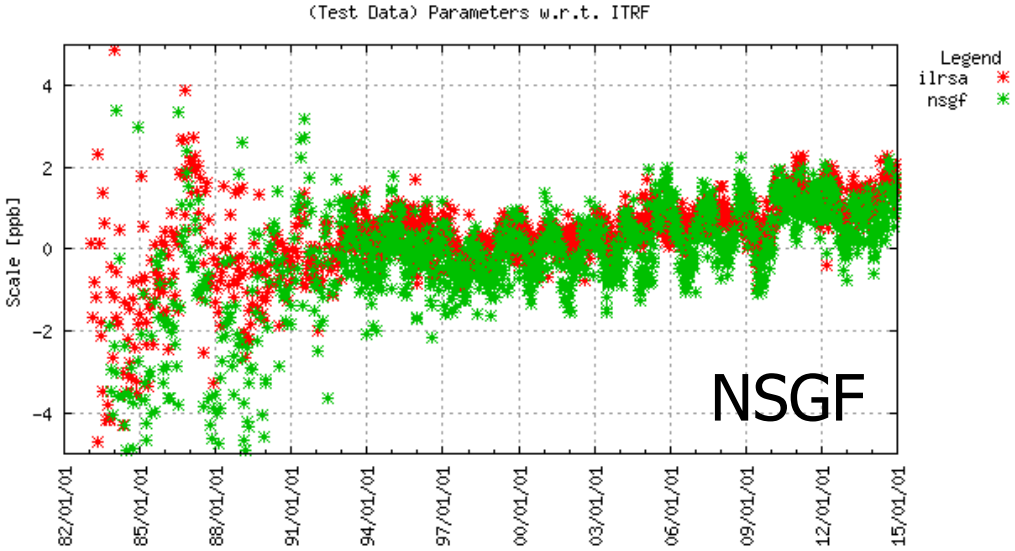


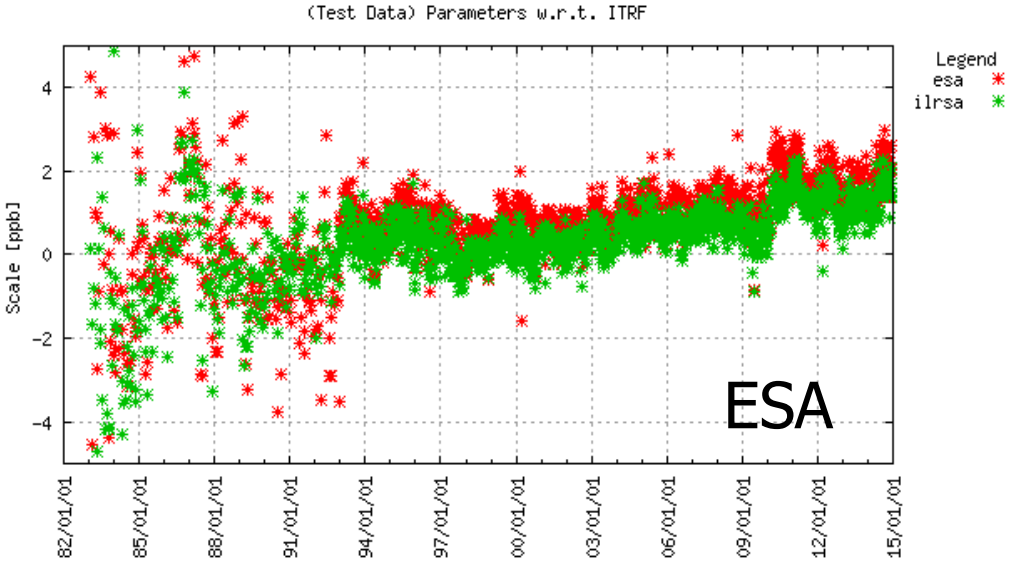


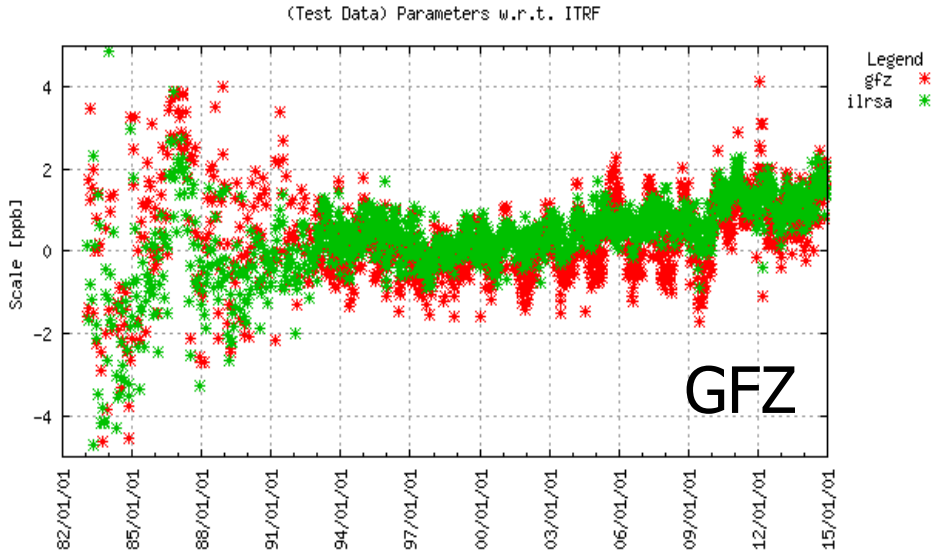




Helmert parameters – AC Scale







Federal Agency for
Cartography and Geodesy

ILRS AC @ BKG

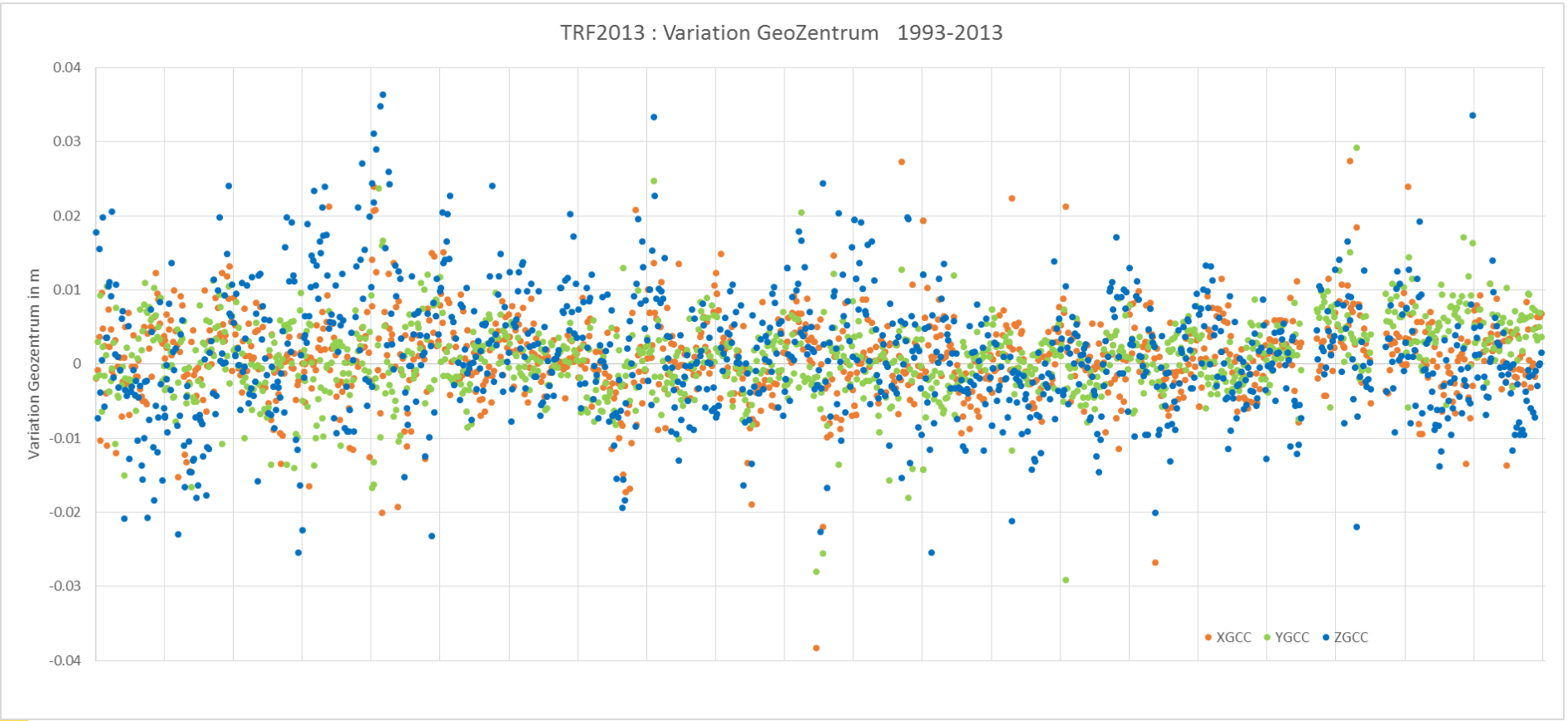
ILRS_AWG , 2015, April, 16th , Vienna

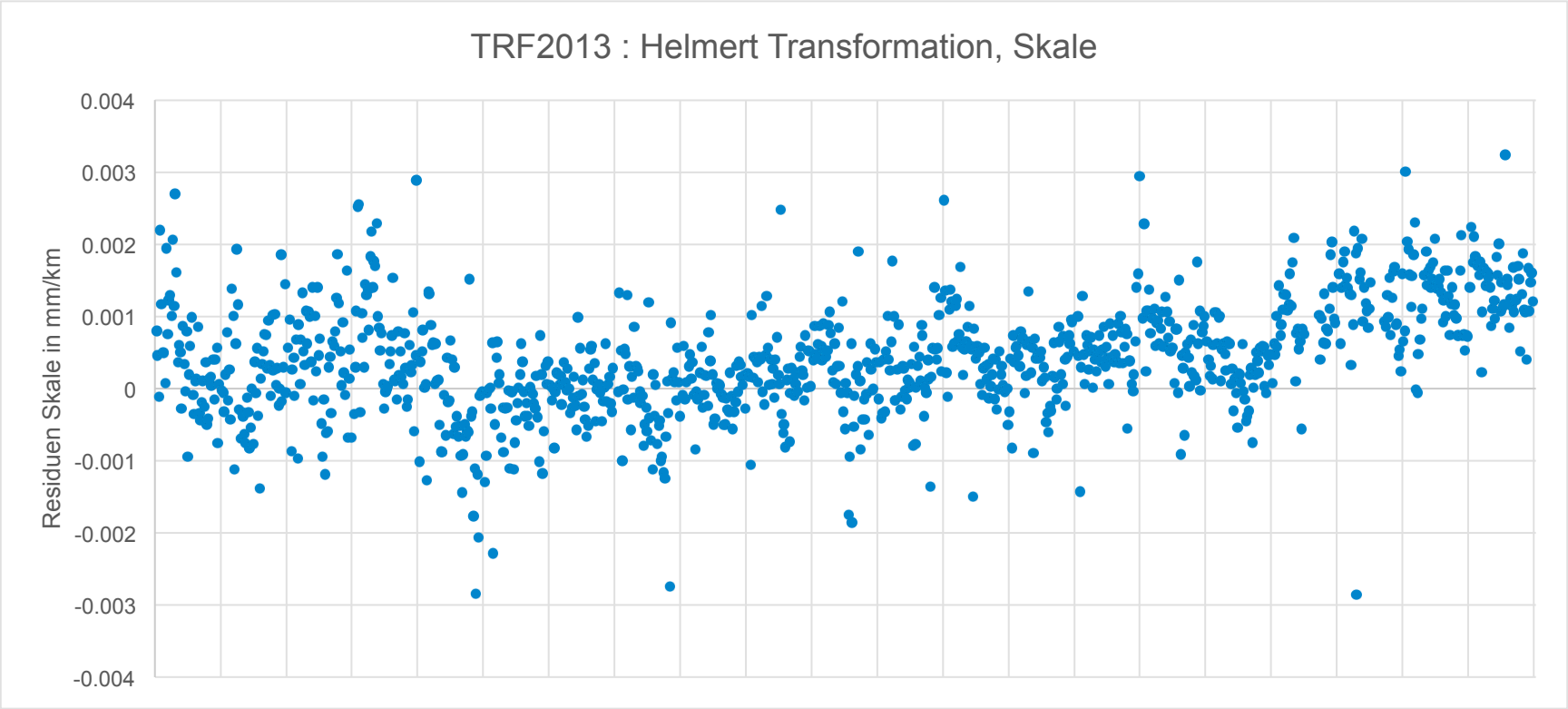
„On The Fly“

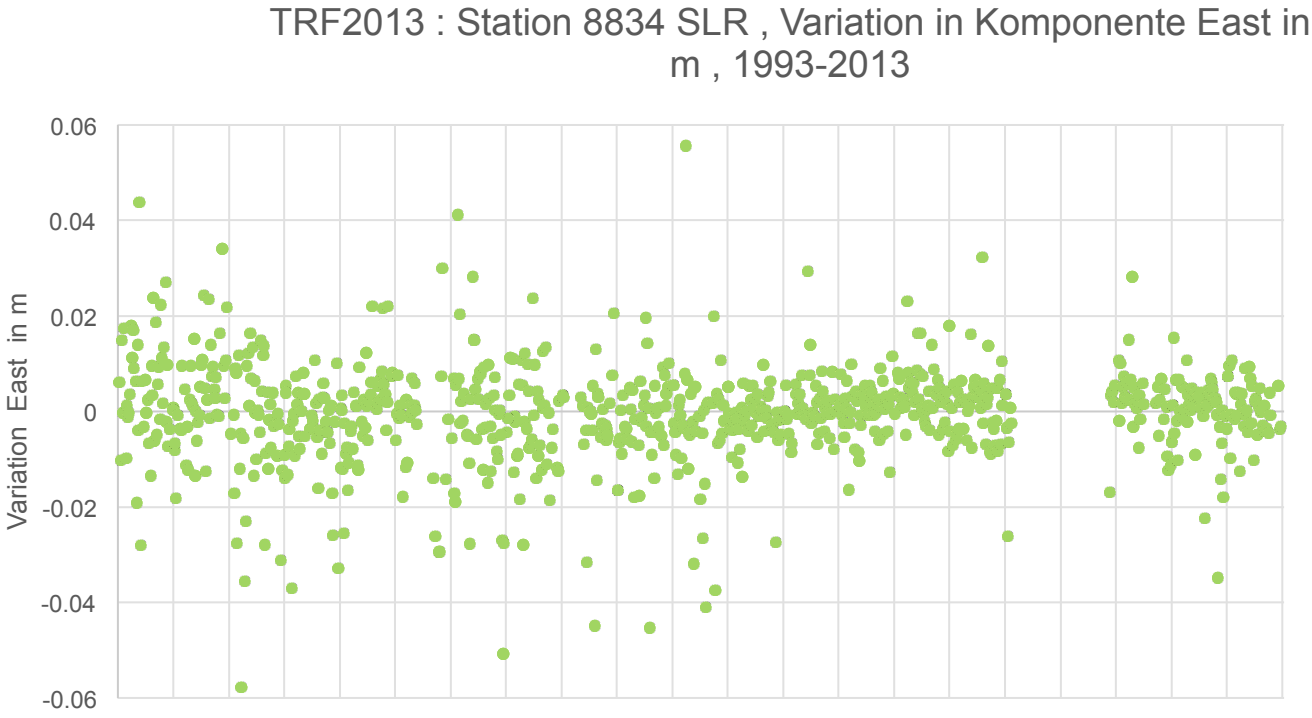
BERN_SLR had to be updated several times to match the ITRF requirements (Models, Data-Handling_file) during the processing,

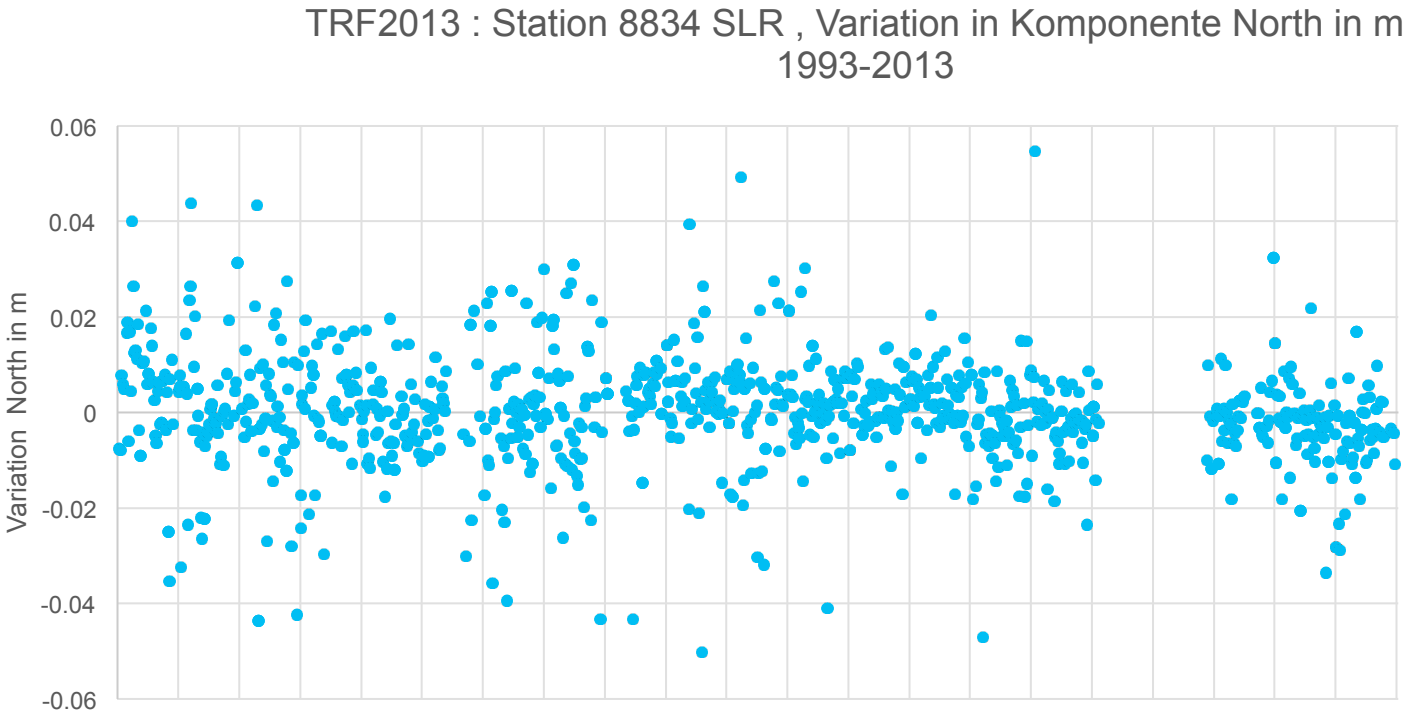
SW development support by colleagues of AIUB

BKG: next reprocessing with ITRF2014
development of analysis/graphic tools

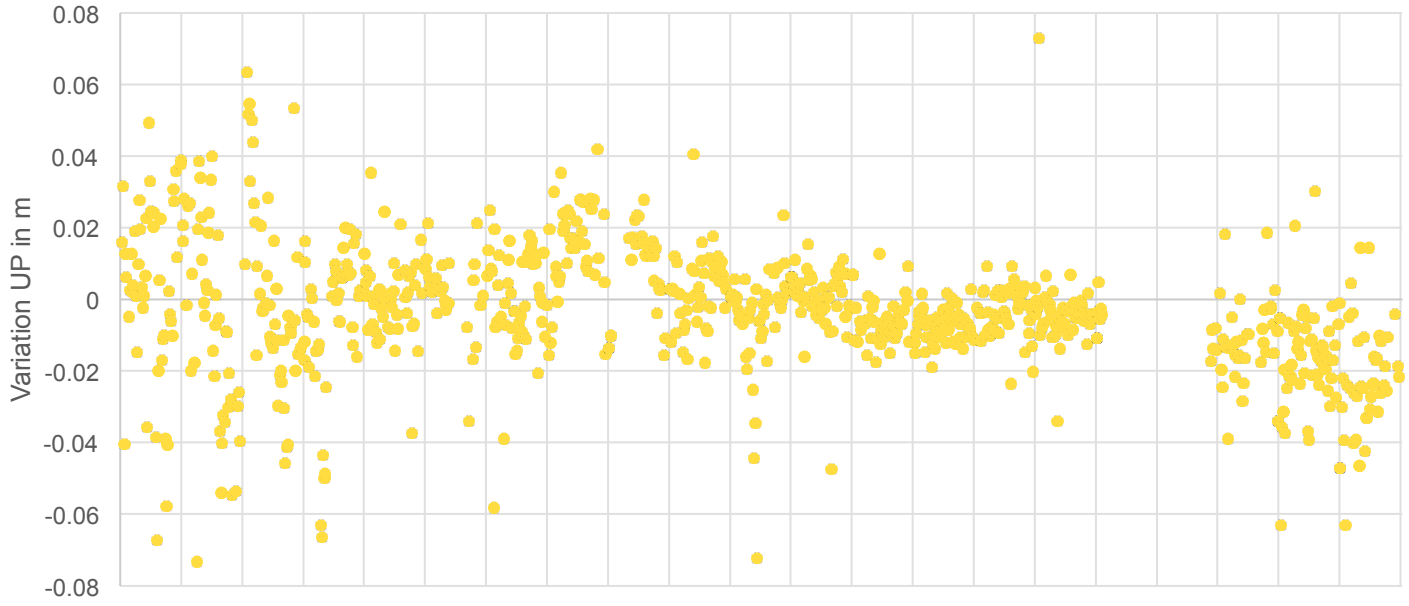

TRF2013 : Variation GeoZentrum 1993-2013
Variation Geozentrum in m
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
XGCC
YGCC
ZGCC

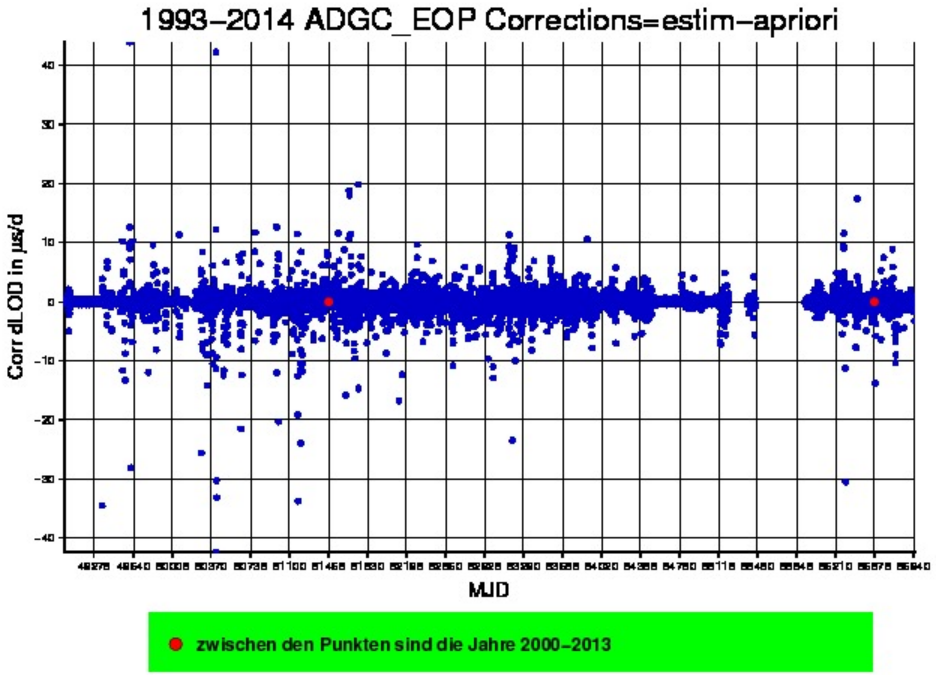

TRF2013 : Helmert Transformation, Skale
Residuen Skale in mm/km
0.004
0.003
0.002
0.001
0
-0.001
-0.002
-0.003
-0.004


TRF2013 : Station 8834 SLR , Variation in Komponente East in m , 1993-2013
Variation East in m
0.06
0.04
0.02
0
-0.02
-0.04
-0.06


TRF2013 : Station 8834 SLR , Variation in Komponente North in m , 1993-2013
Variation North in m
0.06
0.04
0.02
0
-0.02
-0.04
-0.06

TRF2013 : Station 8834 SLR , Variation in Komponente UP in m , 1993-2013



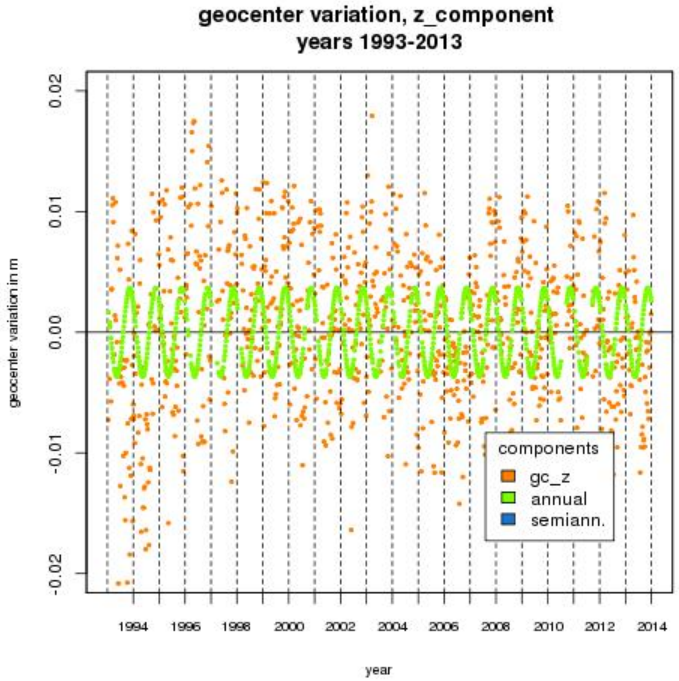

1993–2014 ADGC_EOP Corrections=estim–apriori
Corr dLOD in µs/d
MJD
zwischen den Punkten sind die Jahre 2000–2013

Questions :

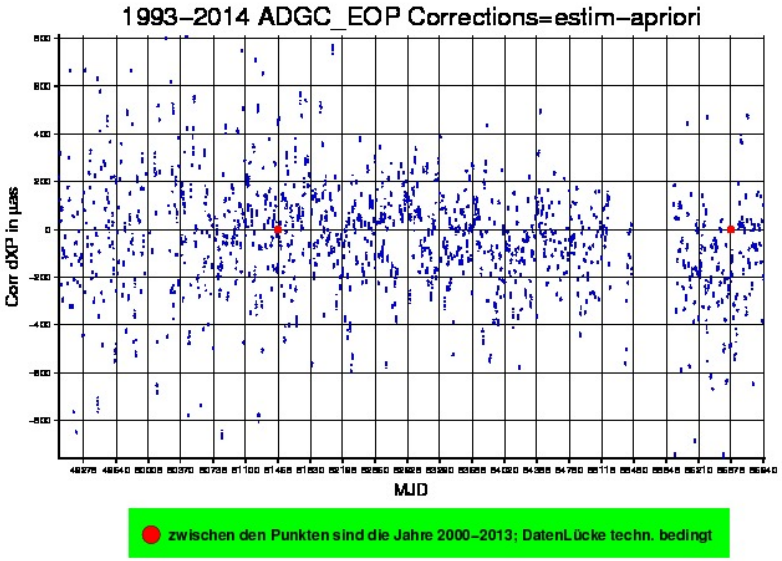
- Harmonization of ILRS Data Center files „allsat“ (daily and monthly)
- Handling of downloading is supported, esp. „switching“ in case of a closed server
- EDC needs a request …
- Needing a letter to the ILRS CB ?

- Finals.daily ; rapid EOP service by MAIA
- Looking for an independent server as backup in case of a closed maia: toshi ??

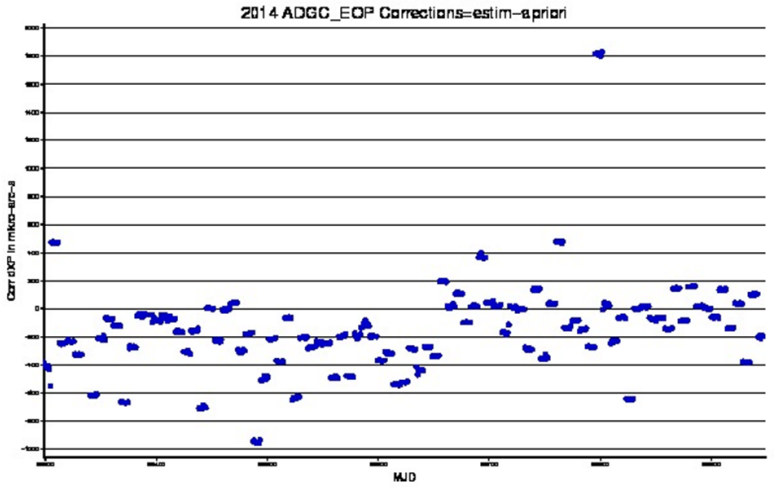
Back up slides


geocenter variation, z_component
years 1993-2013
geocenter variation in m
0.02
0.01
0.00
-0.01
-0.02
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
year
components
gc_z
annual
semiann.

Observations
1993-2014



Observations
2013-2014



MEASUREMENT MODELS

Troposphere Mendes-Pavlis zenith delay model
Mendes-Pavlis mapping function

Relativity scale: TT ,
light propagation corr.(Shapiro),
IERS2010 (Lense-Thirring,geodetic
precession, PPN,GR)

SAT‘s COM Appleby,Otsubo:proceedings of the
ILRS Workshop
held in Japan in November 2013.

pressure direct radiation:

CR:1.13 for L1 and L2; CR:1.20 for E1 and E2

albedo radiation : applied

earth thermal radiation : applied

Model from CERES mission (monthly grids)

Earth shadow model includes: penumbra, lunar eclipses

reemitted radiation: not applied

satellite estimation of empirical (constant and once-per-rev) along-track and (once-per-rev) ; cross-track accelerations (1 set per weekly solution)

ORBIT MODELS

Geopotential GGM05S
static terms through degree and order 70
time dependent terms:from CSR/UT,
C(2,0), C(3,0), C(4,0), C(5,0), C(6,0),
C(2,1), S(2,1);
secular for C(2,0), C(3,0), C(4,0)
Constants

AE = 6378.1363 km
1/F = 298.25642
GM = 398600.4415 km3/s2 (TT scale)

Tidal forces

solid earth tides: IERS Conventions 2010

ocean tides: EOT11A

ocean tidal loading tables
EOT11a_SLR.BLQ (from OLP Scherneck)

atmospheric tides: Ray&Ponte model 2003

ocean pole tide: applied
Desai, IERS Conventions 2010

REFERENCE FRAMES

Terrestrial ITRF2008

tidal uplift: Love model (h2=0.609, l2=0.0852)
ocean loading: Scherneck model,
based on EOT11A and SR „HARDISP“

geocenter tidal frequencies:
included in EOT11A model

pole tide: IERS Conventions 2010

Interconnection:

Nutation	IAU2000R06.NUT
Subdaily pole model	IERS2010XY.SUB

Nutation model : ${X}/GEN/IAU2000R06.NUT
Subdaily pole model : ${X}/GEN/IERS2010XY.SUB
Ocean tidal loading tables : ${P}/TRF22/STA/EOT11a_SLR.BLQ

GRAVIT: ILRS-GGM05S 70 MEANPOLE IERS2010
TIDPOT: IERS2000 ELAS STEP_1+2 POLTID IERS2010
K20=0.30
OTIDES: ICGEM EOT11a IERS2003 XMIN 0.00000 DEG 20
JPLEPH: DE405
PLANET: JUPITER VENUS MARS
RELATV: PPN IERS1996 P
EMPIRI: DRSW ONCE-PER-REV
SHADOW: STEP SPHERE MOON
OTLOAD: EOT11a CMC: Y HARLOAD: 342 tides

DGFI AC Report

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der Technischen Universität München (DGFI-TUM)
Munich
email: horst.mueller@*tum.de*

DGFI contribution ITRF2014

- Two solutions v60 and v61 delivered to data centres

- Weekly, resp. 15-daily Lageos only sinex files
  - Adding Etalon reduced the „looseness“ of the solution
  - Lageos only solution has better quality
  - IERS conventions
  - All ILRS/AWG rules
  - Data from EDC only
  - Single satellite arcs (DOGS-OC) (X,Y-pole, UT1-UTC at 0h UTC)
  - Combination and EOP interpolation,resp. LOD computation with DOGS-CS
  - Sinex files created with additional program

DGFI

DGFI contribution ITRF2014

- Version v60 delivered June to October 2014

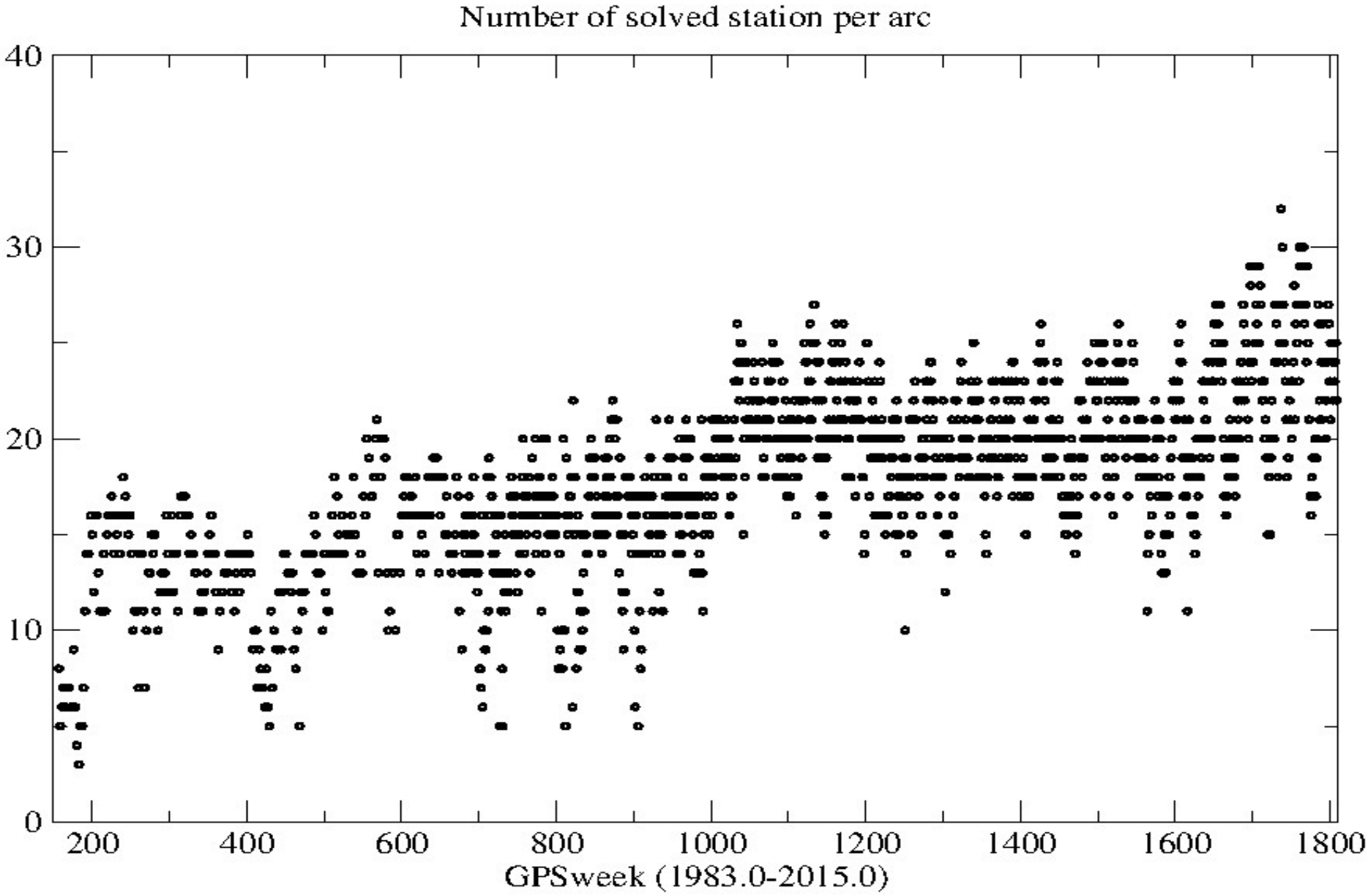
- Strange behavior prior to 1991
  - Software change in DGFI DOGS-OC program for station dependent CoM produced an error for stations with already applied CoM correction (was not removed)
  - Some small other problems in the software had to be corrected

DGFI contribution to ITRF2014

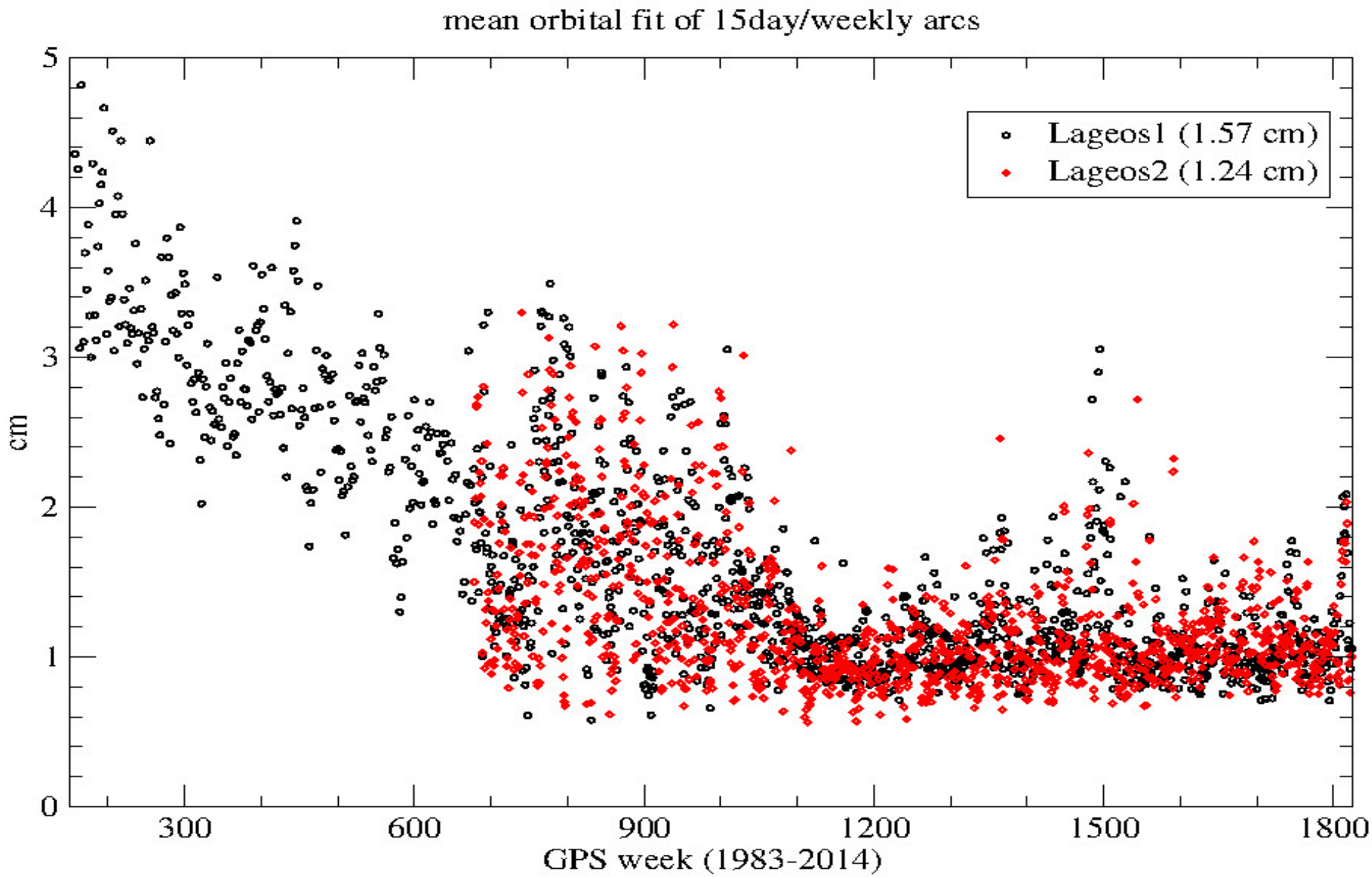
- Version v61 delivered on January 7 2015
  - Lageos 1 only 15-daily sinex files: 242
  - Lageos1 and Lageos2 combined 7-daily sinex files: 1149
  - Few weeks with too many edited stations
- New corrected program version used for processing
- Same program as used for the routine products
- Reprocessing of the whole series is in progress
  - more stations (better outlier detection)
  - plans to include Etalon1/2 again

DGFI

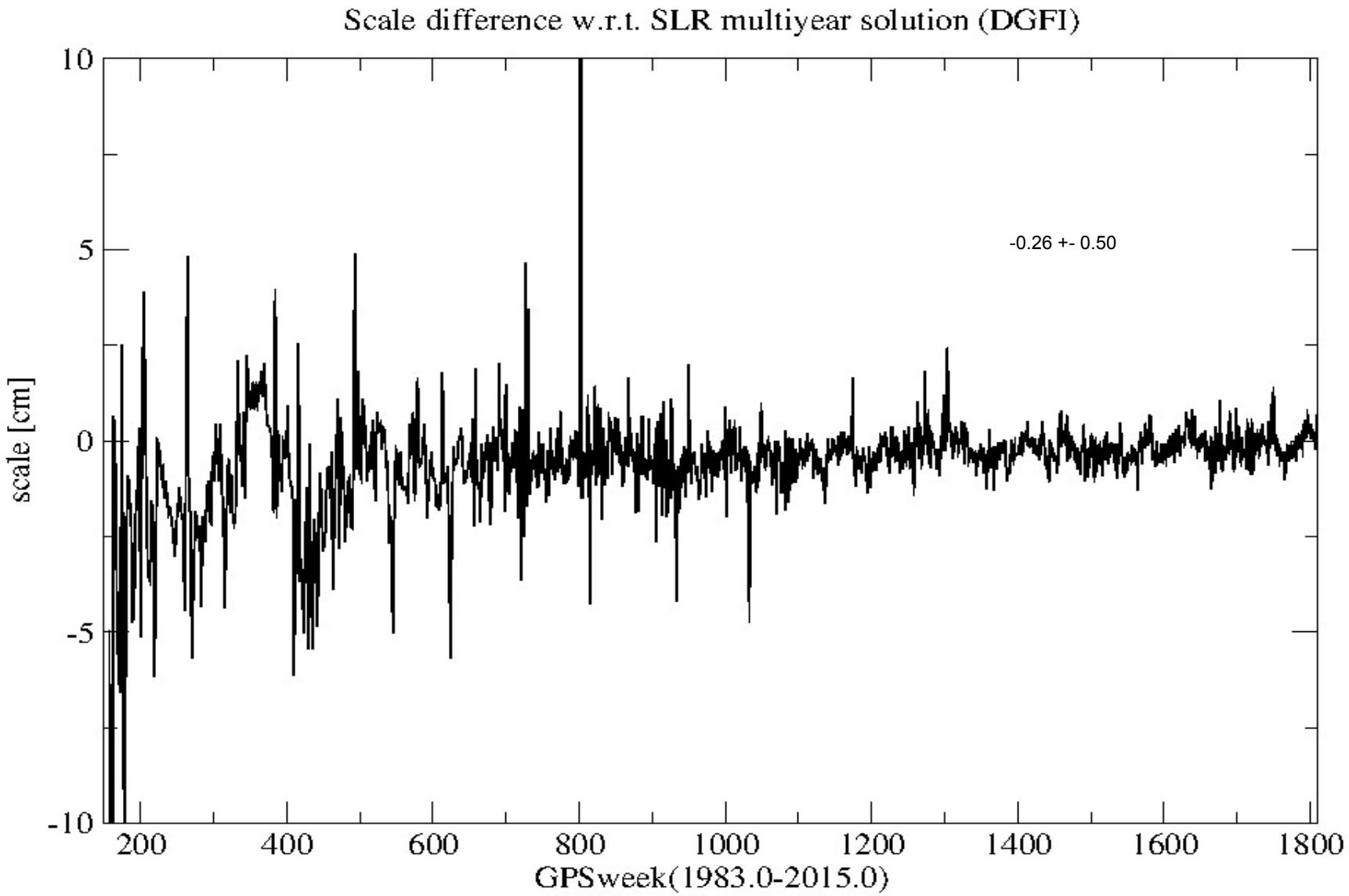
DGFI contribution



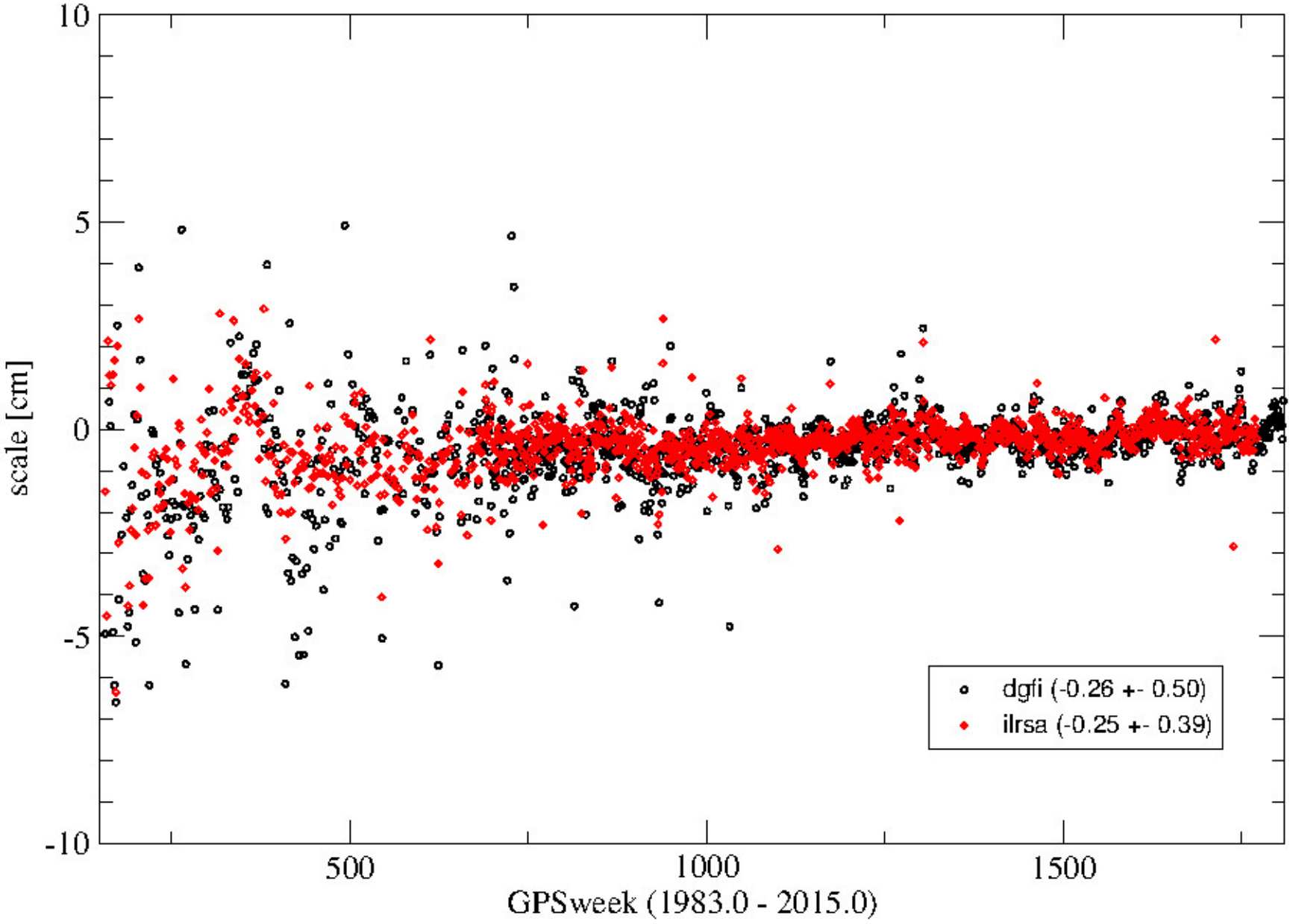
Quality control of 15/7-day solutions



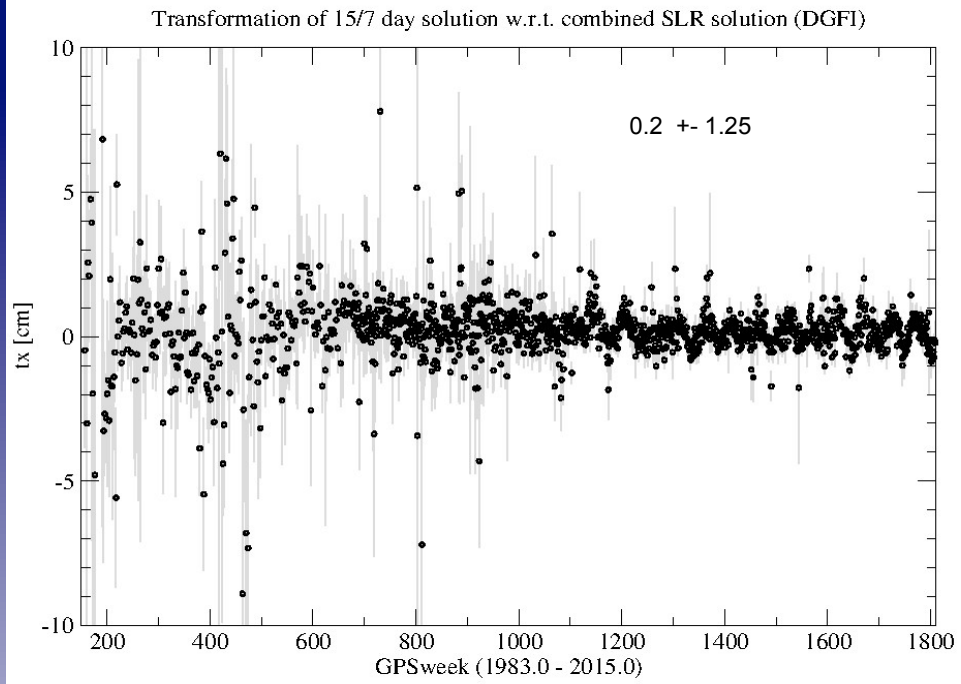
Quality control of 15/7-day solutions

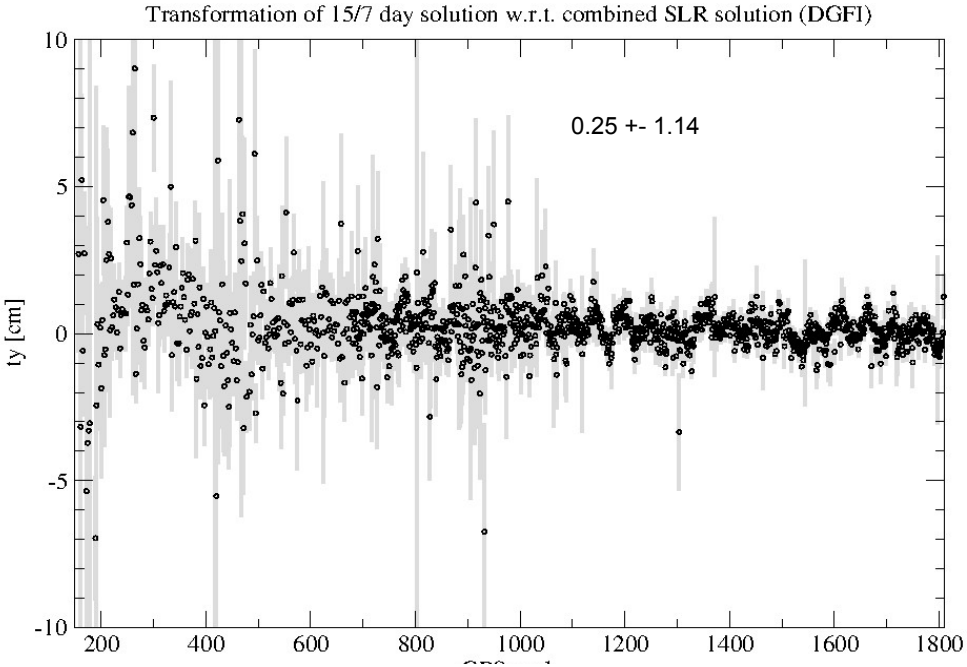


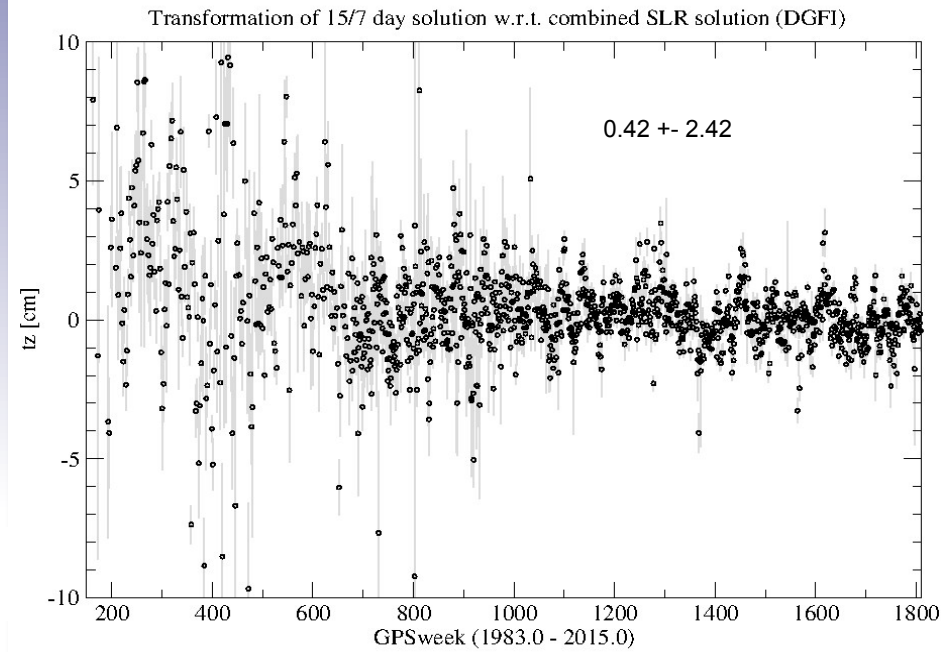
Quality control of 15/7-day solutions

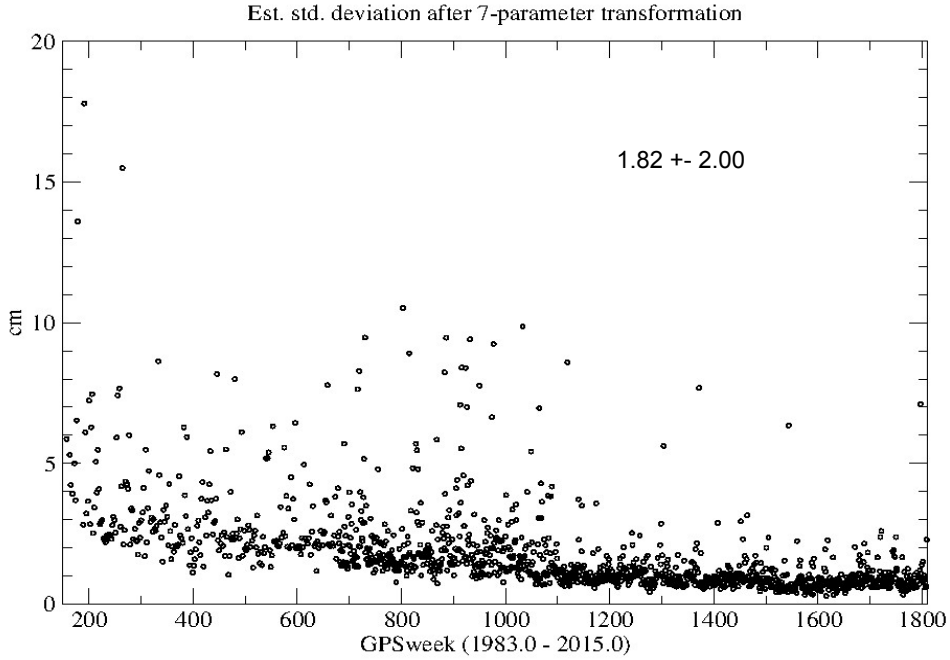


Quality control of 15/7-day solutions









DTRF2014: Results of the analysis and impact of the contribution of the International Laser Ranging Service

Manuela Seitz, Detlef Angermann, Mathis Bloßfeld

Deutsches Geodätisches Forschungsinstitut der
Technischen Universität München (DGFI-TUM), Munich, Germany

e-mail: *seitz@dgfi.badw.de*

Content

DGFI intern

- Motivation
- Input data and parameterization (analysis of SINEX-files)
- Epoch reference frames
- Multi-year reference frames

Motivation

DGFI intern

Many model improvements for SLR w.r.t. ITRF2008 processing

Geophysical modeling

- New gravity modeling (now GGM05S from CSR is used)
- New mean pole model aligned to GGM05S ()
  → this causes inconsistencies w.r.t. the other geodetic space techniques in the pole tide computations!!

Satellite modeling

- New Center of Mass (CoM) corrections applied which depend on
  - Geometric/optical properties of the tracked LRA
  - Site-specific ranging system (time-dependent!!)
  - Raw data processing scheme
  - Operation mode of tracking system (single-/multi-photon detection)

Data handling

- Improved systematic error handling through refined treatment of station-specific changes
- Improved data handling strategies (for station biases, discontinuities, core stations, etc.)

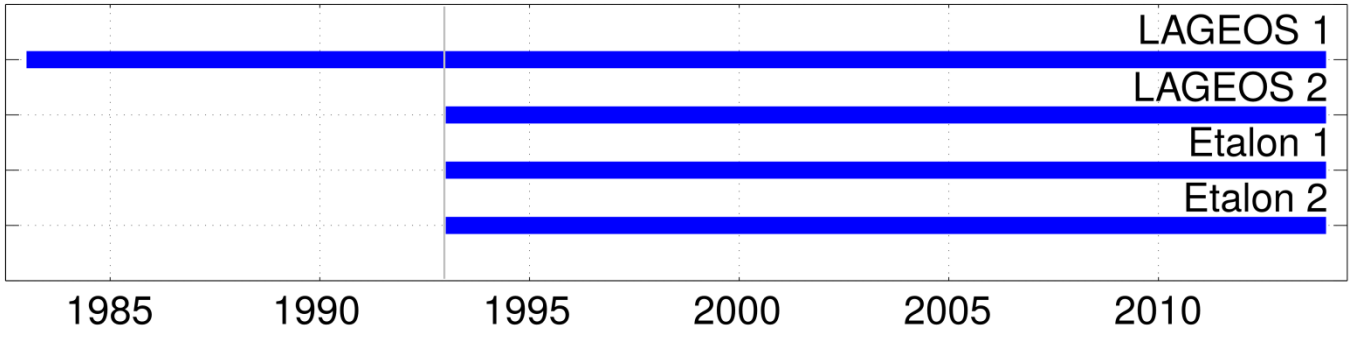
Luceri V., Pace B., Pavlis E., König D., Kuzmicz-Cieslak M., Bianco G.:
Overview of the ILRS contribution to the development of ITRF2013, presentation given at IAG Commission 1 Symposium (REFAG) 2014

Pavlis E., Luceri V., Kuzmicz-Cieslak M., König D., Bianco G.:
Modeling Improvements in the ILRS Reprocessing for ITRF2013, presentation given at IAG Commission 1 Symposium (REFAG) 2014

Input data and parameterization (I)

DGFI intern

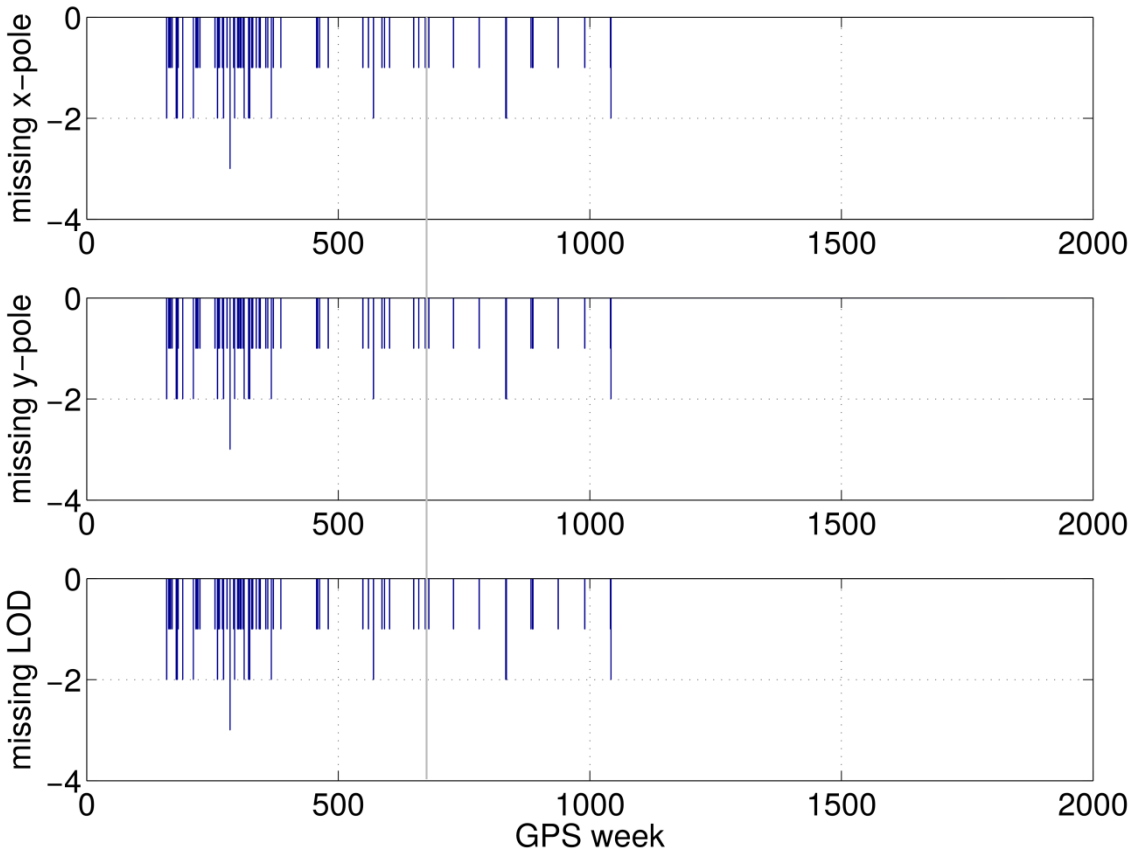
- SINEX files
  - 1392 SINEX files between 27.12.1982 and 03.01.2015
  - Since the 03.01.1993, weekly solutions with daily EOP; before: 15-day solutions with 3-daily EOP
  - 15-day/7-day solutions (loose constraints; 1m for station coordinates and pole coordinates; not booked in SINEX) → introduction of similarity transformation parameters not necessary
- Stations
  - In the ERFs: in total 159 stations, thereof …
    - 142 different DOMES numbers
    - 17 jumps (35 jumps in ILRSA-v60 submission)
  - In the MRF: in total 113 stations since 46 stations are reduced (reduction criteria see one of next slides)
- Satellites
  - Since 1993.0 (GPS week 0678), observations to 2-4 satellites are included
  - The Etalon satellites are not included by all ACs in the reprocessing!



Input data and parameterization (II)

DGFI intern

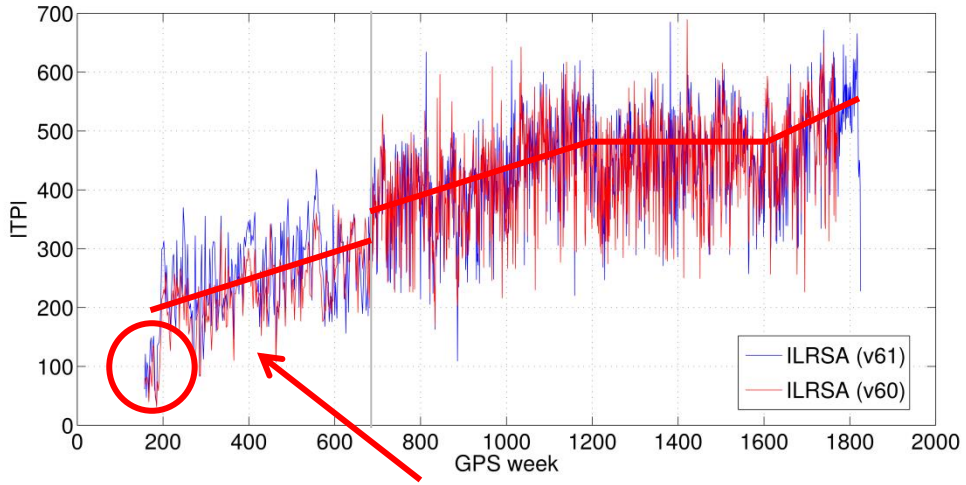
- Number of EOP in SINEX-files
  - Before 1993.0, 5 x-pole, 5 y-pole and 5 LOD values are stored in SINEX-files (3-daily resolution)
  - After 1993.0, 7 x-pole, 7 y-pole and 7 LOD values are stored in SINEX-files (daily resolution)
  - Annual pattern of number of missing EOP due to lack of observations around Christmas and New Year
  - Since 2000, continuous EOP time series

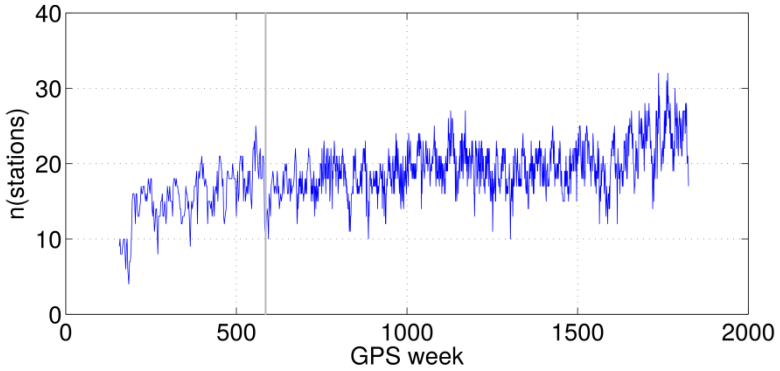


Input data and parameterization (III)

DGFI intern

- 15-day SINEX files contain
  - 3D station coordinates at mid-arc epoch
  - Terrestrial pole coordinates as offsets and LOD at 12h epochs every three days (5 per arc)
- 7-day SINEX files contain
  - 3D station coordinates at mid-arc epoch
  - Terrestrial pole coordinates as offsets and LOD at 12h epochs (7 per arc)
- Squared sum of O-C
  - Jump of lTPl from 15-day arcs to 7-day arcs
  - Slight increase of lTPl between 1993.0 (0677) and 2003.0 (1200) → improvement of network
  - lTPl nearly constant between 2003.0 and 2011.5 (1640) → stagnation of network improvement (NASA stopped financial support of SLR → shutdown of some stations)
  - afterwards again increase → new Russian sites and reopening of NASA stations
  - lTPl correlated with number of stations and number of ACs





DGFI solution is now included in early years!

Input data and parameterization (IV)

- ILRSA resubmitted 27 new SINEX files on 13.03.2015
  - In 22 SINEX files, wrong SOLUTION/EPOCH block entries were corrected

    → these changes doesn't affect the DGFI computations since DGFI's SNX2DOGS routine does not read the SOLUTION/EPOCH block

    → the DOMES number is imported from SITE/ID block and

    → station reference epoch is imported from SOLUTION/ESTIMATE block
  - 5 SINEX files contain different NEQs due to reduced or eliminated stations

    → these resubmitted files are used for TRF computation

SINEX name	GPS week	DOMES	station name	reference epoch [JD2000]
ilrsa.pos+eop.900702.v62.snx	0547	21726S001	Simosato (Japan)	-3476.5
ilrsa.pos+eop.910128.v62.snx	0577	42202S001	Arequipa (Peru)	-2366.5
ilrsa.pos+eop.910925.v62.snx	0611	40442M006	Fort Davis (USA)	-3026.5
ilrsa.pos+eop.930102.v62.snx	0677	10002S001	Grasse (France)	-2561.5
ilrsa.pos+eop.040626.v62.snx	1276	92201M007	Papeete (Tahiti)	1635.5

Input data and parameterization (V)

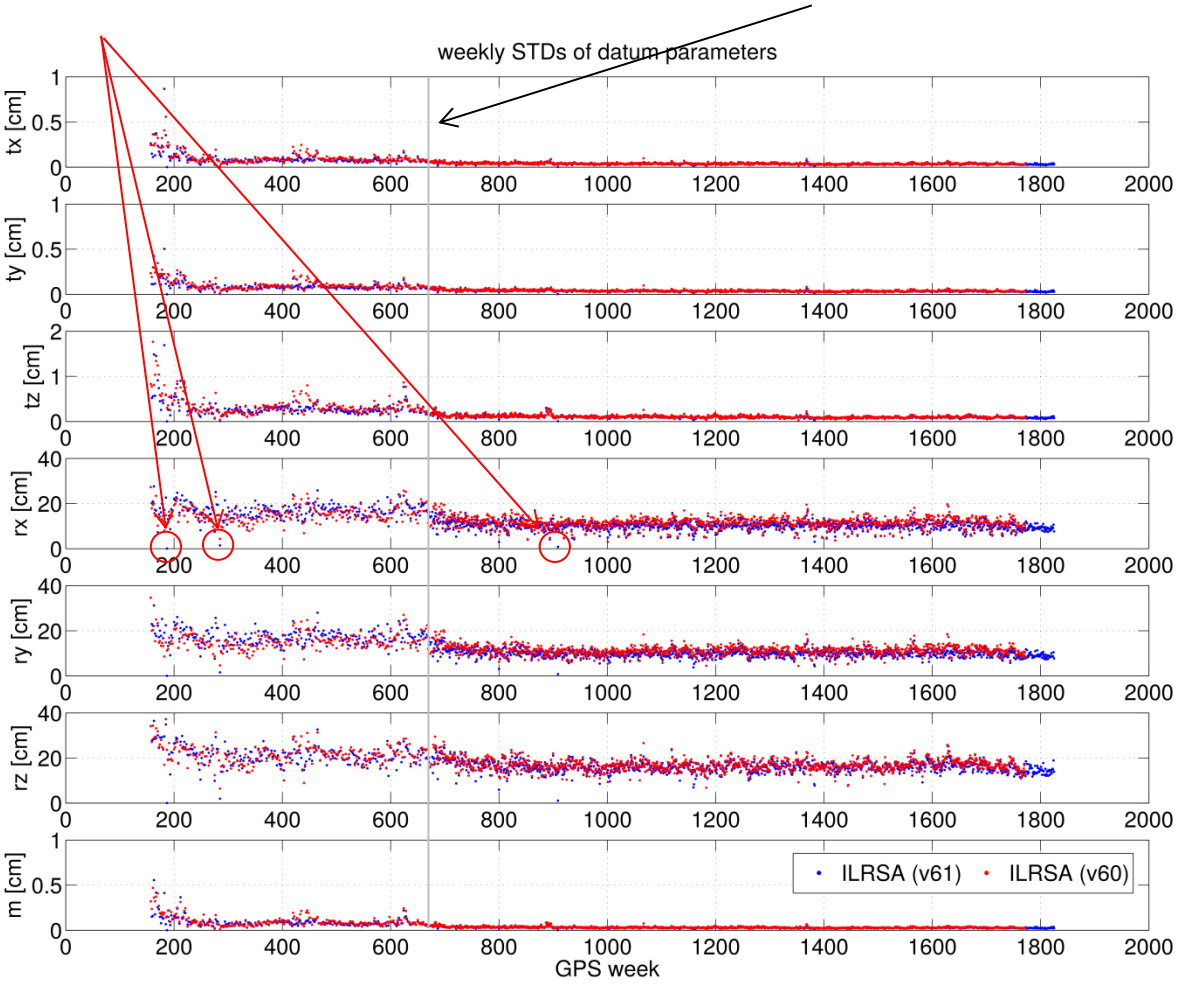
DGFI intern

- Problematic SINEX files / NEQs
  - Out of 1392 SINEX-Files / NEQs, only 3 files / NEQs cause problems:
    - ilrsa.pos+eop.830808.v61.snx
    - ilrsa.pos+eop.850628.v61.snx
    - ilrsa.pos+eop.970614.v61.snx

    } loose constraints too tight → rotations fixed!

  - These 3 files have been neglected in the accumulation process!
  - Origin (Tx, Ty) and scale have STDs below 1mm except very early 15day-arcs
  - Tz has STDs around 1mm
  - Rotations have STDs of ca. 10-15cm in Rx and Ry and ca. 15-20cm in Rz (values agree with values of Luceri et al. (2014)

2/4 satellites observed since 1993.0 (0677)



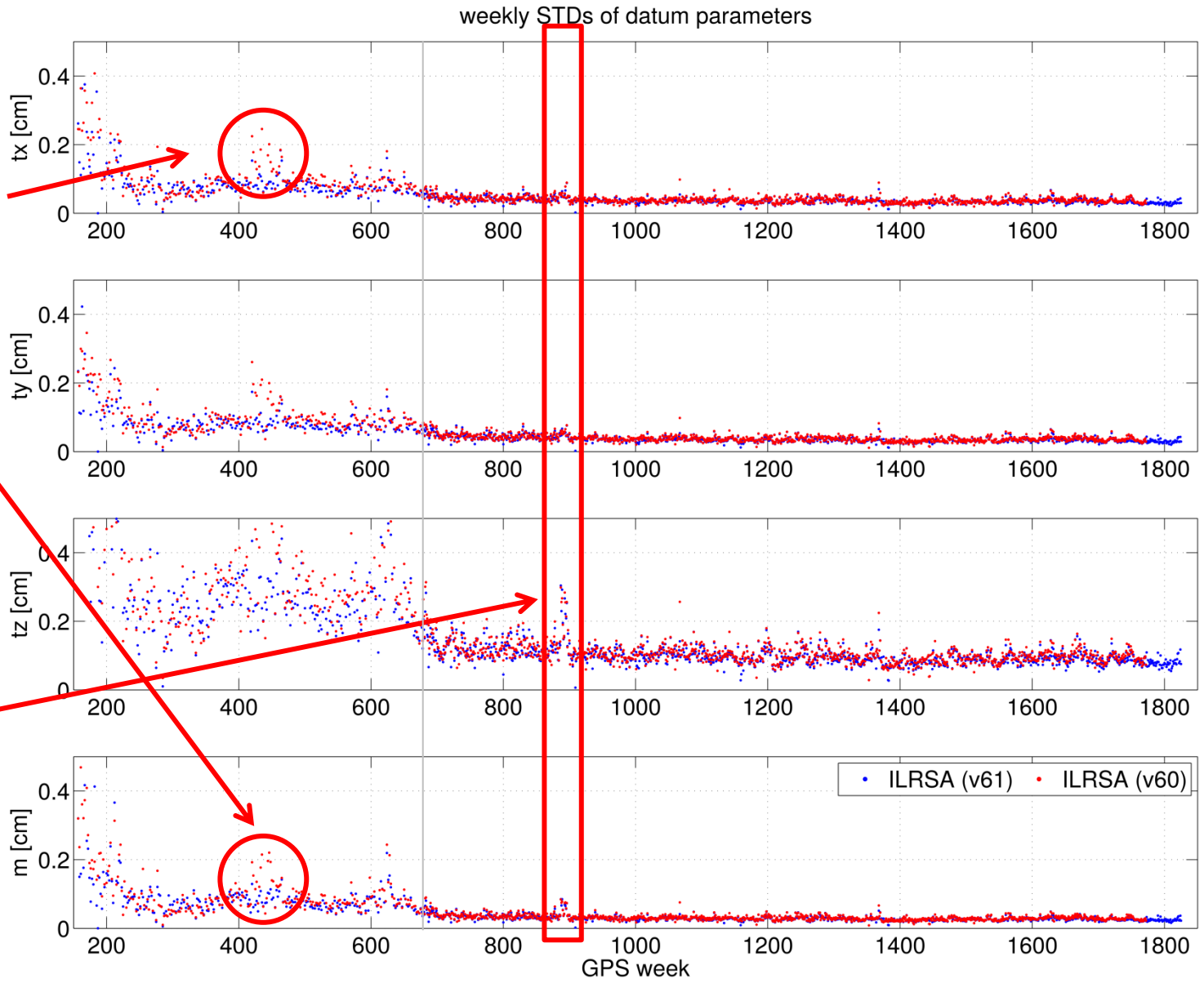
Input data and parameterization (VI)

DGFI intern

- Datum parameters of input solutions

Improvement of new v61 SINEX-files w.r.t. old v60 SINEX-files
→ more observations included in some NEQs (DGFI solution is now included in early years!)

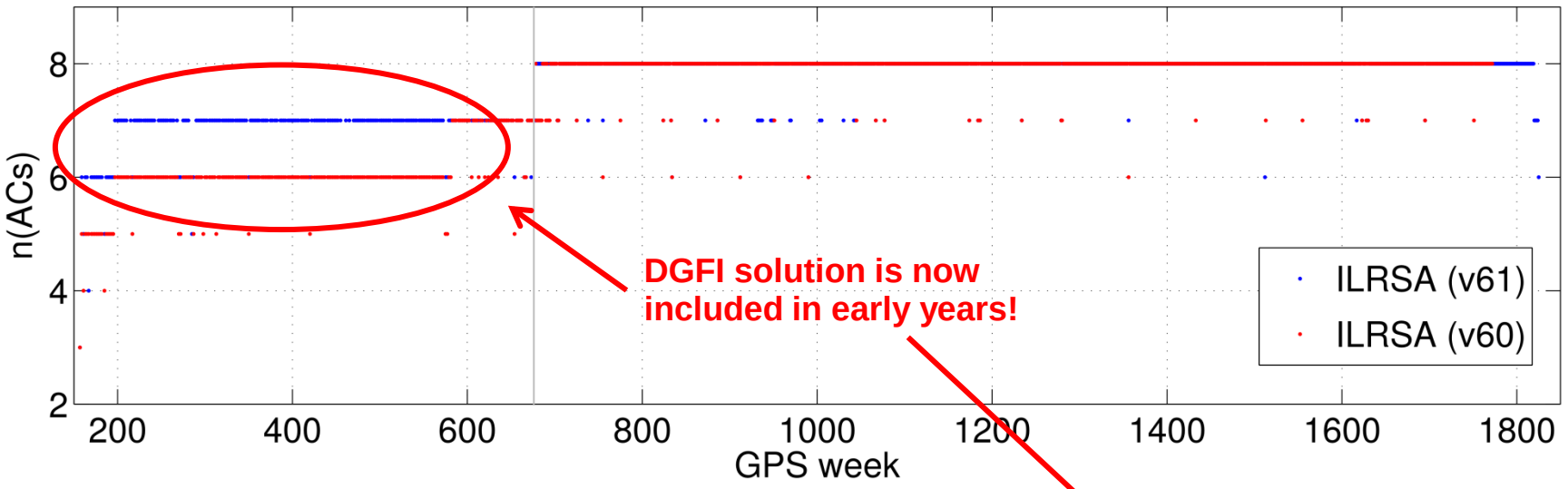
Tidbinbilla (50103S007; Australia) did not observed during GPS week 0887 - 0889 and 0893 - 0895
→ bad network geometry



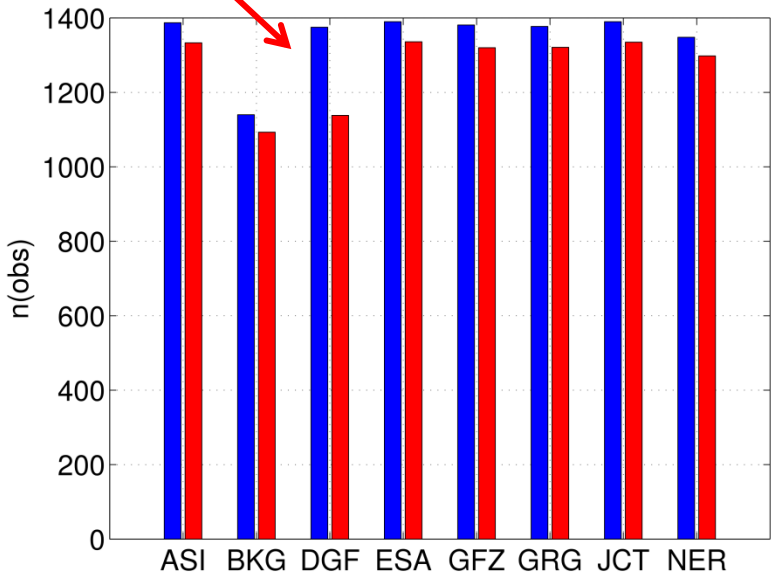
Input data and parameterization (VII)

DGFI intern

- Datum parameters of input solutions



- up to 8 different Analysis Centers (ACs) using 7 different software packages
- number of ACs increased with time; 8 ACs processed 7-day arcs; BKG didn't process 15-day arcs
- weighting of ACs is not booked in SINEX-files



Analysis results: ERFs - Discontinuities

DGFI intern

CDP number	DOMES number	discontinuity epoch [JD2000]	new solution number		description
Discontinuities of ITRF2008 stored in ILRS discontinuity file (version of 04.08.2014)					
1868	12341S001	1249.5	0A02		Komsomolsk
7080	40442M006	-1427.5	0A02		Fort Davis → change of flashlamps
7080	40442M006	1311.5	0A03		Fort Davis
7080	40442M006	2365.5	0A04		Fort Davis
7124	92201M007	571.5	0A02		Papeete
7210	40445M001	-3761.5	0A02		Haleakala
7210	40445M001	-2169.5	0A03		Haleakala
7210	40445M001	262.5	0A04		Haleakala
7249	21601S004	1294.5	0A02		Beijing
7403	42202M003	539.5	0A02		Arequipa → earthquake in Peru
7403	42202M003	583.5	0A03		Post-seismic
7403	42202M003	619.5	0A04		Post-seismic
7403	42202M003	966.5	0A05		Post-seismic
7403	42202M003	1460.5	0A06		Post-seismic
7406	41508S003	2831.5	0A03		San Juan
7811	12205S001	937.5	0A02		Borowiec
7820	21609S002	2908.5	0A02		Kunming
7825	50119S003	2715.5	0A02		Mount Stromlo
7837	21605S001	-1552.5	0A02		Shanghai → installation date of laser
7838	21726S001	1271.5	0A02		Simosato
7839	11001S002	-1465.5	0A02		Graz
7839	11001S002	-50.5	0A03		Graz
7843	50103S007	-2801.5	0A02		Orroral → use of two lasers
7845	10002S002	544.5	0A02		Grasse
8834	14201S018	343.5	0A02		Wettzell
Additional discontinuities of DTRF2008 stored in ILRS discontinuity file (version of 04.08.2014)					
7105	40451M105	-1401.5	0A02		Greenbelt → used in DTRF2008 only
7406	41508S003	2321.5	0A02		San Juan → used in DTRF2008 only
7530	20702M001	-2465.5	0A02		Bay Giyyor → used in DTRF2008 only
7810	14001S007	1593.5	0B02		Zimmerwald → used in DTRF2008 only
7840	13212S001	1011.5	0A02		Herstmonceux → used in DTRF2008 only
Additional discontinuities stored in ILRS discontinuity file (version of 04.08.2014					
7405	41719M001	3709.5	0A02		Concepcion → earthquake in Chile
7406	41508S003	3709.5	0A02		San Juan → earthquake in Chile
New introduced additional discontinuities for ITRF2014					
7110	40497M001	3770.5	0A02		Monument Peak → jump due to offset/drift change in N, E and U on 28.04.2010
7308	21704S002	4086.5	0A02		Koganei → jump due to Tohoku earthquake on 11.03.2011
7821	21605S010	3722.5	0A02		Shanghai → jump due to end of drift in U on 11.03.2010
7838	21726S001	1748.5	0A02		Simosato → jump on 14.10.2004 due to drift change in N and U
7838	21726S001	4086.5	0A03		Simosato → jump due to Tohoku earthquake on 11.03.2011

- previous jump list used for ILRSA-v60 submission was based on **ILRS discontinuity file + other 11 jumps (35 in total)**
- For the ILRSA-v61 submission, 17 jumps are introduced:
- 20 old jumps of ITRF2008 and DTRF2008 were deleted (red rows); 10 were used (5 for post-seismic modeling of Arequipa)
- 2 jumps were stored in ILRS discontinuity file due to Chile earthquake
- 5 new jumps were introduced (green rows); 2 jumps due to Tohoku earthquake in Japan
- In total, 17 jumps are introduced for DTRF2014
- **Unification with IGN/JPL is still missing!**

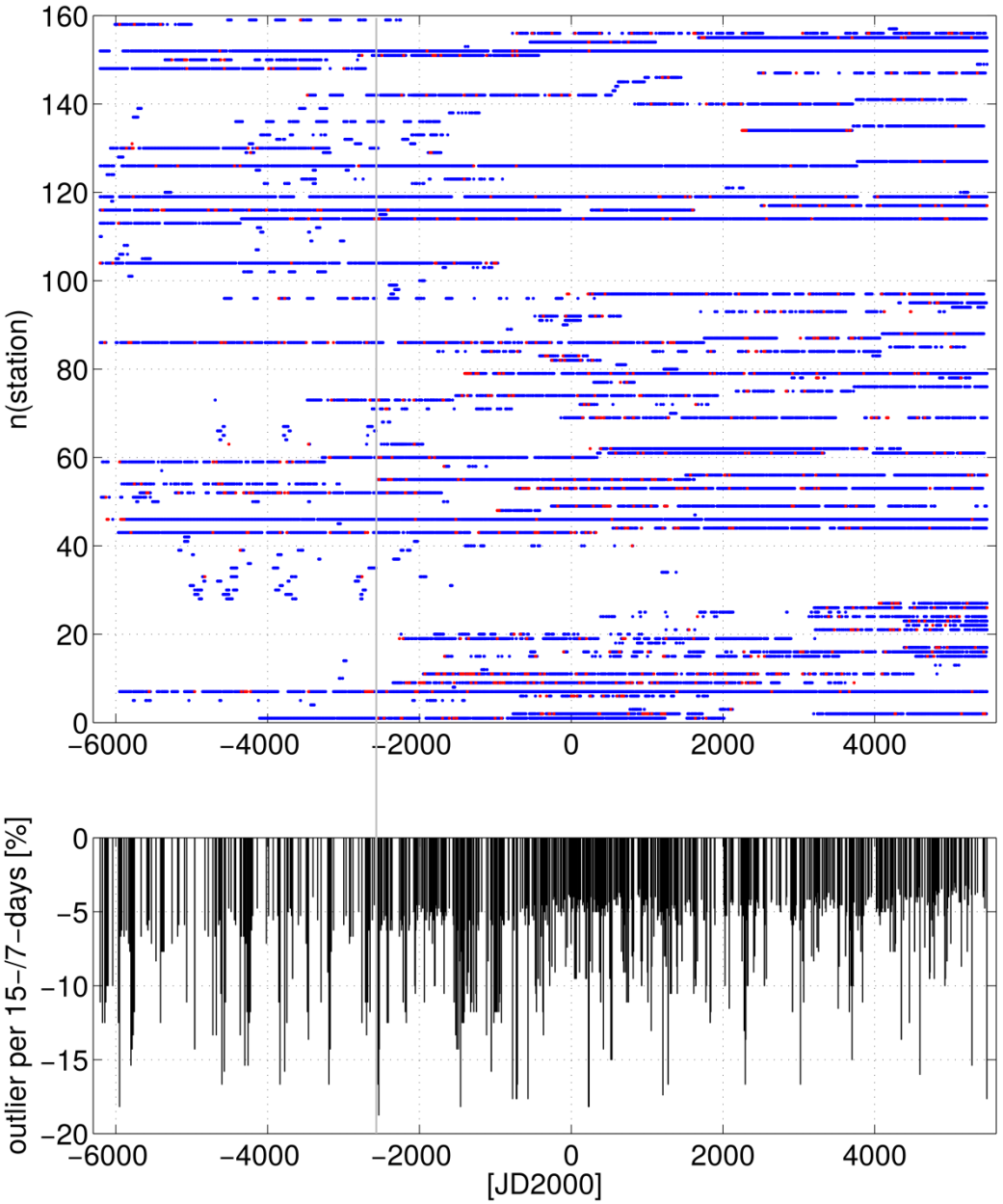
DGFI

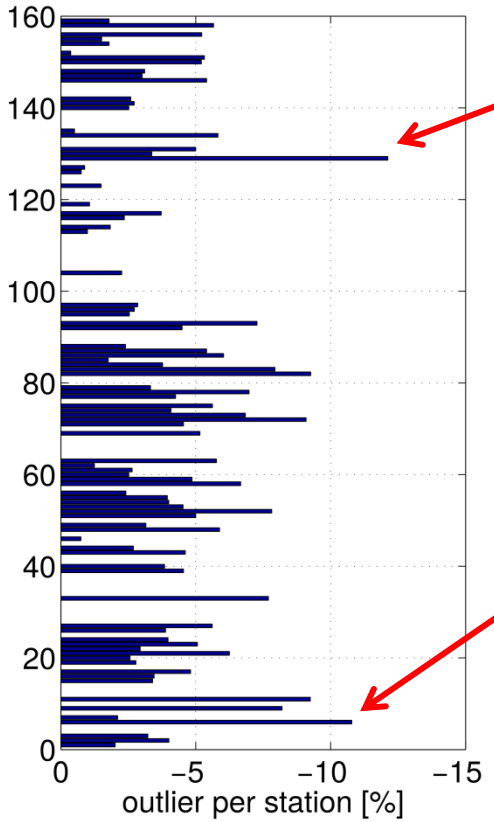
EGE

Analysis results: ERFs - station position outliers

DGFI intern

- Outliers in ERF station position time series





Richmond (USA)

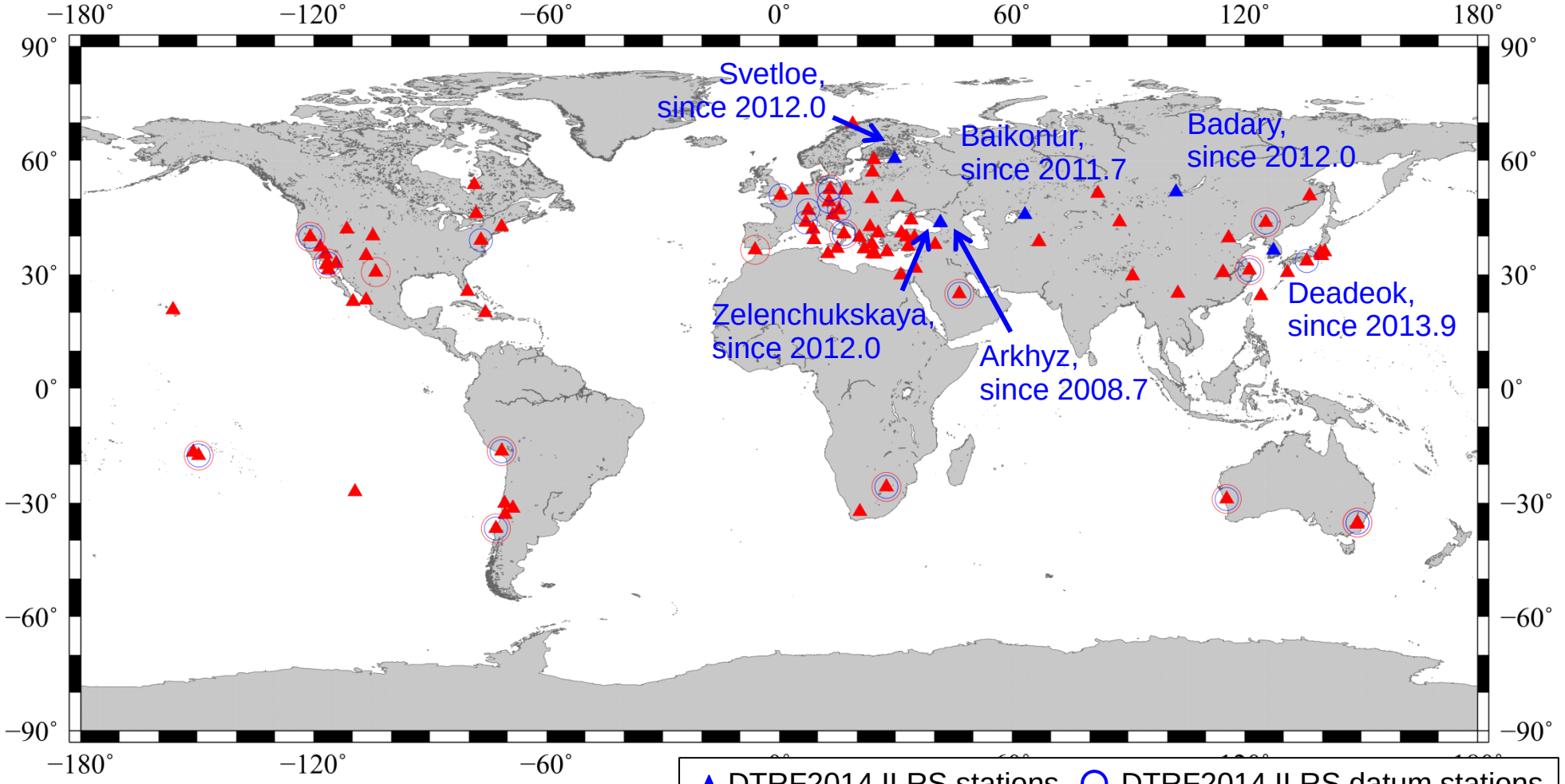
Metsahovi (Finland)

- 27796 15-/7-day station positions in total
- 833 outliers (ca. 3.0%) are reduced based on time series analysis (red dots)
- No systematics can be found in outlier per station plot or outlier per arc plot

Analysis results: ERFs/MRF - datum stations

DGFI intern

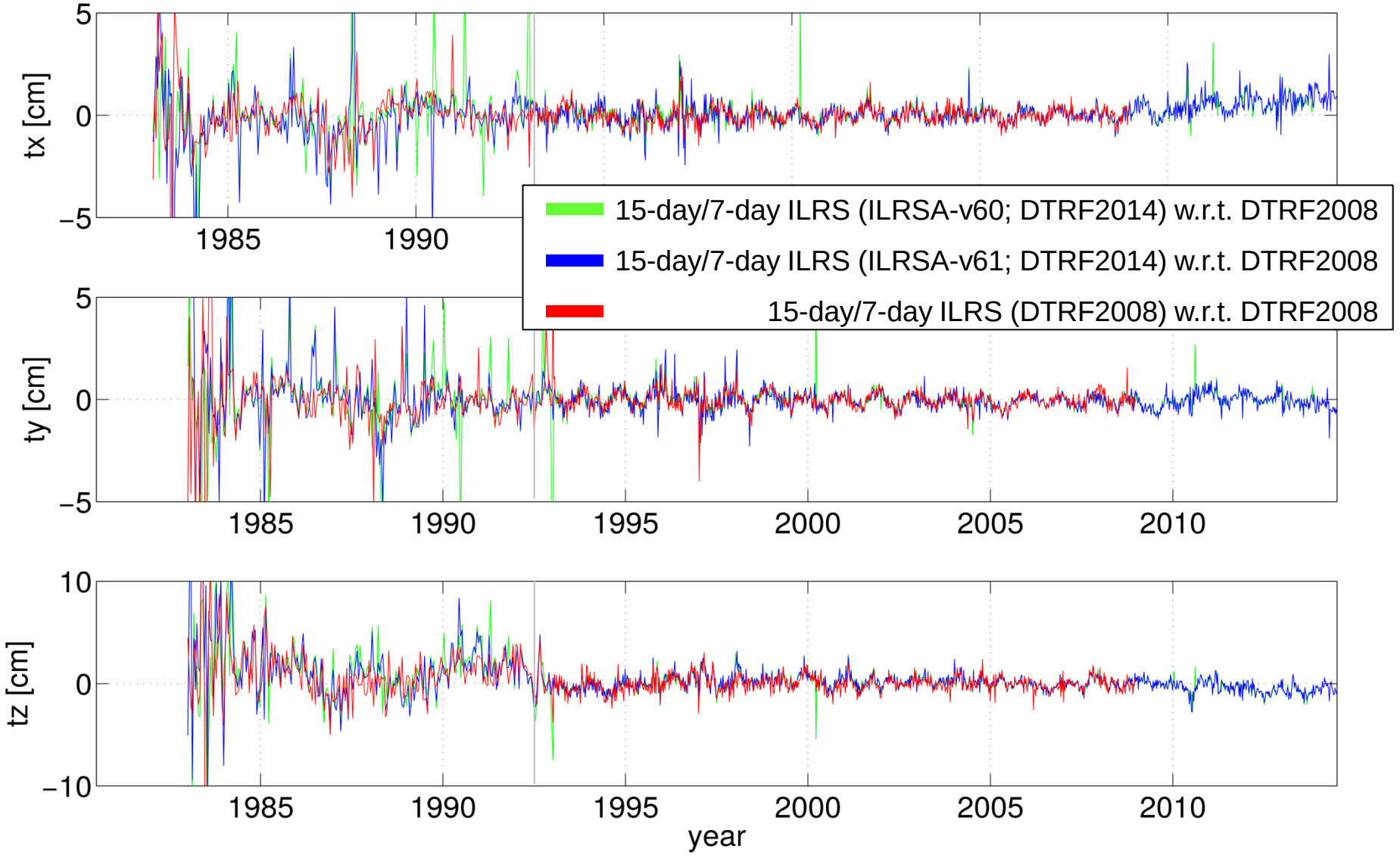
- Number of stations vs. DTRF2008
  - Five new stations in Russia + 1 new station in Korea
  - In total, 24 station were used for the transformation (20 stations already proposed by the ILRS, 4 stations selected manually in addition)



Analysis results: ERFs - datum parameters

DGFI intern

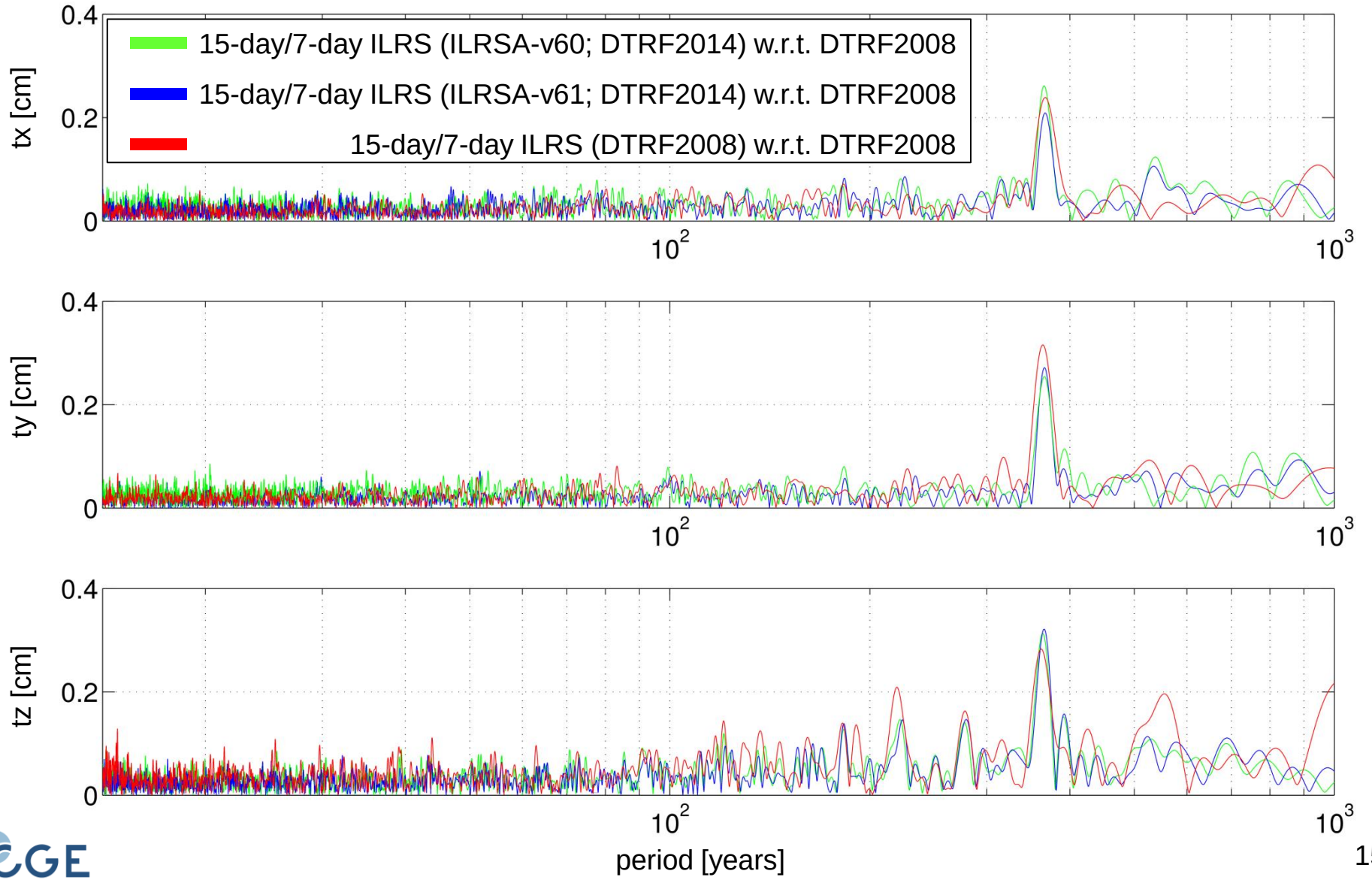
- Datum parameter series vs. DTRF2008



Analysis results: ERFs - datum parameters

DGFI intern

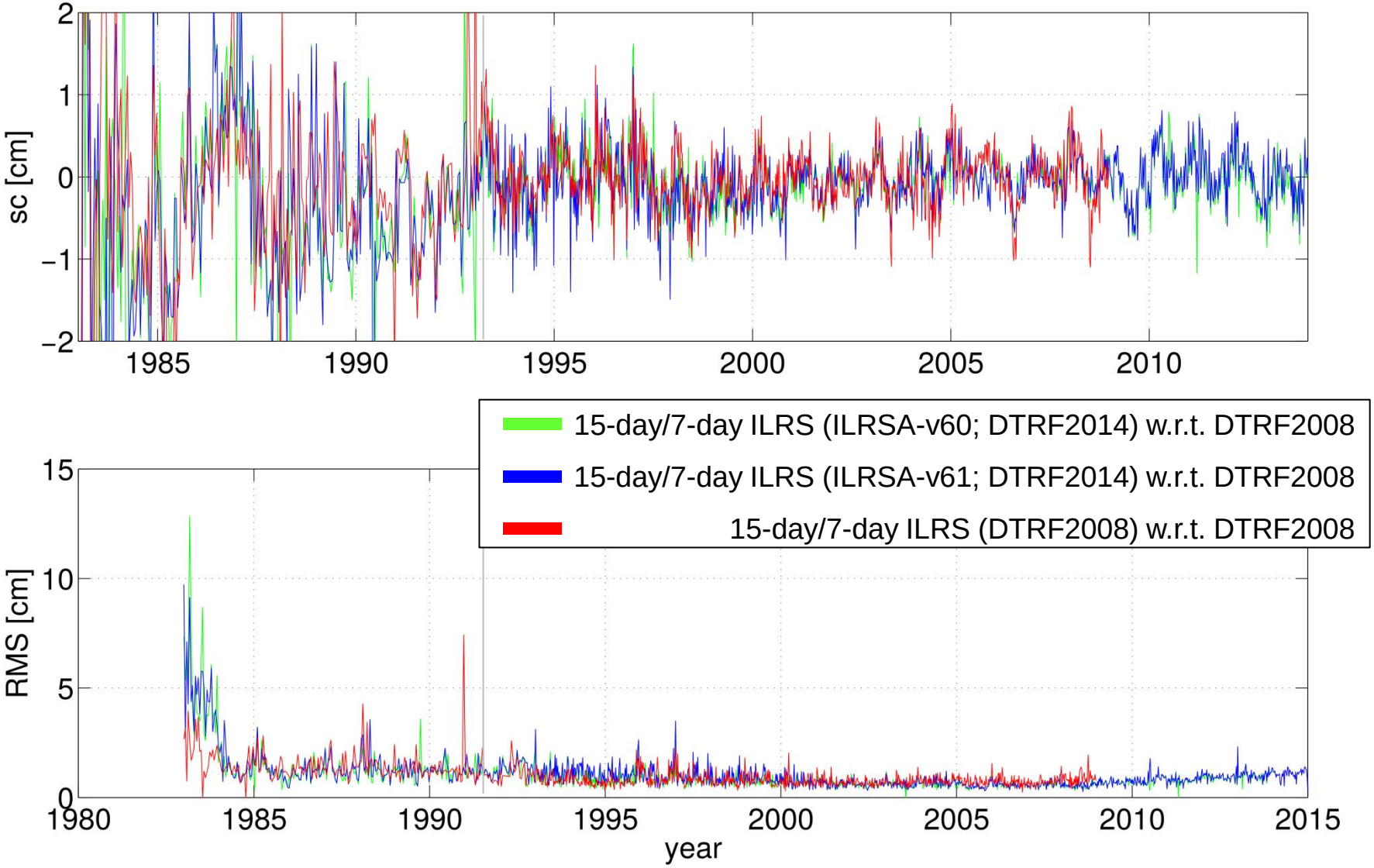
- Datum parameter series vs. DTRF2008 – spectra of translations (1993.0 – 2014.0)



Analysis results: ERFs - datum parameters

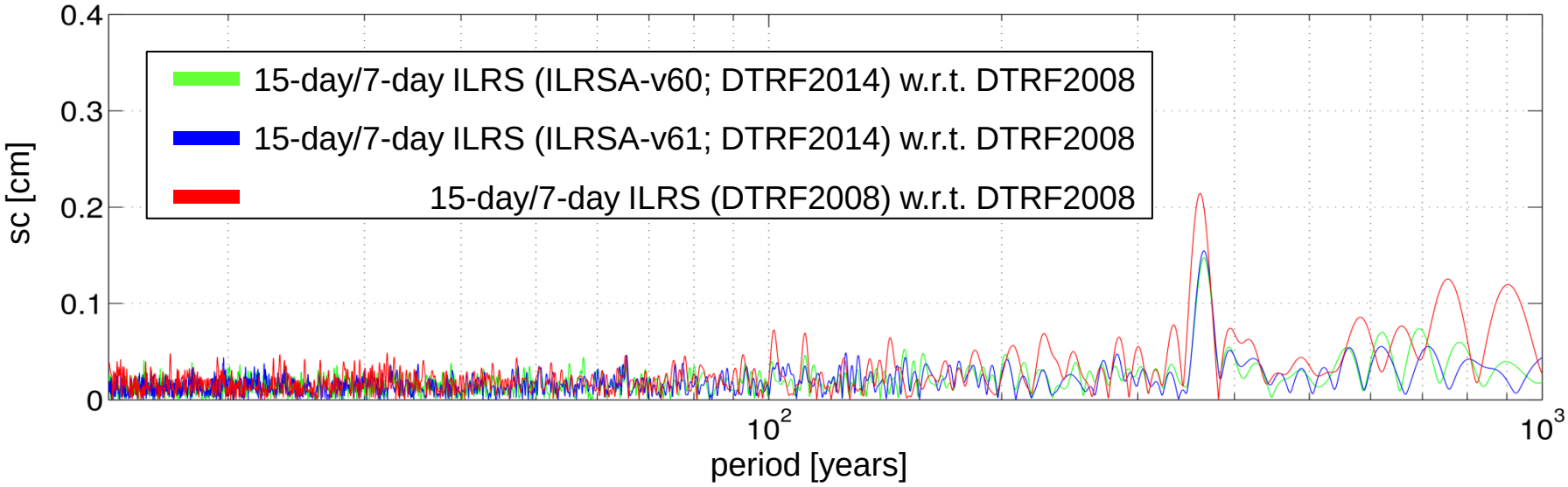
DGFI intern

- Datum parameter series vs. DTRF2008 - scale and RMS of transformation



Analysis results: ERFs - datum parameters

- Datum parameter series vs. DTRF2008 - spectra of scale (1993.0 – 2014.0)

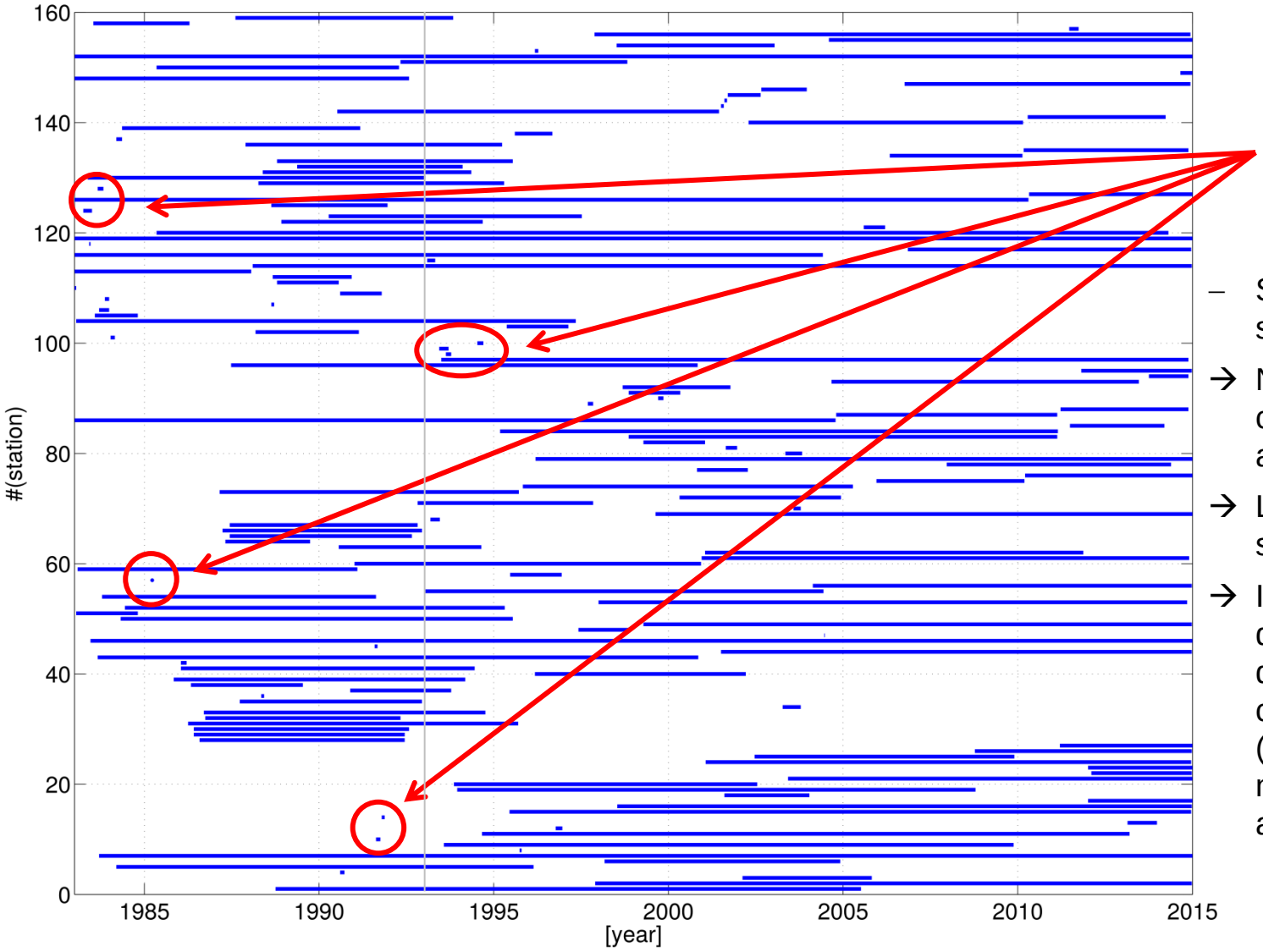


  - Annual amplitude of DTRF2014 scale (ca. 1.5 mm) is smaller than the DTRF2008 scale (ca. 2.1 mm)

Analysis results: MRF - station coordinates

DGFI intern

- Length of continuous station position time series: many short-terms?



Examples for short intervals of station observations

– Selection criteria of stations to be reduced:

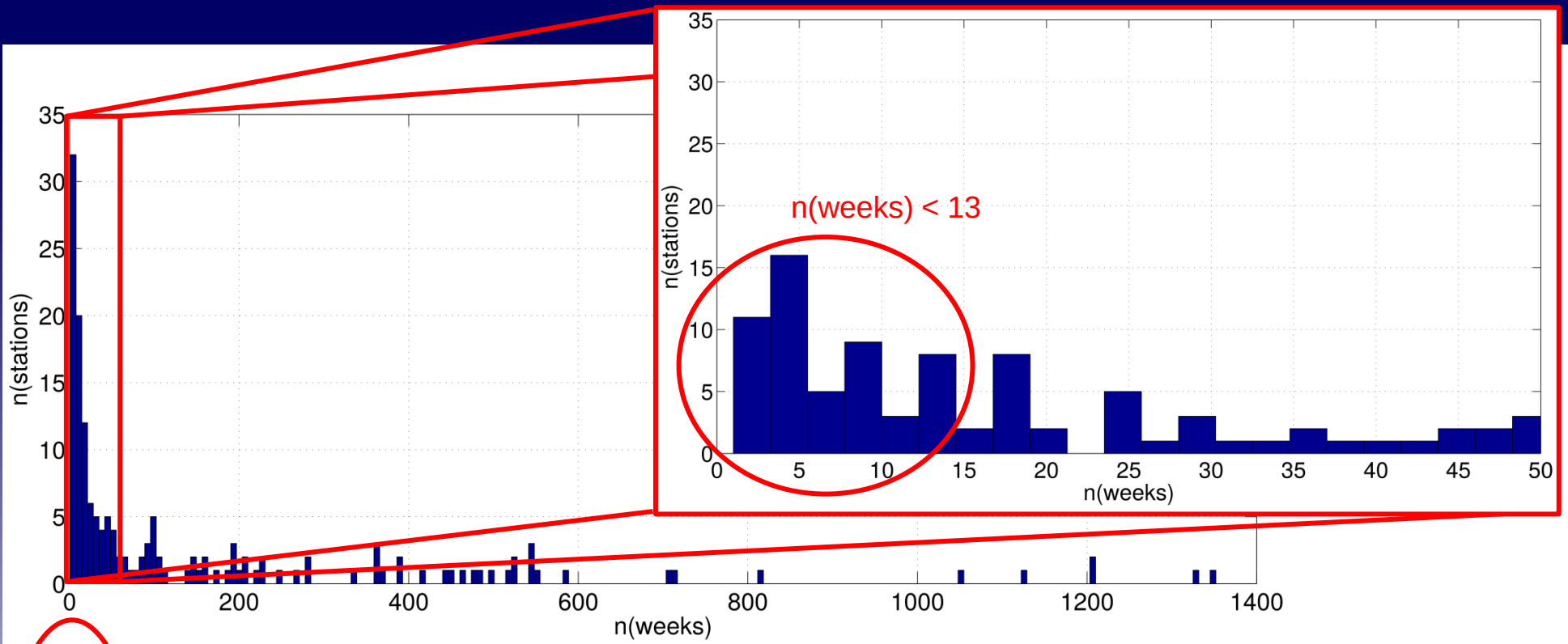
→ Number of weeks containing observations of a station < **13 weeks**

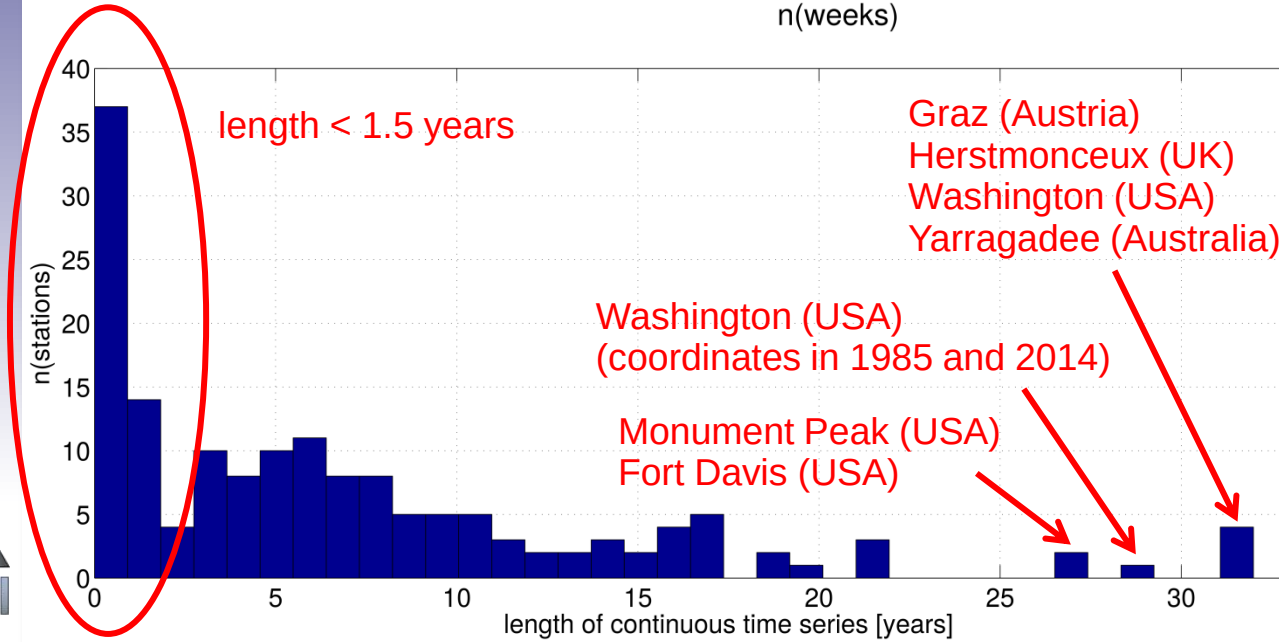
→ Length of continuous time series < **1.5 years**

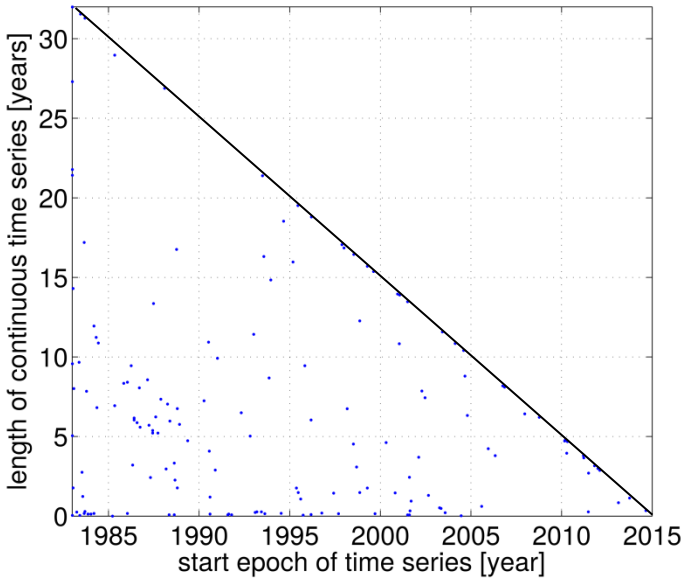
→ In addition, individual decisions are done depending on special conditions of a station (e.g., Is the station totally new? Does the station has a prominent position?)

Analysis results: MRF - station coordinates

DGFI intern







Analysis results: MRF - station coordinates

DGFI intern

DOMES number	solution number	start of continuous time interval [JD2000]	end of continuous time interval [JD2000]		description
10302M002	0A01	-3440.0	-3380.0		only 4 weeks
11101M001	0A01	-1560.0	-1535.0		only 4 weeks
12302M001	0A01	-3060.0	-3010.0		only 3 weeks
12302S006	0A01	-1180.0	-1100.0		only 5 weeks
12309S003	0A01	4700.0	5200.0		only 5 weeks
12337M001	0A01	-3000.0	-2965.0		only 3 weeks
12617M002	0A01	1150.0	1400.0		only 9 weeks
12711M002	0A01	-4260.0	-4225.0		only 3 weeks
12718M002	0A01	-5000.0	-3800.0		only 6 weeks
12734M005	0A01	-5100.0	-5030.0		only 5 weeks
12749M001	0A01	-3075.0	-3040.0		only 3 weeks
13402M005	0A01	1628.0	1635.0		only 2 weeks
14201M004	0A01		-5396.0		only 1 week
20801M001	0A01	-4800.0	-3600.0		only 4 weeks
20802M001	0A01	-5000.0	-2500.0		only 5 weeks
20803M001	0A01	-5000.0	-2500.0		only 8 weeks
20805M001	0A01	-2500.0	-2380.0		only 6 weeks
21601S005	0A01	1300.0	1400.0		only 6 weeks
21612M002	0A01	1220.0	1400.0		only 24 weeks in 180 days
21613M003	0A01	600.0	720.0		only 15 weeks in 120 days
21736S003	0B01	-842.0	-786.0		only 4 weeks
21736S005	0D01	-107.0	-51.0		only 4 weeks
23902S002	0A01	5040.0	5450.0		38 weeks in more than 1 year (new station Deadeok (Korea))
30314M001	0A01	-2330.0	-2270.0		only 8 weeks
40104M003	0A01	-2400.0	-2280.0		only 13 weeks in 120 days
40132M001	0A01	-2000.0	-1930.0		only 8 weeks
40405M006	0A01	-5840.0	-5780.0		only 4 weeks
40433M005	0A01	-5996.0	-5546.0		only 10 weeks in 450 days
40436M002	0A01	-5960.0	-5840.0		only 5 weeks
40436M003	0A01	-4155.0	-4120.0		only 3 weeks
40438M001	0A01	-5900.0	-5840.0		only 3 weeks
40438M002	0A01	-3500.0	-2900.0		only 6 weeks
40439M001	0A01	-6206.0	-6191.0		only 2 weeks
40439M004	0A01	-4100.0	-3400.0		only 5 weeks
40440M001	0A01	-4200.0	-3200.0		only 8 weeks
40442M008	0A01	-2530.0	-2430.0		only 13 weeks in 100 days
40451M102	0A01	-6056.0	-6041.0		only 2 weeks
40451M114	0A01	-5360.0	5260.0		only 13 weeks (Washington: 6 weeks in 1985 and 7 weeks in 2014 → stable velocity)
40451M116	0A01	2041.0	2265.0		only 16 weeks in 224 days
40493M001	0A01	-6120.0	-6020.0		only 6 weeks
40497M002	0A01	-5970.0	-5900.0		only 5 weeks
41705M001	0A01	-5780.0	-5710.0		only 5 weeks
42202M003	0A02	543.0	578.0		only 5 weeks during post-seismic deformation
42202M003	0A03	585.0	613.0		only 4 weeks during post-seismic deformation
42202M003	0A04	620.0	963.0		only 33 weeks during post-seismic deformation in 343 days
48081S001	0A01	5340.0	5480.0		only 9 weeks
50107S009	0A01	-1395.0	-1360.0		only 2 weeks
92201M017	0A01	1500.0	4500.0		14 weeks in total, only 1 weeks in the vey early years → no stable velocity

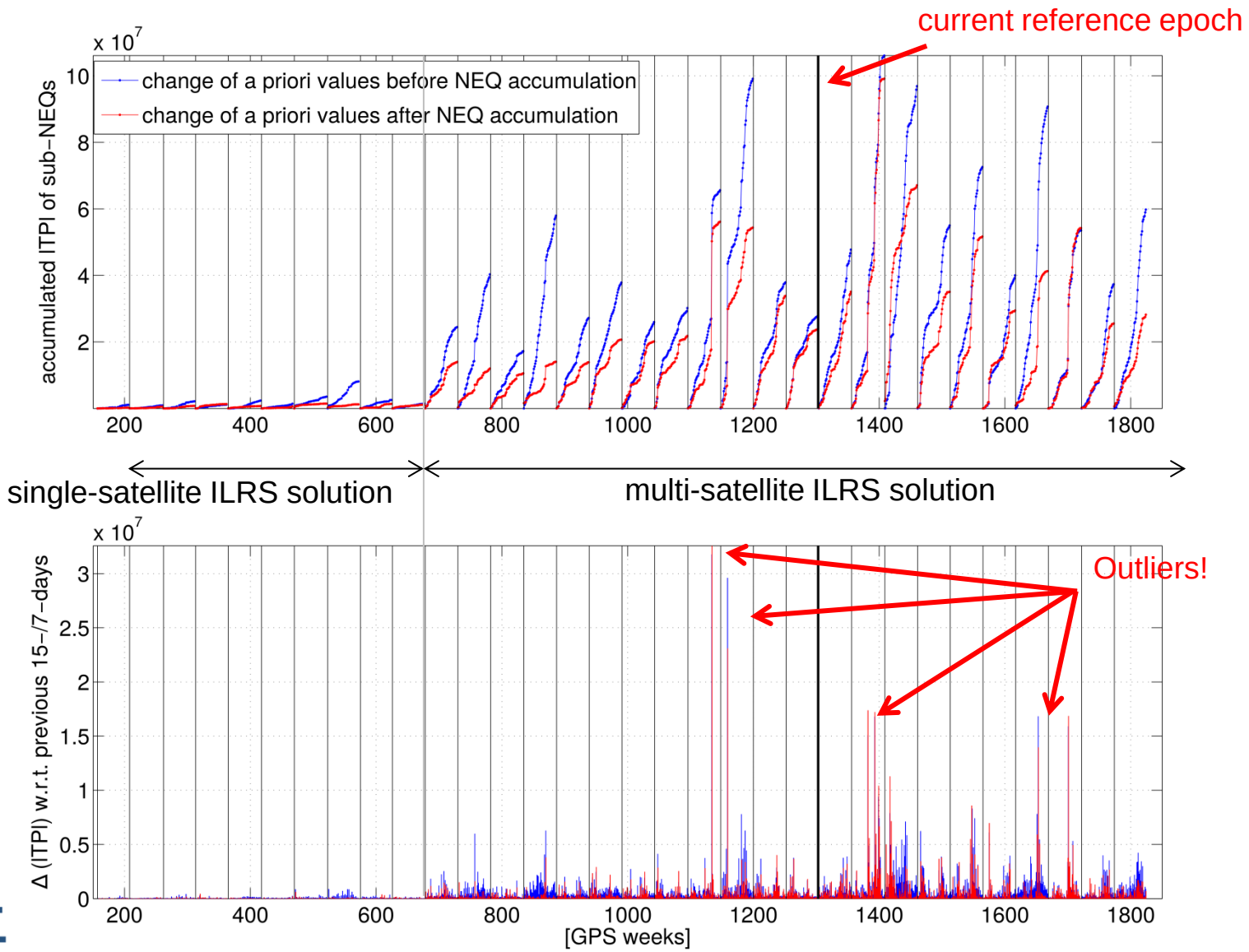
- In total, 46 stations are reduced
- Special treatment of Washington (USA) and Deadeok (Korea)

→ These stations are not reduced (green rows)!

Analysis results: MRF – accumulated ITPI

DGFI intern

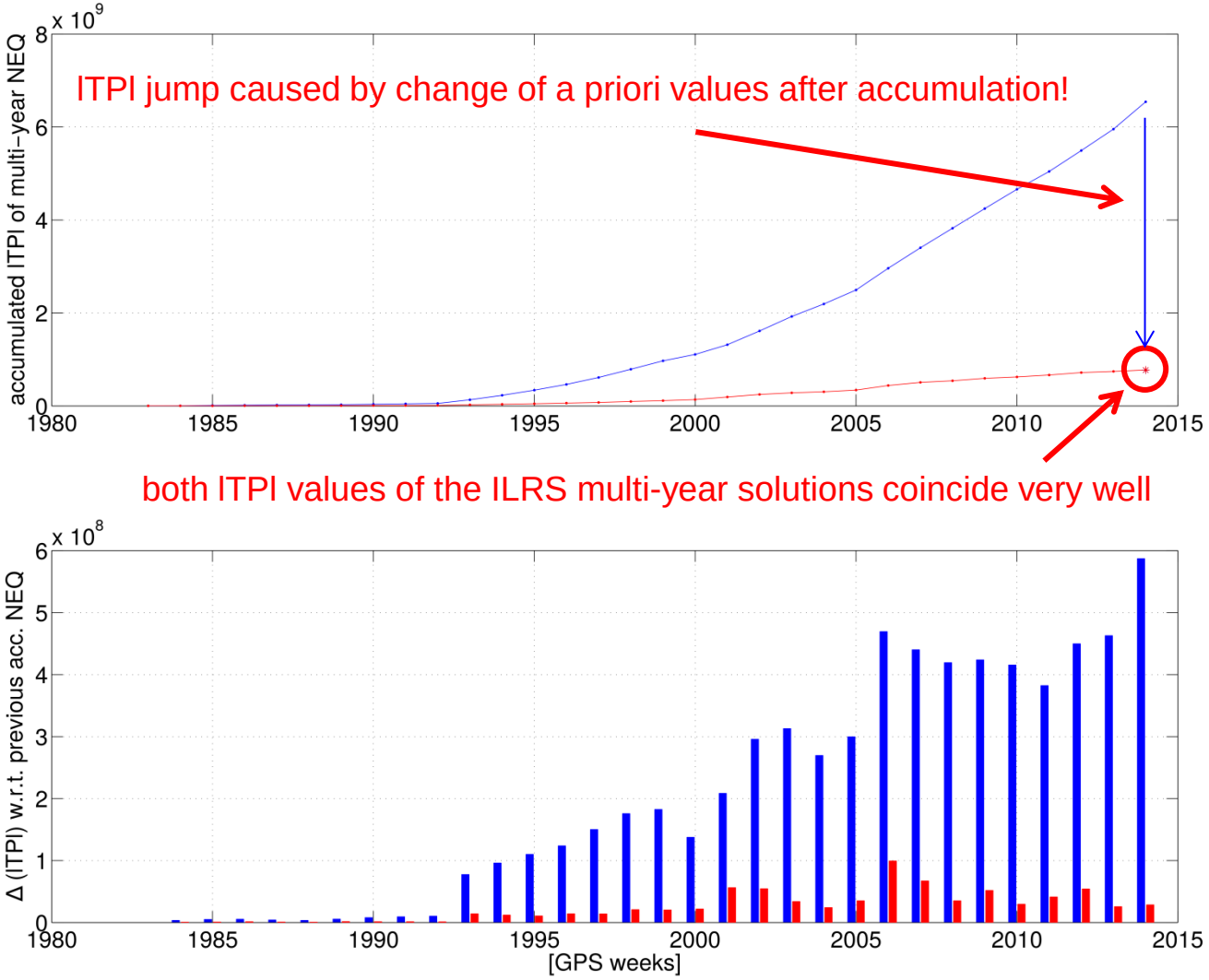
- Accumulated squared sum of O-C
  - Is there an effect, if a priori values are epoch-wise (before the accumulation) changed?



Analysis results: MRF – accumulated lTPl

DGFI intern

- Accumulated squared sum of O-C
  - Is there an effect, if a priori values are epoch-wise (before the accumulation) changed?

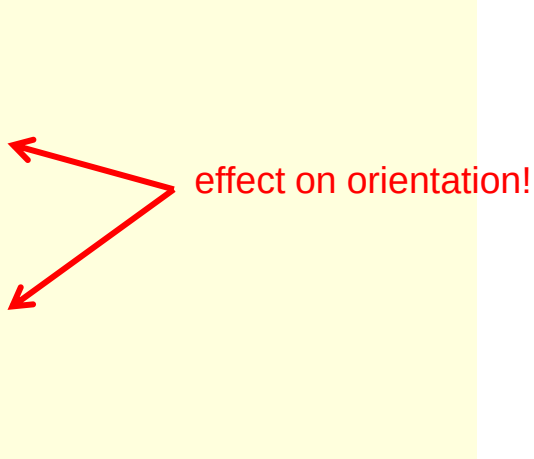


Analysis results: MRF - datum parameters

DGFI intern

- SLR multi-year solution: 14-parameter transformation of …
  - (1) solution where a priori values are changed after accumulation
  - (2) solution where a priori values are changed before accumulation
  - In total, 34 station were used for the transformation (30 stations already proposed by the ILRS, 4 stations selected manually in addition)

```
           Reference epoch:   1826.5000000000000
     Ausreisertest:n F  mit Maxiter=           2  und Sigma=   3.0000000000000000
     weighting:            0 faktor:    1.0000000000000000E-004   extra file for HT-parameters: n

     input dataset 1: ../GESAMT.ngl_datum_nutation.sol
      input dataset 2: GESAMT.ngl_datum_nutation.sol
          14 -parameter Helmerttransformation between coordinate sets:
                     and
   Weights:  Min=   1.0000000000000000       at station 7835A
             Max=   1.0000000000000000       at station 7835A
              ltpl/vtpv/sigma0 :      0.00025     0.00000     0.00000


solved for parameters at  iteration:  1


---- positions  ----

tx  [cm]:        -0.00 +-        0.00
ty  [cm]:         0.00 +-        0.00
tz  [cm]:         0.00 +-        0.00
rx [µrad]:      0.00017 +-     0.00000   [cm]:        0.11
ry [µrad]:      0.00041 +-     0.00000   [cm]:        0.26
rz [µrad]:     -0.00036 +-     0.00000   [cm]:       -0.23
sc [ppm]:     -0.00000 +-     0.00000   [cm]:       -0.00

---- velocities ----

tx  [cm]:        -0.00 +-        0.00
ty  [cm]:         0.00 +-        0.00
tz  [cm]:         0.00 +-        0.00
rx [µrad]:      0.00002 +-     0.00000   [cm]:        0.01
ry [µrad]:      0.00003 +-     0.00000   [cm]:        0.02
rz [µrad]:     -0.00003 +-     0.00000   [cm]:       -0.02
sc [ppm]:     -0.00000 +-     0.00000   [cm]:       -0.00

 mean rms coordinates:    0.00000 velocities:    0.00000
 estimated  standard deviation [cm]:    0.00006
```



Analysis results: MRF - datum parameters

DGFI intern

- SLR multi-year solution: 14-parameter transformation w.r.t. DTRF2008 (ILRS-only)
  - In total, 34 station were used for the transformation (30 stations already proposed by the ILRS, 4 stations selected manually in addition)

```
           Reference epoch:   1826.5000000000000
     Ausreisertest:n F  mit Maxiter=           2  und Sigma=   3.0000000000000000
     weighting:            0 faktor:    1.0000000000000000E-004   extra file for HT-parameters: n

     input dataset 1: scripts/DTRF2008_ILRSonly.sol_trafo
      input dataset 2: GESAMT.ngl_datum_nutation.sol
          14 -parameter Helmerttransformation between coordinate sets:
                        and
   Weights:  Min=   1.0000000000000000       at station 7835A
             Max=   1.0000000000000000       at station 7835A
              ltpl/vtpv/sigma0 :      0.00082     0.00077     0.00244


solved for parameters at  iteration:  1


---- positions  ----

tx  [cm]:        -0.02 +-         0.06
ty  [cm]:        -0.13 +-         0.06
tz  [cm]:         0.06 +-         0.05
rx [µrad]:     -0.00011 +-      0.00011   [cm]:        -0.07
ry [µrad]:      0.00004 +-      0.00010   [cm]:         0.02
rz [µrad]:      0.00002 +-      0.00011   [cm]:         0.01
sc [ppm]:     -0.00006 +-      0.00008   [cm]:        -0.04

---- velocities ----

tx  [cm]:          0.02 +-         0.06
ty  [cm]:         -0.02 +-         0.06
tz  [cm]:         -0.01 +-         0.05
rx [µrad]:     -0.00002 +-      0.00011   [cm]:        -0.01
ry [µrad]:     -0.00002 +-      0.00010   [cm]:        -0.01
rz [µrad]:      0.00001 +-      0.00011   [cm]:         0.00
sc [ppm]:      0.00005 +-      0.00008   [cm]:         0.03

 mean rms coordinates:    0.00239 velocities:    0.00049
 estimated  standard deviation [cm]:    0.24405
```

translation and scale parameter are ok…

very small transformation RMS!

Analysis results: MRF - datum parameters

DGFI intern

- SLR multi-year solution: 14-parameter transformation w.r.t. DTRF2008 (ILRS-only)
  - In total, 24 station were used for the transformation (20 stations already proposed by the ILRS, 4 stations selected manually in addition)
  - good global coverage (see slide 13)

residuals

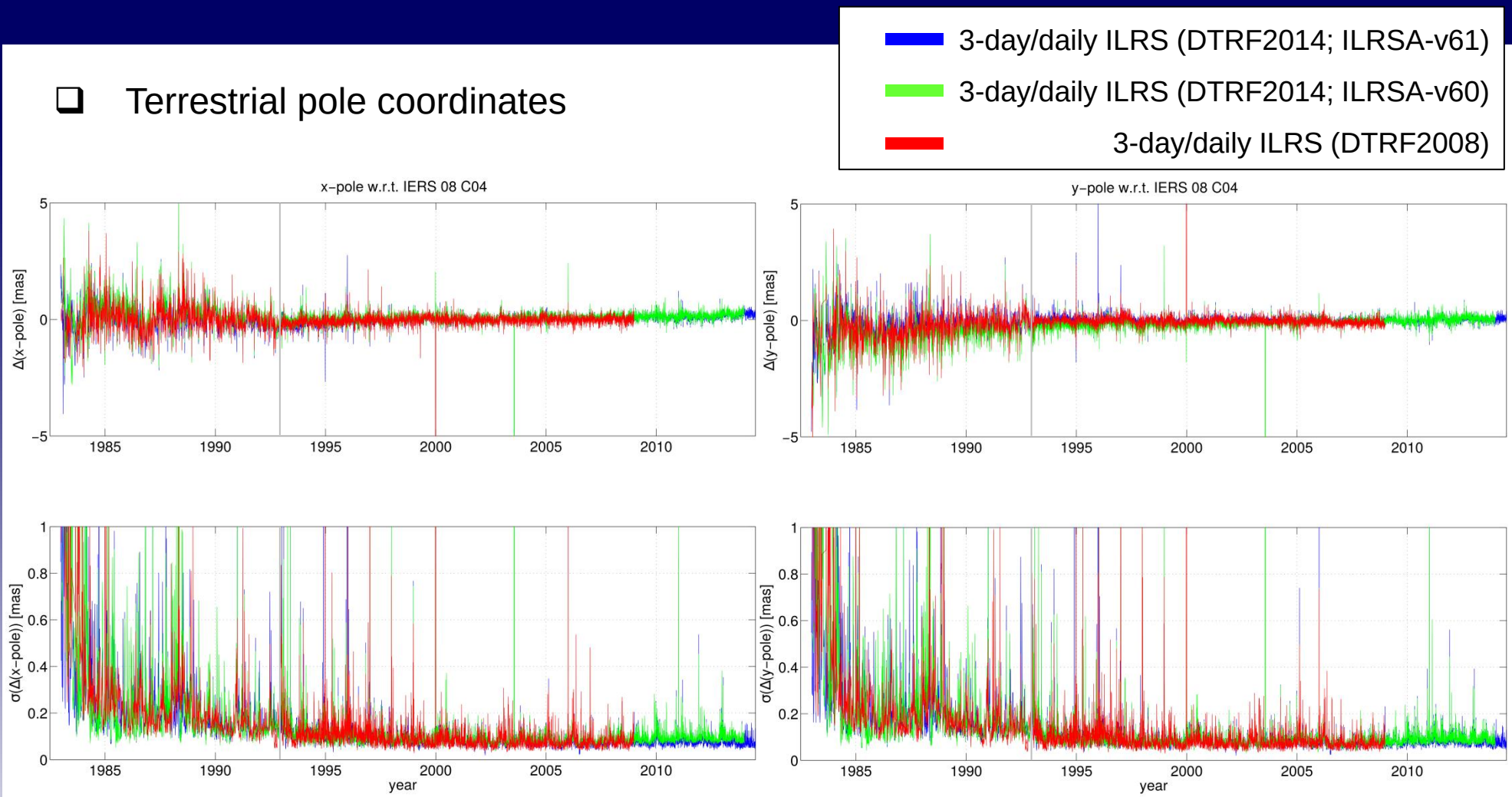
parametername, X-, Y-, Z- , Vx- , Vy- , Vz- coordinate in [cm]

10002S001 A01	-0.05	-0.06	0.09	0.02	-0.00	0.07
11001S002 A01	0.08	0.26	0.52	0.03	0.03	0.07
12734S001 A01	0.70	0.10	0.13	0.02	-0.01	0.00
12734S008 A01	-0.02	-0.08	-0.04	-0.03	-0.06	-0.08
13212S001 A01	-0.11	0.07	-0.02	0.02	0.01	0.05
14001S007 B01	-0.38	-0.16	-0.32	-0.06	-0.03	-0.12
14106S009 A01	-0.01	-0.14	-0.44	0.06	0.02	0.03
14106S011 A01	0.18	-0.10	0.20	-0.08	-0.03	-0.21
14201S018 A01	0.10	0.25	-0.56	0.02	0.04	-0.04
14201S018 A02	-0.01	-0.10	-0.13	0.03	-0.04	-0.02
20101S001 A01	-0.00	-0.02	-0.03	0.05	0.02	-0.02
21605S001 A02	-0.20	-0.21	0.46	-0.06	-0.06	0.11
21611S001 A01	-0.64	0.33	0.74	-0.24	0.08	0.14
21726S001 A01	0.14	-0.42	-0.87	0.01	-0.03	-0.08
30302M003 A01	-0.05	-0.03	-0.28	0.02	-0.04	-0.07
40433M002 A01	0.00	0.23	-0.85	-0.00	-0.01	-0.02
40451M105 A01	-0.17	0.43	0.63	0.02	-0.00	0.10
40497M001 A01	-0.06	-0.09	0.24	-0.01	-0.02	0.06
41719M001 A01	0.01	-0.60	-0.31	-0.05	0.02	0.02
42202M003 A01	0.32	-0.31	0.35	0.07	-0.06	0.06
50107M001 A01	0.06	-0.07	0.23	0.01	-0.03	-0.01
50119S001 A01	0.06	0.13	0.52	-0.00	0.05	0.04
50119S003 A01	-0.16	-0.03	0.10	0.04	-0.01	0.03
92201M007 A01	0.21	0.60	-0.38	0.13	0.15	-0.10

Analysis results: MRF - pole coordinates

DGFI intern

- Terrestrial pole coordinates

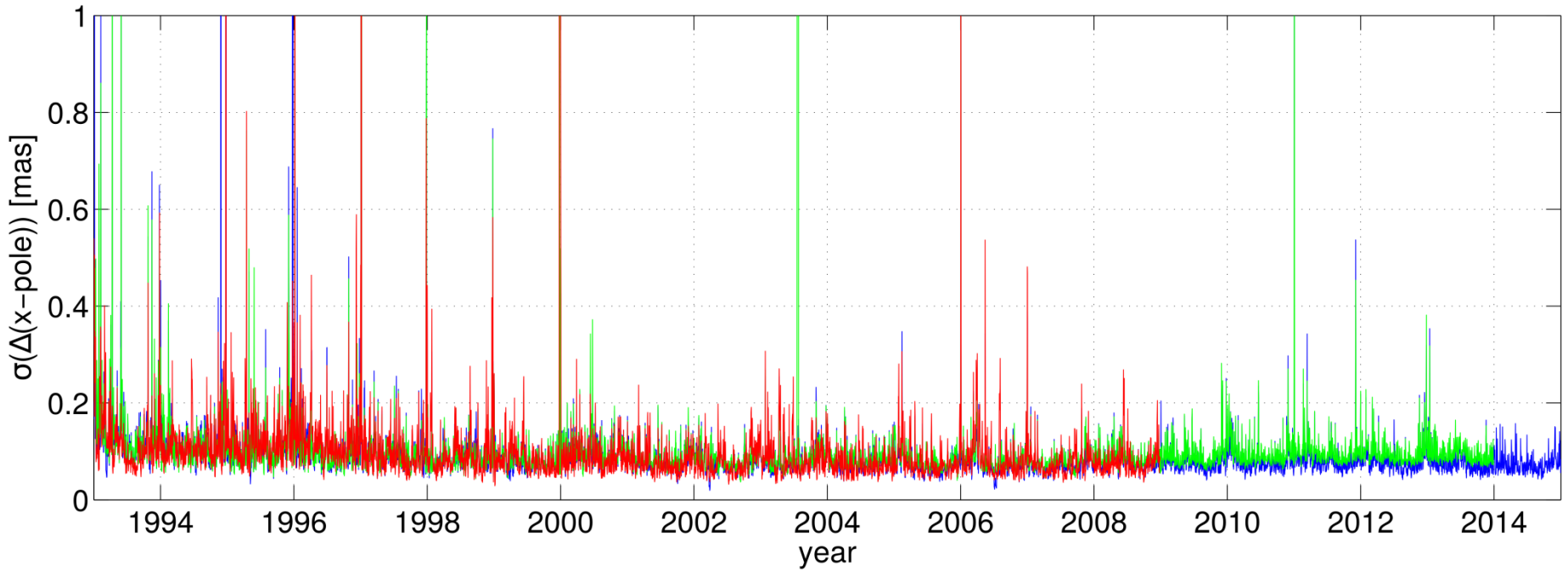


- DTRF2014 SLR-only solution contains still outliers
- STDs of DTRF2008 SLR-only solution has to be scaled with 1/100 for comparison! Why? → Maybe error in stochastic model of DTRF2008 ILRS solution; the multiyear TRF has a very high a posteriori variance factor

Analysis results: MRF - pole coordinates

DGFI intern

- Terrestrial pole coordinates
  - STDs of x-pole (zoomed between 1993.0 and 2015.0)



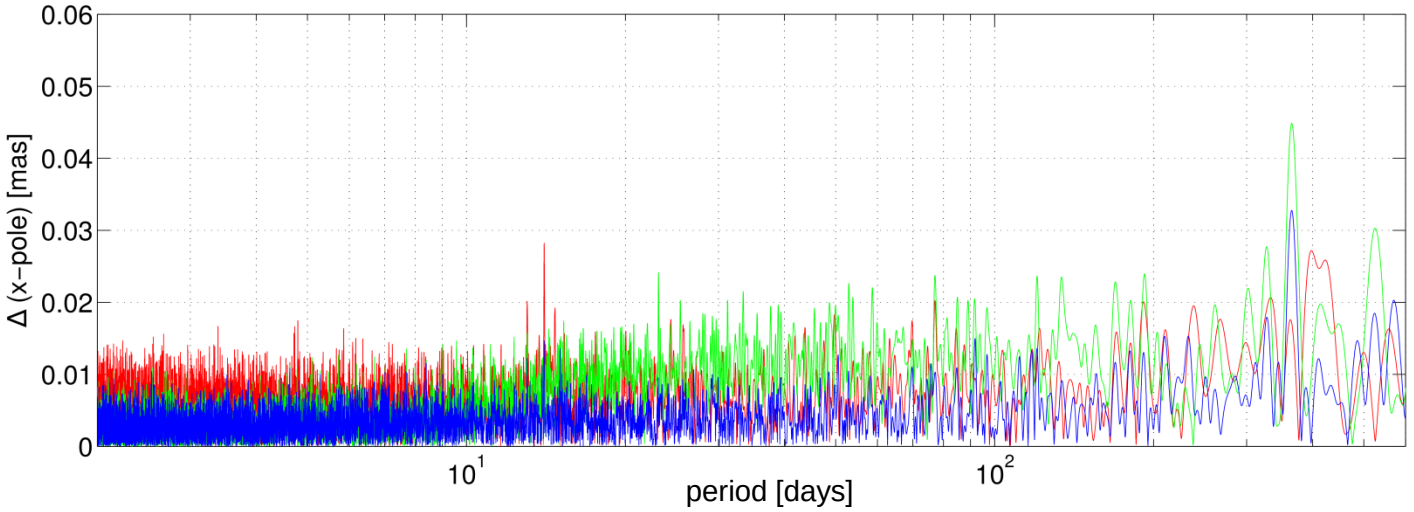
  - SLR “new year effect” → STDs during Christmas holidays are very large!
  - The same behavior occurs for the y-pole
  - ILRSA-v61 EOP show smaller STDs especially since 2005.0

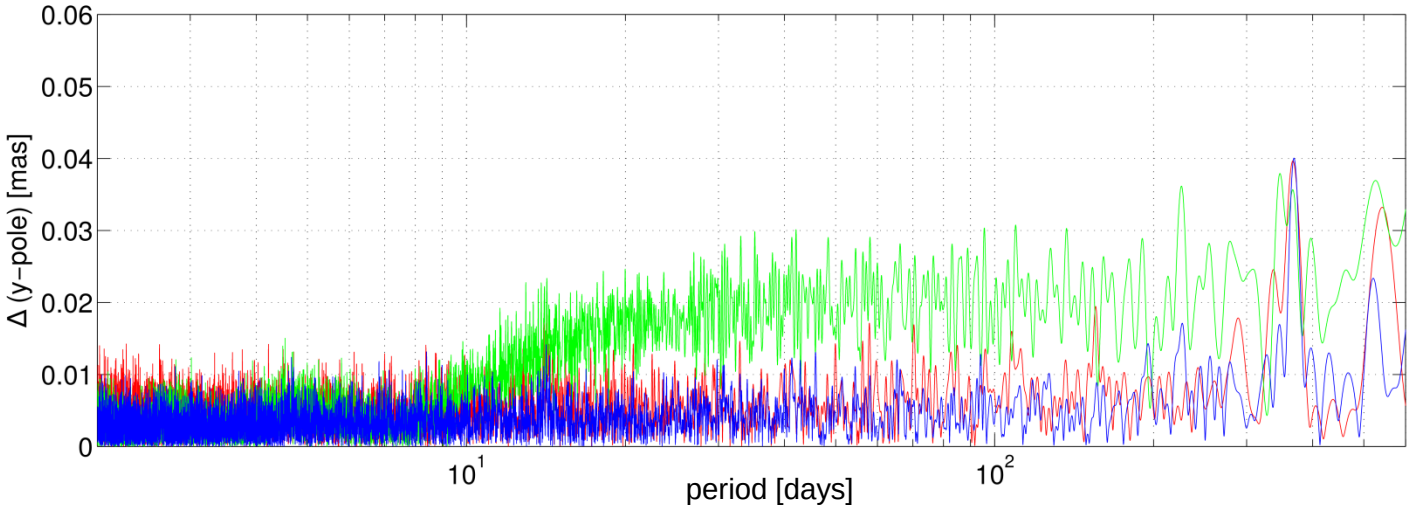
Analysis results: MRF - pole coordinates

DGFI intern

- Terrestrial pole coordinates – spectra

3-day/daily ILRS (DTRF2014; ILRSA-v61)
3-day/daily ILRS (DTRF2014; ILRSA-v60)
3-day/daily ILRS (DTRF2008)





- different annual amplitudes in x-pole differences w.r.t. IERS 08 C04
- Scatter of ILRSA-v61 submission is the smallest
- Scatter of ILRSA-v60 submission in x- and y-pole differences much higher than in ILRSA-v61 submission

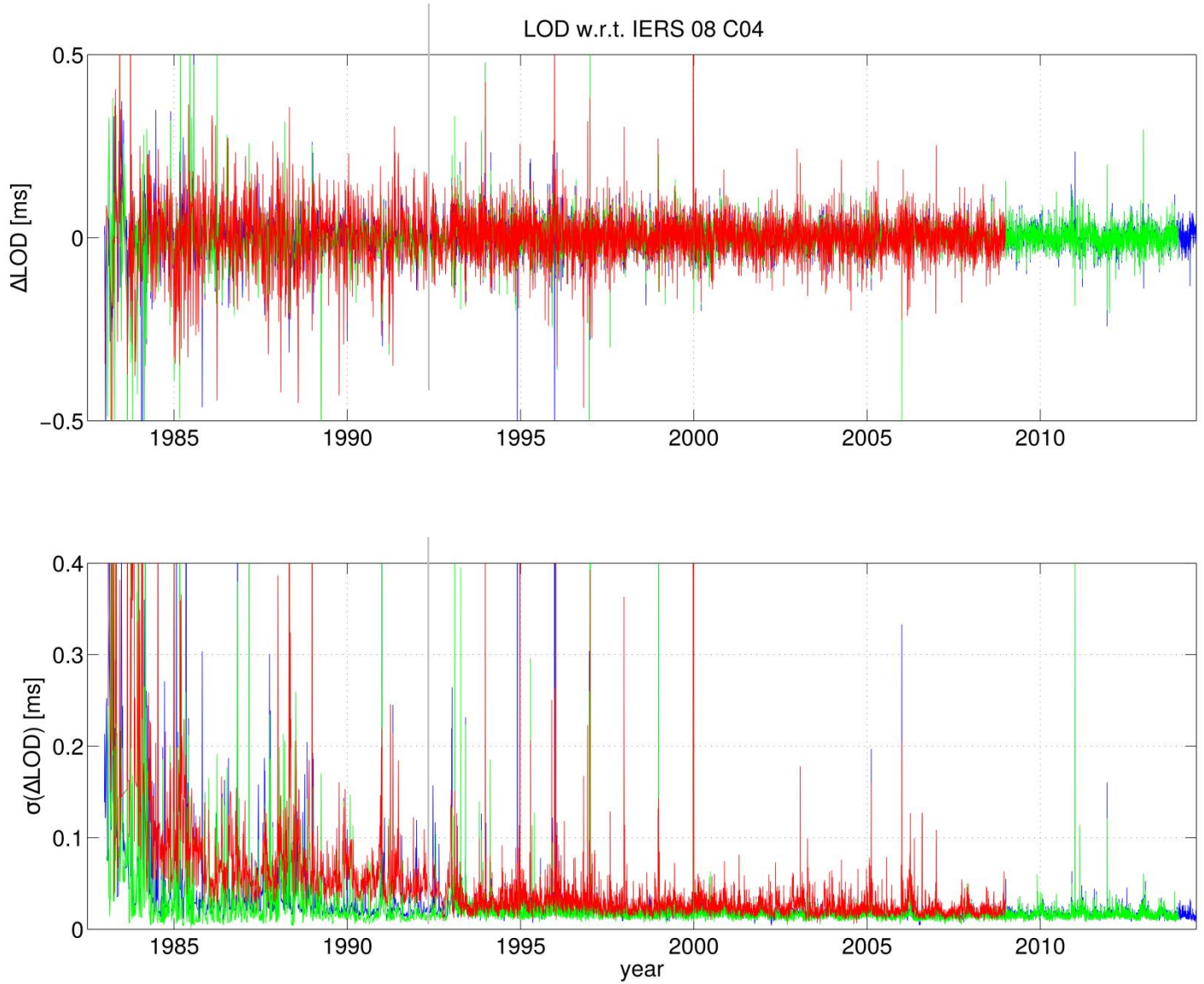
→ Caused by outliers?

Analysis results: MRF - LOD

DGFI intern

- LOD w.r.t. IERS 08 C04

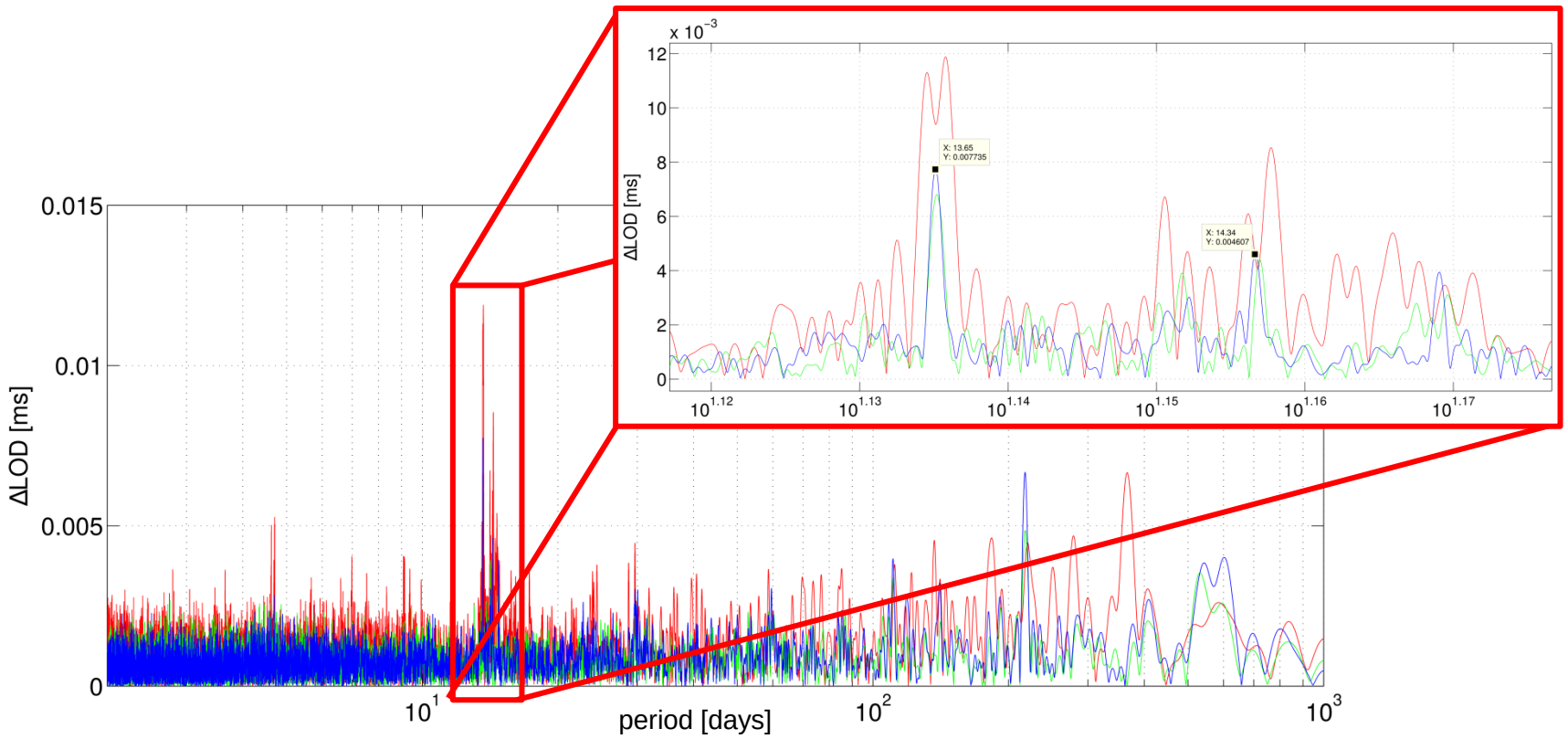
3-day/daily ILRS (DTRF2014; ILRSA-v61)
3-day/daily ILRS (DTRF2014; ILRSA-v60)
3-day/daily ILRS (DTRF2008)



Analysis results: MRF - LOD

DGFI intern

- LOD – spectra (1993.0 – 2009.0)



- Tidal frequency (13.67 and 14.34 days) clearly seen in all time series
- Scatter of DTRF2008 solution higher than in both DTRF2014 ILRS solutions
- Annual signal of DTRF2008 ILRS solution totally disappears in both DTRF2014 ILRS solutions
- Increase of semi-annual amplitude in both DTRF2014 ILRS solutions

DGFI

EGE

Analysis results: MRF – EOP statistics

DGFI intern

- EOP statistics

EOP	ILRS-v61		ILRS (DTRF2008)	
	WRMS w.r.t. IERS 08C04 [mas/ms]	Offset at 2005.0 w.r.t. IERS 08C04 [mas/ms]	WRMS w.r.t. IERS 05C04 [mas/ms]	offset at 2005.0 w.r.t. IERS 05C04 [mas/ms]
x-pole	0.1942	-0.0143 +- 0.0044	0.2051	-0.0265 (DTRF comb.)
y-pole	0.1794	-0.0872 +- 0.0045	0.2040	-0.0644 (DTRF comb.)
LOD	0.0334	0.0014 +- 0.0007	0.0274 (IVS-only)	-0.0001 (DTRF comb.)

Analysis results: MRF – loose constraints

DGFI intern

- Is there an effect of the loose constraints (applied by ILRS) on the estimated velocities?
  - 14-parameter transformation of ILRS solution without NNR constraint w.r.t. ILRS solution with NNR constraint:

```
           Reference epoch:   1826.5000000000000
     Ausreisertest:n F  mit Maxiter=           2  und Sigma=   3.0000000000000000
     weighting:            0 faktor:    1.0000000000000000E-004   extra file for HT-parameters: n

     input dataset 1: ../backup_nw_anpassung_vor_acc/GESAMT.ngl_datum_nutation.sol
      input dataset 2: GESAMT.ngl_datum_nutation.sol
          14 -parameter Helmerttransformation between coordinate sets:
                     and
   Weights:  Min=   1.0000000000000000       at station 7835A
             Max=   1.0000000000000000       at station 7835A
              ltpl/vtpv/sigma0 :      0.00457     0.00000     0.00000


solved for parameters at  iteration:  1


---- positions  ----

tx  [cm]:         0.00 +-        0.00
ty  [cm]:        -0.00 +-        0.00
tz  [cm]:        -0.00 +-        0.00
rx [µrad]:     -0.00100 +-     0.00000   [cm]:        -0.64
ry [µrad]:     -0.00223 +-     0.00000   [cm]:        -1.42
rz [µrad]:     -0.00124 +-     0.00000   [cm]:        -0.79
sc [ppm]:      0.00000 +-     0.00000   [cm]:         0.00

---- velocities ----

tx  [cm]:         0.00 +-        0.00
ty  [cm]:        -0.00 +-        0.00
tz  [cm]:        -0.00 +-        0.00
rx [µrad]:     -0.00040 +-     0.00000   [cm]:        -0.26
ry [µrad]:     -0.00027 +-     0.00000   [cm]:        -0.17
rz [µrad]:     -0.00017 +-     0.00000   [cm]:        -0.11
sc [ppm]:      0.00000 +-     0.00000   [cm]:         0.00

 mean rms coordinates:    0.00000 velocities:    0.00000
 estimated  standard deviation [cm]:    0.00049
```

effect on orientation at cm-level!

Summary & Outlook

DGFI intern

- Many model improvements for SLR since DTRF2008
- Annual amplitudes in Tx and Tz agree well whereas the amplitude of Ty is smaller for DTRF2014 than for DTRF2008 (effect of improved network?)
- Annual amplitude of DTRF2014 scale (ca. 1.5 mm) is smaller than the DTRF2008 scale (ca. 2.1 mm)
- STDs of pole coordinates show “new year effect” → STDs during Christmas holidays are very large!
- STDs of DTRF2014 LOD are smaller than STDs of DTRF2008 LOD
- Tidal frequencies (13.67d/14.34d) in all LOD time series
- annual signal only in LOD of DTRF2008; semi-annual signal more prominent in DTRF2014 ILRS solutions
- LOD of ILRSA-v61 solution shows smallest scatter

Outlook

- Unification of discontinuity list with IGN and JPL
- Application of a posteriori NT-ATML correction at normal equation level
- **Therefore, results may slightly change!**

Remarks

- Ocean tide model of www.holt.oso.chalrmers.se/loading/#select (Scherneck)

  → CMC=1 means that CoM of Earth coincides with center of solid Earth + atmosphere/ocean. This correction model is used by ILRS ACs

  → In contrast to this, IVS (communication with Ralf, John Gibson) uses an ocean tide correction model with CMC=0 (differences to CMC=1 can reach several millimeters). Any problems caused by this inconsistency? Scale difference between SLR and VLBI?
- Reference epoch for DTRF2014 currently set to 2005.0 (1826.5 JD2000). Ok?
- Handling of jumps ok? The main focus was on introducing discontinuities as less as necessary
- Should we also have a look on the ILRSB-v61 contribution?
- Should we prepare a paper of our analysis? Maybe together with Erricos and Cinzia and a comparison of ILRSA and ILRSB…
- Should we test a solution where we introduced similarity transformation parameters (3 rotations) in order to eliminate any loose constraint effect?

Thank you very much for your attention!

Many thanks to the ILRS for providing the data!

DTRF2014: Results of the analysis and impact of the contribution of the International Laser Ranging Service

Manuela Seitz, Detlef Angermann, Mathis Bloßfeld

Deutsches Geodätisches Forschungsinstitut (DGFI), Munich, Germany

e-mail: *seitz@dgfi.badw.de*

For more details on DTRF2014, please visit ***http://dgfi.badw.de/en/products/dtrf2013***

DGFI

CGE

Centre of Geodetic Earth System Research

Status Analysis Center GFZ

Rolf König

Summary

- Ammendments to ITRF2013 submission
  - Few arcs where epoch of station coordinates was not exact 43200
  - Kunming added in period 2007 to 2013
- Update of standards for operational products:
  - EGM96
  - No albedo
  - Sun, Moon, planets JPL ephemeris 405
  - etc
- Open issues
  - EOPs
    - Large variation of first & last EOP estimates in 7-day arc
    - Long-period oscillation of mean
- Other relevant activities
  - Variations of degree two harmonics for GGFC
  - Atmospheric loading for all ITRF2008 stations from ECMWF data for GGFC

AWG GRGS ILRC AC

Florent Deleflie[1], David Coulot[2,1],
and Franck Reinquin[4]

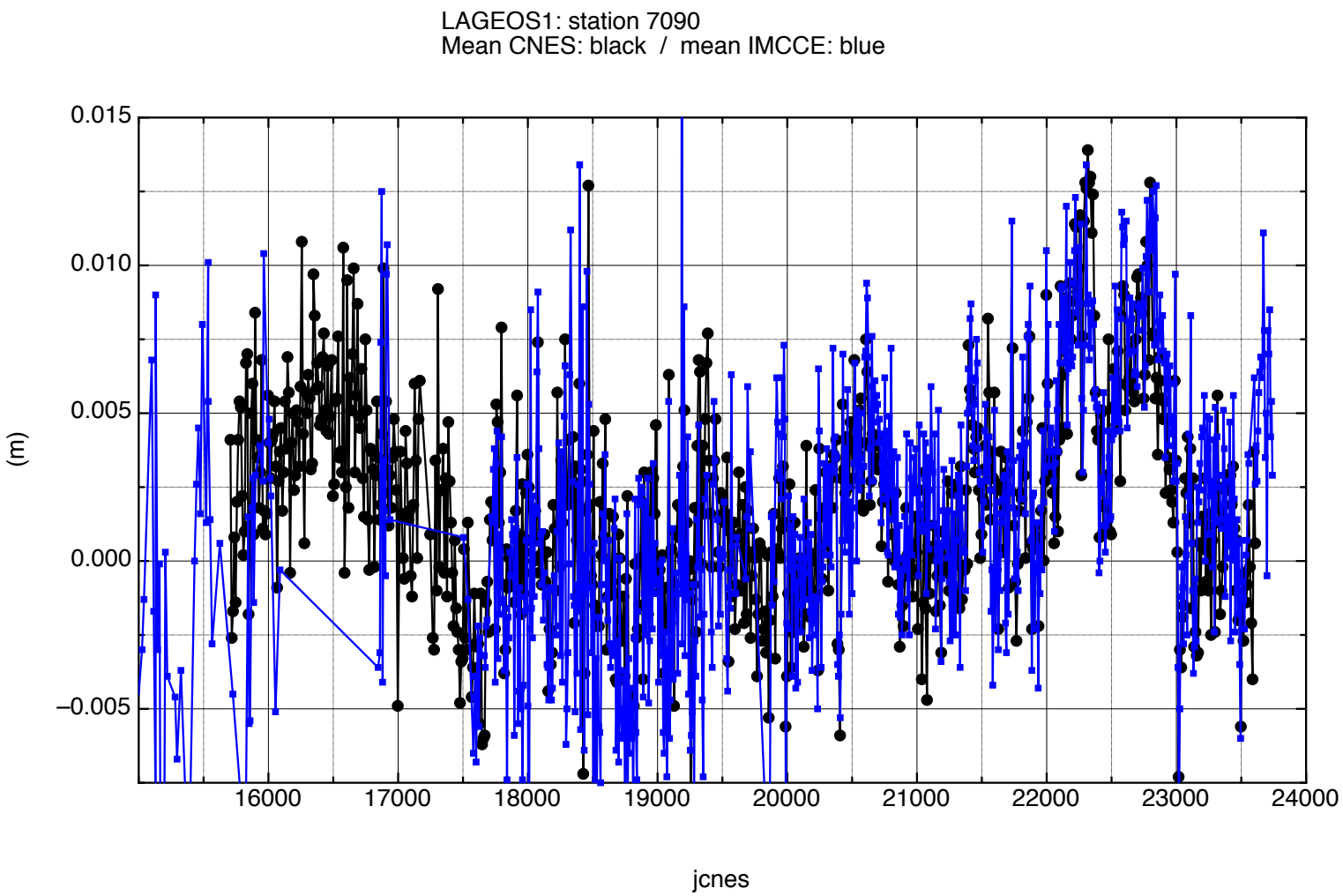
[1] Institut de Mécanique Céleste et de Calcul des Ephémérides/GRGS, Paris
[2] IGN/LAREG/GRGS, Université Paris Diderot, Paris, France
[3] Observatoire de la Côte d'Azur/GRGS, Caussols, France
[4] Centre National d'Etudes Spatiales/GRGS,Toulouse, France

27th October, 2014

Orbital Computations and ILRS related products

- Satellites:
  - LAG1: Nov. 1982 - Dec. 2014
  - LAG2: Nov. 1992 - Dec. 2014
  - ETA1: Dec. 1990 - Dec. 2014
  - ETA2: Dec. 1990 - Dec. 2014
- Modelling: as the one recommended by AWG for ITRF2013
- Data a priori corrections, accordingly
- Elimination critera in the gins s/w: 4σ, and a priori greater than 1400m (ETA), and 100m (LAG)
- Related products:
  - SSC and EOP: 1 value every day or 3 days ("historical period")

Some bias detected for some stations: Yarragadee



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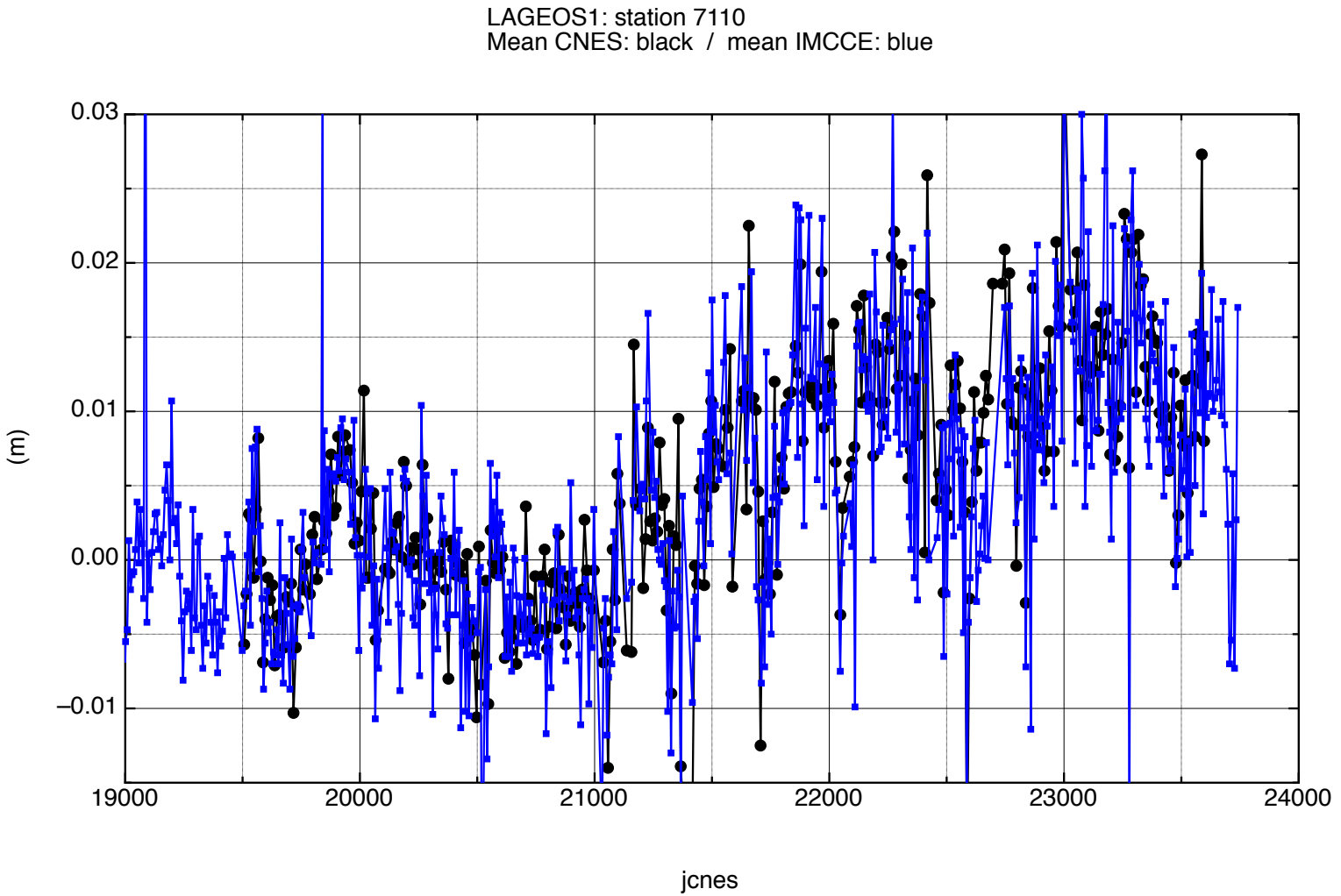
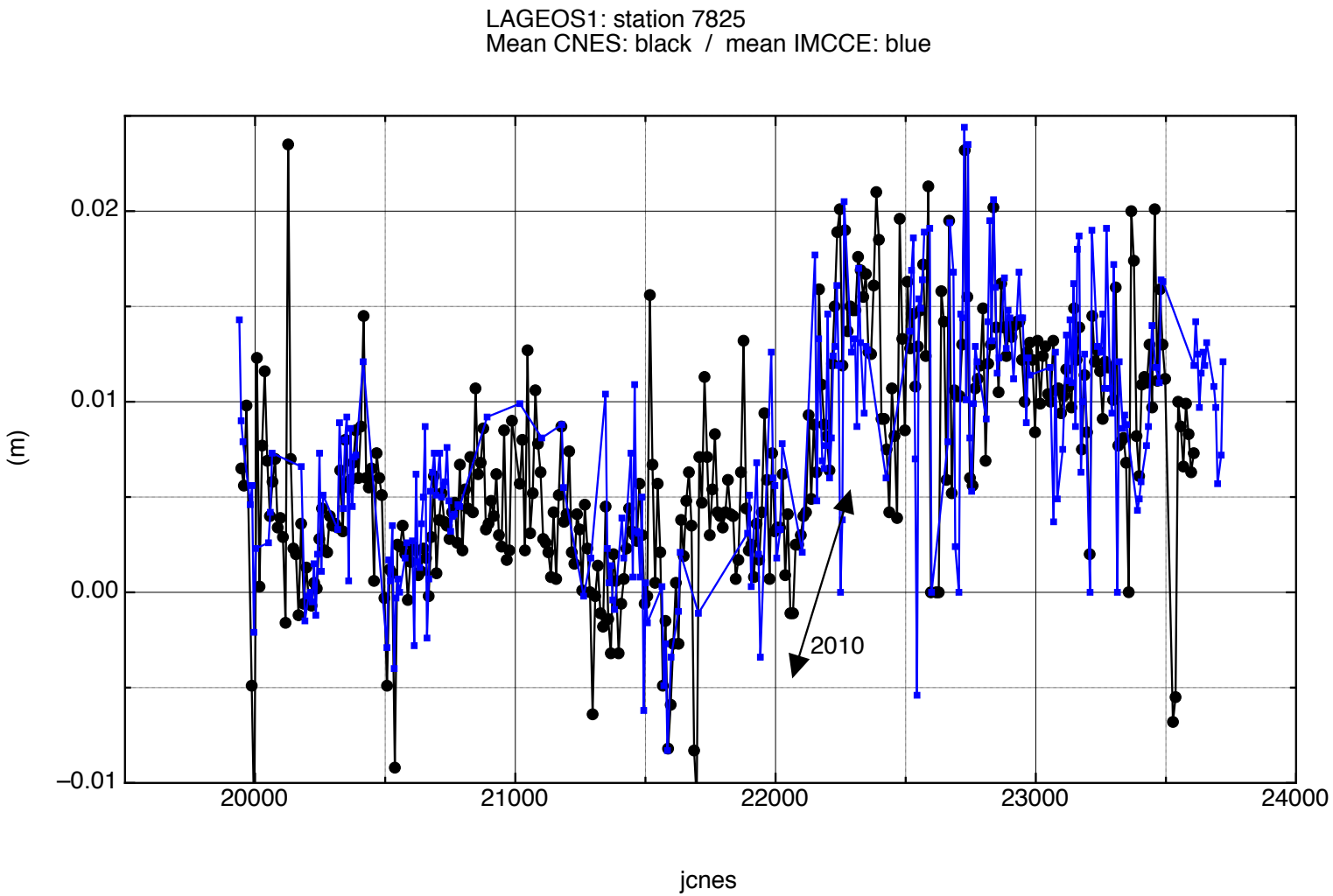


Some bias detected for some stations: Yarragadee



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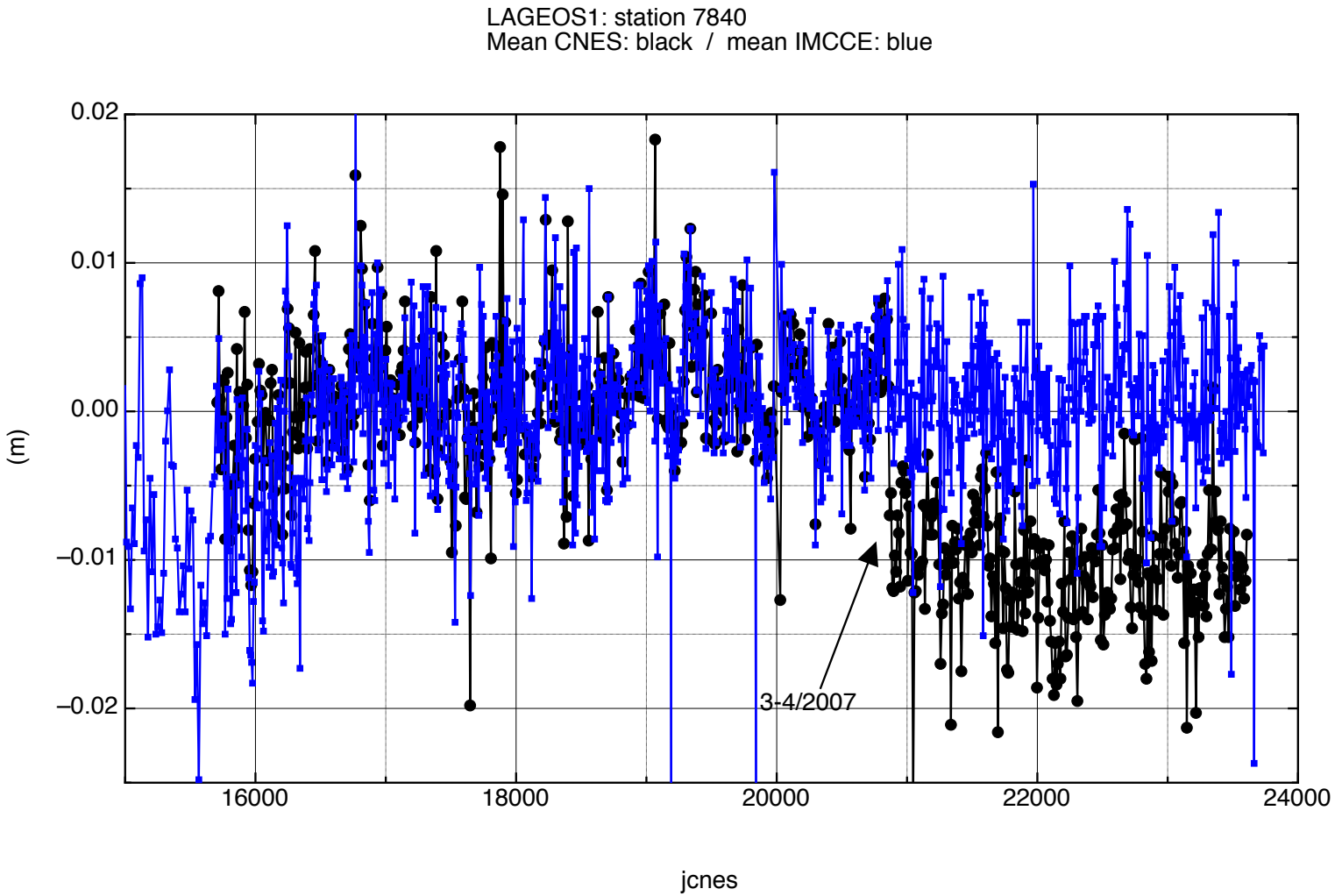
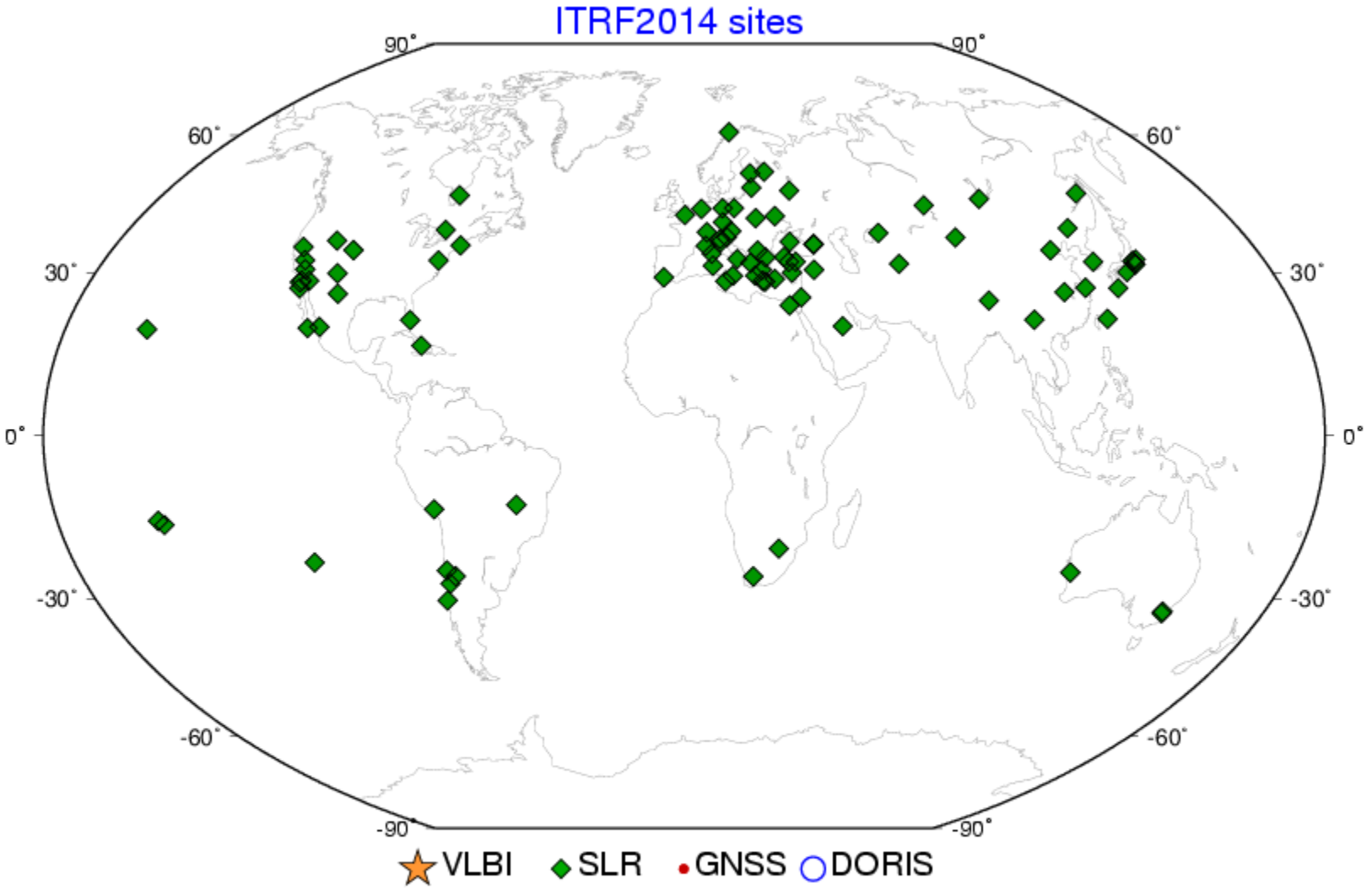


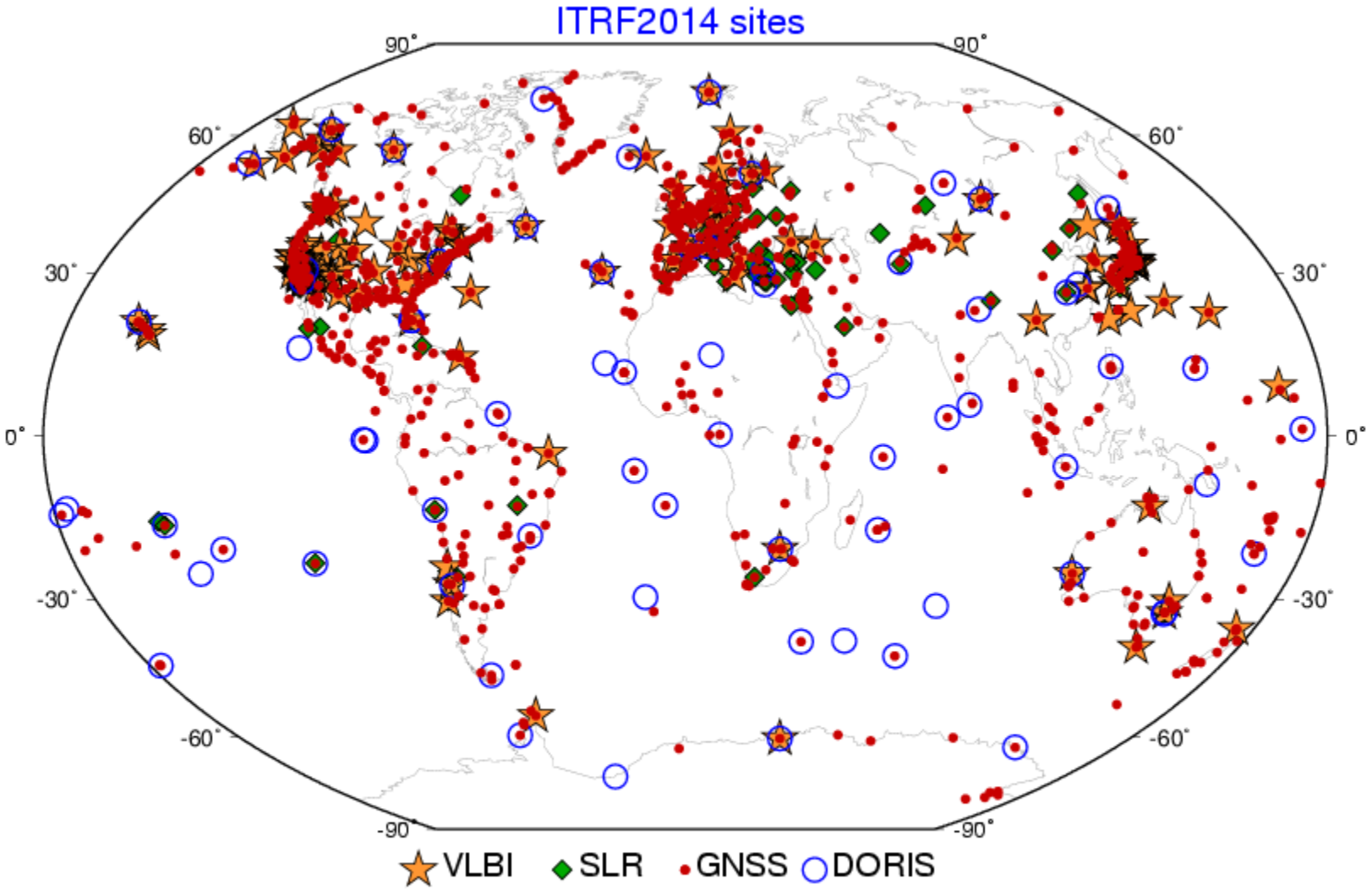
ITRF2014 status, data analysis and results

Zuheir Altamimi
Xavier Collilieux
Paul Rebischung
Laurent Métivier
IGN, France

ITRF2014 Network : SLR

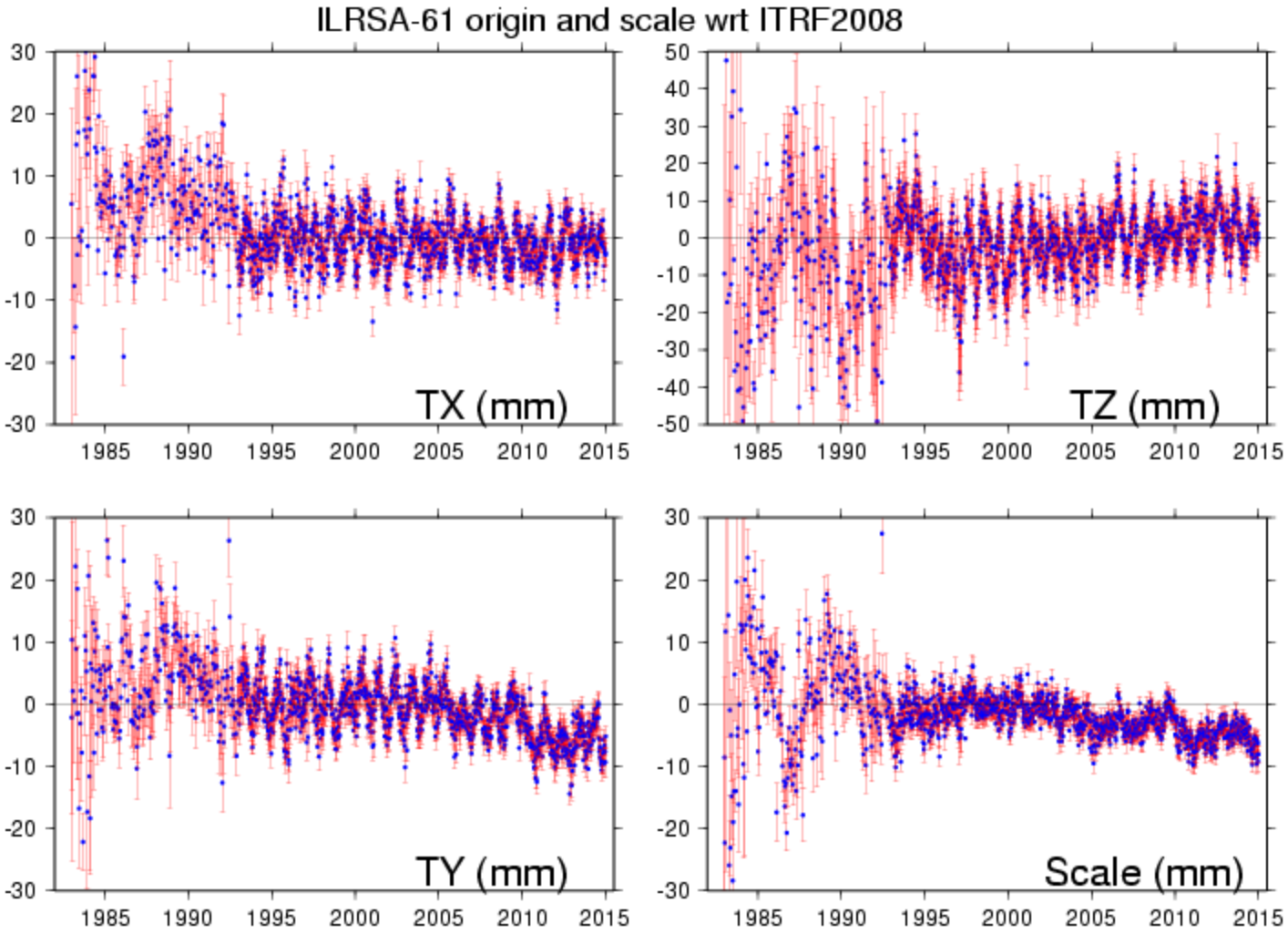


ITRF2014 Network



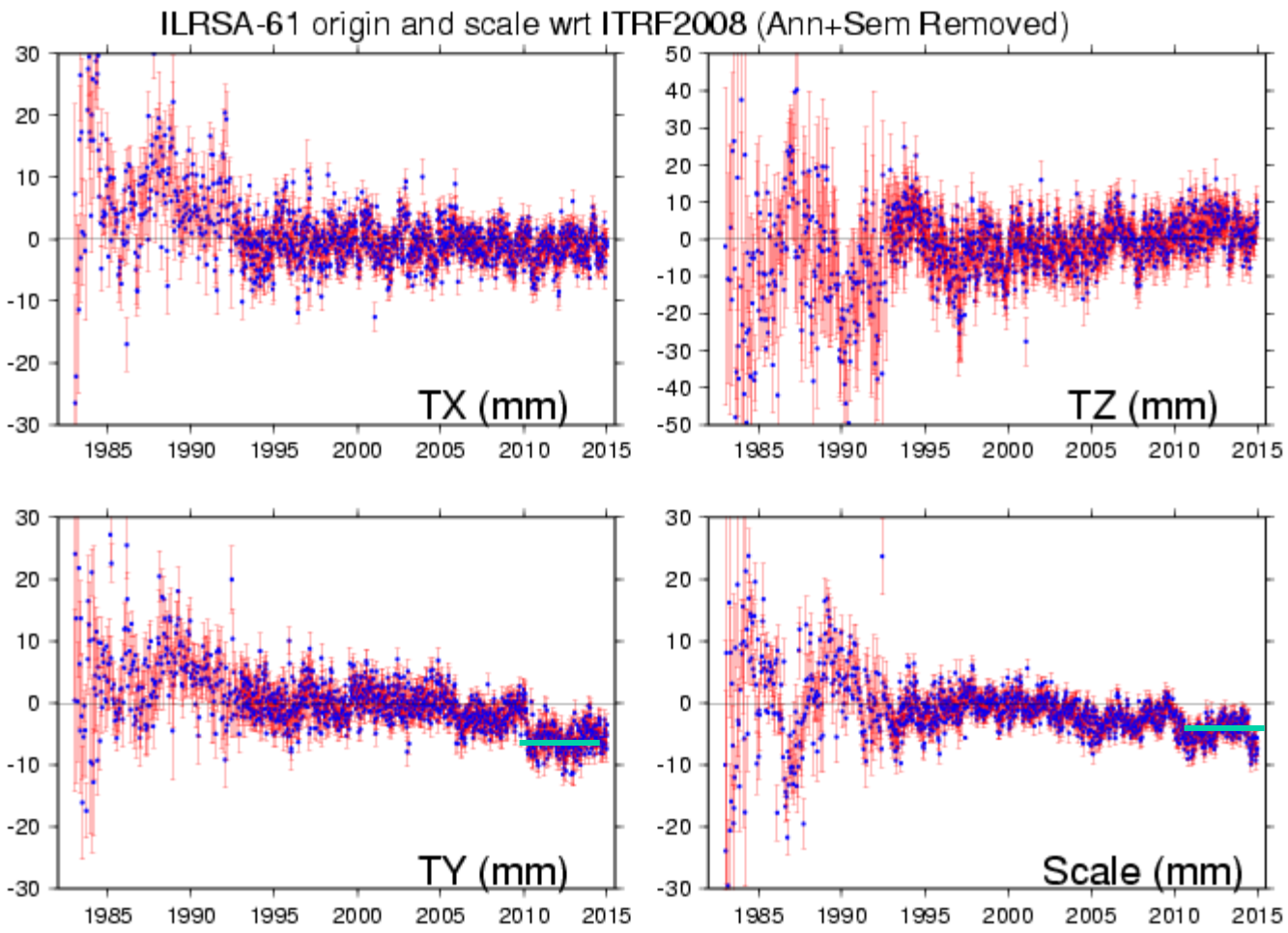
Origin & Scale stability with time ?

SLR/ILRS Origin & Scale WRT ITRF2008



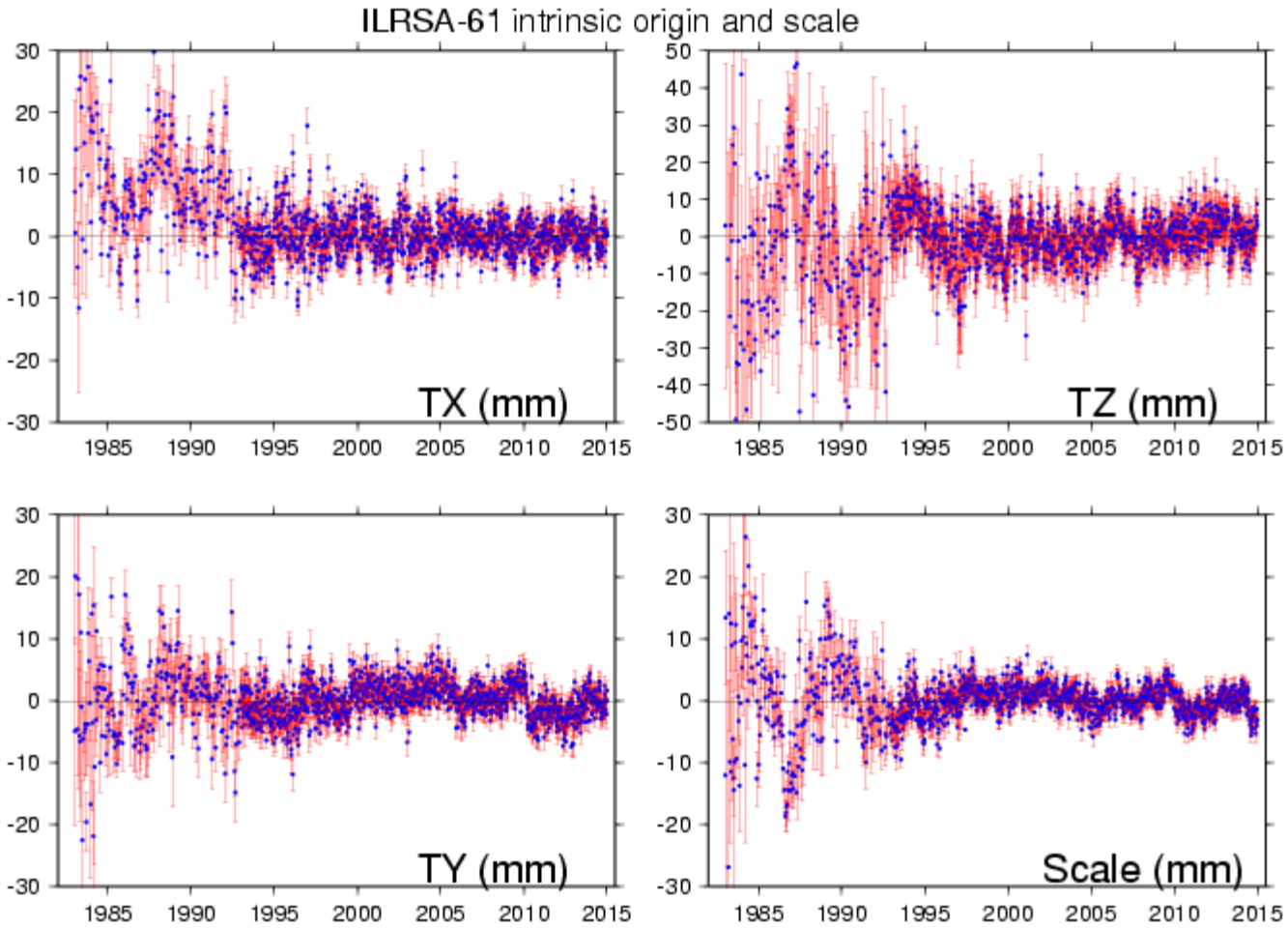
SLR/ILRS Origin & Scale WRT ITRF2008

Remove Annual + Semi-annual + Post-seismic deformation

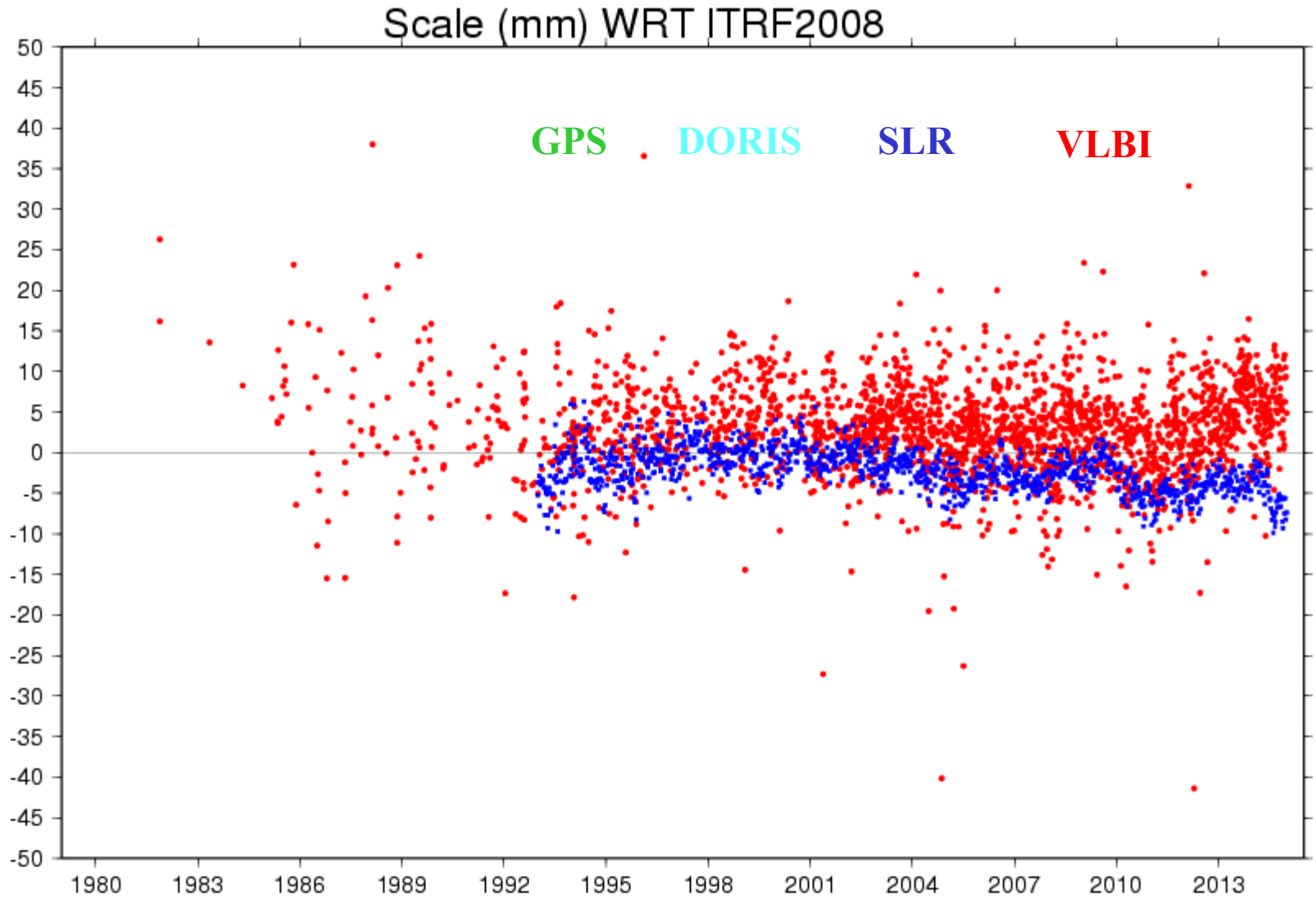


SLR/ILRS Intrinsic Origin & Scale

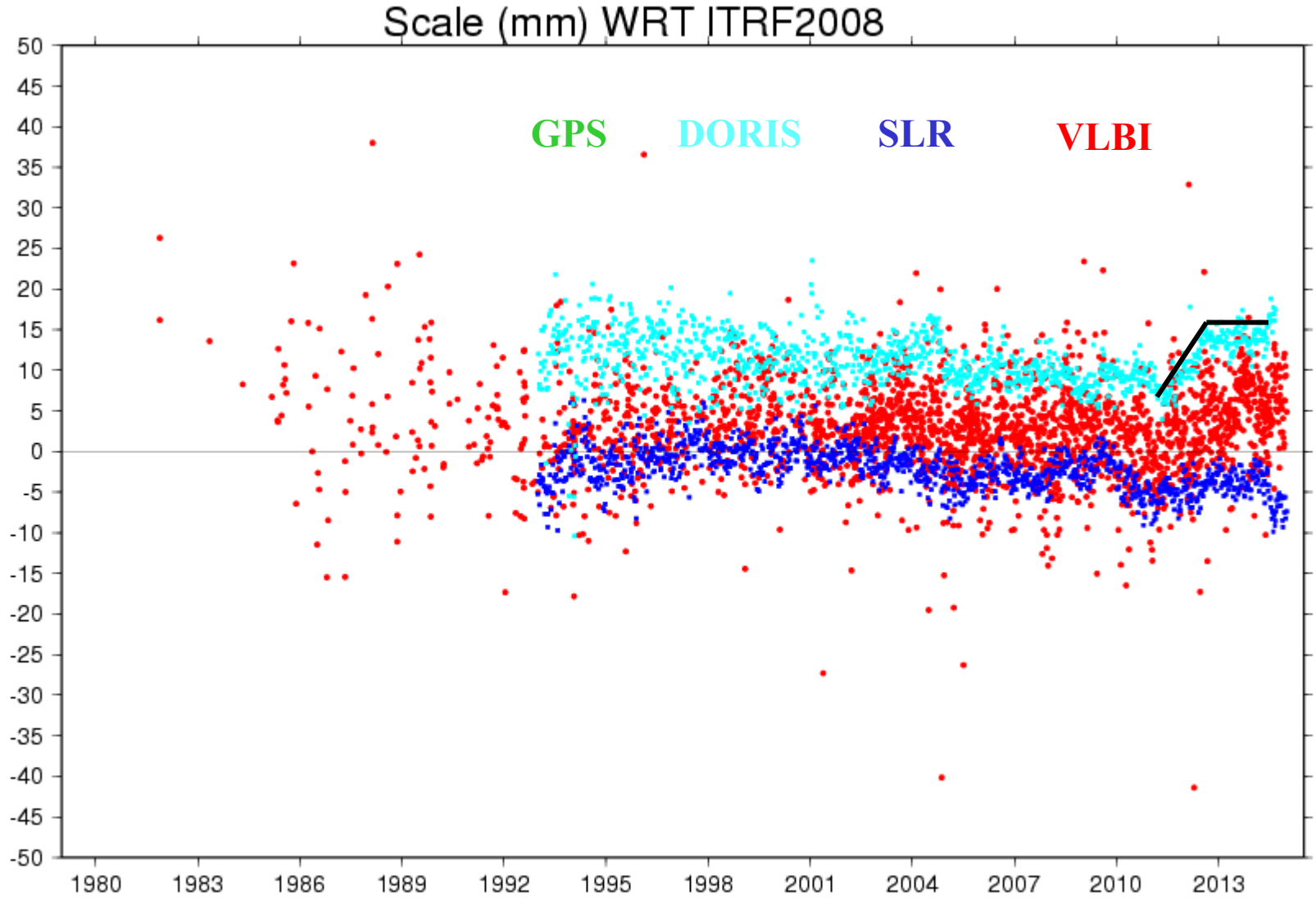
Remove Annual + Semi-annual + Post-seismic deformation



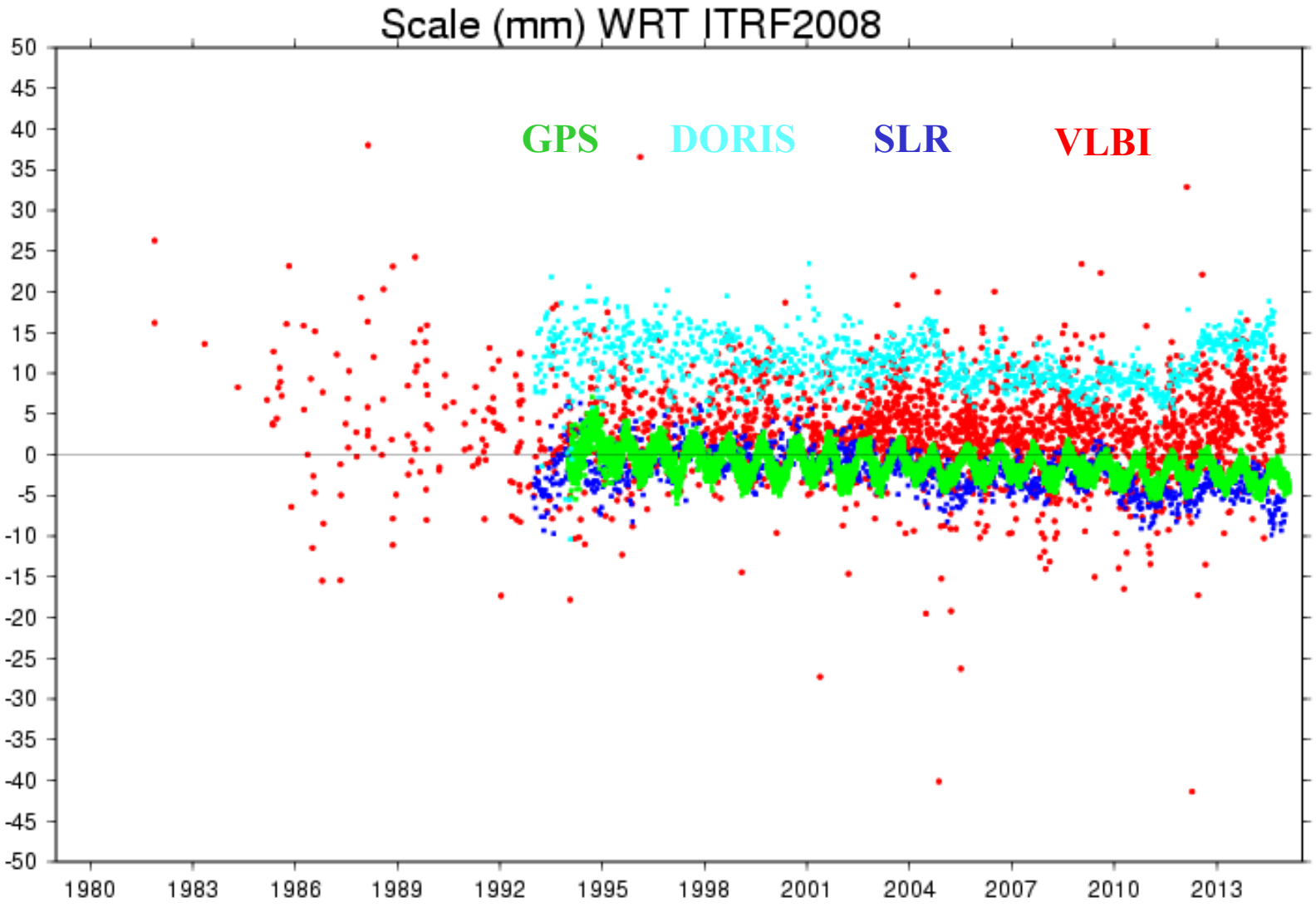
VLBI, SLR, DORIS & GPS Scales wrt ITRF2008



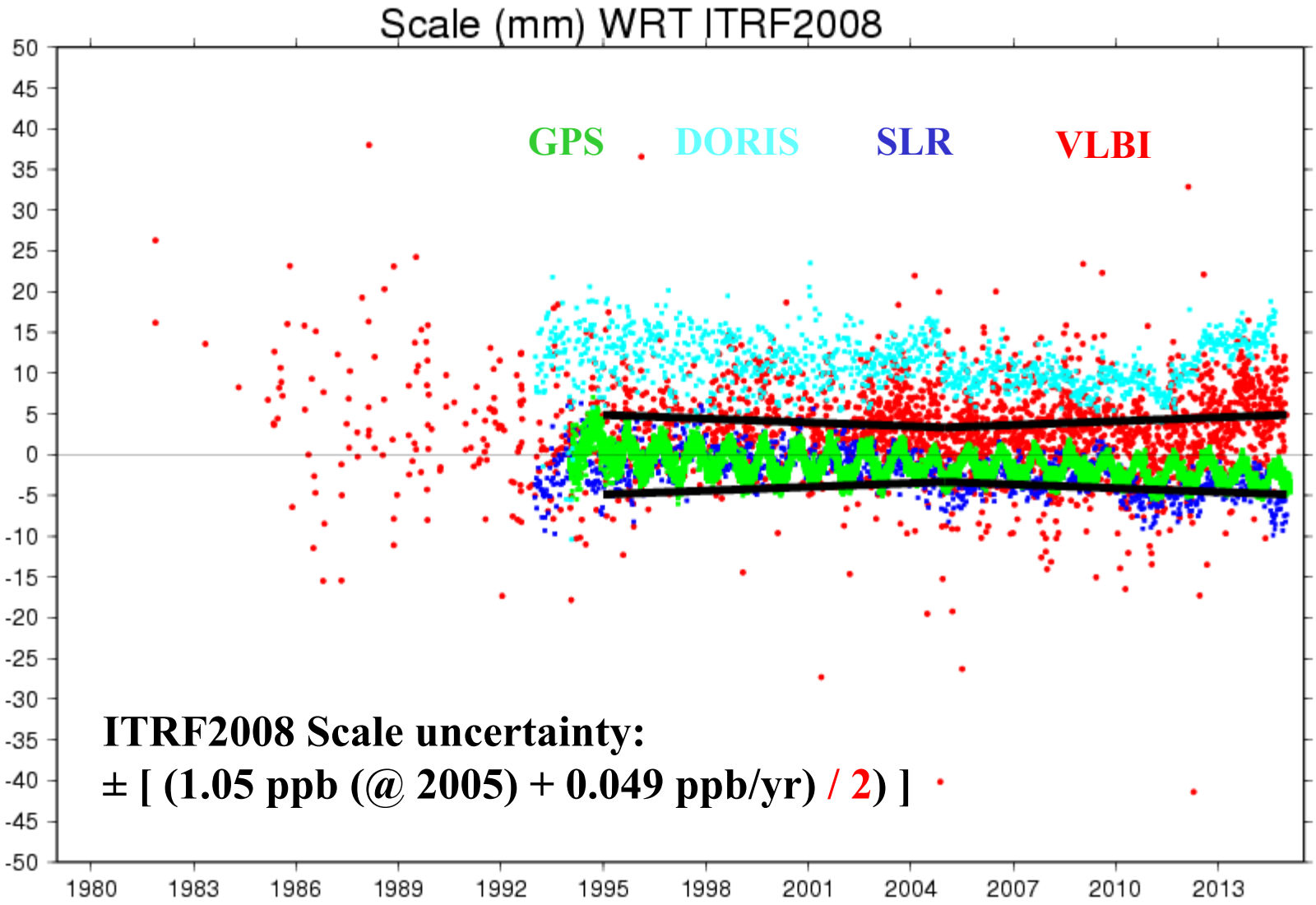
VLBI, SLR, DORIS & GPS Scales wrt ITRF2008



VLBI, SLR, DORIS & GPS Scales wrt ITRF2008



VLBI, SLR, DORIS & GPS Scales wrt ITRF2008

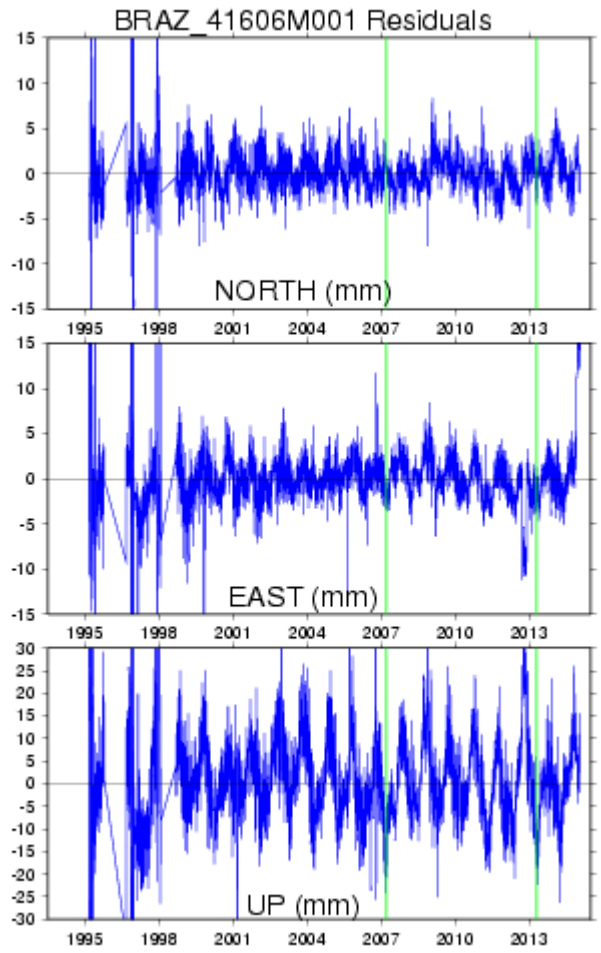


ITRF2008 Scale uncertainty:
± [(1.05 ppb (@ 2005) + 0.049 ppb/yr) / 2)]

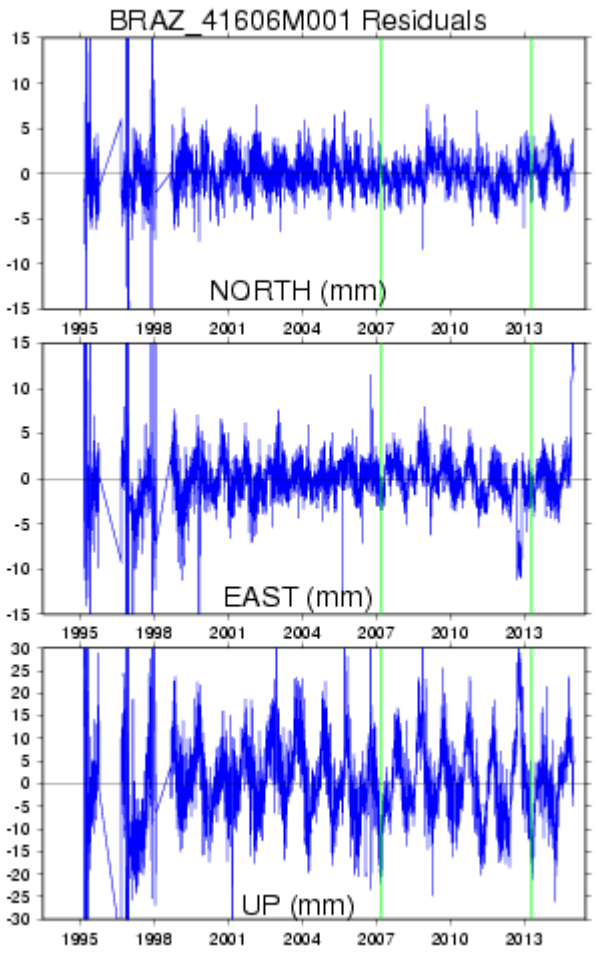
Estimating seasonal signals
vs
applying NATML model ?

Brasilia GNSS site

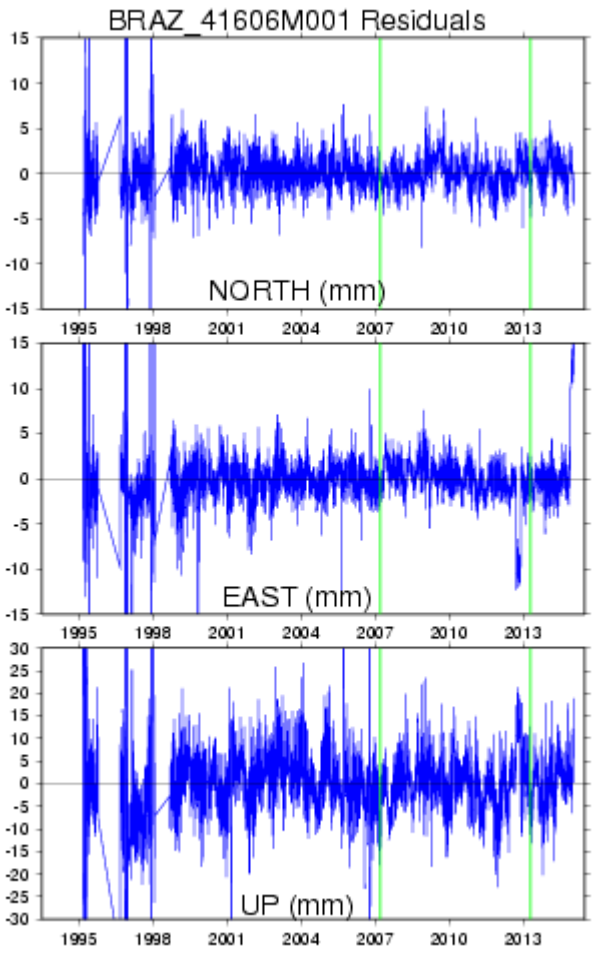
Standard residuals



ATML-corrected before stacking

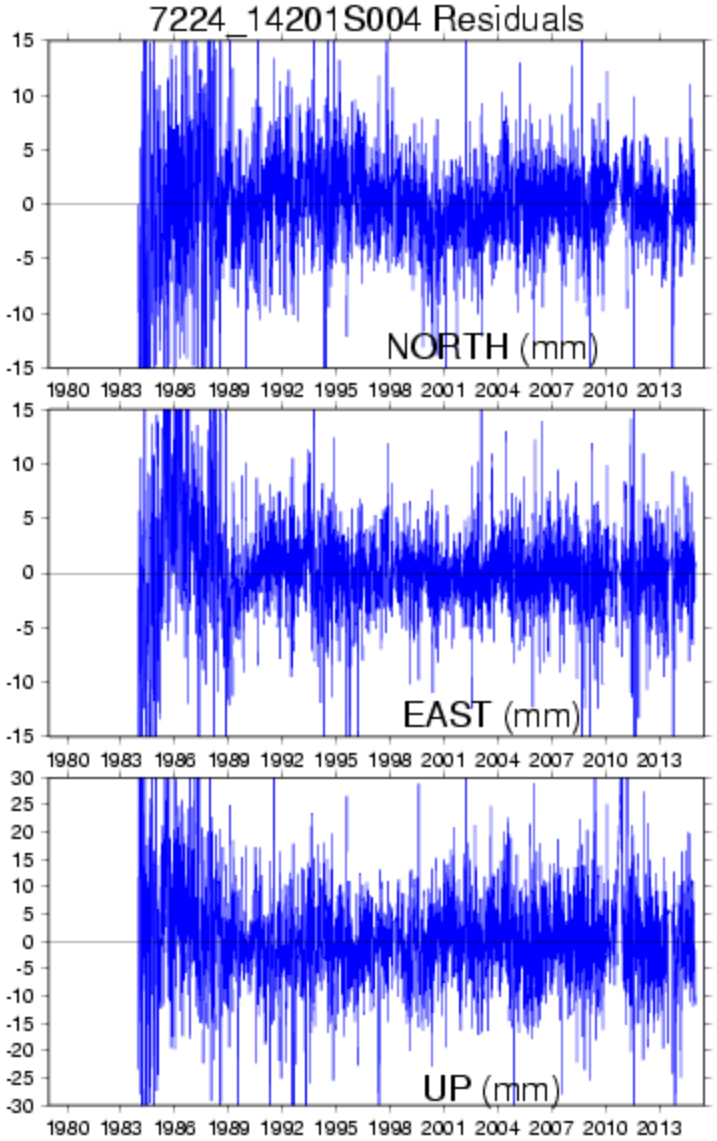


Annual & semi-annual estimated



Wettzell VLBI site

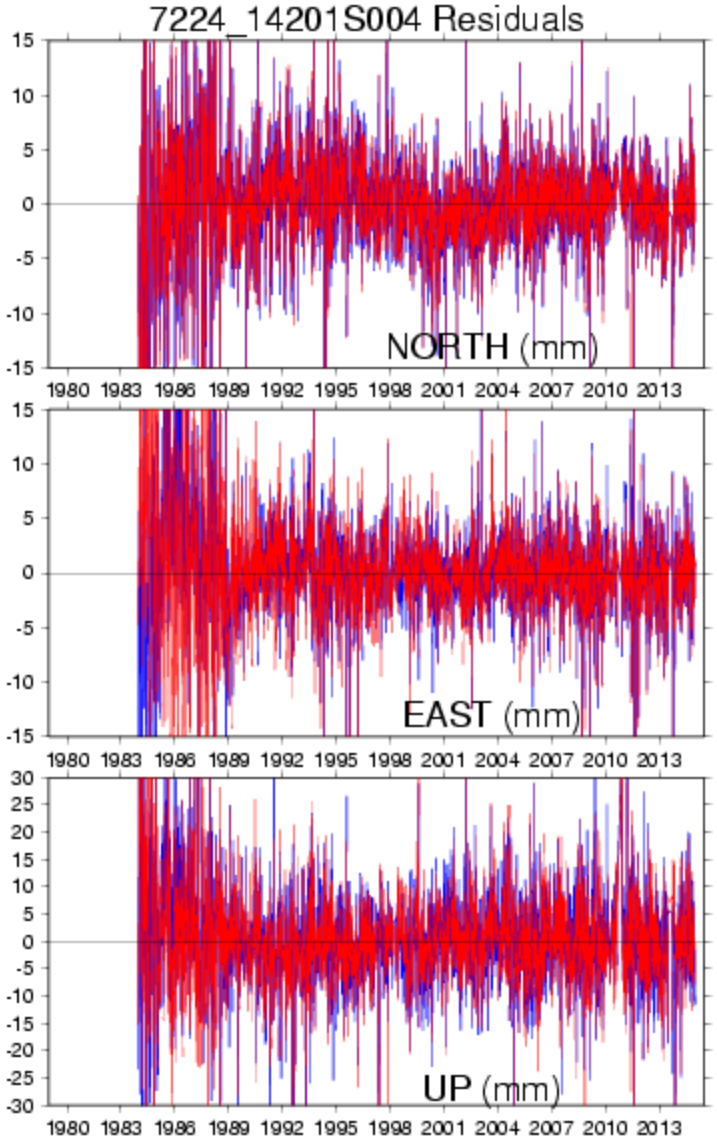
Scale NOT estimated



Standard residuals

Wettzell VLBI site

Scale NOT estimated

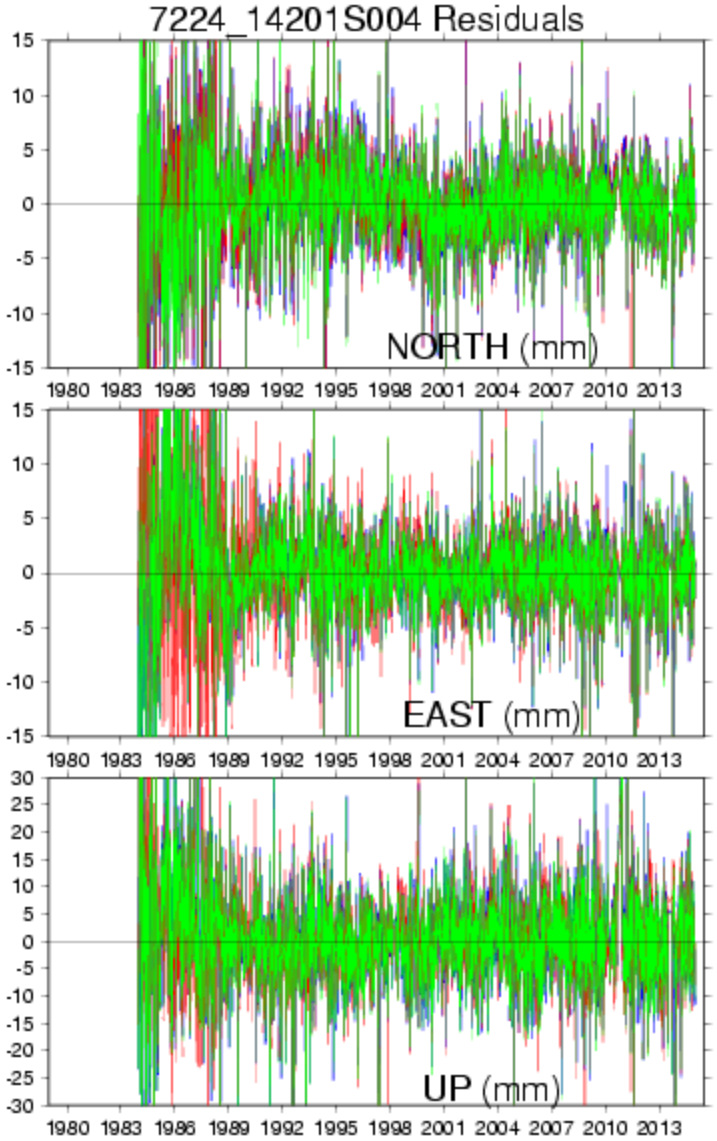


Standard residuals

ATML-Corrected before stacking

Wettzell VLBI site

Scale NOT estimated



Standard residuals

ATML-Corrected before stacking

Annual & semi-annual estimated

WRMS Averages

GNSS (co-location sites), daily

Solution	East	North	Up
STD	2.07	2.02	5.88
ATML/CF	2.02	1.97	5.29
F2	1.97	1.90	5.32
F6	1.92	1.85	5.21

VLBI, session-wise

Solution	East	North	Up
STD	4.20	4.34	8.98
ATML/CF	4.18	4.32	8.80
F2	4.17	4.28	8.81

SLR, weekly

Solution	East	North	Up
STD	9.10	10.97	8.28
ATML/CM	9.09	10.82	8.22
F2	8.98	10.55	8.08

DORIS, weekly

Solution	East	North	Up
STD	14.09	10.64	12.58
ATML/CM	14.08	10.64	12.61
ATML/CF	14.08	10.62	12.61
F2	13.94	10.35	12.23

STD: Standard solution
ATML: Atmospheric load model applied/CM(F): Center of Mass (Figure)
F2: Annual and semi-annual signals removed
F6: F2 + 4 draconitics

Conclusions

- **Work in progress: still a lot to do!**
- **When? hopefully by summer 2015**

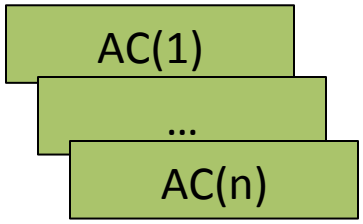
The JCET AC/CC Contribution to ITRF2014 and the ILRS-B Combination

April 16, 2015

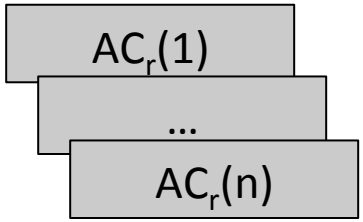
E. C. Pavlis, M. Kuzmicz-Cieslak and D. König,

Principle of ILRS-B Combinations

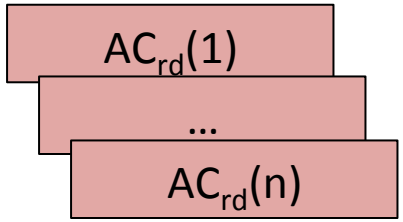
SINEX Submissions



Reducing Range Biases
Eliminating Bad Stations/EOP



Deconstraining The NEQs



Determining Core Stations For NNR-Constraints

Minimum-Constraints Solution (positions, EOP)

(1) for each AC separately by
- adding NNR-constraints

(2) as the ILRS-B combination by
- accumulating the NEQs
- adding NNR-constraints

Quality Assessment (c.f. SUM files)
- RMS of parameter corrections
- Helmert transformation w.r.t SLRF2008
- Trend Analysis of EOP

Input SINEX Files

Number of SINEX Files Available

st_determine_number_of_SINEX_submissions.ksh

AC	<yy> 83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	sum
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bkg	0	0	0	0	0	0	0	0	0	0	52	53	52	52	52	52	52	52	52	52	52	52	53	52	52	52	52	52	52	52	47	0	1	1141
dgfi	23	25	24	24	25	24	24	25	24	24	52	53	52	52	52	52	52	53	52	52	52	52	53	52	52	52	52	52	53	52	52	52	0	1390
esa	24	25	24	24	25	24	24	25	24	24	52	53	52	52	52	52	52	53	52	52	52	52	53	52	52	52	52	52	53	52	52	52	1	1392
gfz	23	25	24	24	25	24	24	25	24	24	52	53	52	52	52	52	52	53	52	52	52	52	53	52	52	52	52	52	53	52	52	52	1	1391
grgs	24	25	24	24	25	24	24	25	24	24	52	53	52	52	51	50	49	50	52	52	52	52	53	52	52	52	50	52	53	52	51	52	1	1380
jcet	24	25	24	24	25	24	24	25	24	24	52	53	52	52	52	52	52	53	52	52	52	52	53	52	52	52	52	52	53	52	52	52	1	1392
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Number of SINEX Files Actually Used

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sum																																		10660

Number of Files Created

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SNX	24	25	24	24	25	24	24	25	24	24	52	53	52	52	52	52	52	53	52	52	52	52	53	52	52	52	52	52	53	52	52	52	01	1392
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Input SINEX File Issues - 1

	Issues Encountered With SINEX Files
	Description
	---
(0)	corrupted files
(1)	format violation in header line
(2)	empty SITE/ID
(3)	biases reported in BIAS/EPOCHS do not appear in SOLUTION/ESTIMATE
(4)	epochs stated in SOLUTION/EPOCHS do not match the actual time spans of the data used
(5)	wrong reference epochs in SOLUTION/ESTIMATE (supposed to be 48200s)
(6)	missing footer line '%ENDSNX'
(7)	wrong <yymmdd> in SINEX file name
	Example files
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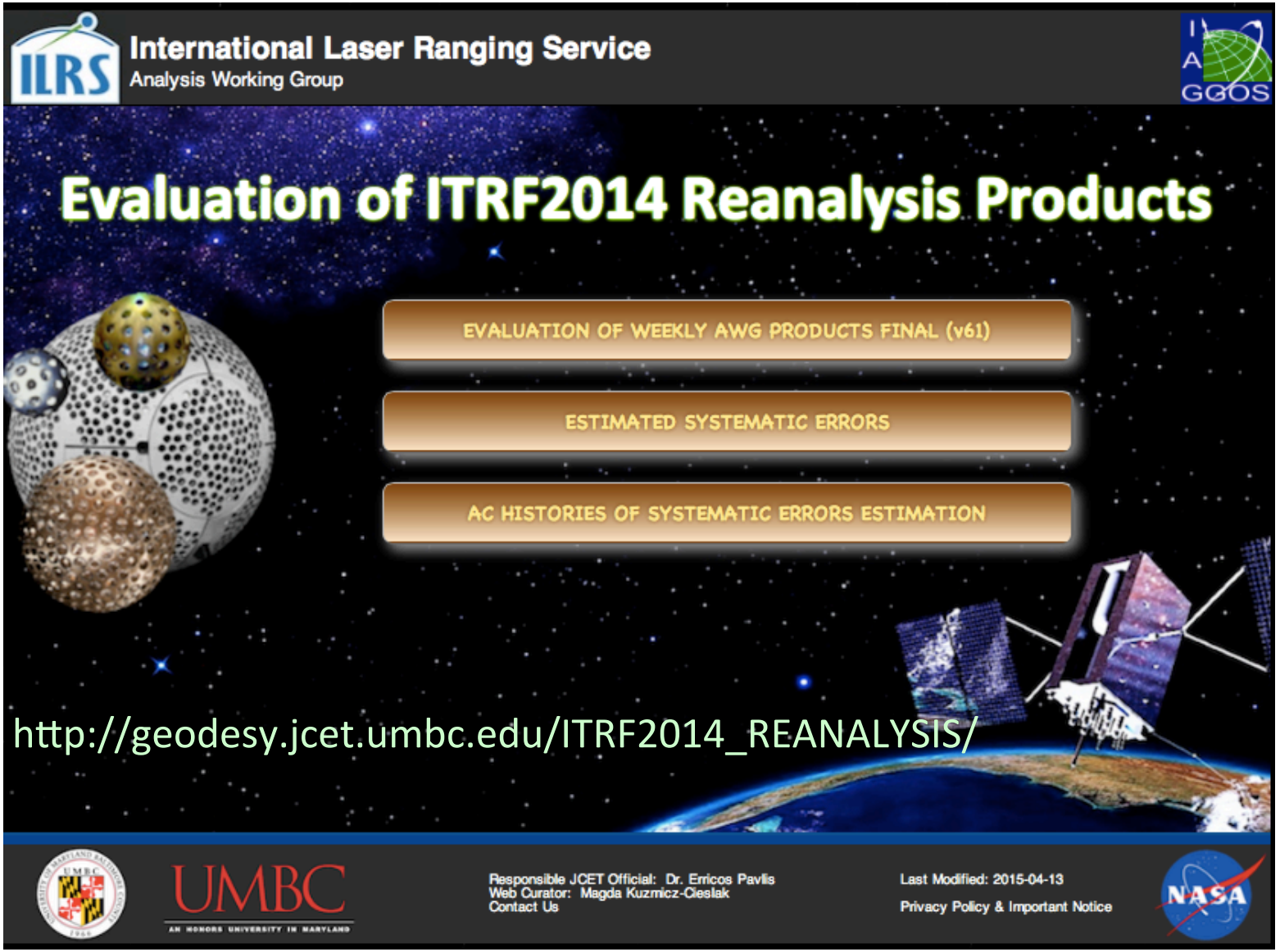
(0)	in /nobackup/dkonig/ilrsb_reproc/v60_snxs/NSGF_v60:
	* nsgf.pos+eop.021012.v62.snx:
	+SOLUTION/ESTIMATE
	...
	30 STAZ 7838 A 1 02:282:43200 m 2 0.35075730736744E+07 0.18400E+00
	0 ^@^@^@^@^@^@ ^@^@^@^@ ^@^@ ^@^@^@^@ 00:000:00000 ^@^@^@^@ ^@ 0.00000000000000E+00 0.00000E+00
	0 ^@^@^@^@^@^@ ^@^@^@^@ ^@^@ ^@^@^@^@ 00:000:00000 ^@^@^@^@ ^@ 0.00000000000000E+00 0.00000E+00
	0 ^@^@^@^@^@^@ ^@^@^@^@ ^@^@ ^@^@^@^@ 00:000:00000 ^@^@^@^@ ^@ 0.00000000000000E+00 0.00000E+00
	34 STAX 7840 A 1 02:282:43200 m 2 0.40334635276075E+07 0.16397E+00
(1)	in /nobackup/dkonig/ilrsb_reproc/v60_snxs/CORRUPTED_v62:
	* nsgf.pos+eop.040111.v60.snx
	%=SNX 2.00 ner **:553:00000 ner 04:005:07867 04:011:79822 L 00067 2 S E
(2)	NSGF!

Input SINEX File Issues - 2

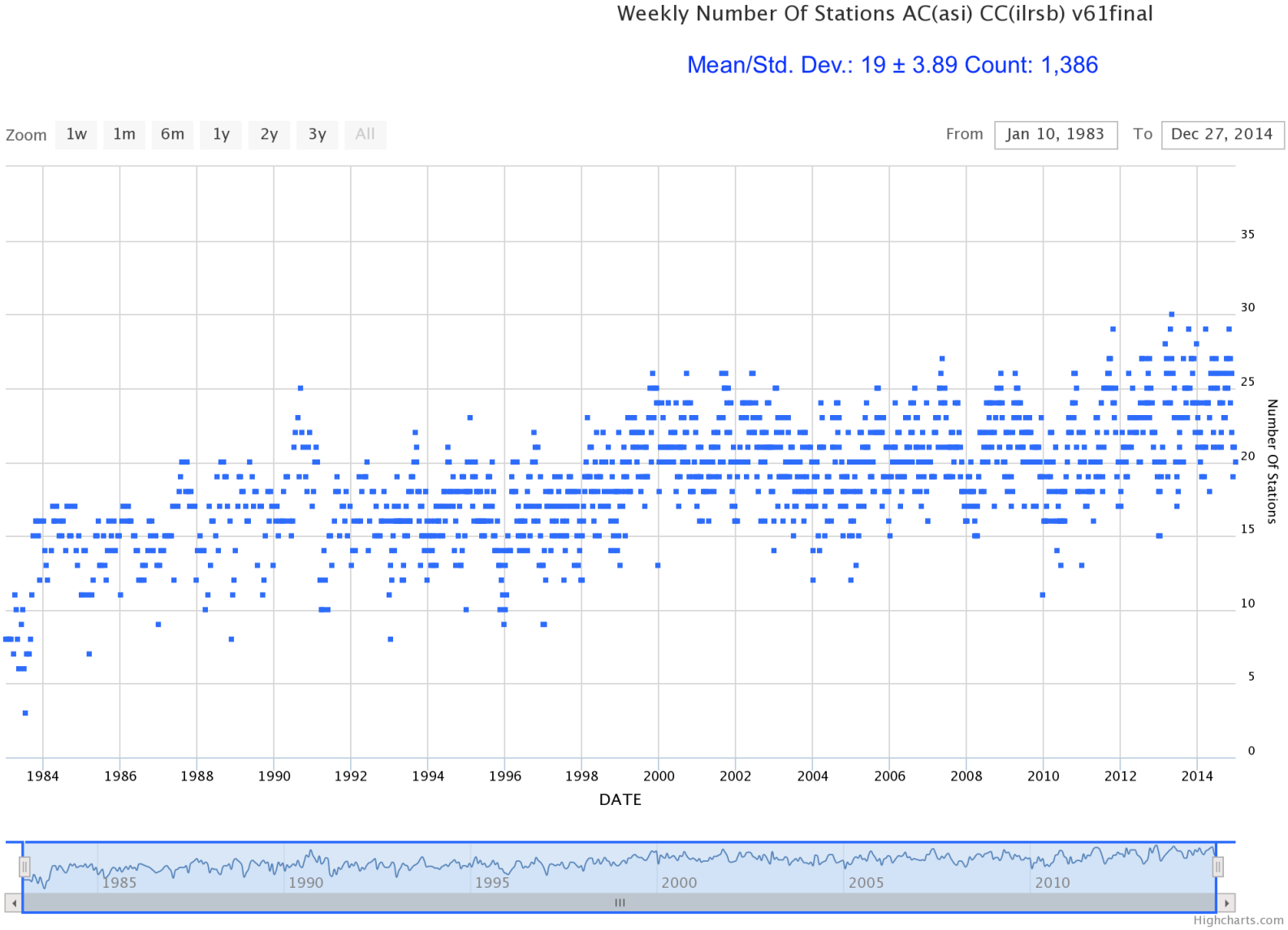
```
|  (3) | in /nobackupp8/dkonig/ilrsb_reproc/v60_snxs/DGFI_v60:                                                  |
|      | * dgfi.pos+eop.061216.v60.snx:                                                                           |
|      |                                                                                                          |
|      |   +BIAS/EPOCHS                                                                                           |
|      |   *CODE PT SOLN T _DATA_START_ __DATA_END__ _MEAN_EPOCH_                                                  |
|      |    1864 LC    1 L 06:344:24358 06:347:35776 06:346:73267                                                  |
|      | >  7249 LC    1 L 06:349:24651 06:350:31845 06:350:71448   ?                                              |
|      |    7308 LC    1 L 06:347:51788 06:349:54046 06:348:52917                                                  |
|      |    7810 LC    1 L 06:344:81544 06:350:80330 06:347:80937                                                  |
|      | >  7840 LC    1 L 06:344:55253 06:350:43136 06:347:05994   ?                                              |
|      |   -BIAS/EPOCHS                                                                                           |
|      |                                                                                                          |
|      |   +SOLUTION/ESTIMATE                                                                                     |
|      |   *INDEX TYPE__ CODE PT SOLN _REF_EPOCH__ UNIT S __ESTIMATED VALUE____ _STD_DEV___                        |
|      |        1 RBIAS  1864 L1    1 06:347:43200 m    0 -.222396937401592E-01 .583099E-02                        |
|      |        2 RBIAS  1864 L2    1 06:347:43200 m    0 0.559928233336292E-02 .738345E-02                        |
|      |        3 RBIAS  7810 L1    1 06:347:43200 m    0 -.103850066642450E-02 .740812E-03                        |
|      |        4 RBIAS  7810 L2    1 06:347:43200 m    0 -.279392257760790E-02 .796702E-03                        |
|      |        5 RBIAS  7308 L1    1 06:347:43200 m    0 -.919118002757085E-04 .957406E-02                        |
|      |        6 STAX   7839  A    1 06:347:43200 m    0 0.419442666500007E+07 .644647E-01                        |
|      |                                                                                                          |
|  (4) | in /nobackupp8/dkonig/ilrsb_reproc/v60_snxs:                                                            |
|      | * esa.pos+eop.070407.v62.snx:                                                                            |
|      |                                                                                                          |
|      |   %=SNX 2.02 ESA 15:012:76546 ESA 07:091:00000 07:098:00000 L 00081 2 S E                                 |
|      |   +SOLUTION/EPOCHS                                                                                       |
|      |   *SITE PT SOLN T START_TIME__ END_TIME____ MEAN_TIME___                                                  |
|      |    1893  A    1 L 07:091:00000 07:098:00000 07:094:43200                                                  |
|      |                                                                                                          |
|  (5) | in /nobackup/dkonig/ilrsb_reproc/v60_snxs/GFZ_v60:                                                      |
|      | * gfz.pos+eop.090103.v60.snx:      22 STAX   7839  A    1 08:366:47519 m    2 +4.19442576616770e+06 8.11884e-02 |
|      | * gfz.pos+eop.971122.v60.snx:      49 RBIAS  7308 L2    1 97:322:43150 m    2 +3.64458908575920e-02 8.99997e-03 |
|      |                                                                                                          |
|  (6) | GRGS!                                                                                                    |
|      |                                                                                                          |
|  (7) | /nobackup/dkonig/ilrsb_reproc/v60_snxs/WRONG_DATES_v62:                                                 |
|      | * gfz.pos+eop.960105.v62.snx  instead of  gfz.pos+eop.960106.v62.snx                                     |
|      |             ^^^^^^                                  ^^^^^^                                               |
|      |                                                                                                          |
  -------------------------------------------------------------------------------------------------------------
```

http://geodesy.jcet.umbc.edu/ITRF2014_REANALYSIS/

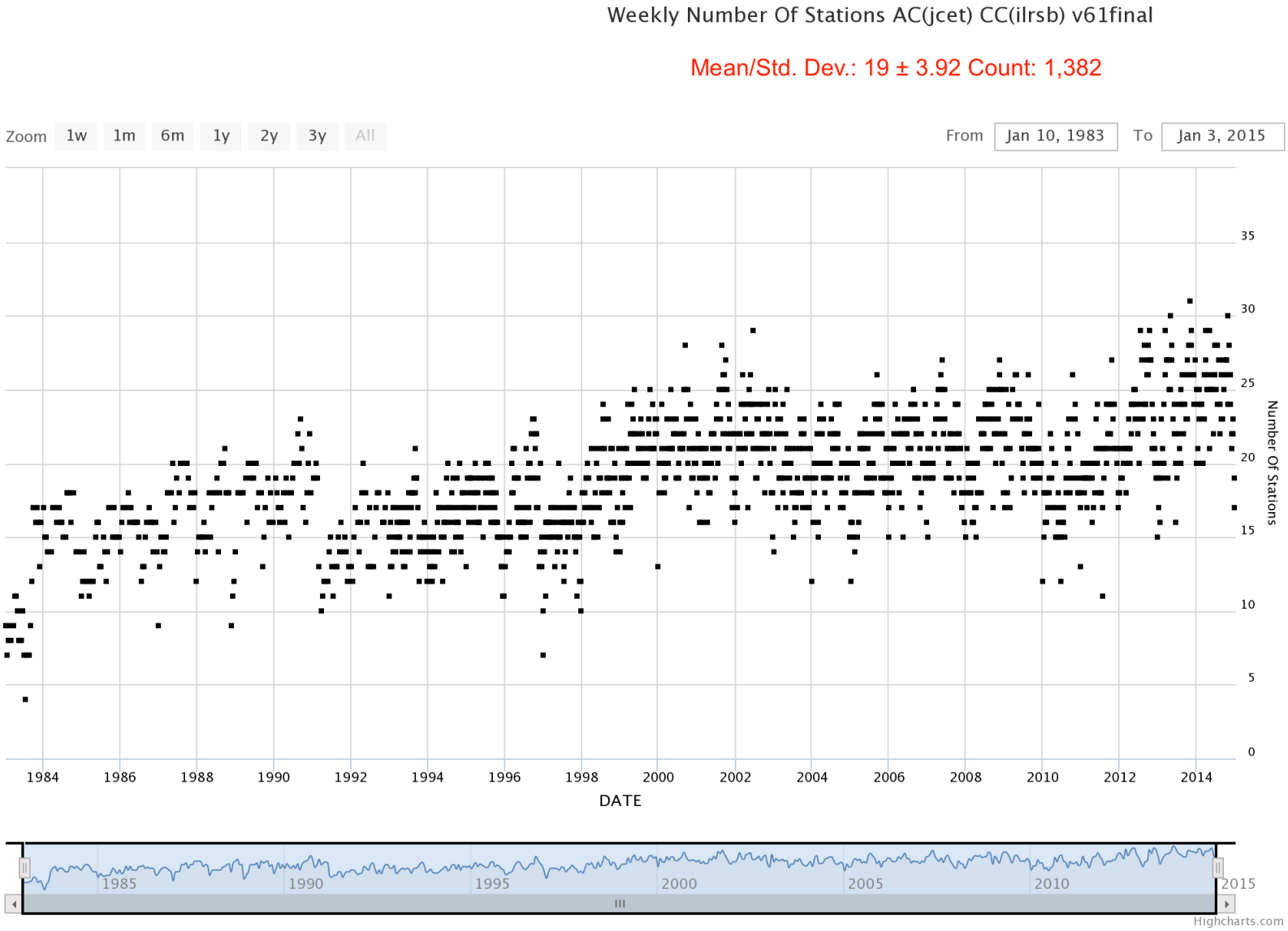
ILRS-A & B "FINAL v61" Visualization Site



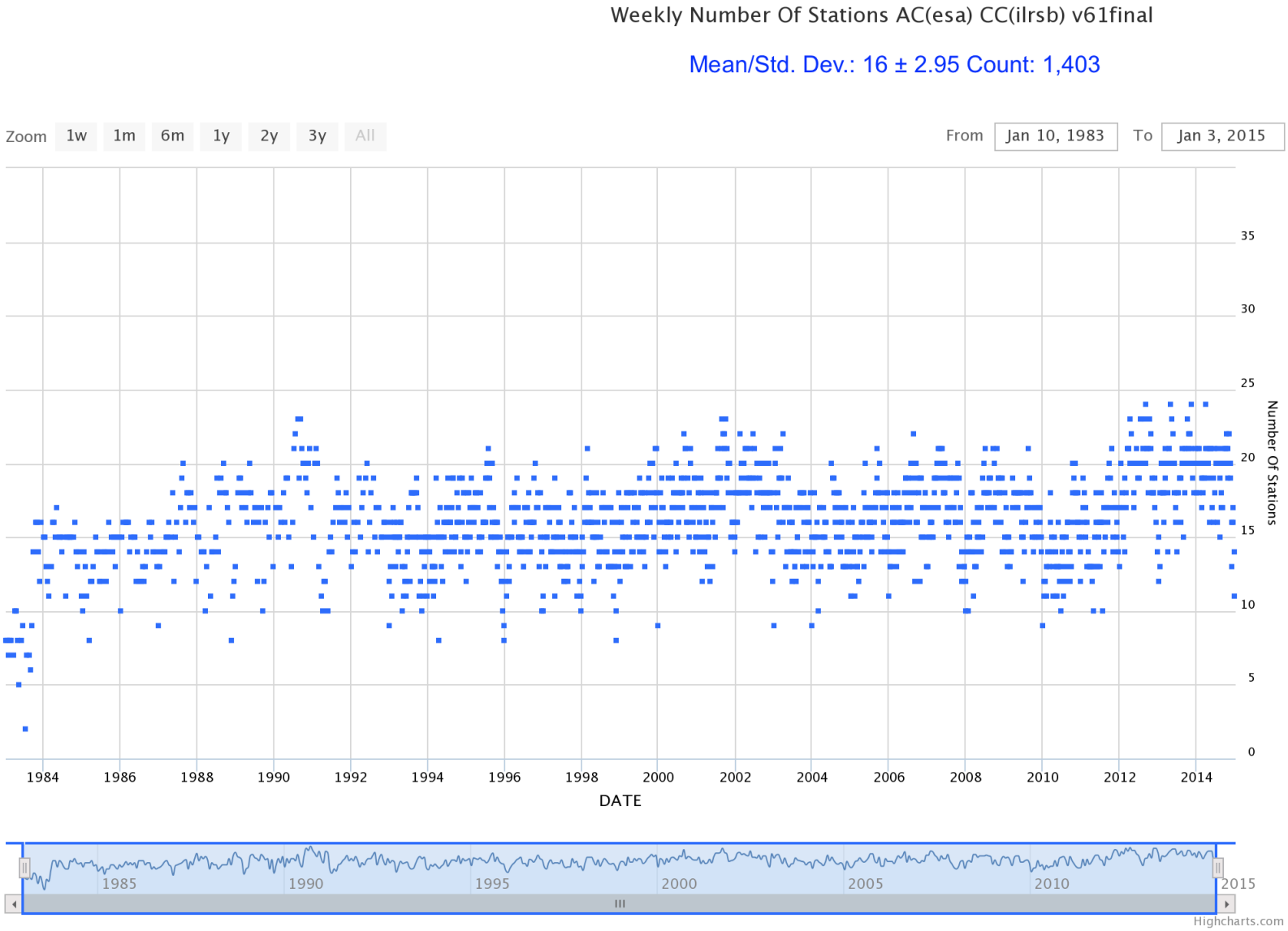
Number of Stations Used Weekly by ASI



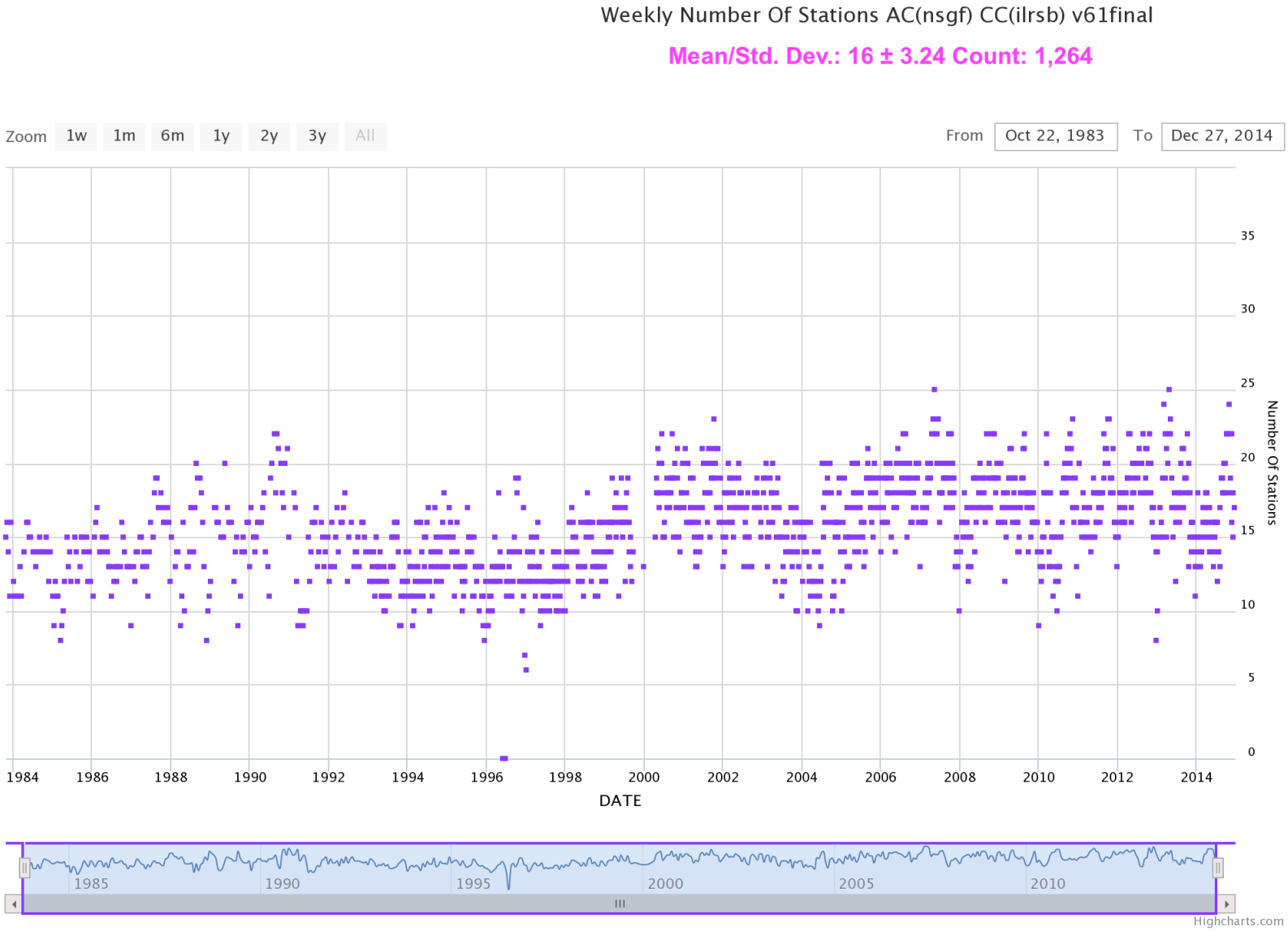
Number of Stations Used Weekly by JCET



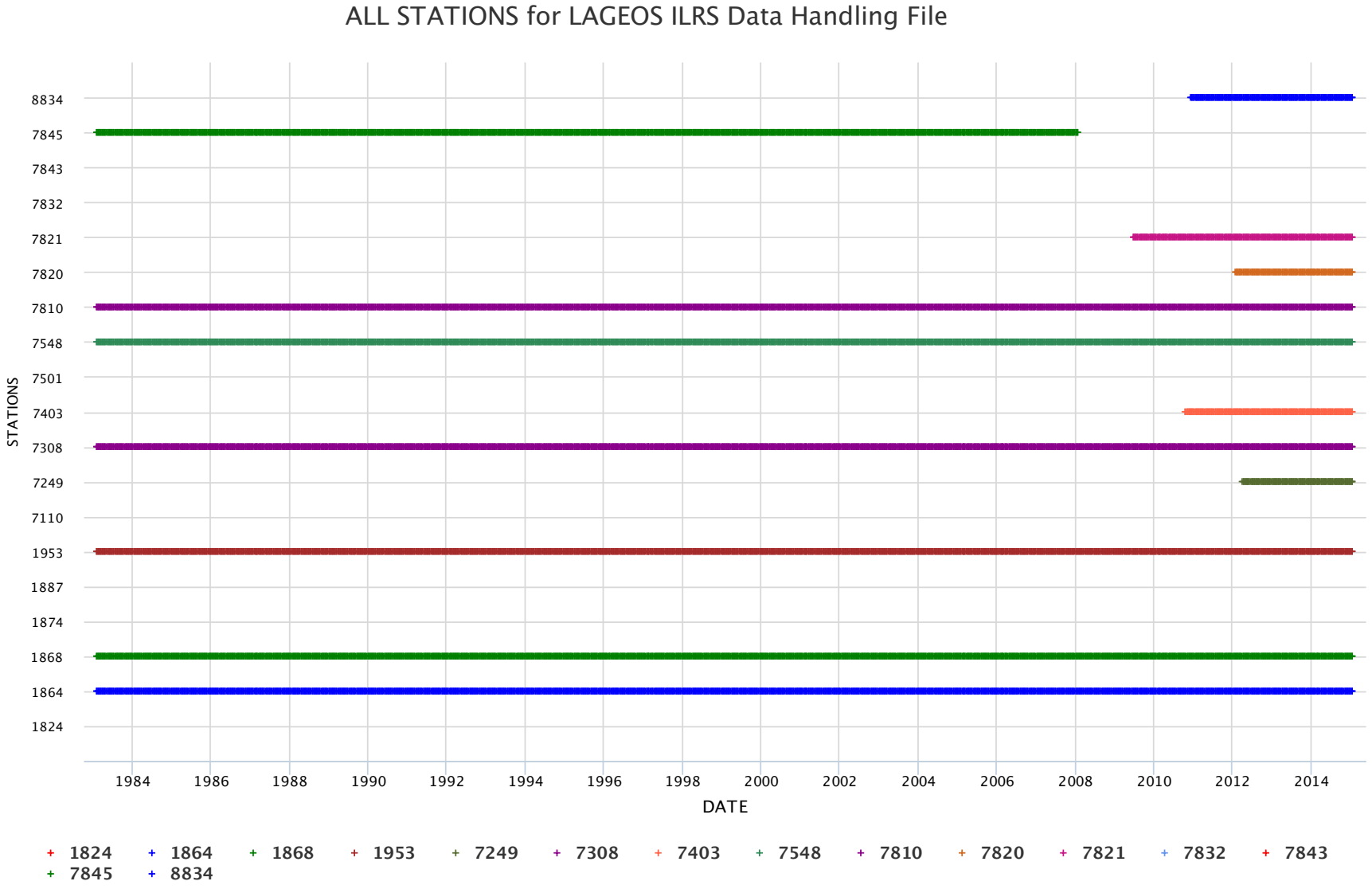
Number of Stations Used Weekly by ESA



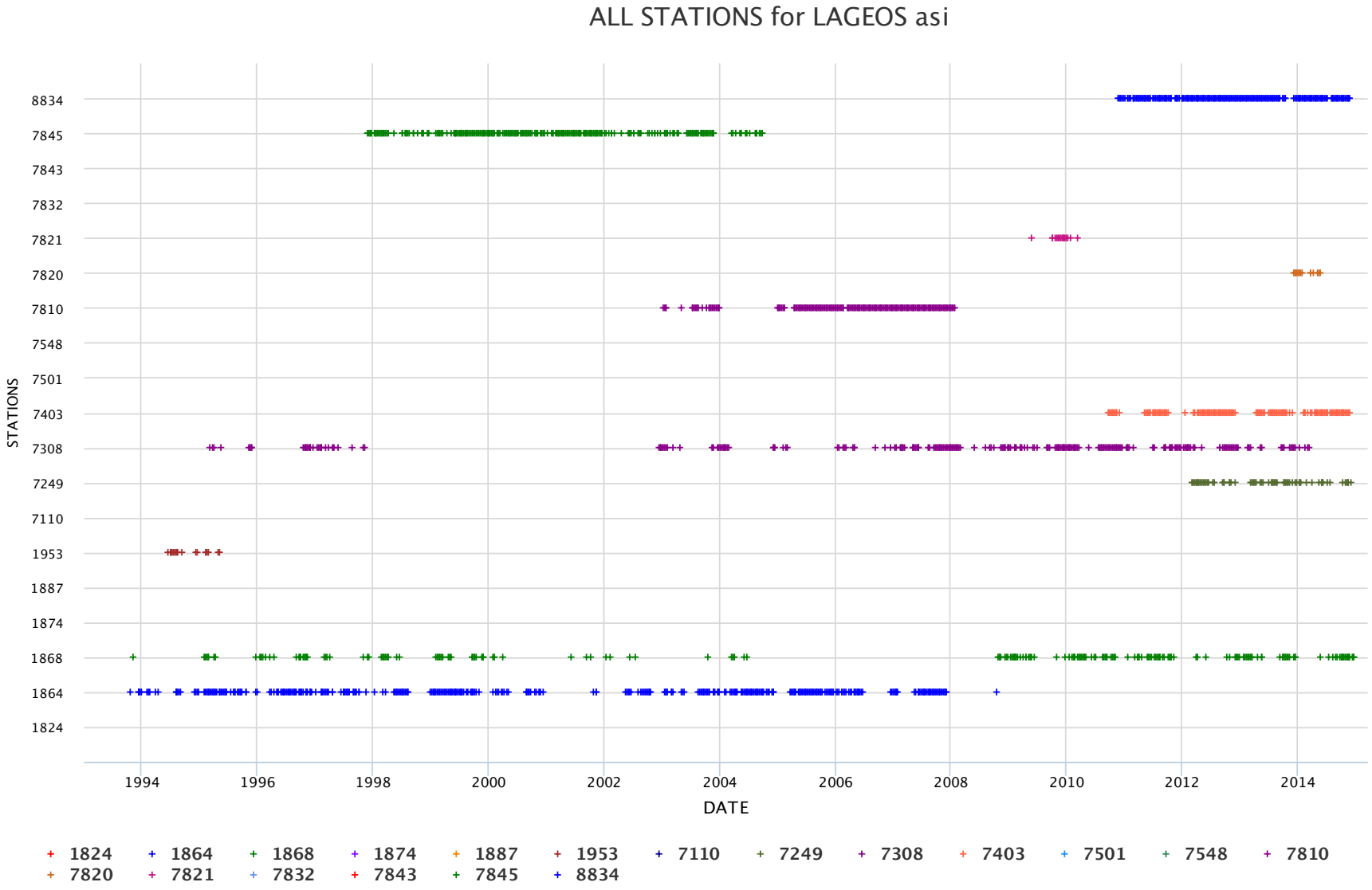
Number of Stations Used Weekly by NSGF



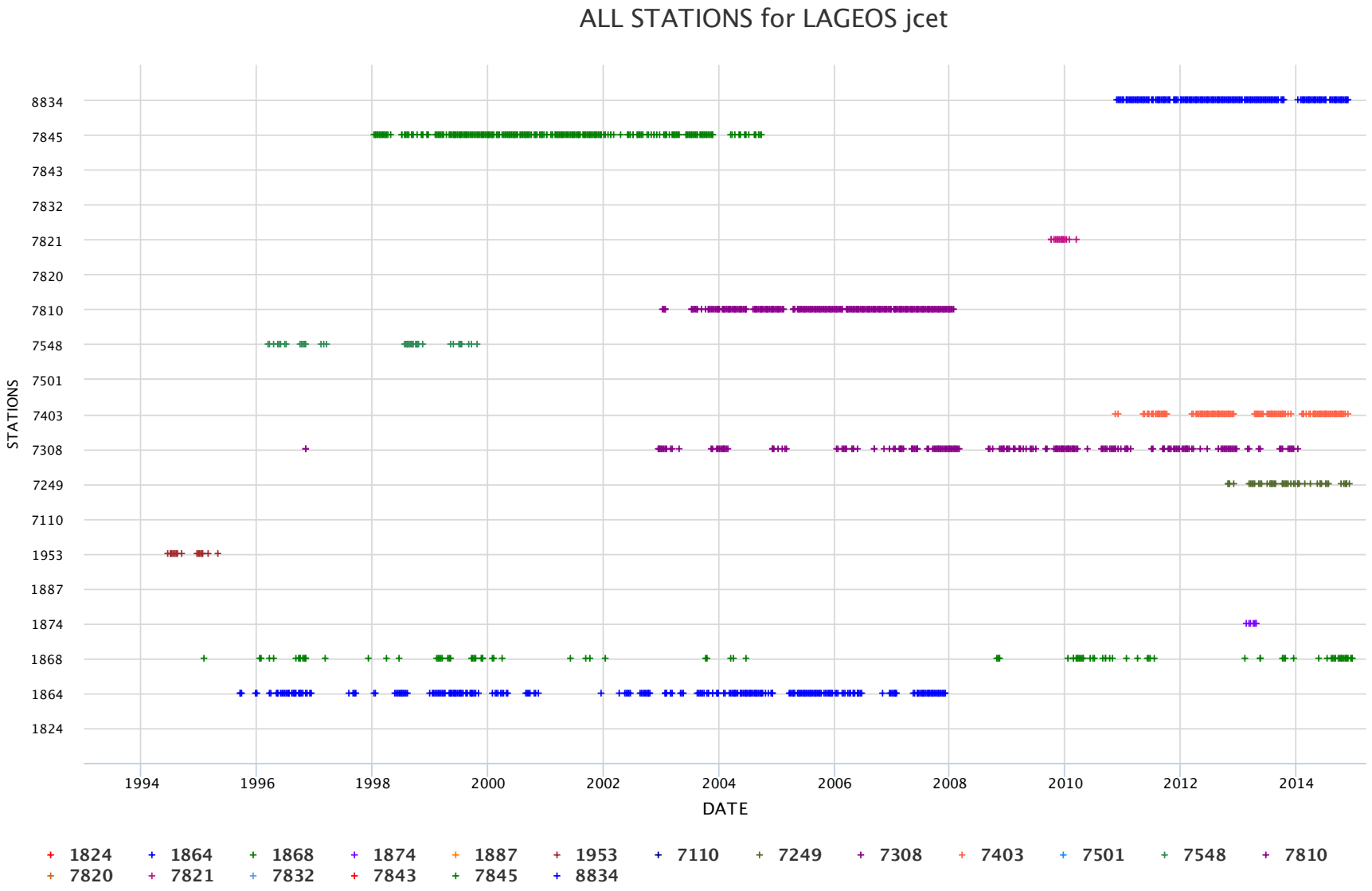
Systematic Error Model from DH File



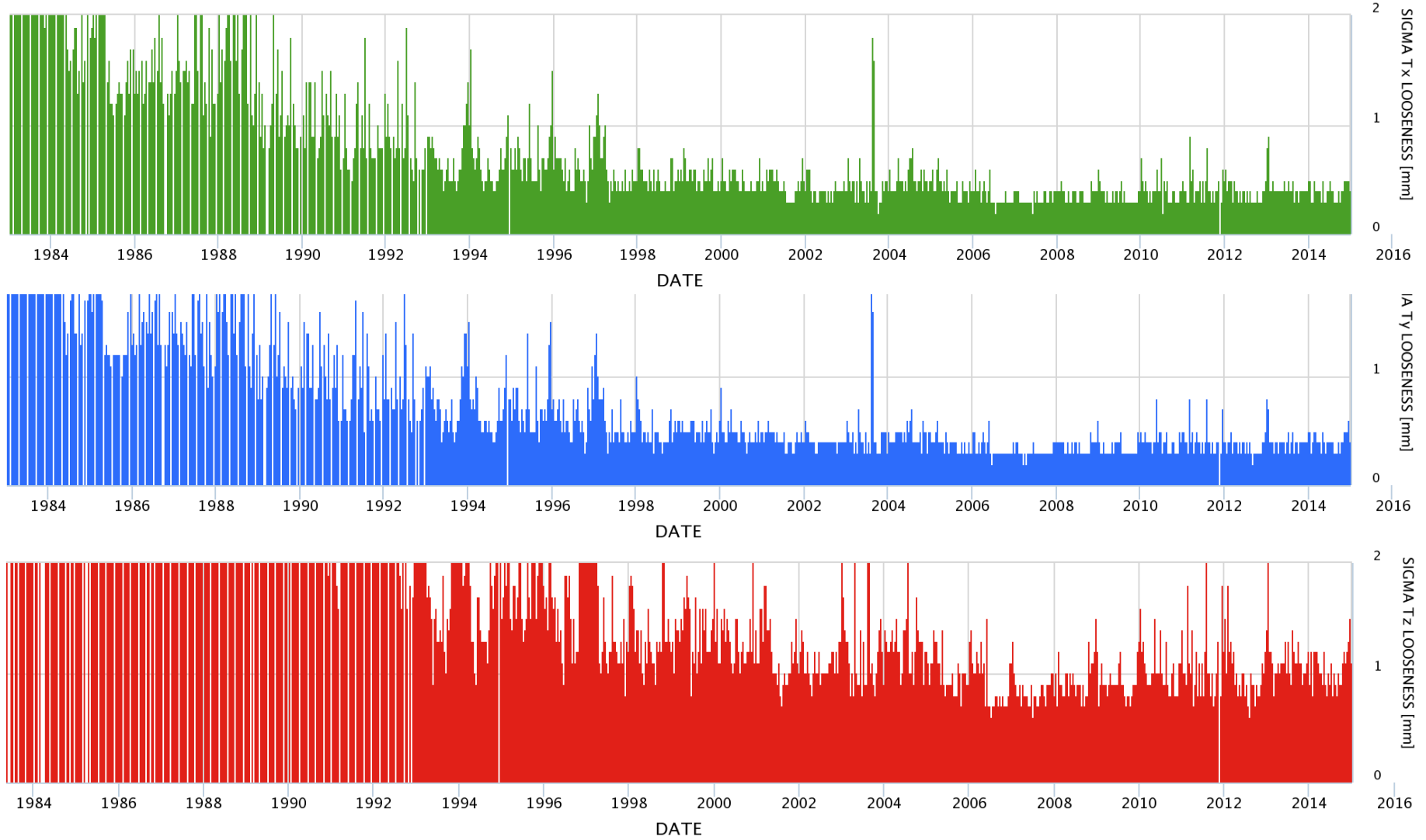
Estimated Systematic Errors (ASI)



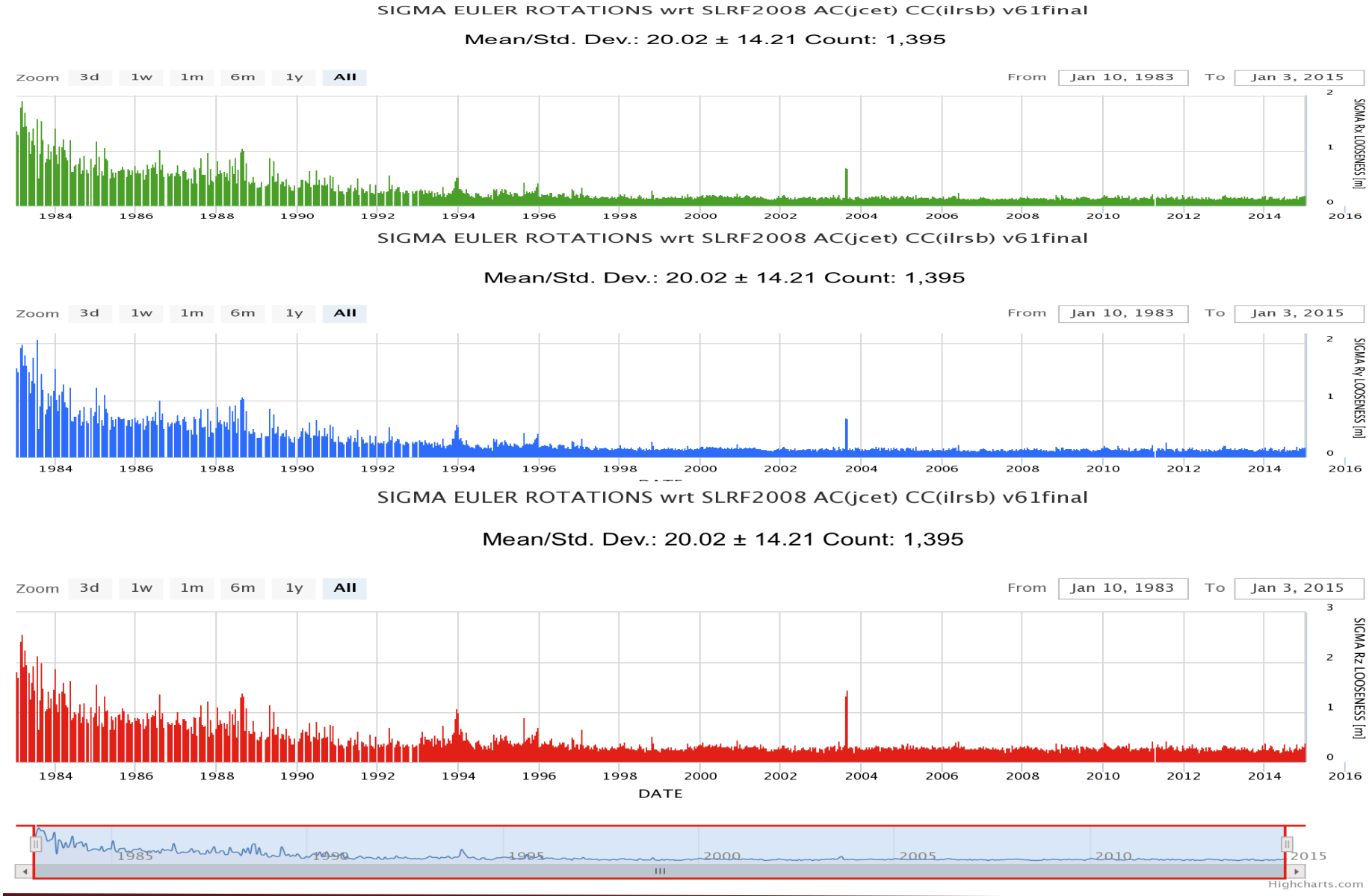
Estimated Systematic Errors (JCET)



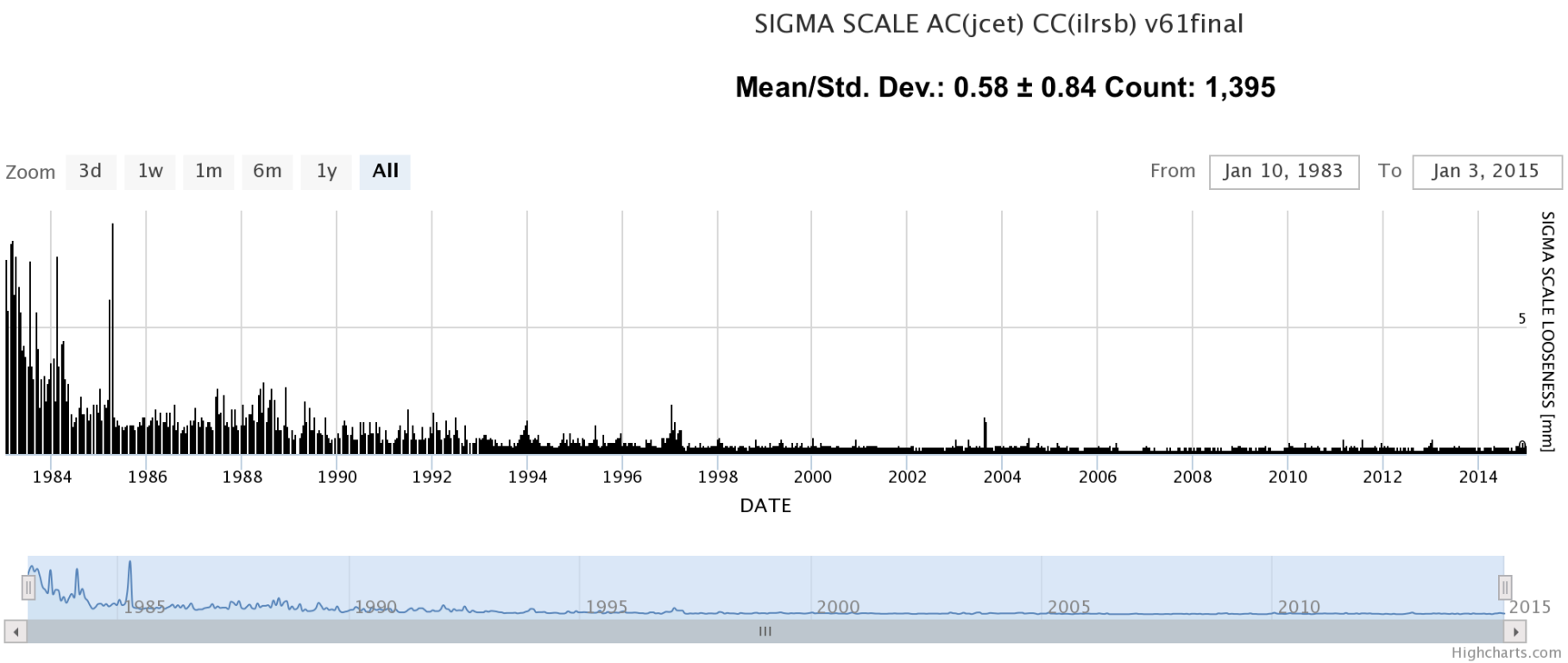
Sensitivity of Contribution (Translations) (JCET)



Sensitivity of Contribution (Rotations) (JCET)

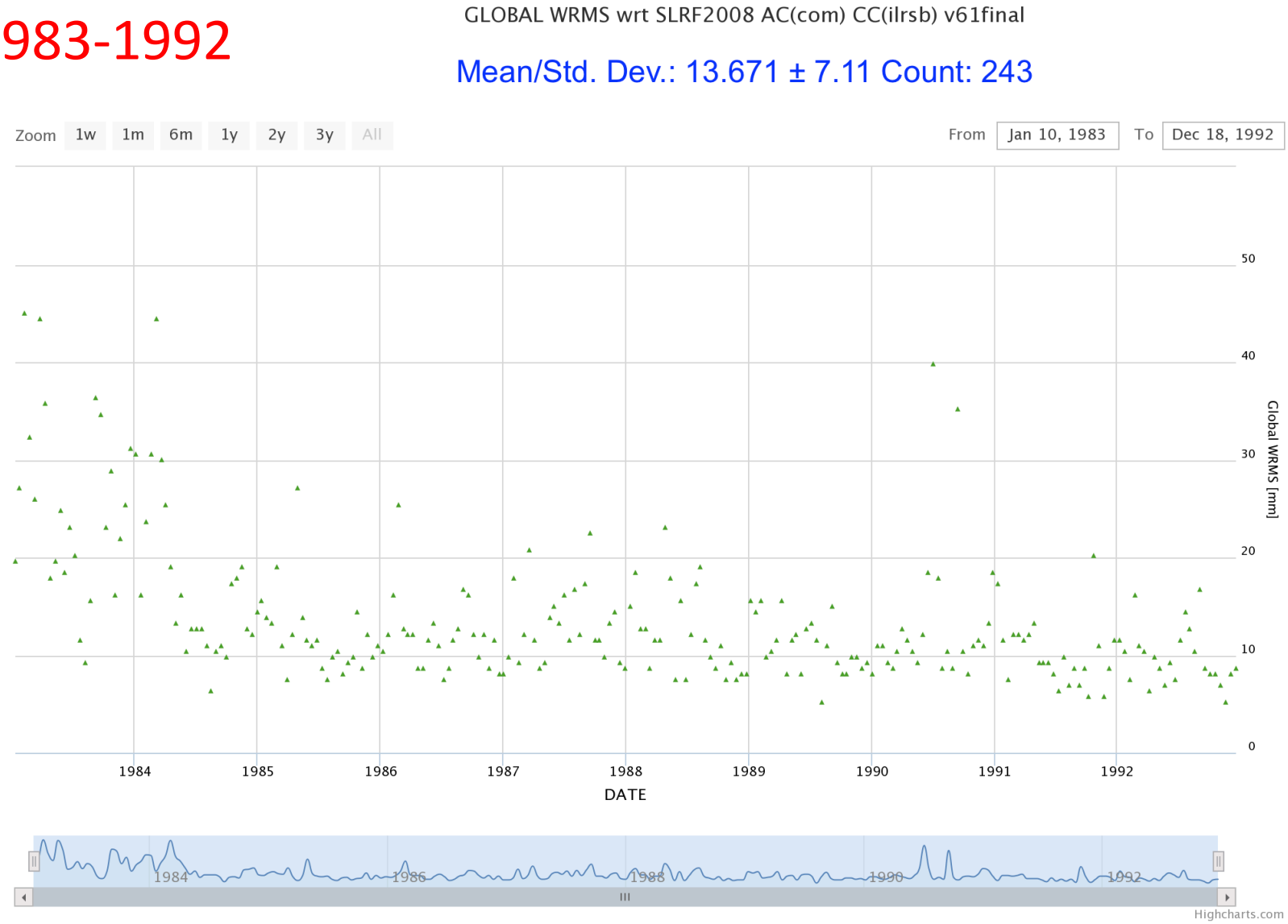


Sensitivity of Contribution (Scale) (JCET)



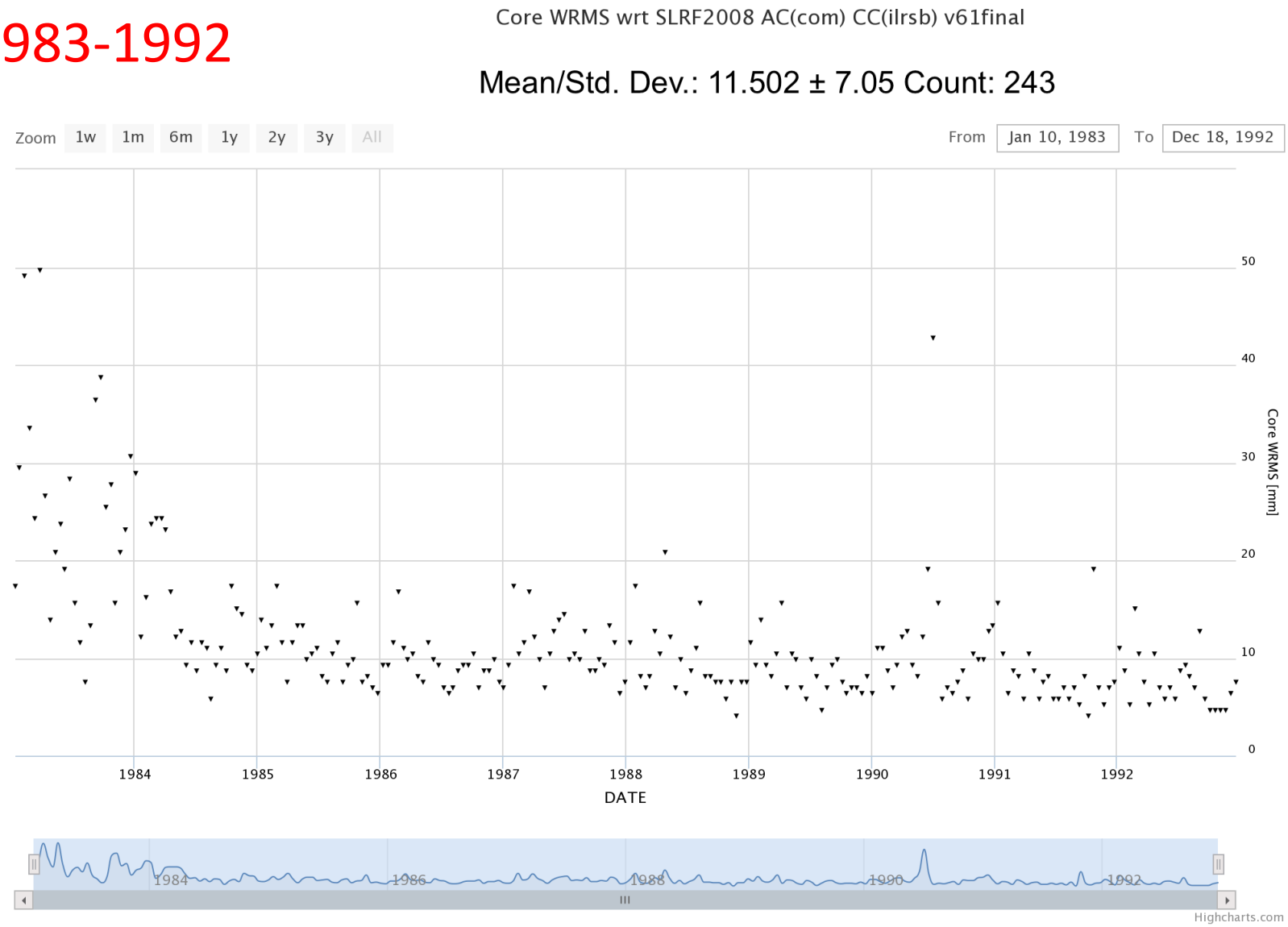
GLOBAL 3D-WRMS Combination ILRS-B

1983-1992



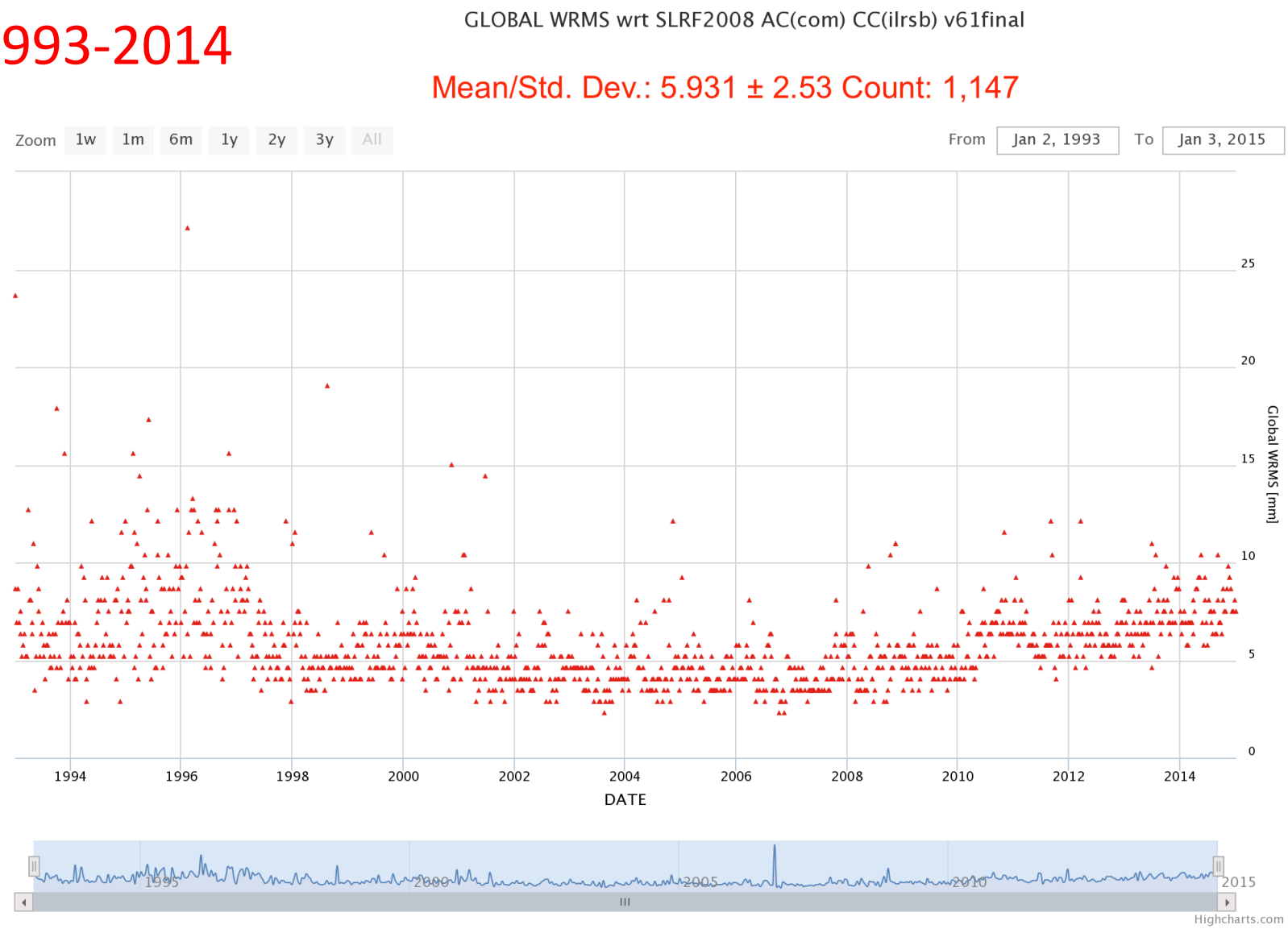
CORE 3D-WRMS Combination ILRS-B

1983-1992



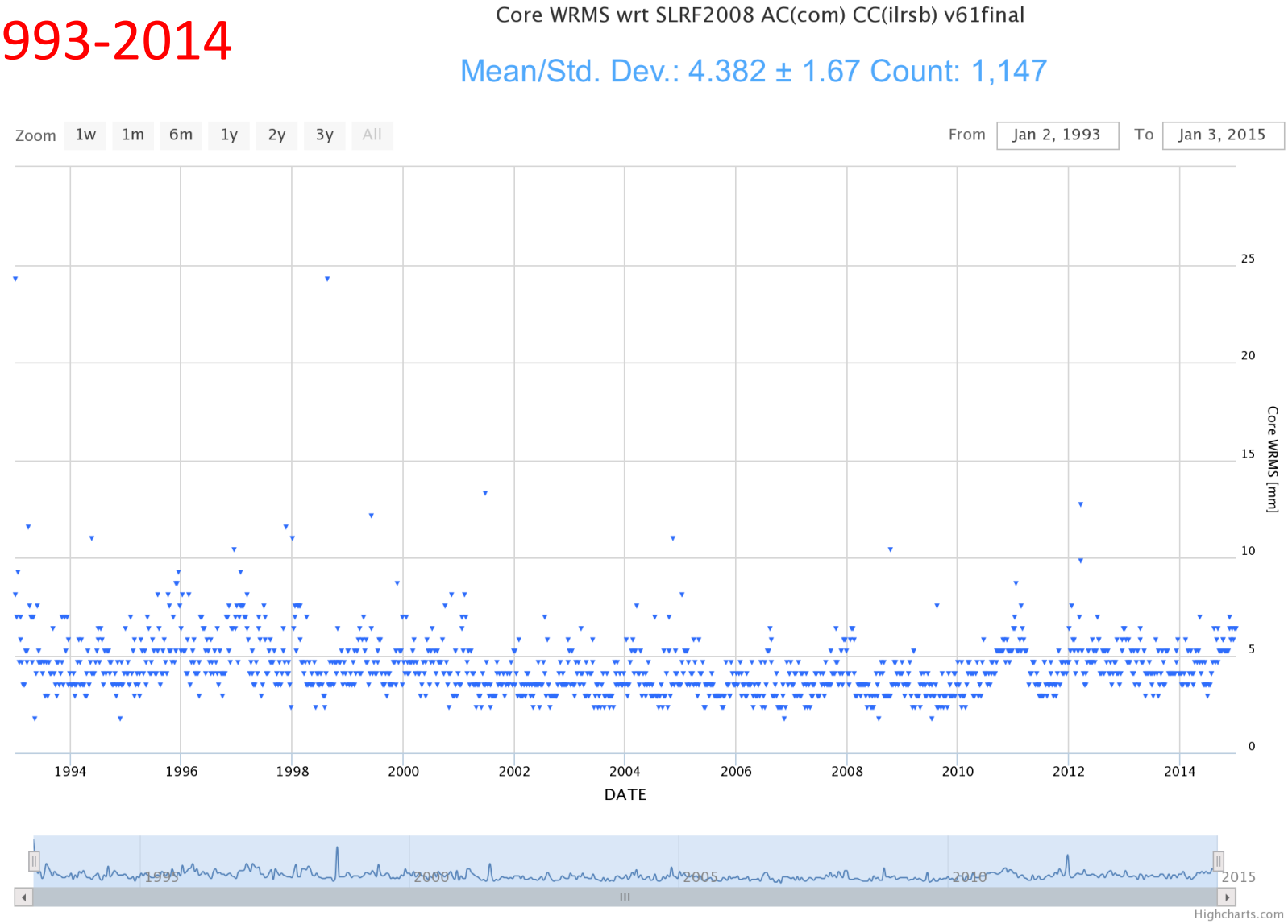
GLOBAL 3D-WRMS Combination ILRS-B

1993-2014

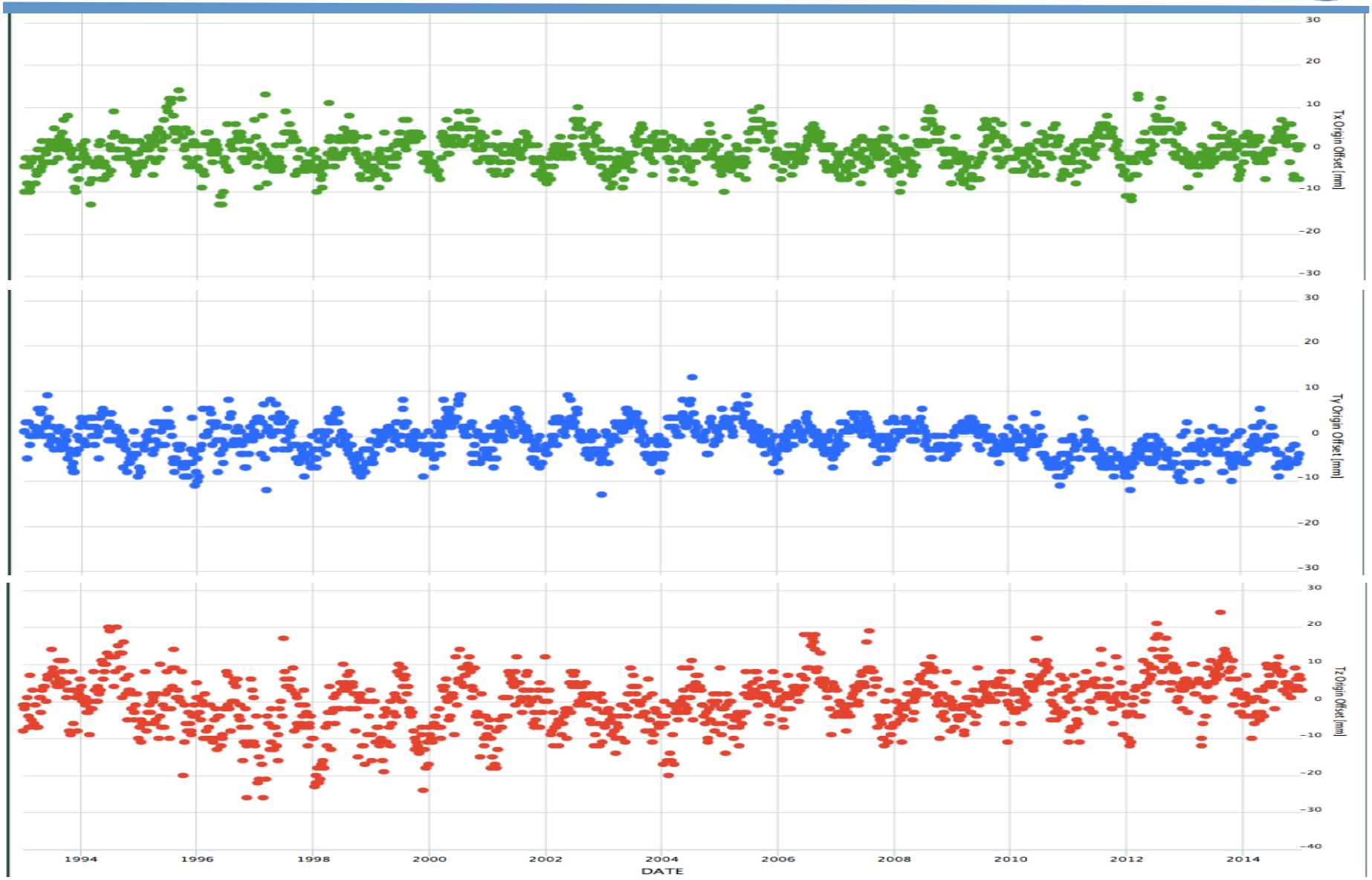


CORE 3D-WRMS Combination ILRS-B

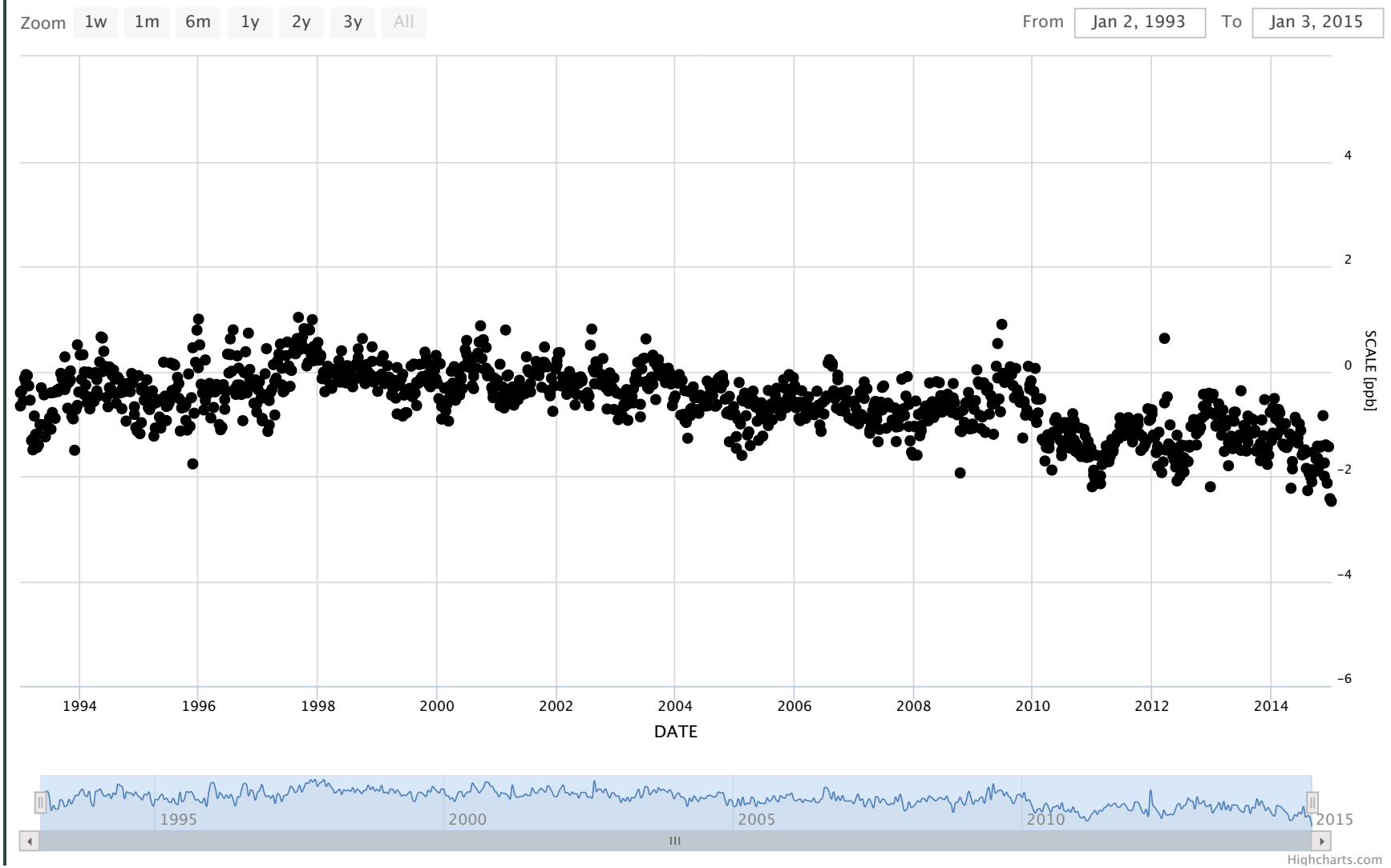
1993-2014



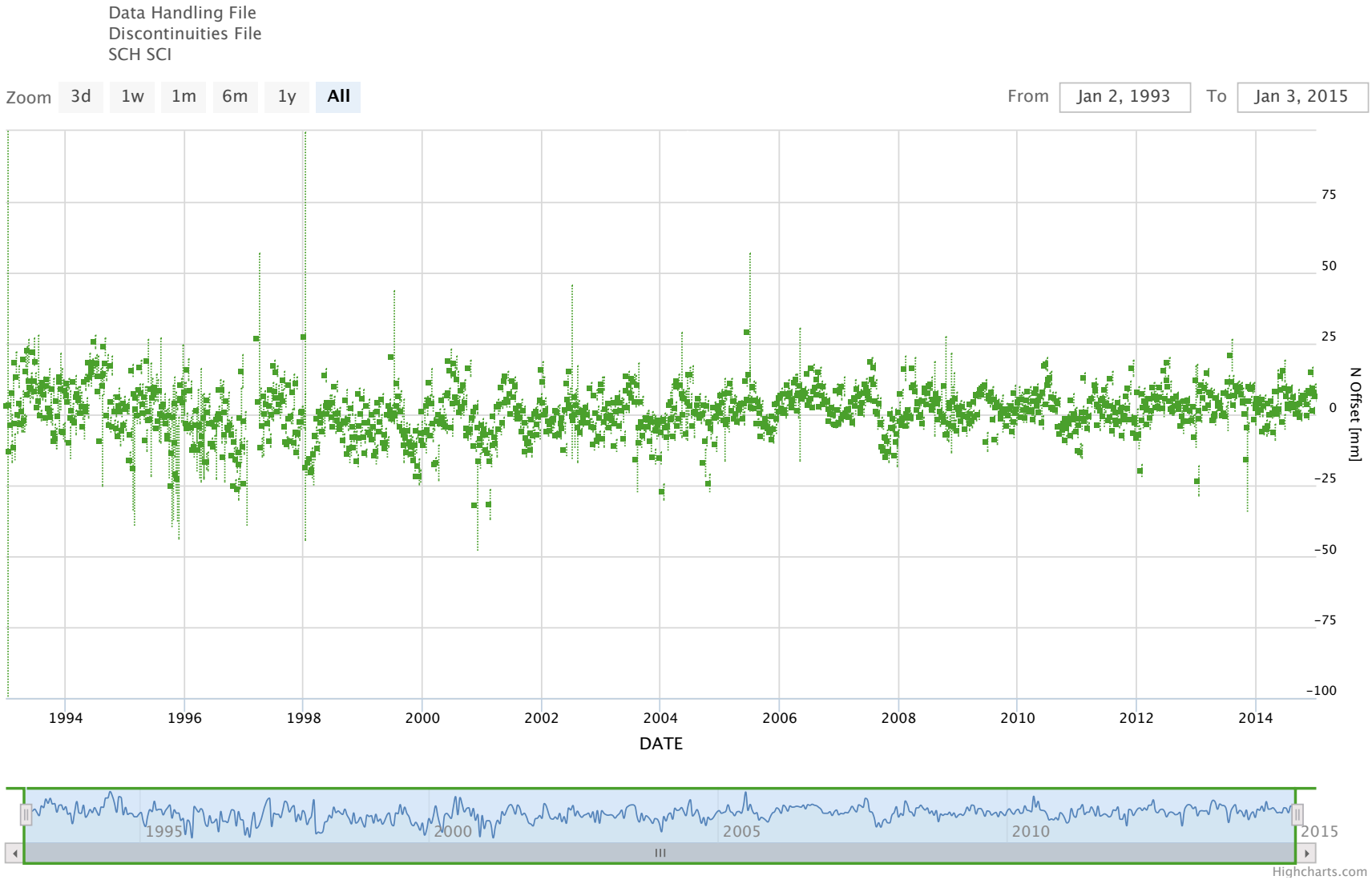
ILRS-B TRF Origin wrt SLRF2008: 1993-2014



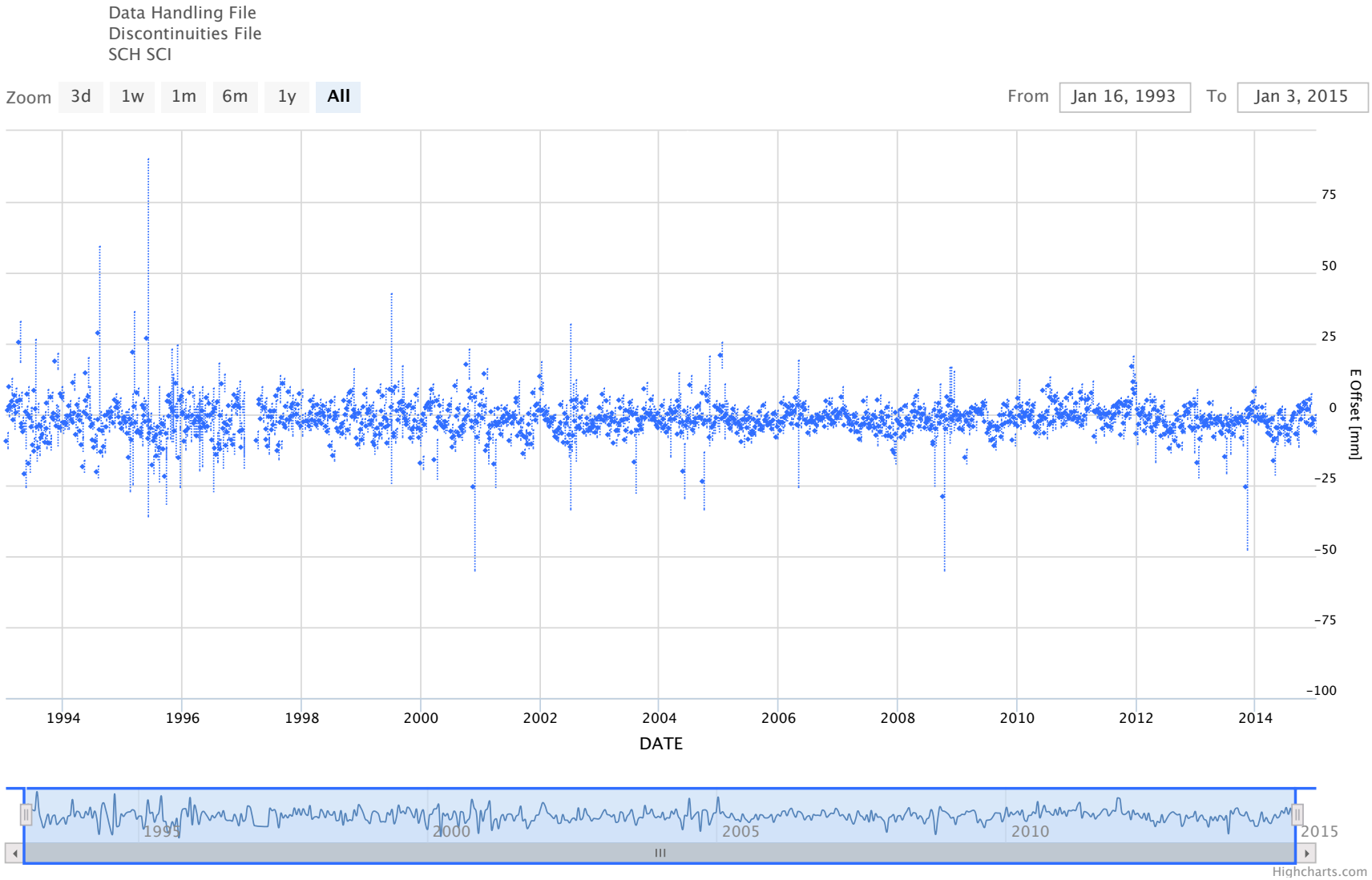
ILRS-B TRF Scale wrt SLRF2008: 1993 - 2014



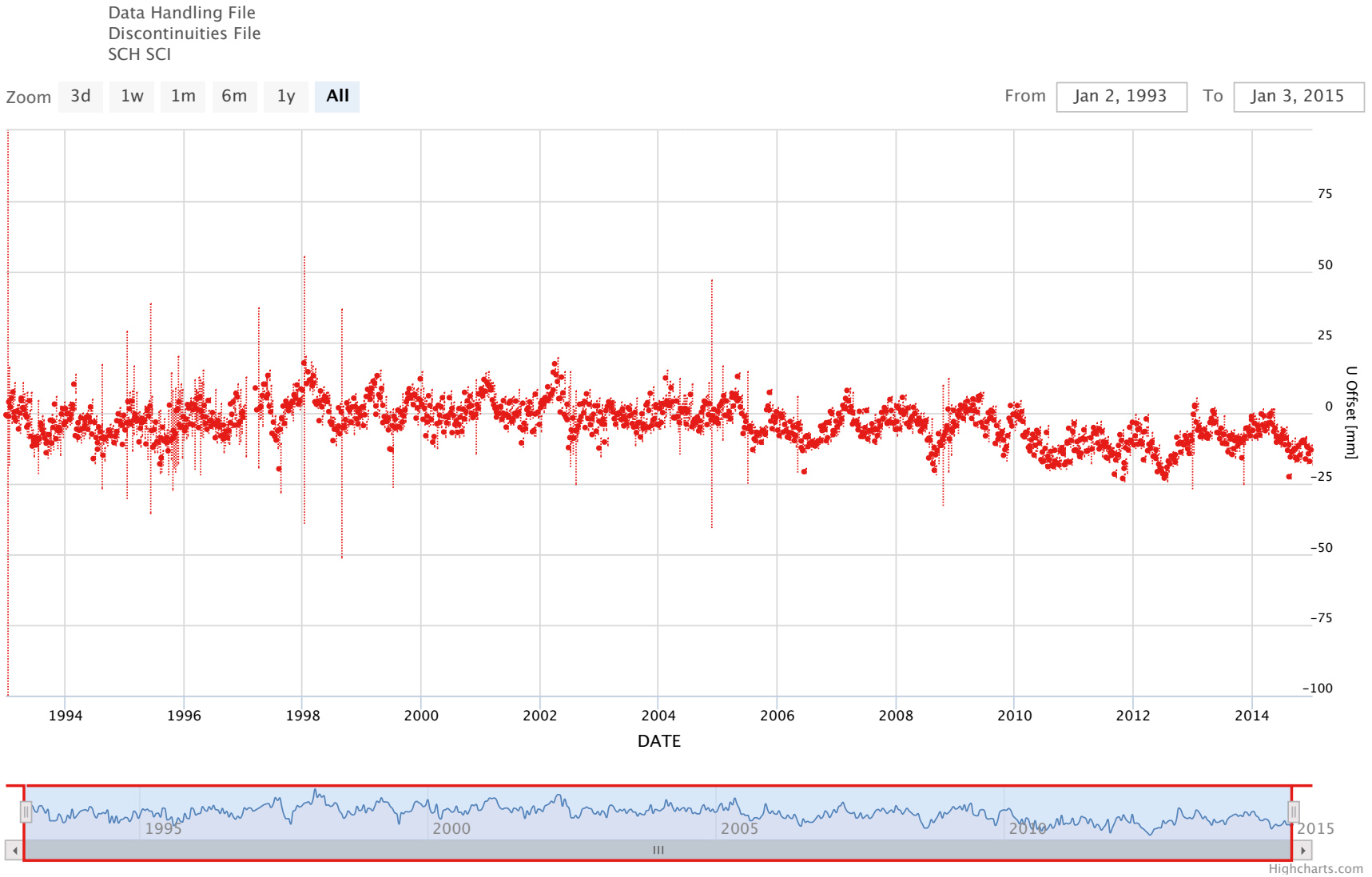
Yarragadee (7090) North – ILRS-B



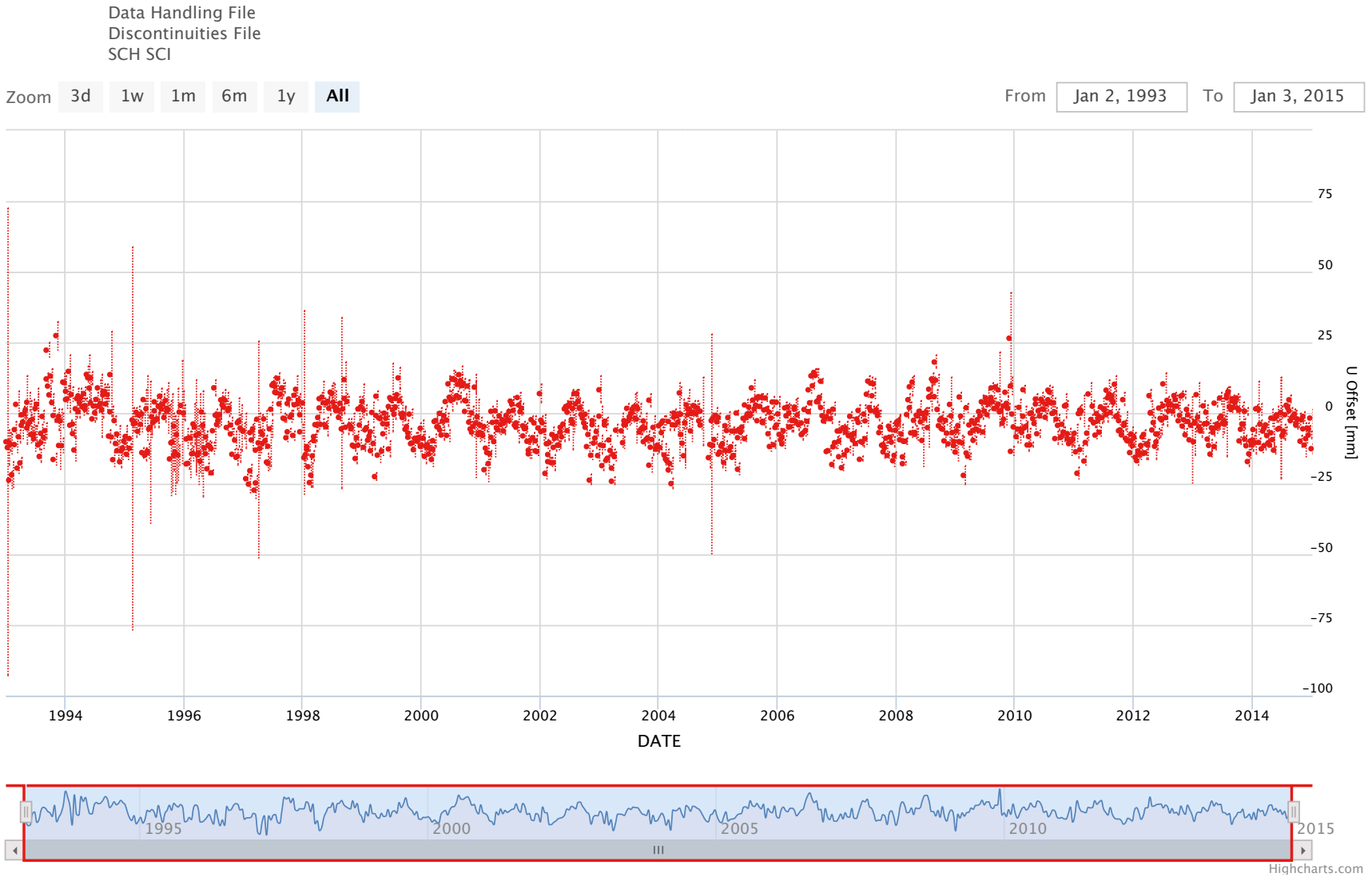
Yarragadee (7090) East – ILRS-B



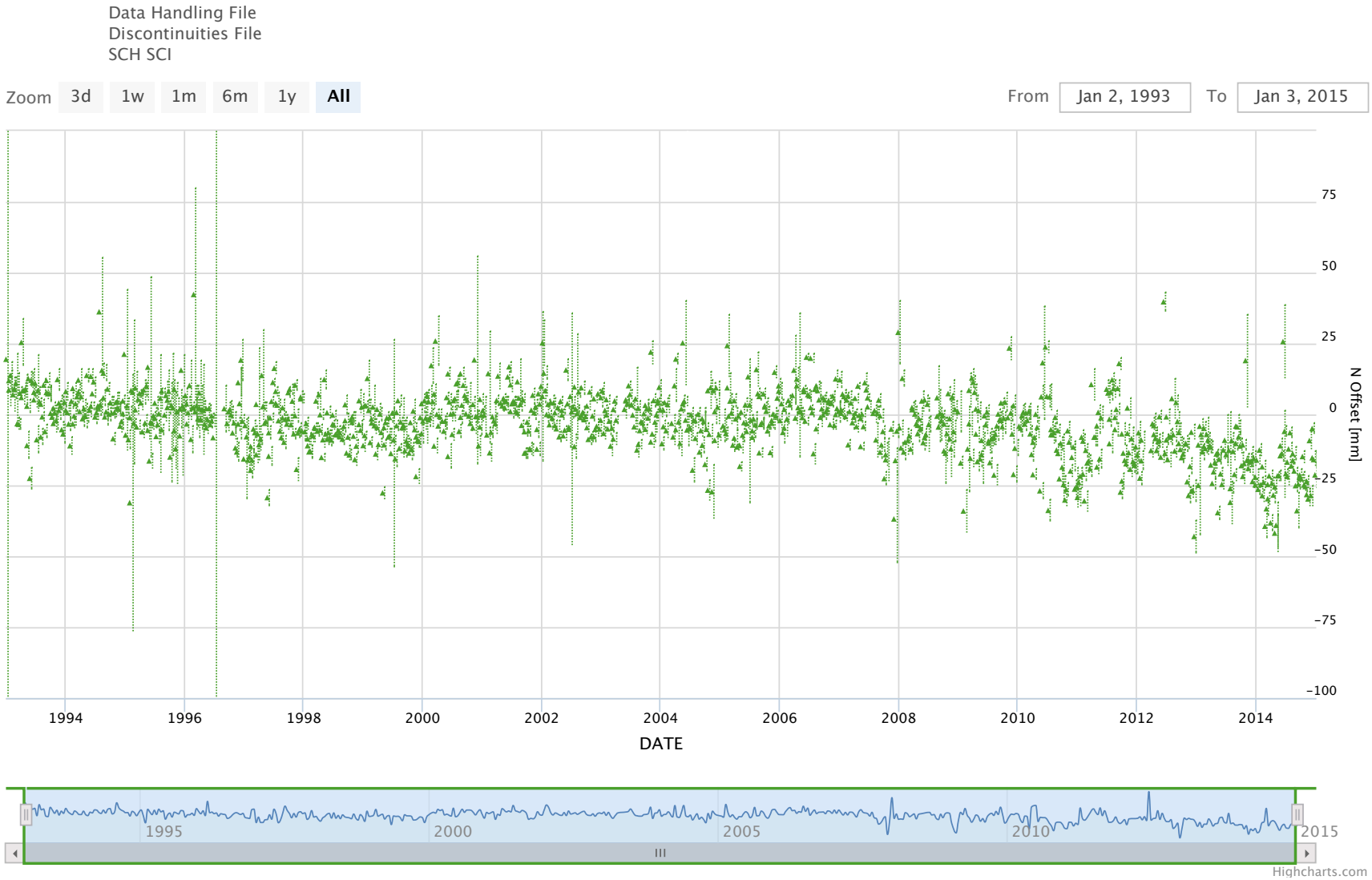
Yarragadee (7090) Up – ILRS-B



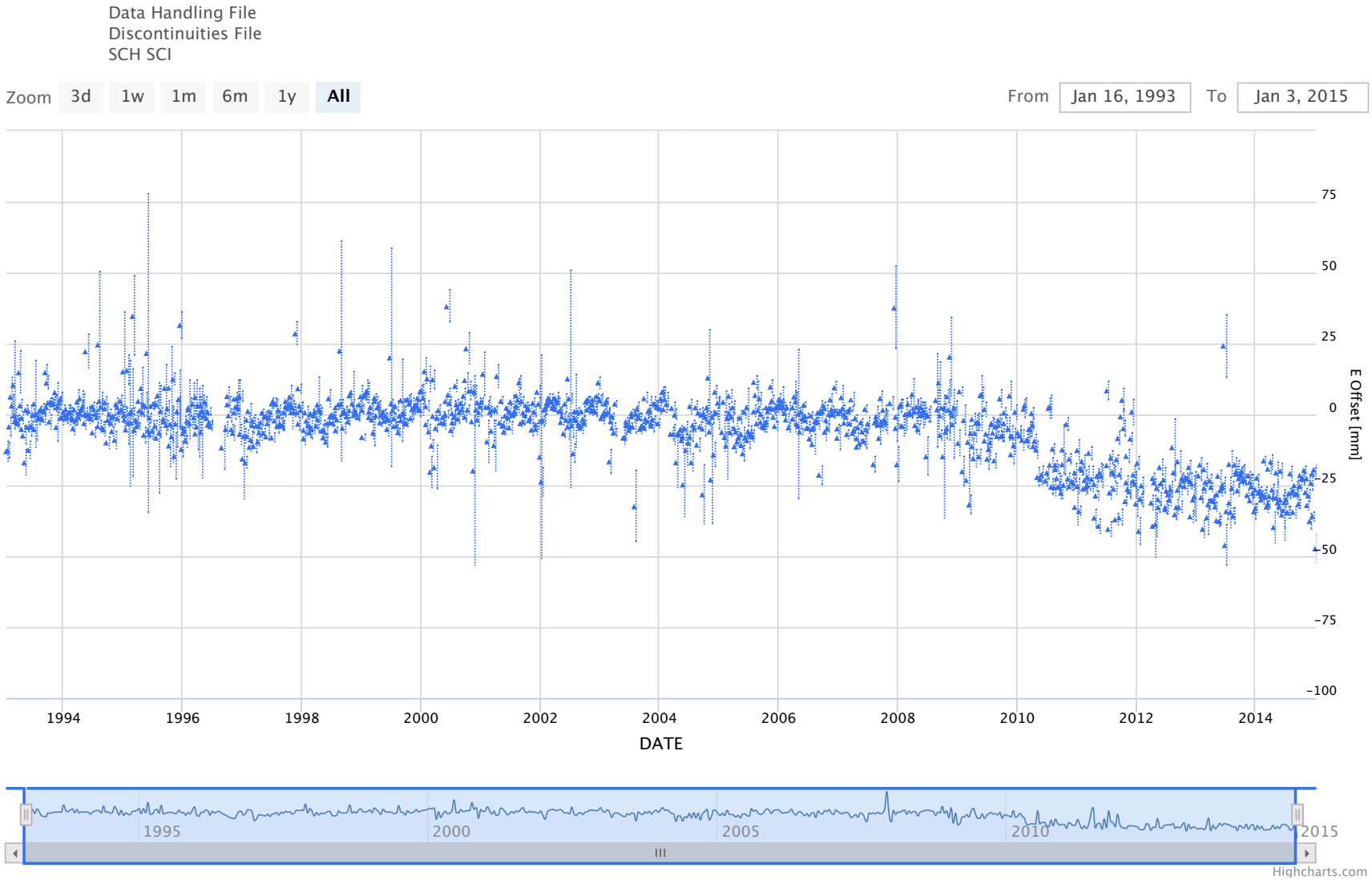
Herstmonceux (7840) Up – ILRS-B



Mon. Peak (7110) North – ILRS-B



Mon. Peak (7110) East – ILRS-B



Mon. Peak (7110) Events (recent)

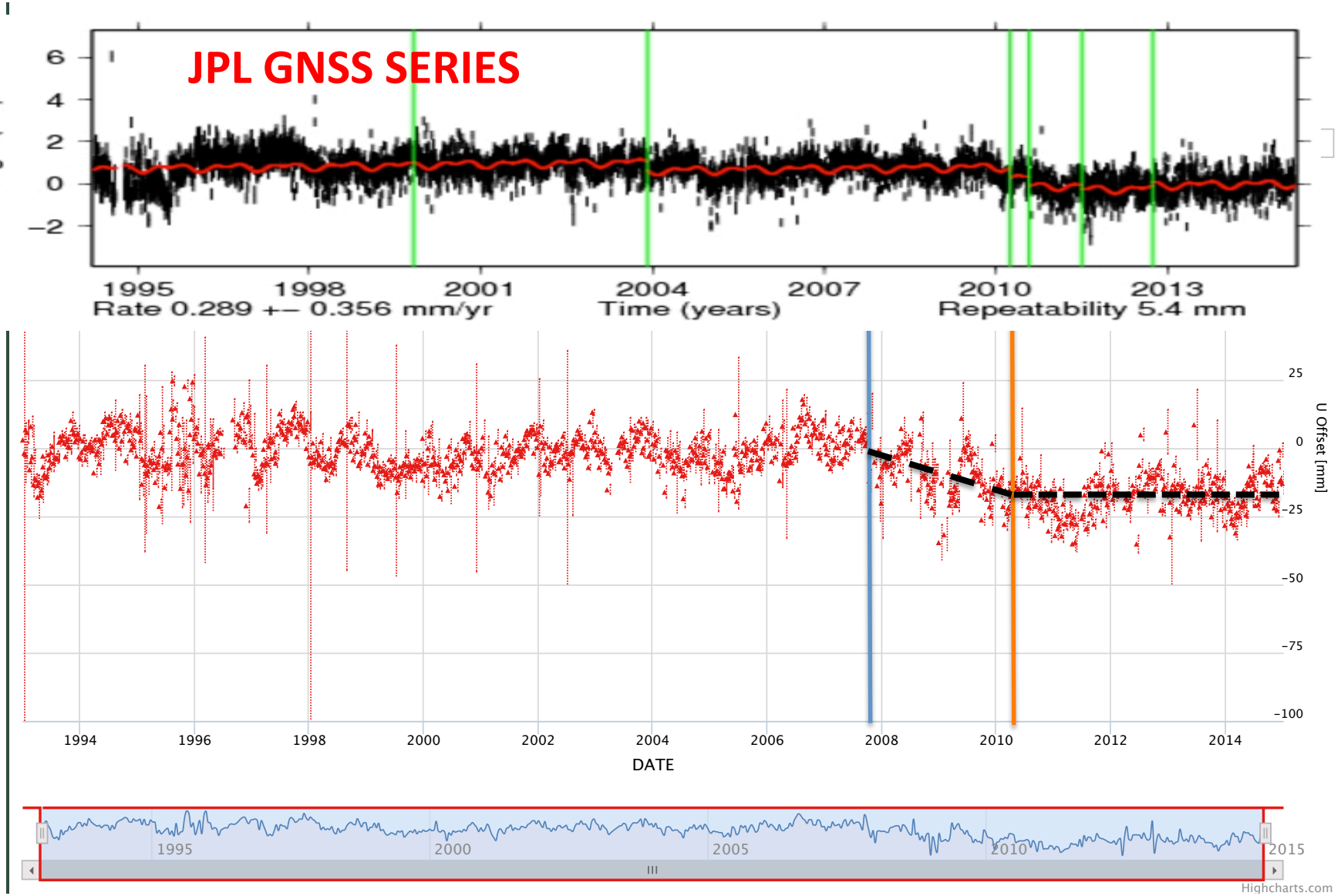
```
14.01 Date                      : 2013-03-11 16:56:06
      Event                     : Earthquake
      Additional Information    : 4.7 Earthquake 20km ESE of Anza, CA
                                : Centered 33.502 degrees N 116.457 degrees W

14.02 Date                      : 2010-06-15 04:26:58.48
      Event                     : Earthquake
      Additional Information    : 5.8 Magnitude
                                : Lat 32.7N Lon 115.921W
                                : Aftershock due to Baja Earthquake

14.03 Date                      : 2010-04-04 22:40:43.10
      Event                     : Baja Earthquake
      Additional Information    : 7.2 Magnitude and multiple 5.4 mag
                                : aftershocks on same day
                                : Lat 32.297N Lon 115.047W
```

JPL Time Series Break estimates and errors

Break estimates and errors in mm.
Break times in years.

	N	E	V	SN	SE	SV
MONP 1999.8329	7.653	1.037	0.351	0.645	0.565	2.202
MONP 2003.9151	2.435	-0.619	-3.995	0.685	0.596	2.345
MONP 2010.2587	**-2.136**	**-20.263**	**-5.040**	**1.190**	**1.005**	**3.985**
MONP 2010.5872	-1.614	-6.373	-4.401	1.281	1.081	4.292
MONP 2011.5126	6.696	-4.520	-1.679	0.900	0.757	3.111
MONP 2012.7501	-7.891	-1.277	1.680	0.765	0.640	2.658

Mon. Peak (7110) Up – ILRS-B

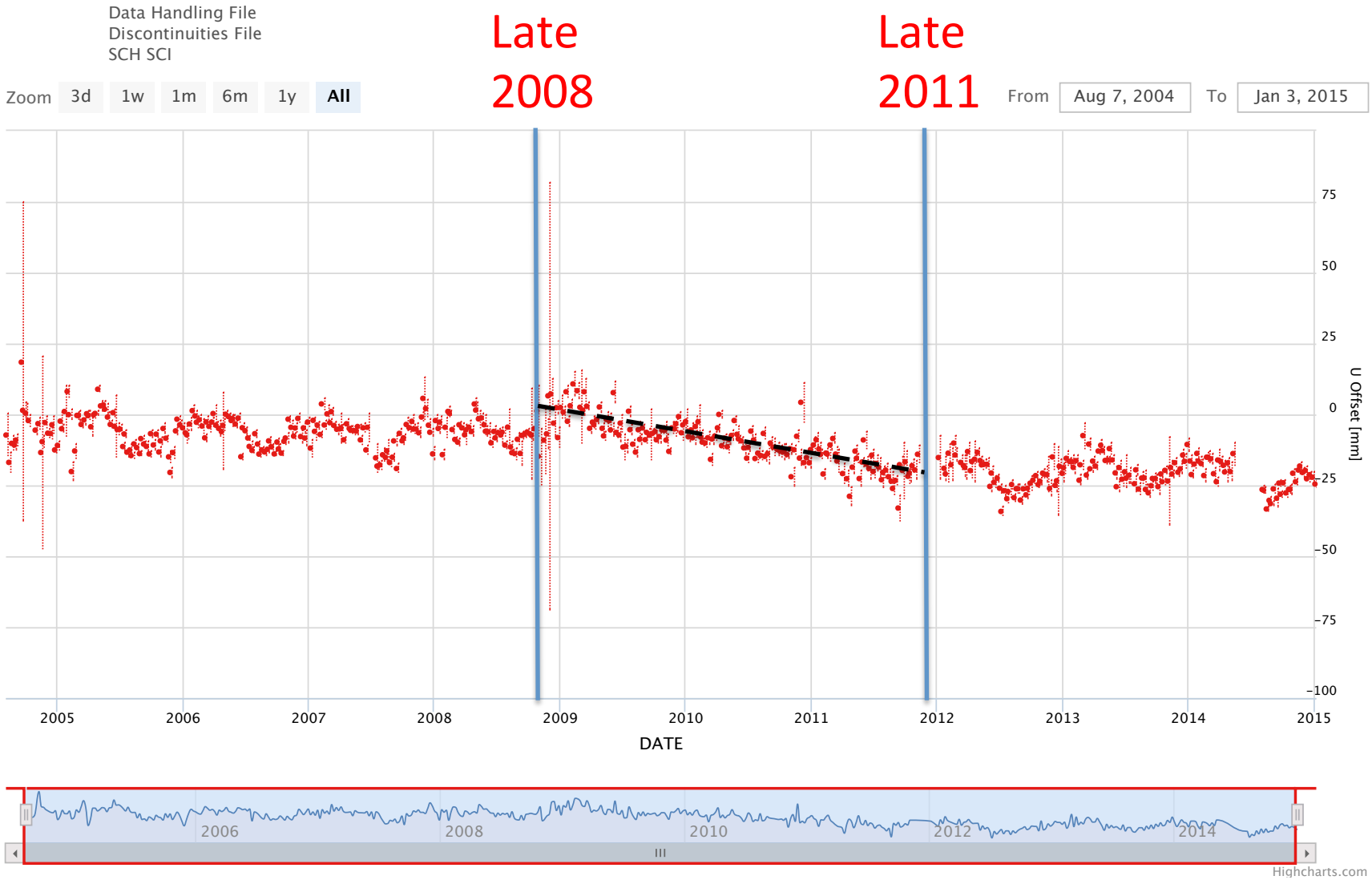


http://geodesy.jcet.umbc.edu/sch_sci_query/

Mon. Peak (7110) "Station History Change Logs"

2006-04-06	0	7110	412	0	0	1	1	5.01	Installed new PMT.
2006-05-22	20.2667	7110	412	0	0	1	0	9.01.01	Installed new RB standard G78422; time reset STA-RB = 3.992/3 microsecs; STA-CNS = -4.0213 at 2026Z.
2006-11-16	19.7167	7110	412	0	0	1	2	6	Replaced receive cable.
2008-06-11	0	7110	412	0	0	1	0	12.03.01	New MET3 Installed.
2008-08-25	0	7110	412	0	0	1	1	9	Replaced TIU with spare (original not working - 04 error could not clear).
2008-08-29	0	7110	412	0	0	1	0	5.01	Laser Upgrade Installation in progress since 8/15/08.
2009-02-04	0	7110	412	0	0	1	0	12.03.01	Replaced Met-3 with G78606 (out G78636)
2009-02-16	0	7110	412	0	0	1	0	12.03.01	Replaced Met-3 with G78636 (out G78606)
2009-04-18	0	7110	412	0	0	1	1	6	Installed G77365 discriminator; removed G77110.
2009-04-30	0	7110	412	0	0	1	0	12.03.01	Replaced MET-3 with G78440 (out G78636).
2009-09-22	0	7110	412	0	0	1	0	99	Installed LRC 10PPS board.
2010-03-18	0	7110	412	0	0	1	1	6	Installed/tested new PMT .1 better RMS; ran disc/stability on new PMT at -3200 volts
2010-04-04	22.6667	7110	412	0	0	1	2	99	M7.2 Baja Earthquake and multiple M5.4 earthquakes
2010-05-17	0	7110	412	0	0	1	1	9	Installed TIU G78409, optimized -.31 & -.28; removed G77075. G78409 showed a drift of 99.77 nanosecs to 99.84 nanosecs on bench test.

Mt. Stromlo (7825) Up – ILRS-B



http://geodesy.jcet.umbc.edu/sch_sci_query/

Mt. Stromlo (7825) "Station History Change Logs"

2009-09-03	1	7825	9001	0	0	1	4	10.02	Installed updated post processing software and scripts. .
2009-09-16	1	7825	9001	0	0	1	4	10.02	Installed new post processing and Profits software. Version 5.2.5.
2009-10-20	1	7825	9001	0	0	1	3	12.03.01	Installed new Vaisala static pressure head on mets mast.
2009-11-09	1	7825	9001	0	0	1	1	08.02	Survey of calibration piers performed by Geoscience Australia.
2009-11-10	23	7825	9001	0	0	1	1	08.02	Survey of 1m Telescope IVP completed by Geoscience Australia.
2009-11-11	1.98333	7825	9001	0	0	1	2	06.01.01	New MRCS timing card installed.
2009-12-24	1	7825	9001	0	0	1	2	08.02	Positions of pier targets updated using new survey data. Approximately 1mm change in STN range.
2010-04-12	3	7825	9001	0	0	1	2	99	Old SLR tracking camera replaced and new camera system aligned on a star.
2010-04-19	0	7825	9001	0	0	1	1	13.01	Installation of JAXA equipment completed and monitoring of QZS satellites commenced.
2010-05-12	1.98333	7825	9001	0	0	1	1	13.01	GA installed new DORIS equipment.
2010-06-09	3	7825	9001	0	0	1	3	99	Modified scripts to automatically send *.NPT files in addition to *.NP files.
2010-07-07	3	7825	9001	0	0	1	1	99	Motor driving the T/R main disk failed. Replaced with a spare.
2010-08-07	1	7825	9001	0	0	1	4	99	Incorrect timebias applied for a period.
2010-11-29	0	7825	9001	0	0	1	1	05.02	SLR regen chiller temperature sensor failed. Chiller replaced.

http://geodesy.jcet.umbc.edu/sch_sci_query/

Mt. Stromlo (7825) "Station History Change Logs"

2011-04-15	1	7825	9001	0	0	1	1	09.02.01	GA installed new Symmetricon 5071A Cesium atomic clock.
2011-05-24	3	7825	9001	0	0	1	2	06.01.01	New Semrock spectral filter installed in front of the CSPAD.
2011-06-20	1	7825	9001	0	0	1	1	99	New spinning disk mount and coupling installed.
2011-07-15	1	7825	9001	0	0	1	2	99	All ILRS satellite names were modified to lower case in response to request from EDC.
2011-08-01	0	7825	9001	0	0	1	1	99	Minor upgrade of control system modules. Version 2.1.4.
2011-08-15	1	7825	9001	0	0	1	2	05.02	Regen Pockels Cell Driver Unit failed. Replaced by spare (low voltage) unit pending repair.
2011-09-09	1	7825	9001	0	0	1	2	05.02	New Pockels cell installed after the regen amplifier stage to filter pre-pulses.
2011-09-15	1	7825	9001	0	0	1	2	99	Software upgrade of ranging server to improve collision band avoidance.
2011-09-26	1	7825	9001	0	0	1	4	10.02	New Profits installed to support manual processing with manual entry of mets data. Version 5.2.7.
2011-09-28	1	7825	9001	0	0	1	3	99	Software upgrade of ranging server to improve collection of vernier calibration measurements.
2011-10-06	1	7825	9001	0	0	1	3	12.03.02	Vaisala WXT520 met station installed as temporary replacement of existing MAWS. Met data collected automatically.
2011-11-16	1	7825	9001	0	0	1	1	05.03	SHG crystal replaced with an old spare crystal, while waiting for delivery of a new crystal.
2011-11-17	1.98333	7825	9001	0	0	1	2	05.03	Current Pockels cell (low voltage) driver failed. Replaced by serviced high voltage driver unit.
2011-11-19	1	7825	9001	0	0	1	1	05.03	Replacement SHG crystal also found to be degraded. Laser beam diameter enlarged to avoid further damage.
2011-12-01	1	7825	9001	0	0	1	1	05.03	Beam expander mirror replaced.
2011-12-01	1.98333	7825	9001	0	0	1	2	05.03	New SHG crystal installed. Beam divergence increased to reduce energy density on the crystal.

Summary

- **ILRS-B Combination Series**
  - 1983-2014 completed
  - 1983-1992 w/o BKG (as agreed)
  - Input SINEX file issues:
    * wrong/missing EOP epochs (e.g. bkg, esa)
    * reporting of range biases in BIAS/EPOCHS
      but not found in SOLUTION/ESTIMATE (DGFI)
    * outliers in estimates (all ACs)

- **Software completed for checking/validating SINEX submissions + SUM files**
  - produces tables of estimated range biases & position std. dev.
  - gives information about stations (used/core stations/not used sites)

International Laser Ranging Service

LLR Status Report
- 2015 -

Jürgen Müller

Institut für Erdmessung (Institute of Geodesy) and

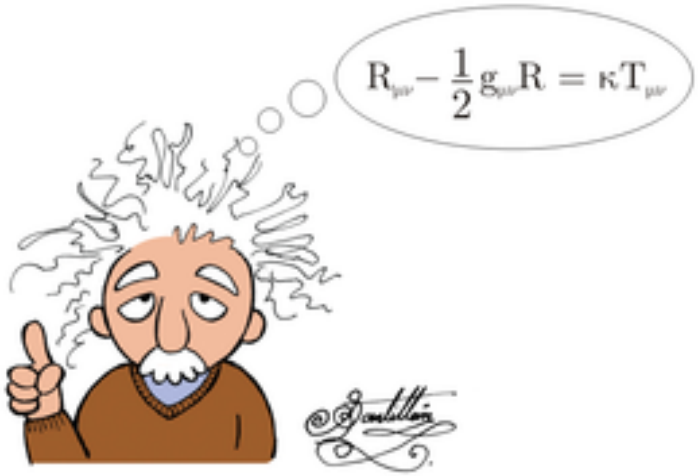
Leibniz Universität Hannover (University of Hannover)

ife

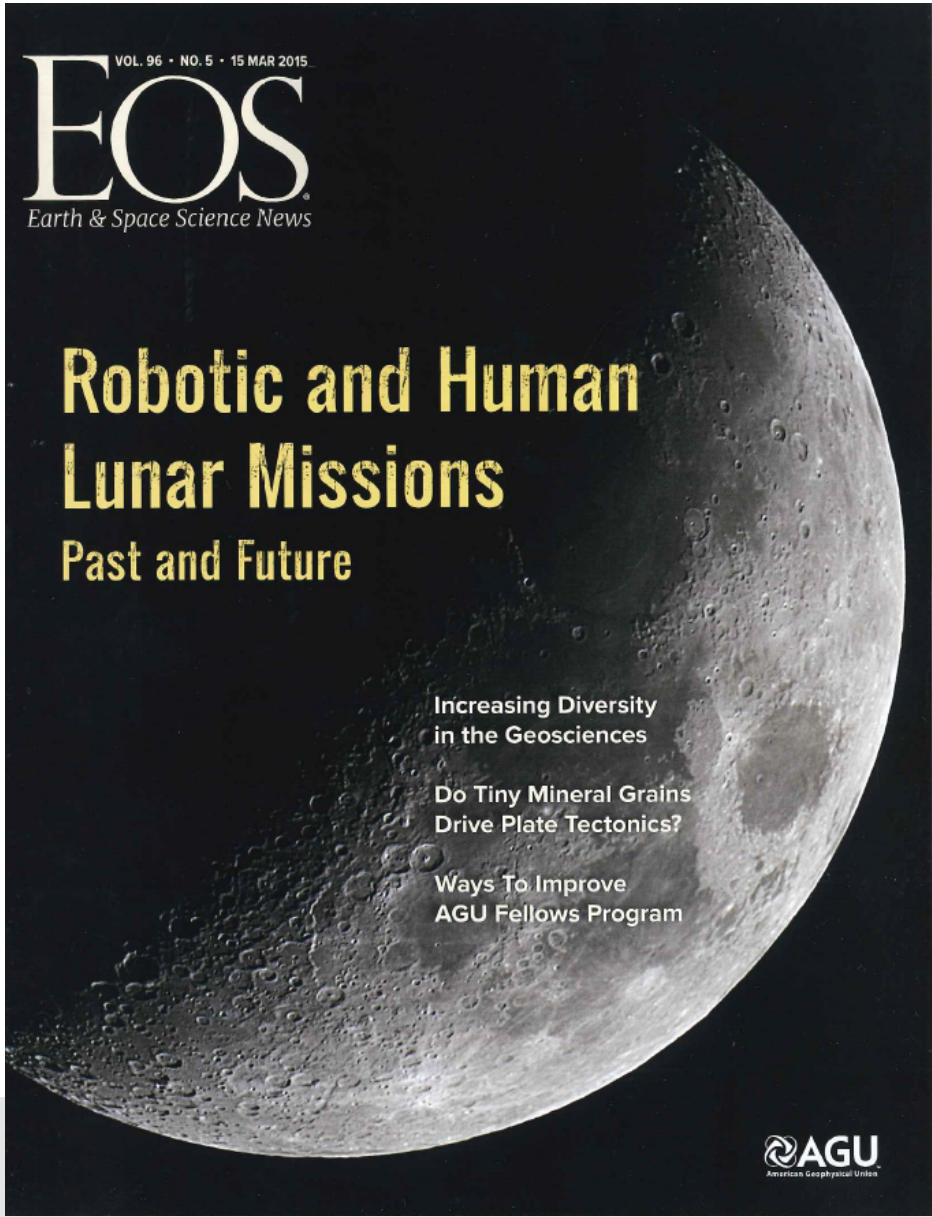
Leibniz Universität Hannover

The Moon is very attractive

100th anniversary of Einstein's theory of general relativity

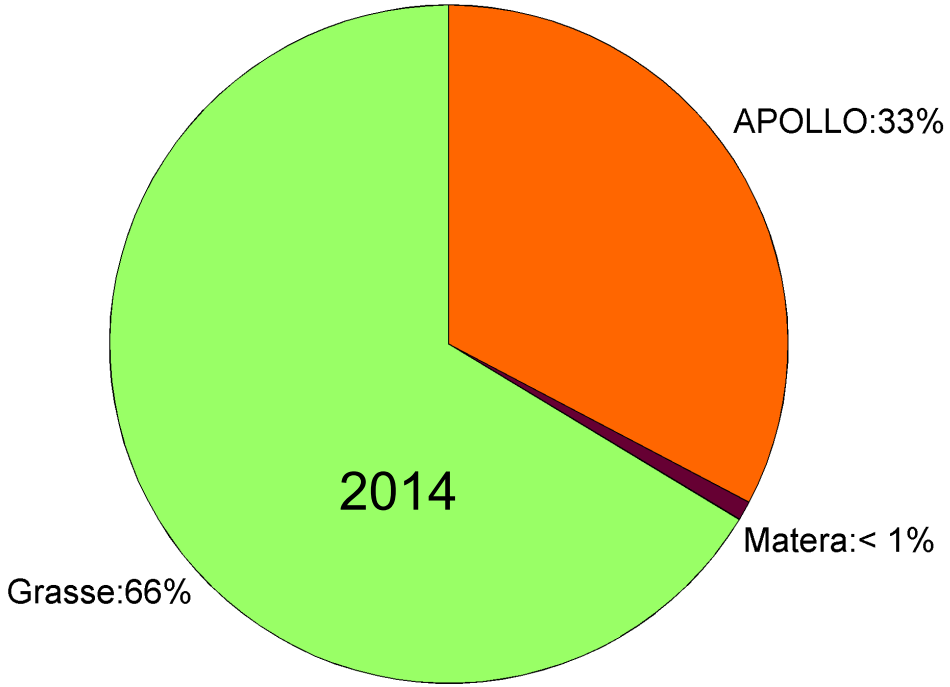


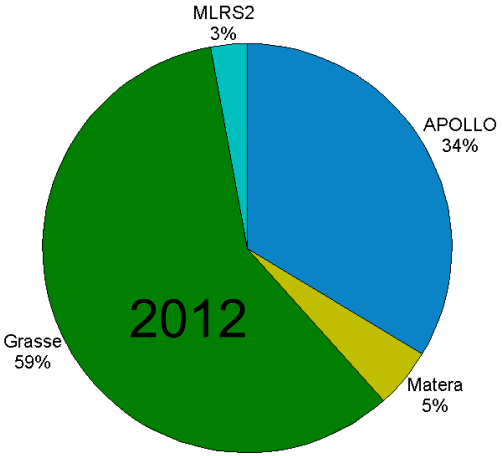
LLR analysis steadily reduces the margins for a possible violation and impressively underpins its validity.

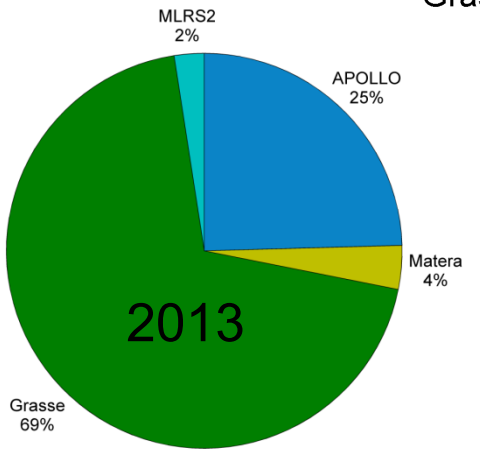


Statistics – observatories 2014

Normal points	2013	2014
APOLLO	151	212
McDonald	15	--
Grasse	427	430
Matera	22	6
In total	**615**	**648**





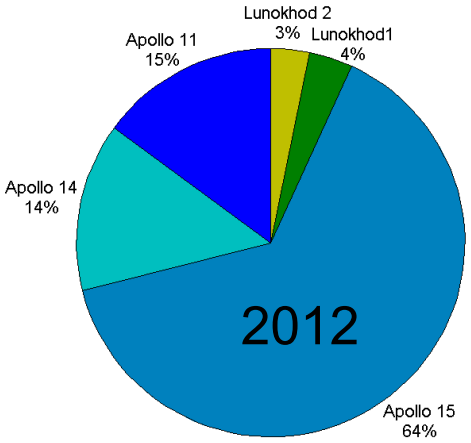


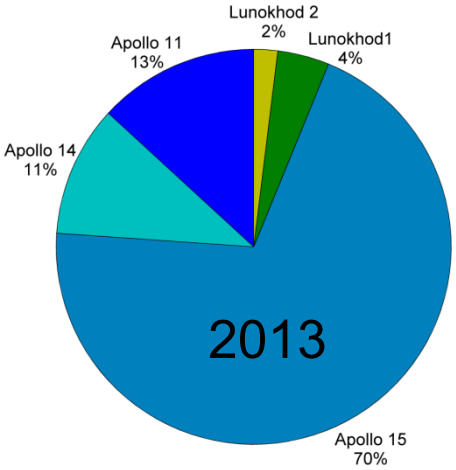
Status, perspective at the LLR sites

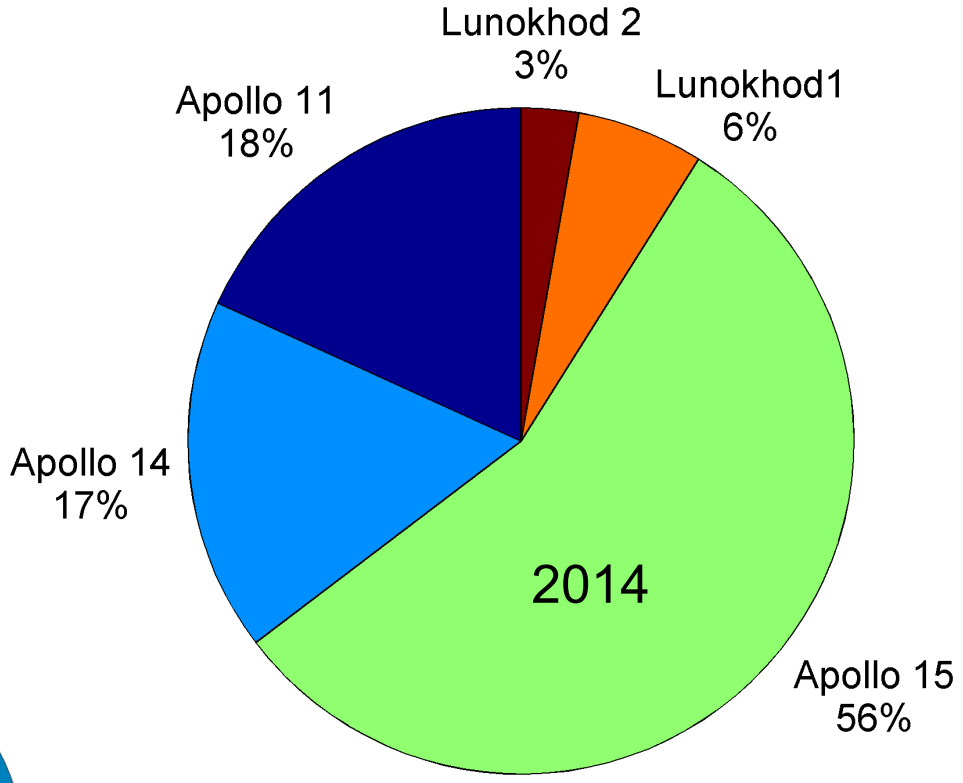
- McDonald – no LLR tracks in 2014, i.e. the first gap year for decades
- Matera (since 2010) - lunar tracking at very low level
- APOLLO - good LLR data, reduced accuracy 2011-2012 (i.e. cm instead of mm level)
- Grasse (re-start in 2009), very good performance since end of 2011
- Wettzell LLR tracking is still pending

Statistics – retro-reflectors 2014

Normal points	2013	2014
Apollo 11	81	118
Apollo 14	66	111
Apollo 15	430	361
Lunokhod 1	26	40
Lunokhod 2	12	18
In total	**615**	**648**

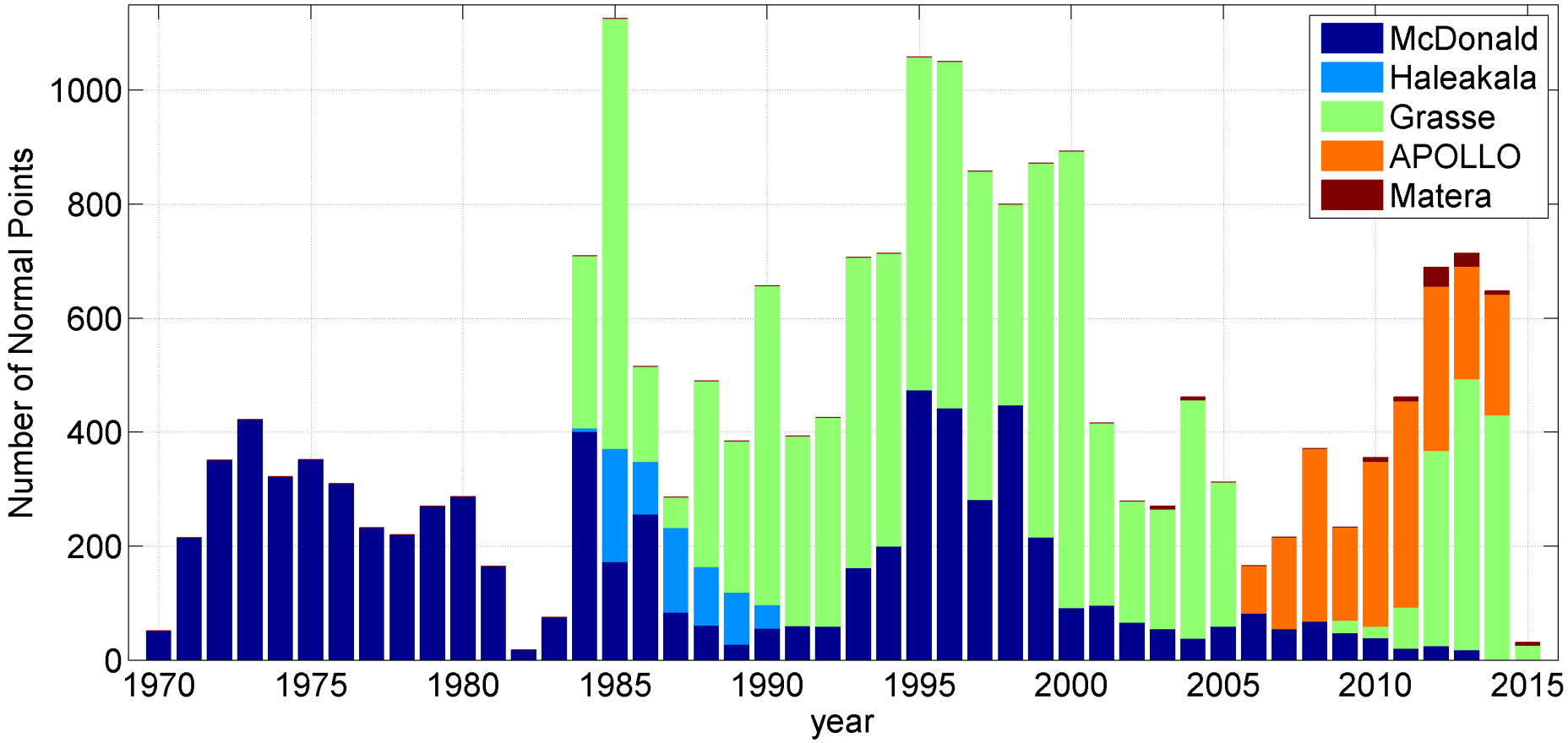






Number of normal points

1970 - 2014: ca. 20,860 normal points



Major LLR-related activities

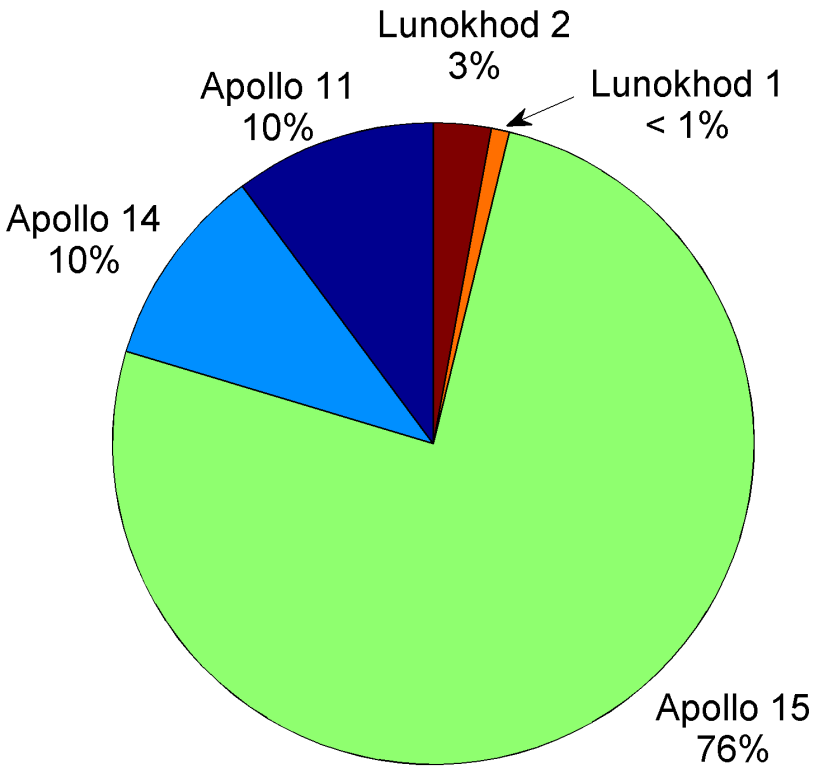
- 6 LLR analysis centers: JPL (USA); CFA (USA); POLAC (France); IfE (Germany); INFN (Italy); SOKENDAI (Japan)

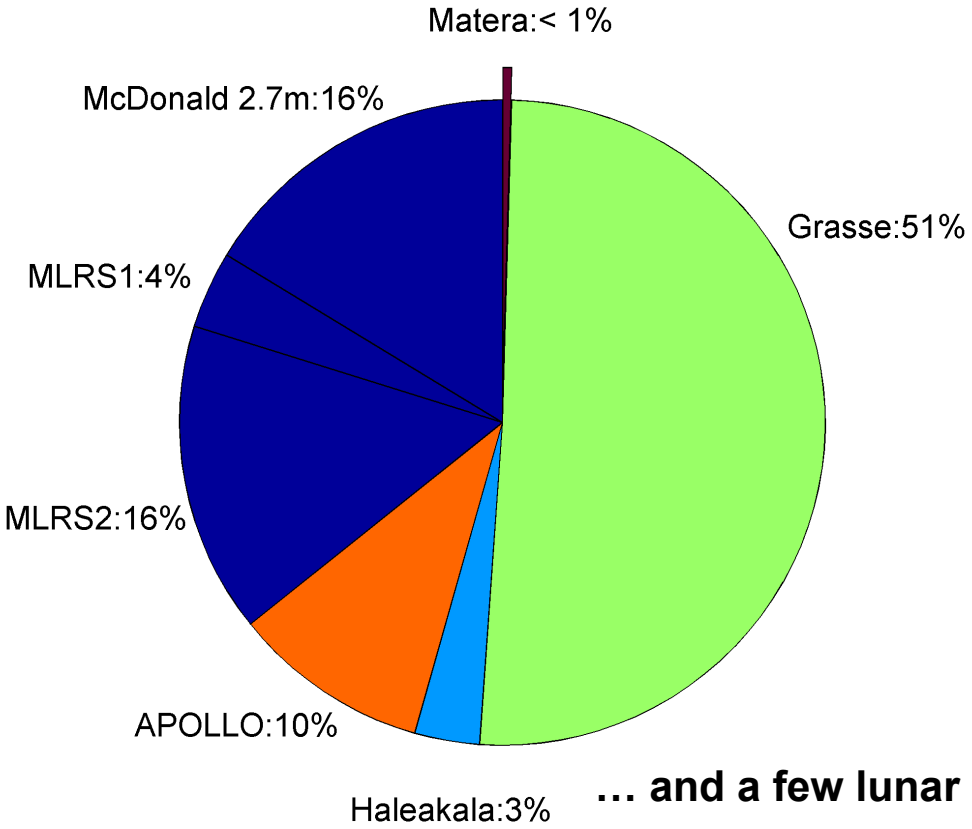
  - with different focus (relativity, lunar interior, etc.)

- Comparison of LLR software ongoing work between ACs
- Continued funding of 2 LLR projects at IfE, Germany
- Simulation of impact of new LLR sites and/or reflectors with various options – ongoing with D. Currie
- Various studies on combined use of LLR, GRAIL and LRO data
- Continuous publishing of LLR results
- LLR part on ILRS website has to be updated

Statistics – retro-reflectors and observatories

Time span **1970-2014**





now about **20,860** LLR normal points

… and a few lunar tracks from

- **Orroral**
- **Wettzell**

ILRS AC work at SGF Herstmonceux

Brief update

Graham Appleby, Jose Rodriguez

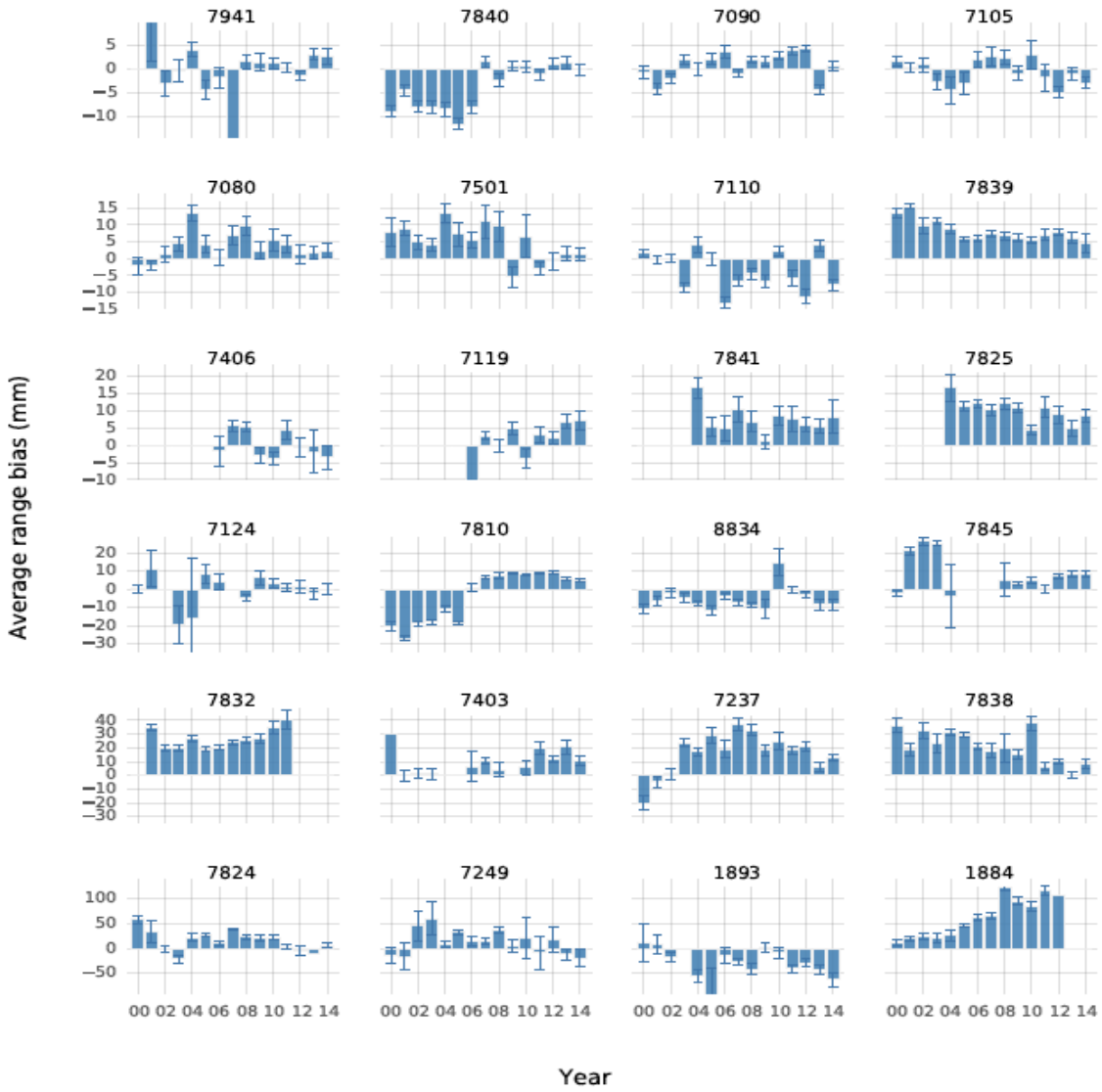
SGF Herstmonceux, UK

SGF Herstmonceux

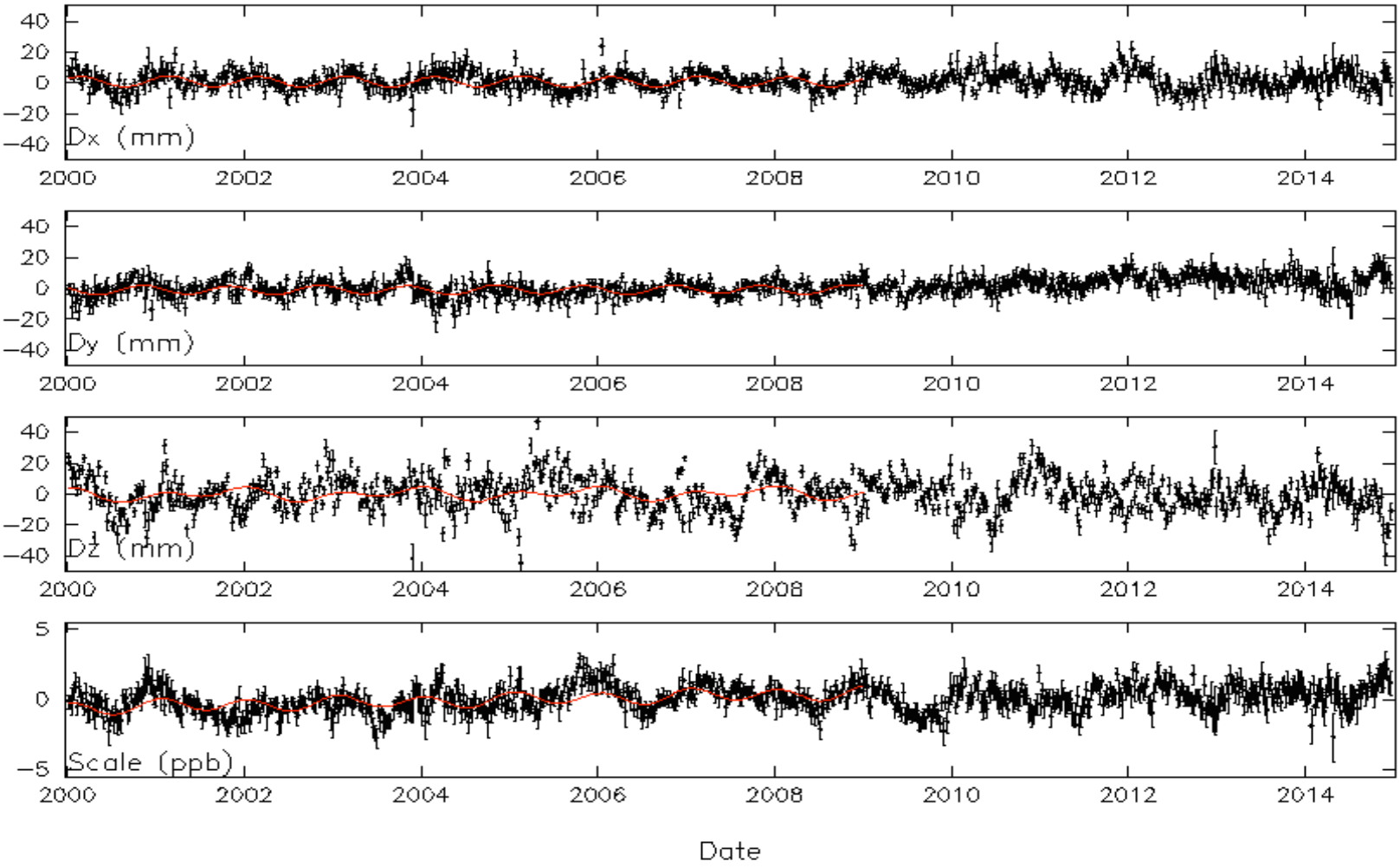
- Laser ranging solutions from 1983 to 2015.0 submitted for combination towards ITRF2014.

- Work on station bias issues:
  - While under development, presented at AWG/ EGU 2014, UAW 2014, AGU 2014
  - Full paper drafted, including rigorous sensitivity tests, GM estimates.
- Main results:

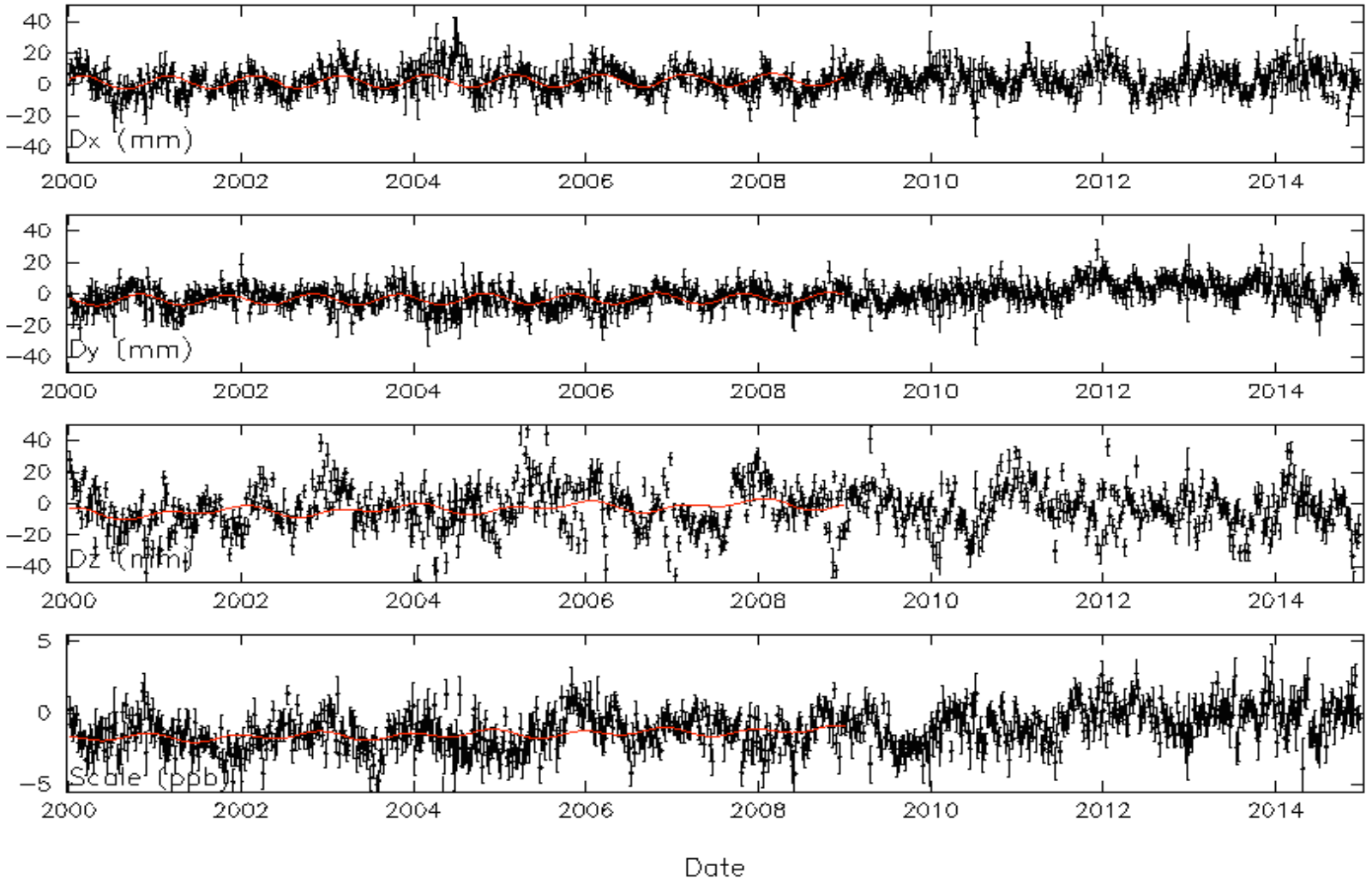
One-year av RB solutions for major sites – zero a-priori



Translations and scale wrt ITRF2008 – 'ILRS standard' solutions



Translations and scale wrt ITRF2008 – ‘all range bias’ solutions



Numerical results (mm and ppb)

Translation and Scale with respect to ITRF2008

	Regular solution			Range Bias Solution		
	mean	s.e.	σ^2	mean	s.e.	σ^2
ΔX	+0.8	0.4	24	+0.9	0.7	51
ΔY	-1.1	0.4	21	-4.0	0.5	31
ΔZ	-0.6	1.1	128	-6.8	1.4	212
Scale	-0.6	0.1	0.6	-1.8	0.1	1.5

(annual and semi-annual and linear terms fitted to weekly values)

Conclusion

- Weekly L1 & L2 Solutions for 2000-2015.0
- 'standard' AWG-agreed RB solutions
  - Translation and scale agree with ITRF2008 SLR
- 'all RB' solutions are possible, with 1 RB per station, per week, using L1+L2 combined
  - Increased solution variance, but systematic-free
  - Scale change 1.2ppb
  - T_y and T_z non-zero and significant
- RB at stations almost certainly of technical and/or modeling (CoM) origin