ASI AC&CC report

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ILRS AWG Meeting, 28 April 2014, Vienna

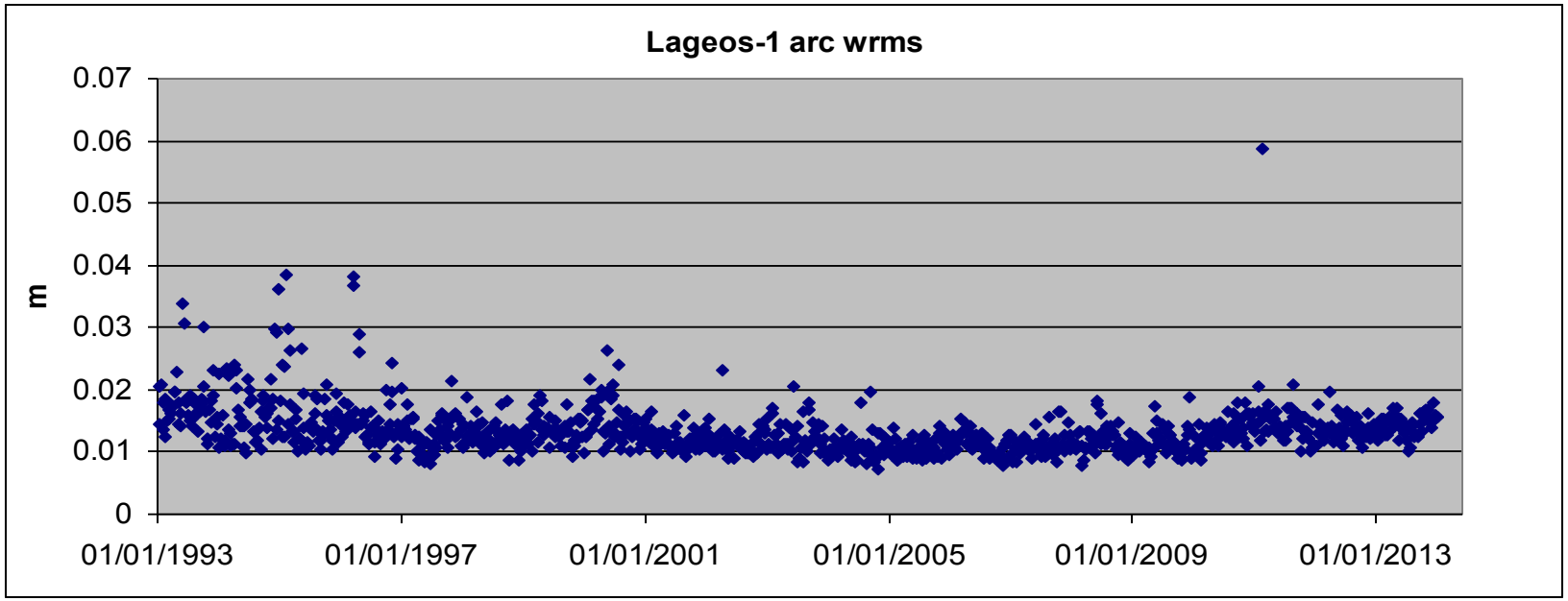
Main activities

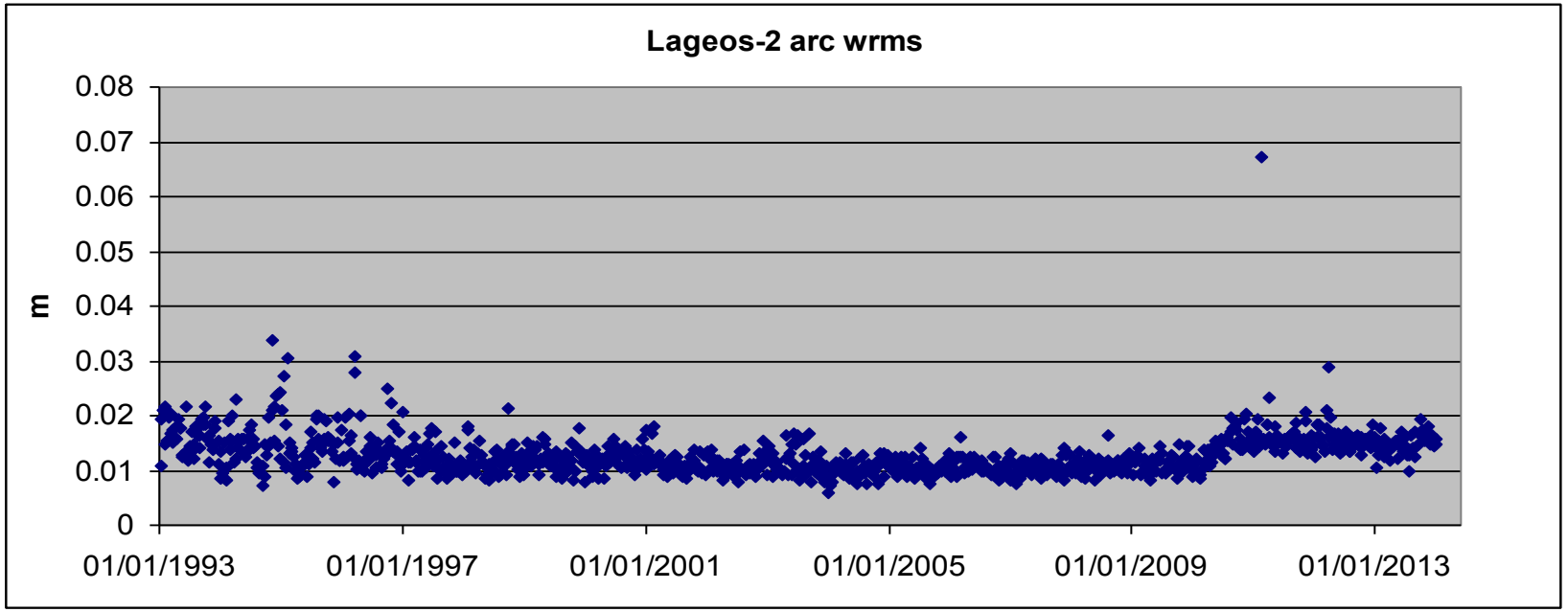
- Update of SLRF2008
- Contribution to the review of the data handling file and core station list
- 1993-2013 v60 time series for ITRF

Updated models

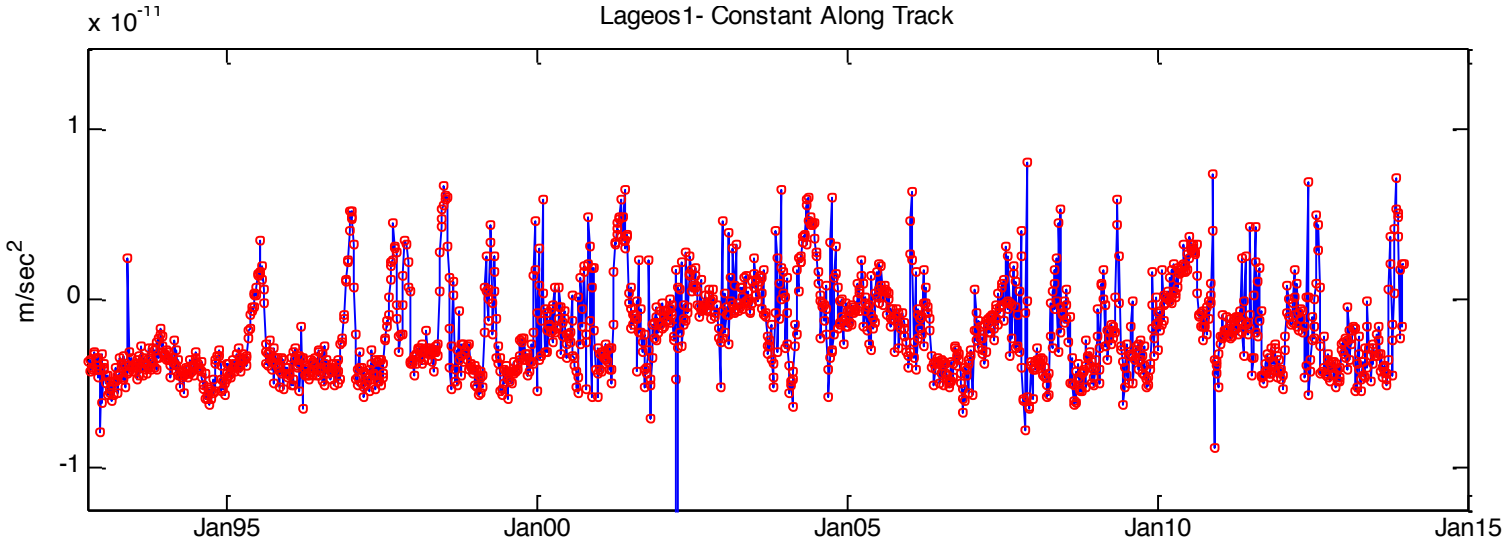
	ITRF2013	ITRF2008
Gravity field, static	GGM05S	EGM96
Gravity field, time dependent	C20,C21,S21,C30,C40,C50,C60 from CSR/UT	C(2,0), C(2,1), S(2,1) as EGM96 specs
Atmospheric tides	Ray&Ponte model 2003	NONE
A priori reference frame	SLRF2008	SLRF2005
Mean pole	Value and rate time series	IERS convention
Center of Mass correction	according to CoM corr tables	Lageos .251 m (.245 for 7840) Etalon .580 or .610 m

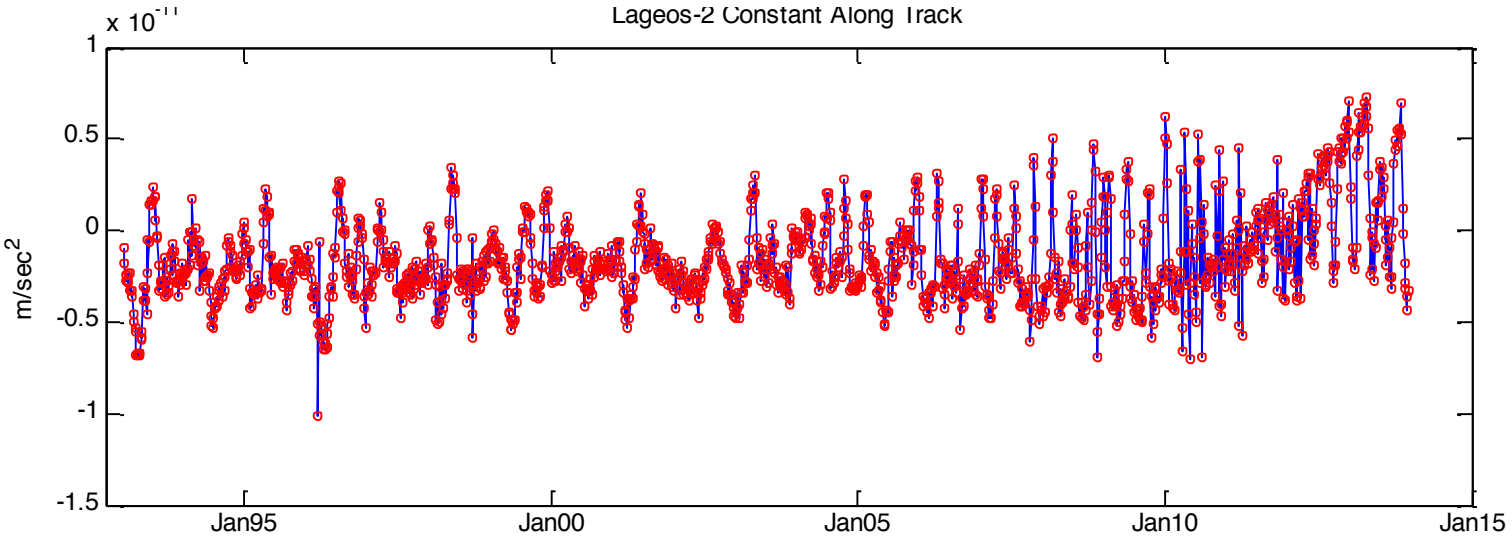
Arc residual wrms





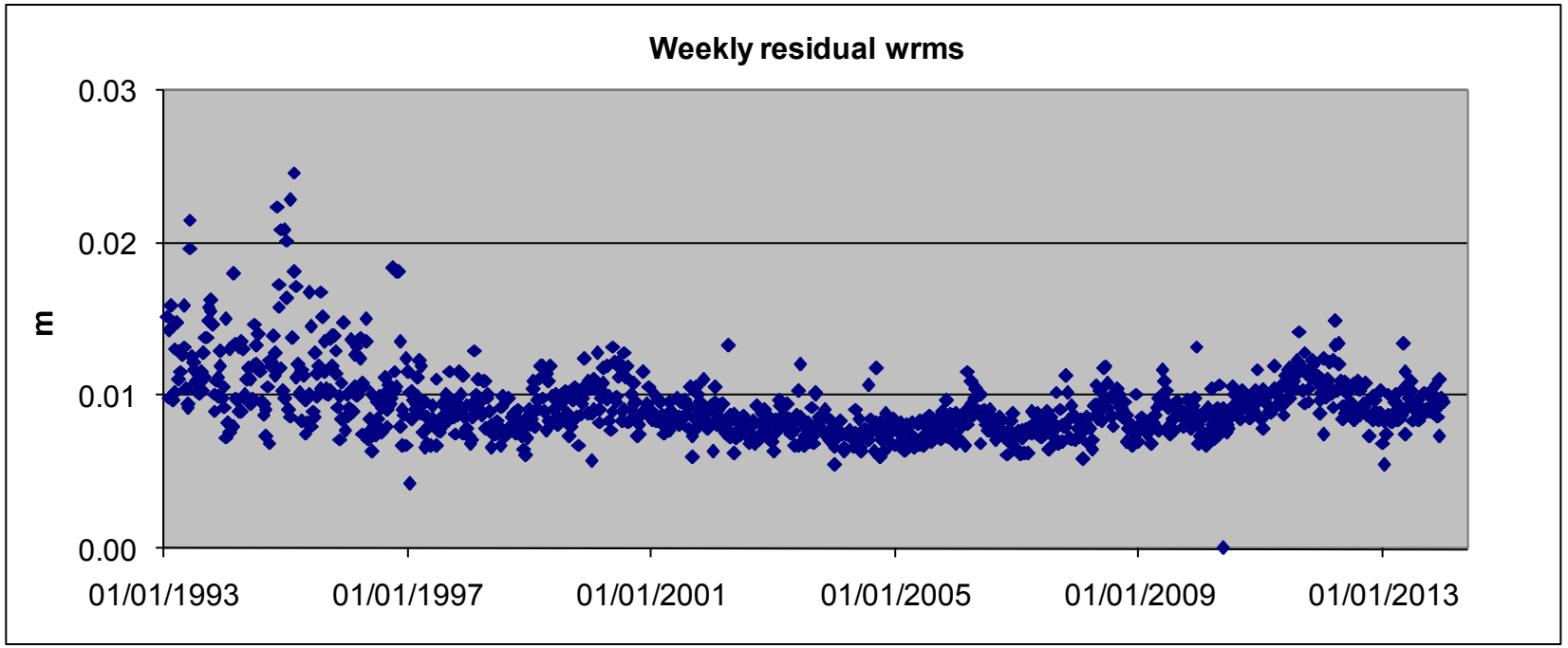
Lageos empirical accelerations



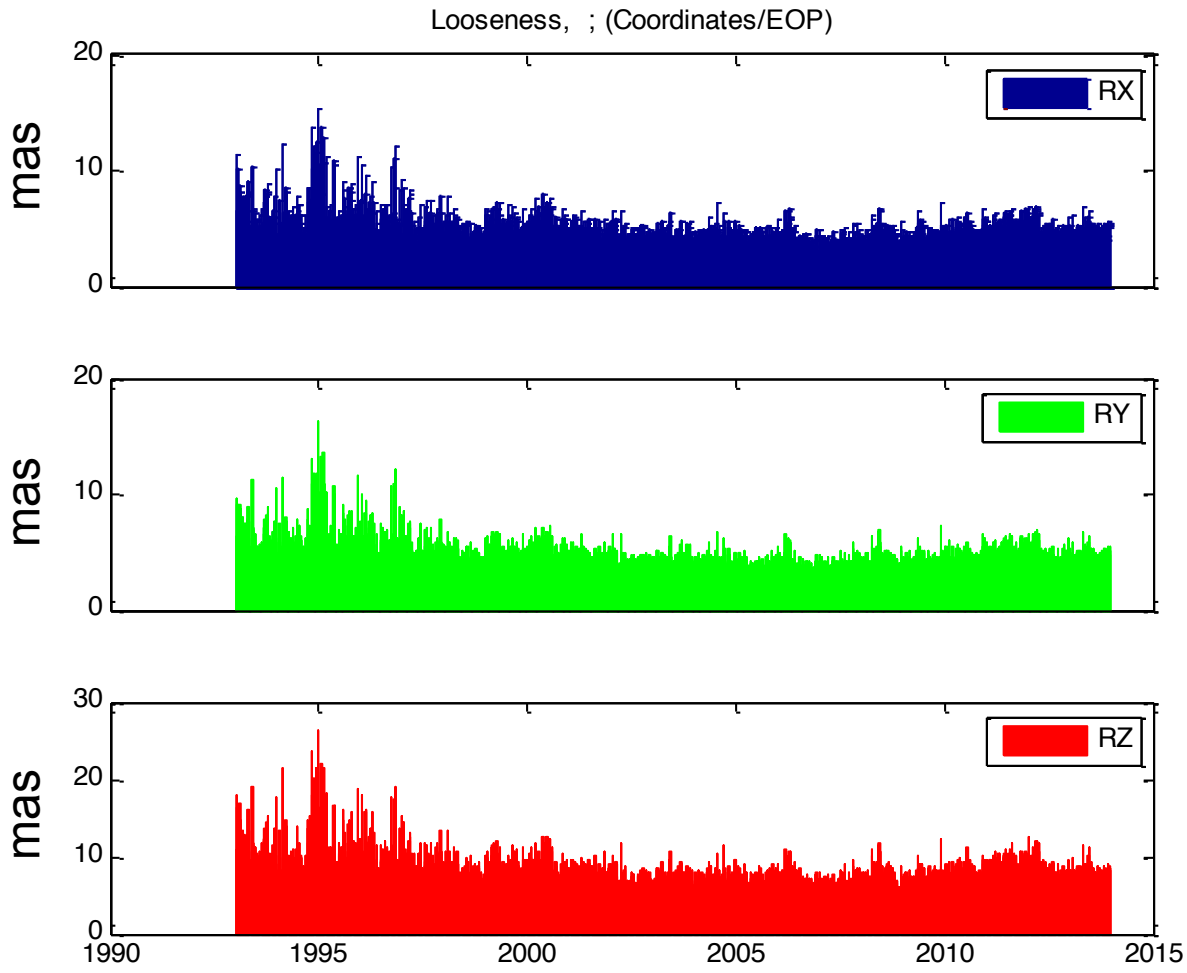


Weekly residual wrms

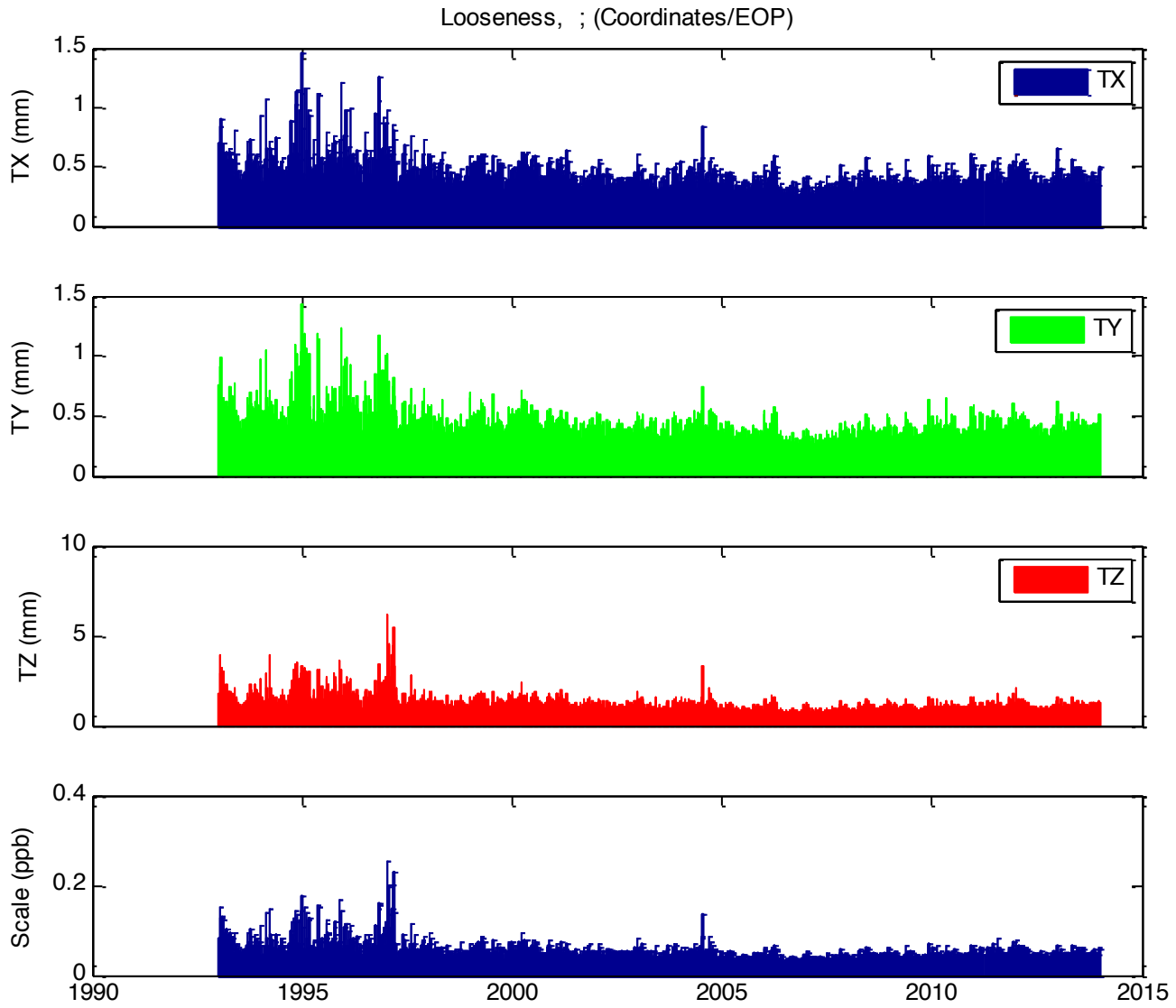
Residual WRMS of the weekly solutions (Lageos and Etalon), after coordinates and eop estimation



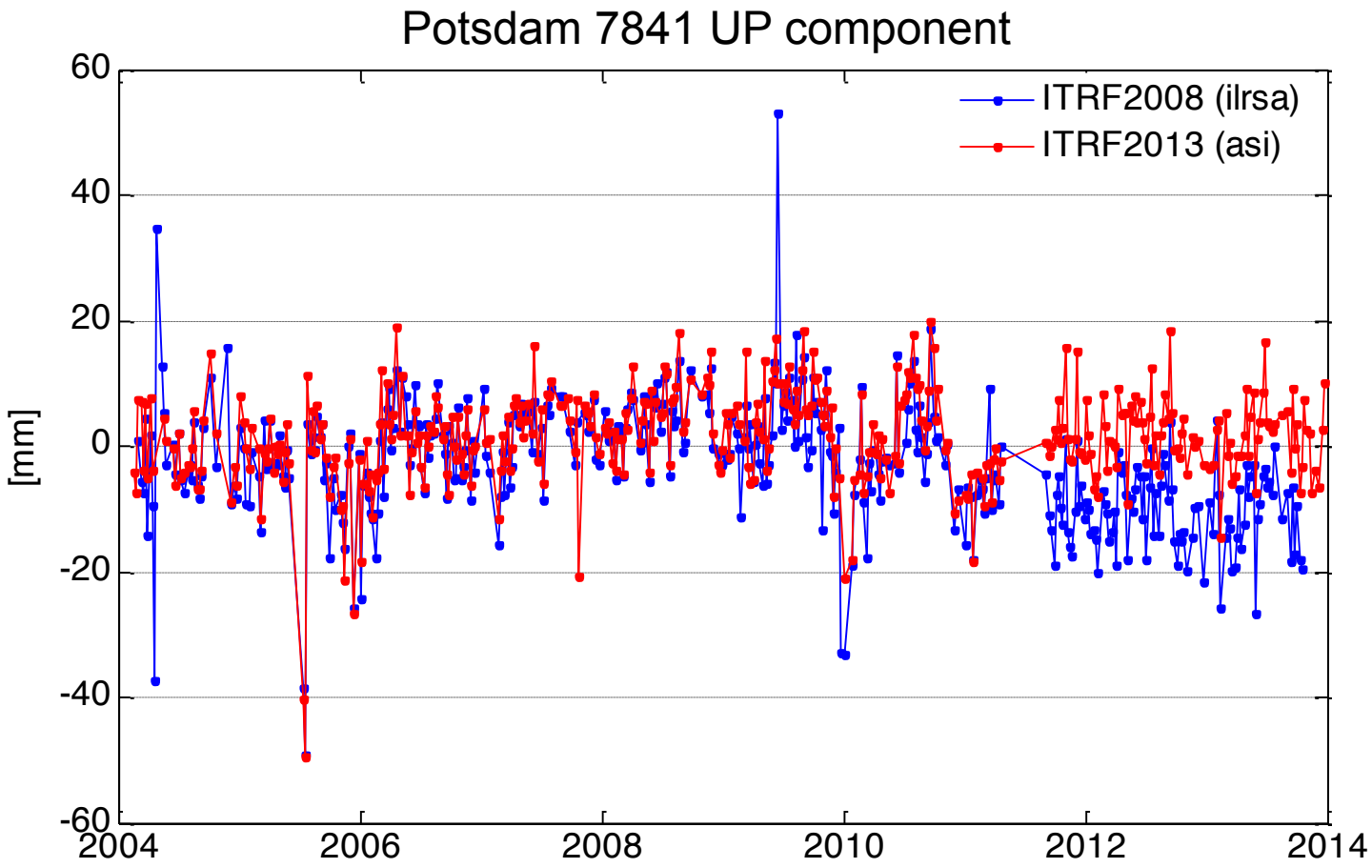
Looseness


Looseness, ; (Coordinates/EOP)
mas
20
10
0
RX
mas
20
10
0
RY
mas
30
20
10
0
RZ
1990
1995
2000
2005
2010
2015

Looseness


Looseness, ; (Coordinates/EOP)
TX (mm)
1.5
1
0.5
0
TX
TY (mm)
1.5
1
0.5
0
TY
TZ (mm)
10
5
0
TZ
Scale (ppb)
0.4
0.2
0
1990
1995
2000
2005
2010
2015

Satellite CoM model application

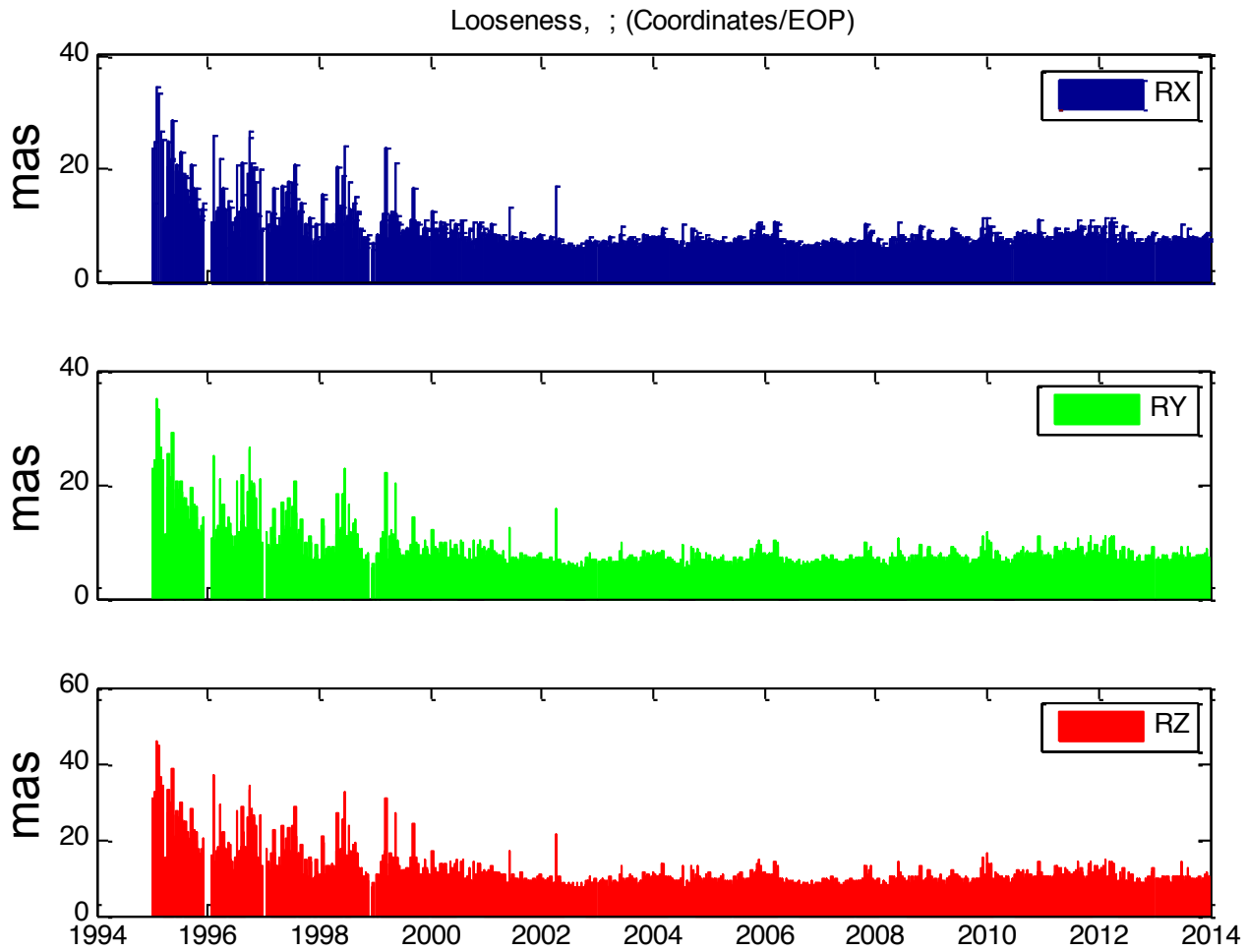


First steps towards ITRF2013

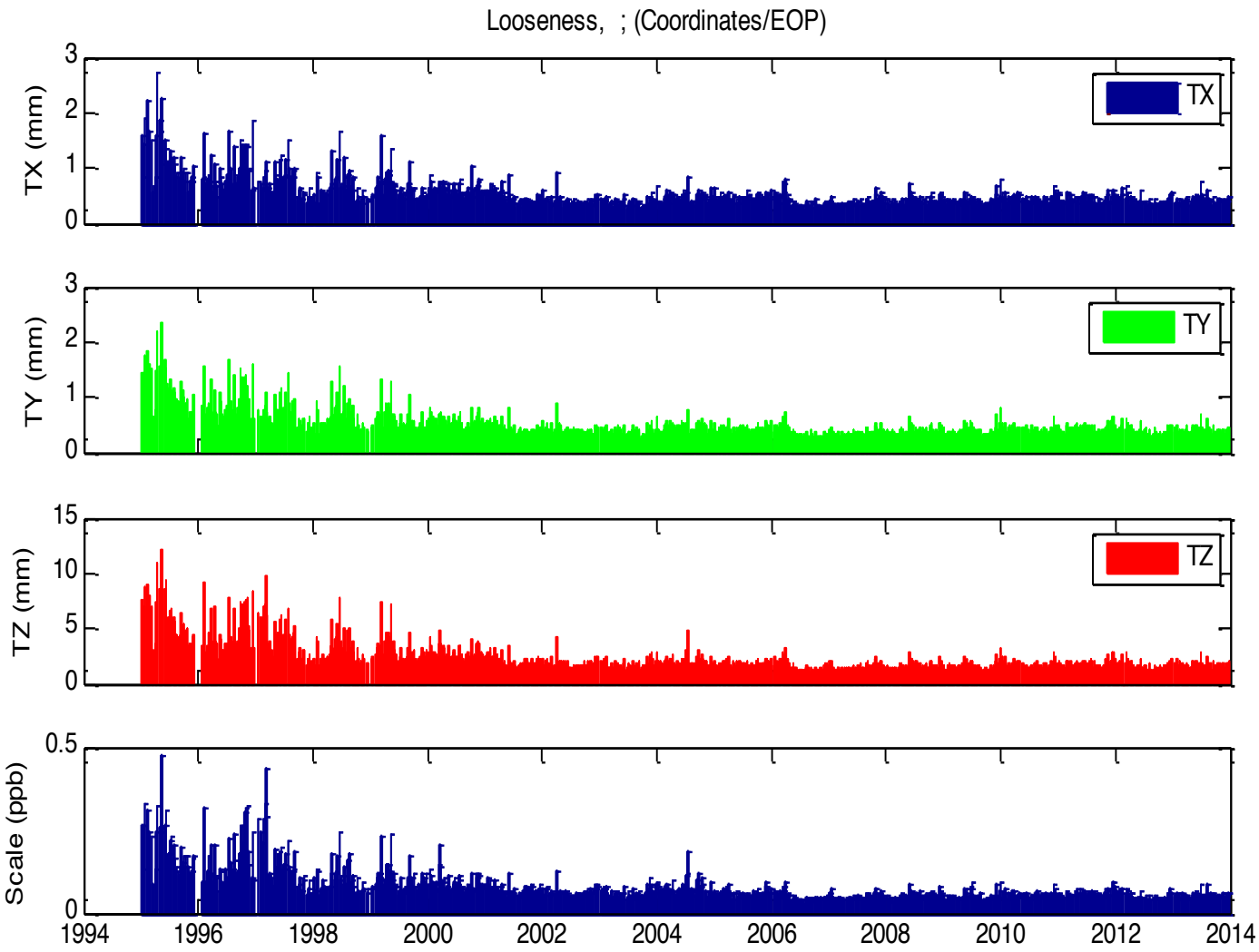
AC solution submitted so far:

AC	ver	period	notes
ASI	v60	1993-2013	
DGFI	v60	1998-2013	more than 80 files with zero line in the varcov matrix.
ESA	v59	1995-2013	Preliminary time series with old models
GRGS	v60	10/2008- 2013	
JCET	v60	1993-2013	

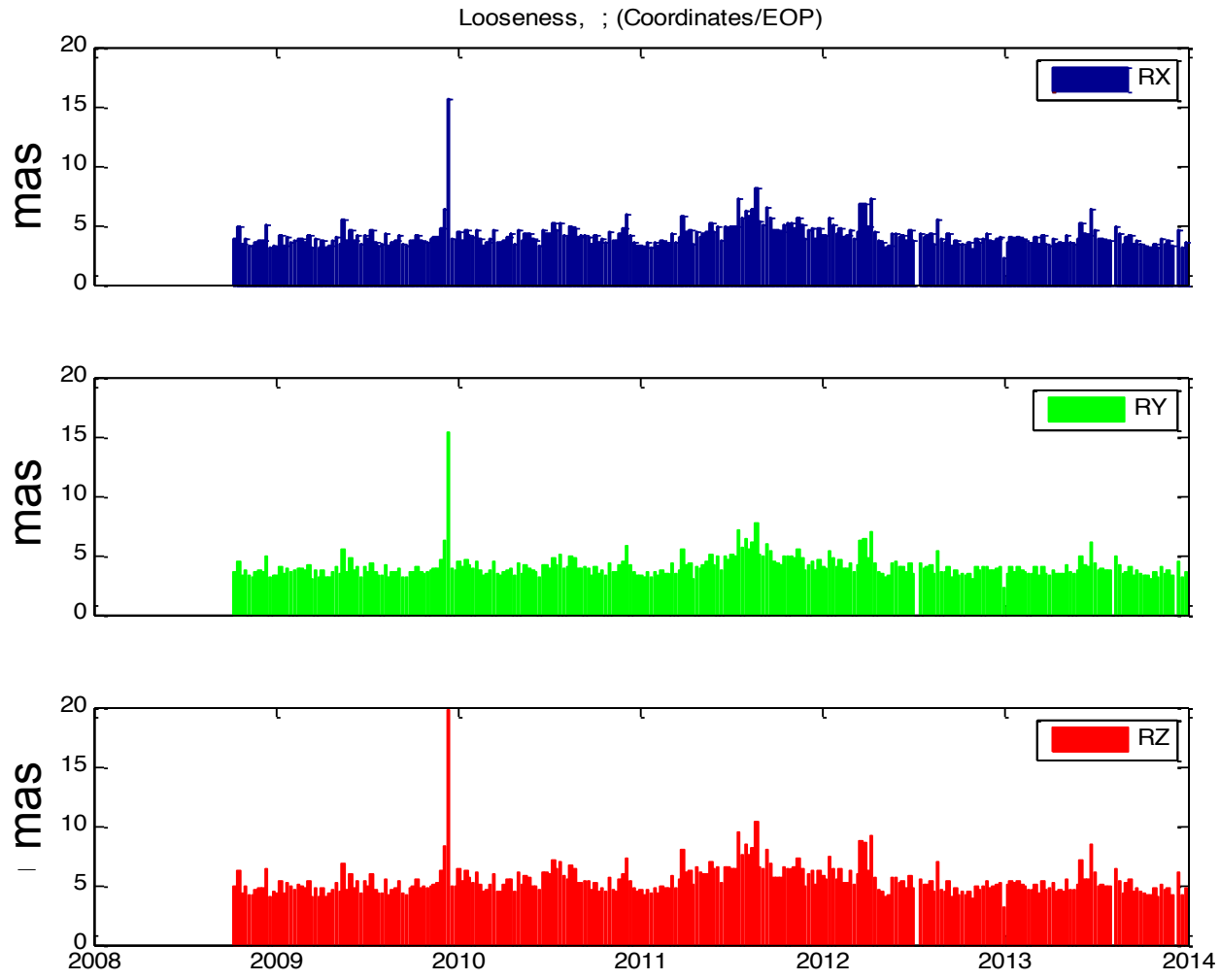
ESA looseness



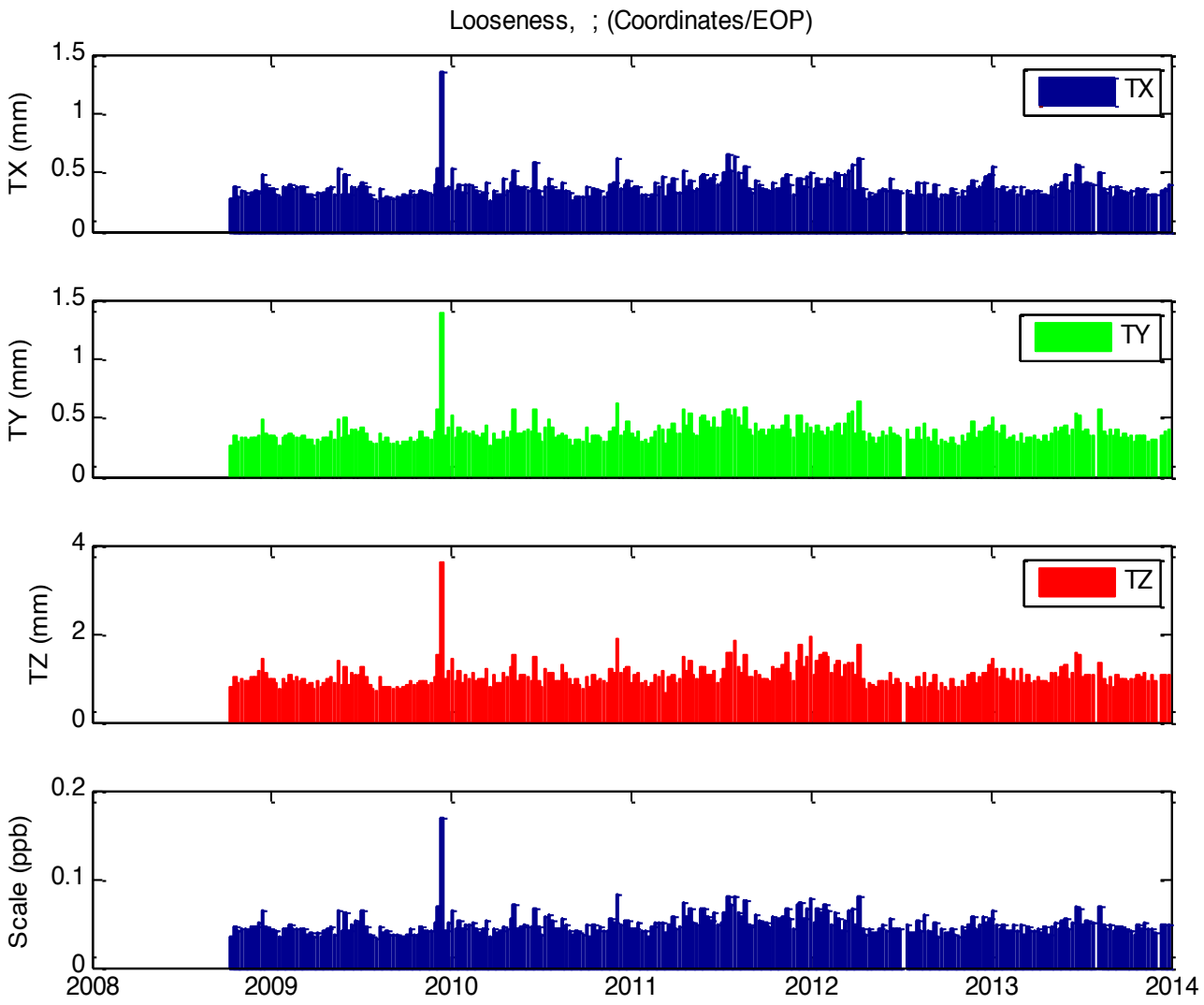
ESA looseness



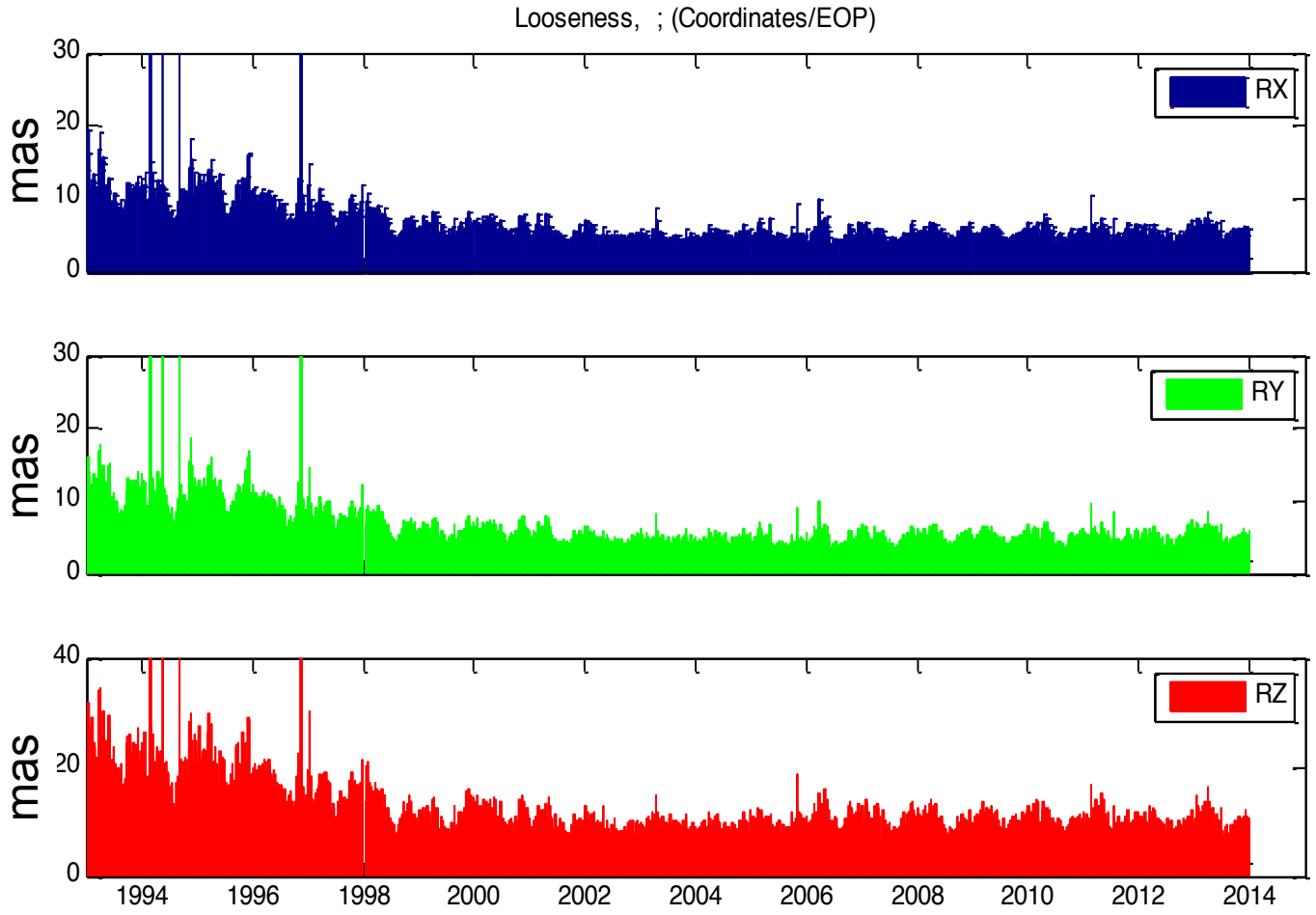
GRGS looseness



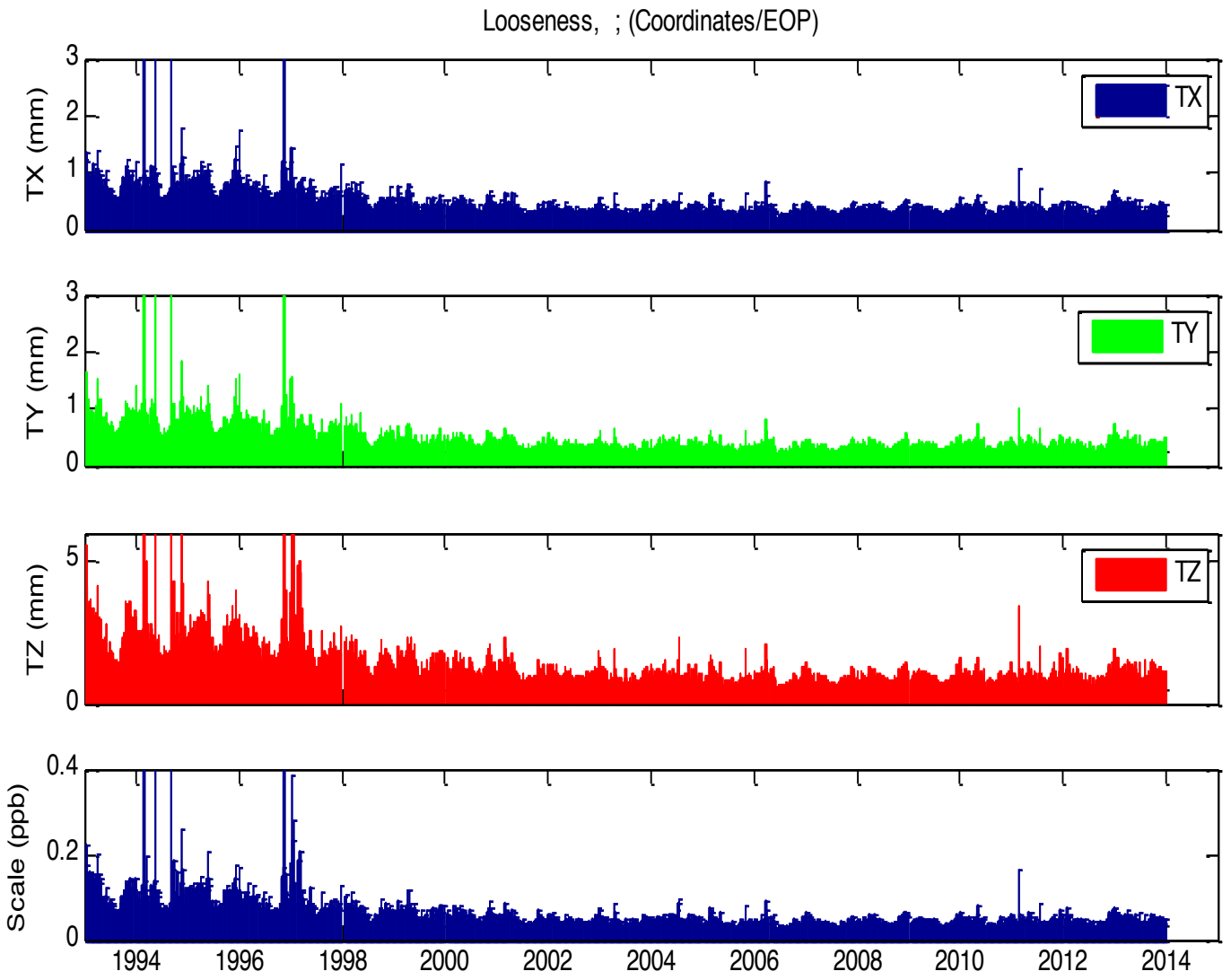
GRGS looseness



JCET looseness

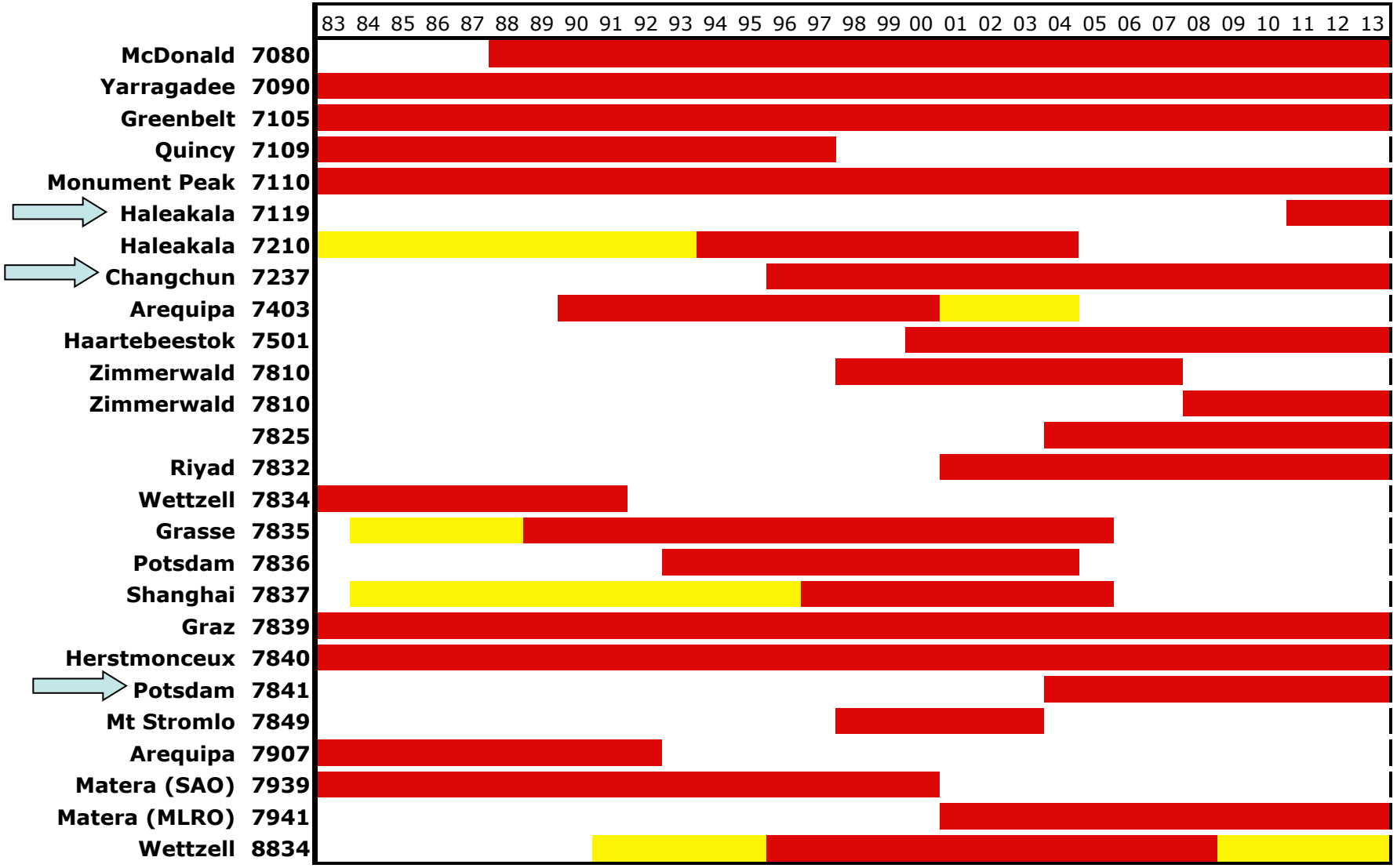


JCET looseness



Core sites

The core sites are used by the CC only to evaluate the AC solutions



ILRS AWG meeting Vienna
ESA/ESOC status

T. Springer, E. Schoenemann, R. Zandbergen
28/04/2014

Reprocessing Status

- 1993-2013
  - Done with normal (V40) setup. Submitted with label "V59" for Cinzia
  - Done second time with IGS and IDS modelling
    - Very close to ILRS proposed models
- 1983-1992
  - Done a first "rough" time
  - Except for some initial issues with handling the "old" data format no real problems encountered

Reprocessing Model Differences

- Current ESOC IGS/IDS models deviations from ILRS models
  - Gravity field: EIGEN-6S2
    - Difference should be small
    - But lacking the 15-day C20 and C/S21 values
    - -> We are implementing GGM05S
  - Ocean loading: EOT11A
    - Differences to GOT4.7 should be insignificant
  - Mean pole
    - Currently using IERS model (polynomial)
    - Expected difference?

Open Questions

- 15-day C/S21: Can these be computed using the standard IERS convention equation using the mean pole and the C20 (and C/S22) value? Or do we have to take them from the files?

- Are the mean pole values significantly different from the IERS 2010 polynomial?
    - Prefer to keep using the IERS polynomial (safes implementation effort)

Main Issues

- Implementation of reading the 15-day C20 values
  - And, if needed, the C/S21 values
- Ocean Pole Tide
  - We consider only effect on C21 and S21 not 20x20
    - That is 90% of the total effect
    - Are the higher terms really needed, i.e., are they significant?
- Can we use IERS 2010 mean pole polynomial?
- (post ITRF2013) Implementation of estimation of gravity field coefficients

Announcement

ESA/ESOC is organising a dedicated POD conference at ESOC, Darmstadt, Germany in May 2015 (TBC). Details will be announced in June 2014. The POD conference will cover all areas of POD, including:

- **Constellations and orbits**

  GNSS, LEO, MEO, GTO, GEO

- **Techniques**

  GNSS, Satellite Laser Ranging, Doris, Radar Altimetry

- **Algorithms and models**

  Force models, Data processing, Optimisation, …

- **Hardware and Processing concepts**

  Onboard Receivers, Real Time, Batch processing …

- **Interaction between different POD stake holders**

  Service providers, System providers, Science community, End Users,…

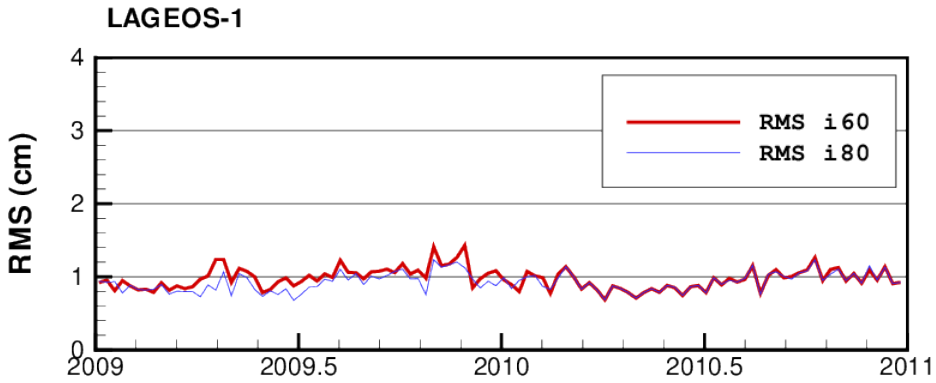
Contact: Werner.Enderle@esa.int

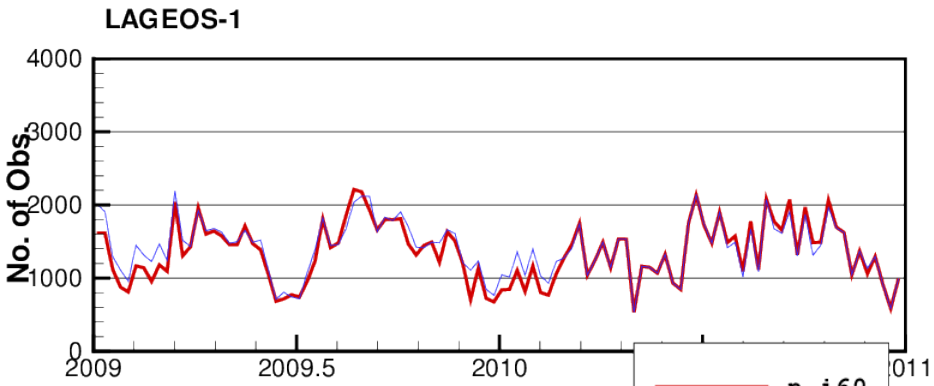
Status GFZ Contribution to ITRF2013

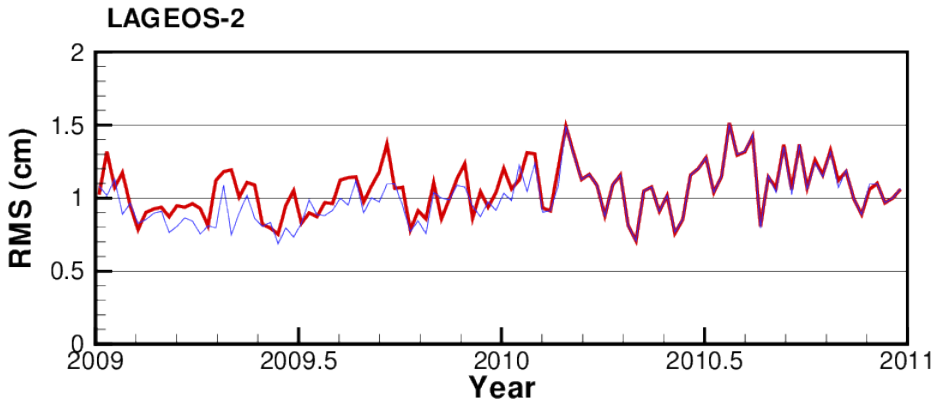
- As a basis arcs 1983 – 2011 are available based on one standard (which is not the one requested)
- Based on these arcs
  - SLRF2008_140210_final has been adopted and tested
  - Data Handling File including latest changes as of 04-APR-2014 has been adopted and tested
    - Except some station bias issues
- Open:
  - Some station bias issues
  - Adopting and testing GGM05S
  - Adopting and testing of Cheng's time variable gravity coefficients
  - Adopting and testing of Pavlis' meanpole series
  - Checking and eventually upgrading and testing of FES2004 ocean tide loading displacements
  - Testing of Knocke albedo modelling

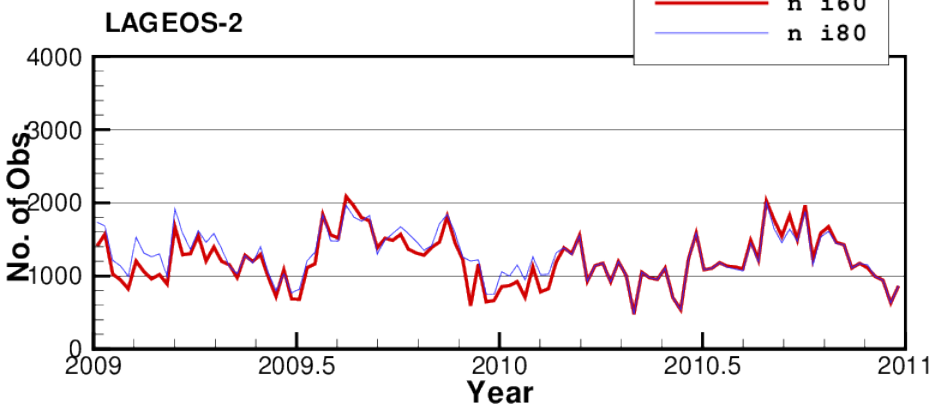
Status GFZ Contribution to ITRF2013

- i60 ... old standard
- i80 ... new SLRF2008 and data handling









JCET Contribution to ITRF2013 Reanalysis

Erricos C. Pavlis
GEST/UMBC, Baltimore, MD, USA

Spring AWG 2014, TU Vienna, Austria
April 30, 2014

Modified Gravitational Modeling

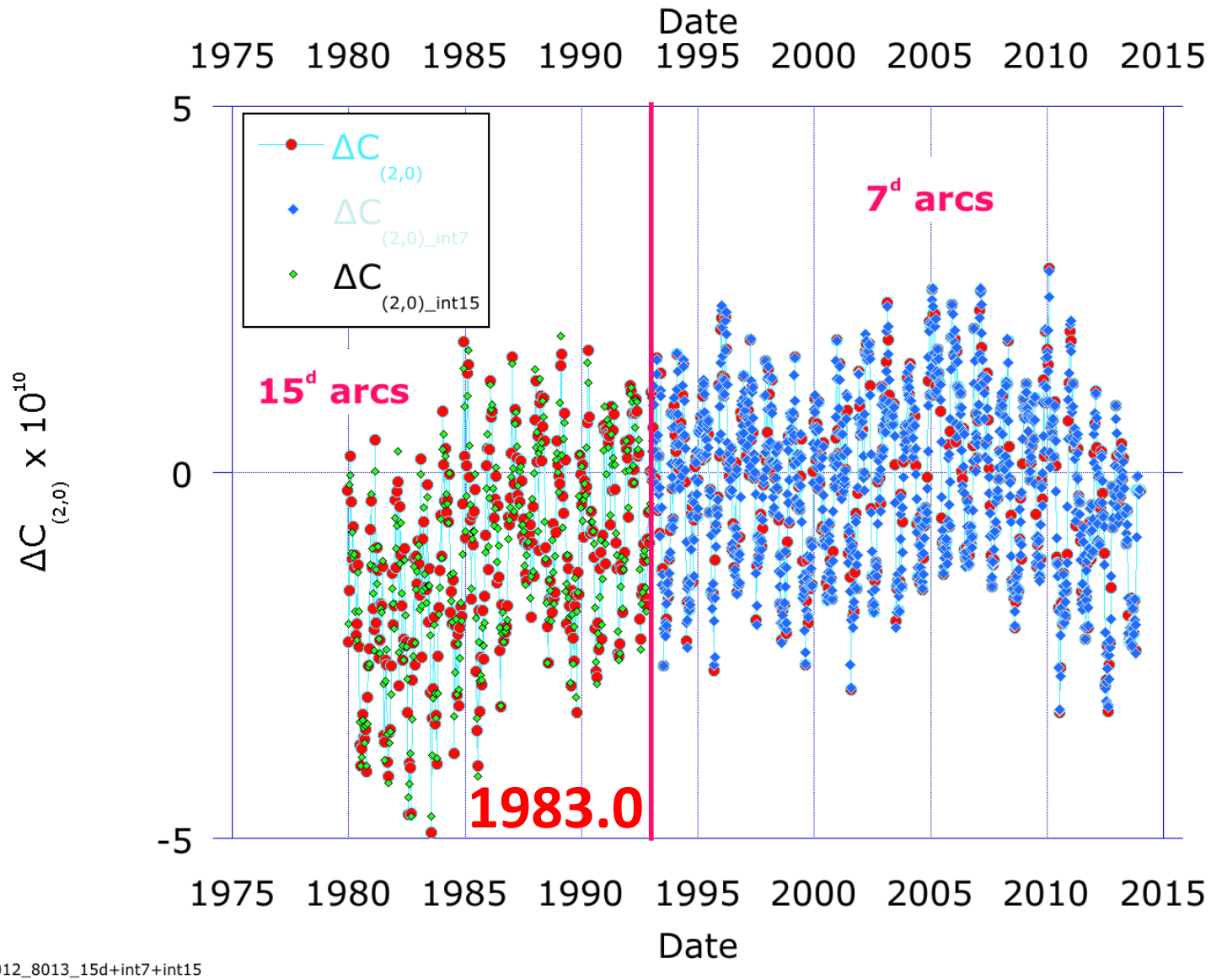
- New static model adopted: GGM05S

1) $C_{(2,0)}$ & $C/S_{(2,1)}$ from CSR's 15-day series, interpolated and evaluated on the mid-arc epoch of our 15-day arcs (one file per arc)
2) $C_{(2,0)}$ & $C/S_{(2,1)}$ from CSR's 15-day series, interpolated and evaluated on the mid-arc epoch of our 7-day arcs (one file per arc)
3) The nominal zonal terms' values for our use (from CSR's GGM05S) and their rates from *Cheng et al., 1997*
4) The zonals for degrees 3 to 6 (from #3), evaluated at the 15-day arc mid-arc epochs using the linear rates given in #3 above
5) As in #4 above, but for the 7-day arcs

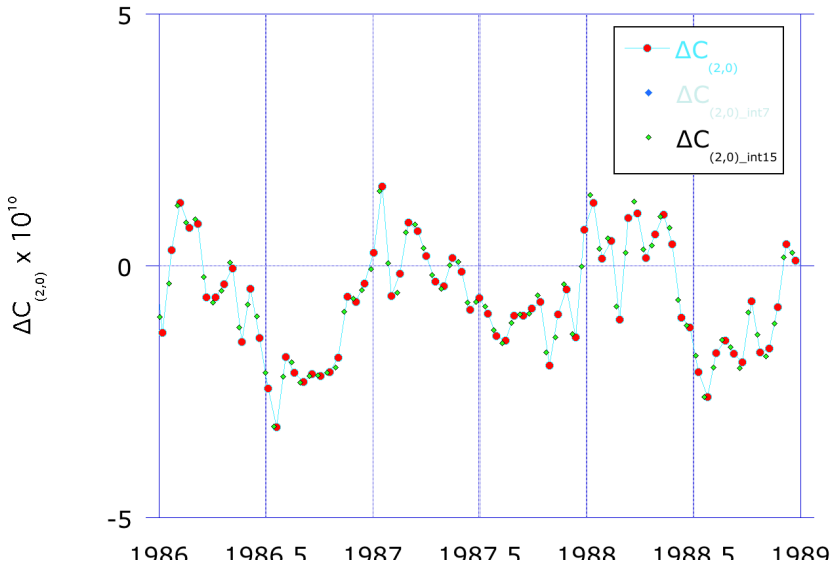
Modified Gravitational Modeling – cont.

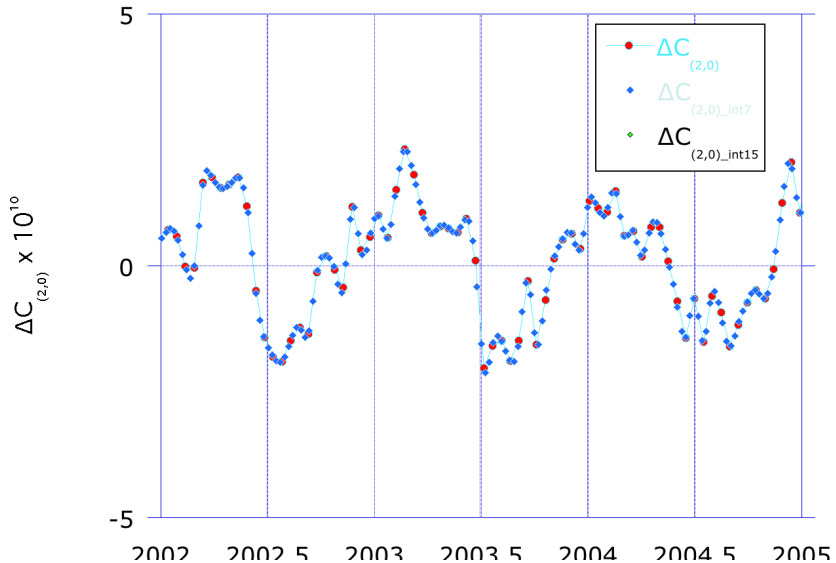
1) A series with the daily mean pole coordinates and rates in GEODYN-formatted POLDYN records from the interpolated/extrapolated IERS mean pole series, tagged with the 15-day arcs' starting date (see explanation in the appropriate document and for a format description see #3)
2) As in #1) above, but for the 7-day arcs
3) Description of the format for the GEODYN "POLDYN" cards
4) The final version of SLRF2008 to be used as the starting positions and velocities for the re-analysis
5) The official release "gfc"-formatted version of GGM05S (with zero-tide and tide-free versions of $C_{(2,0)}$ by ECP)

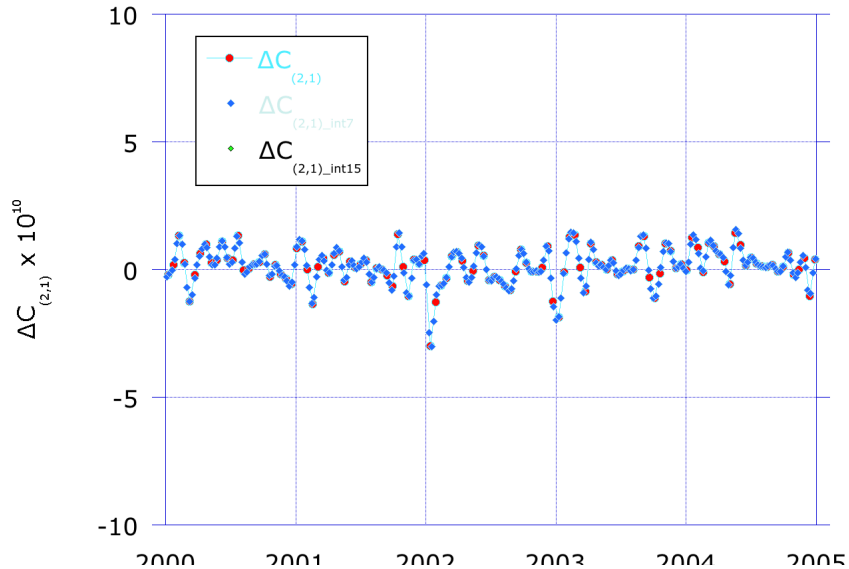
$C_{(2,0)}$ Gravitational Modeling

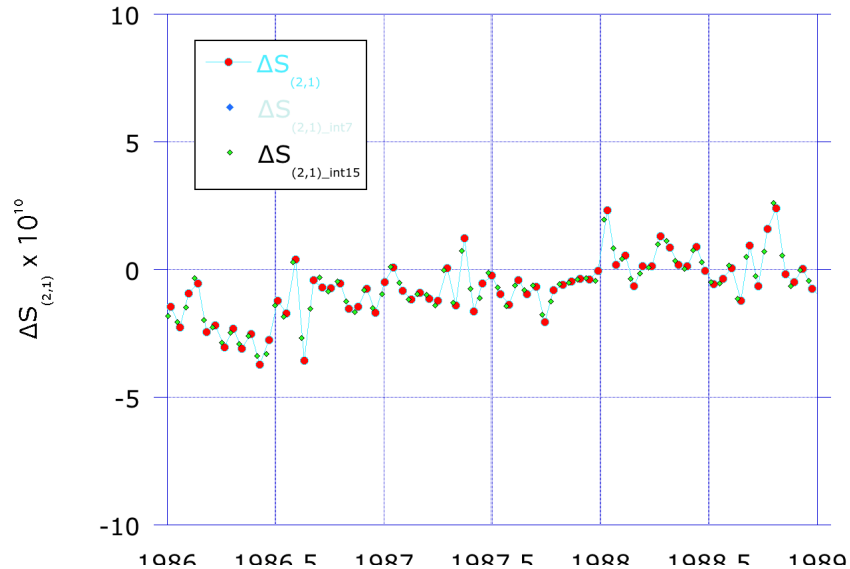


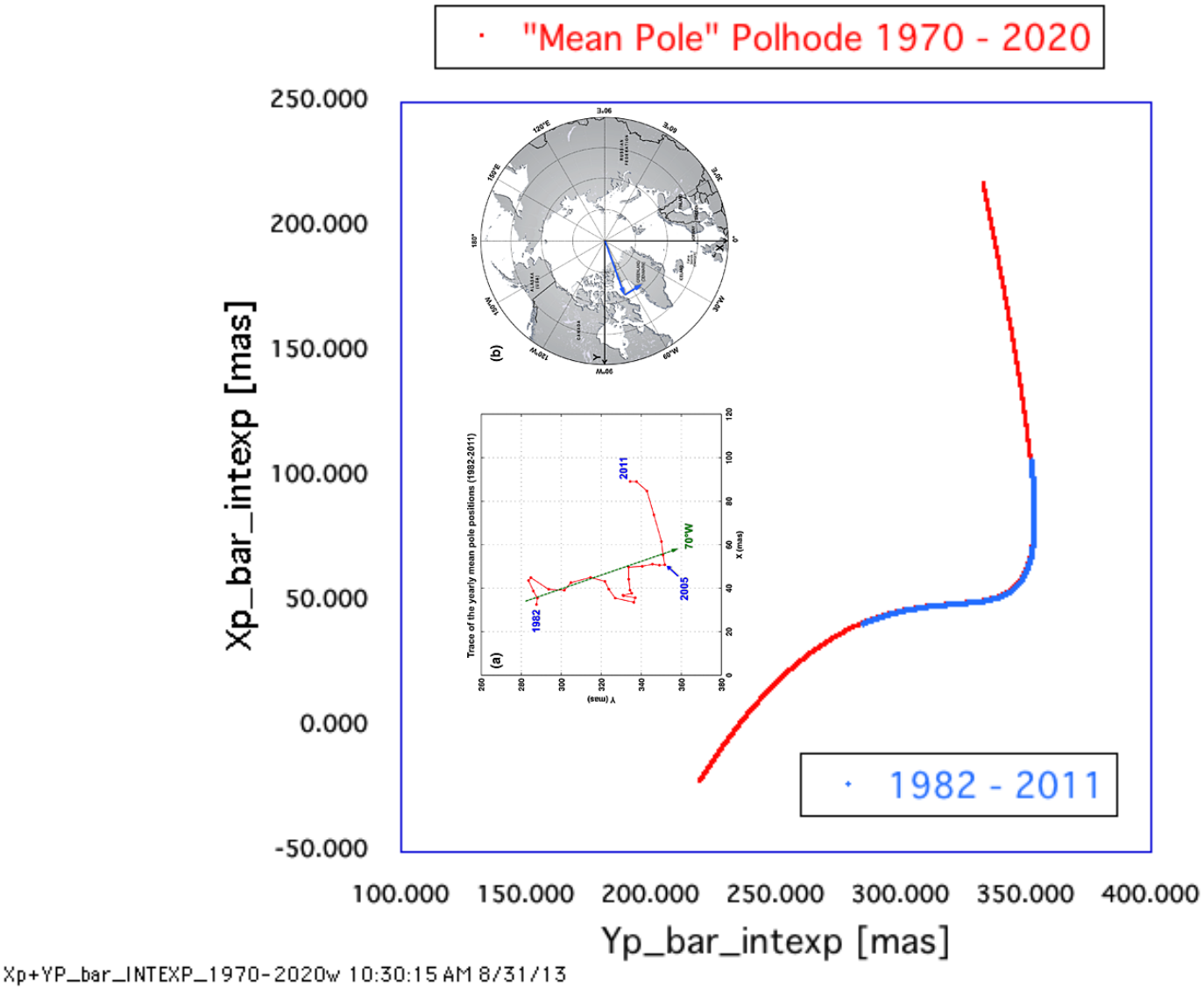
$C_{(2,0)}$ & $C/S_{(2,1)}$ Interpolation







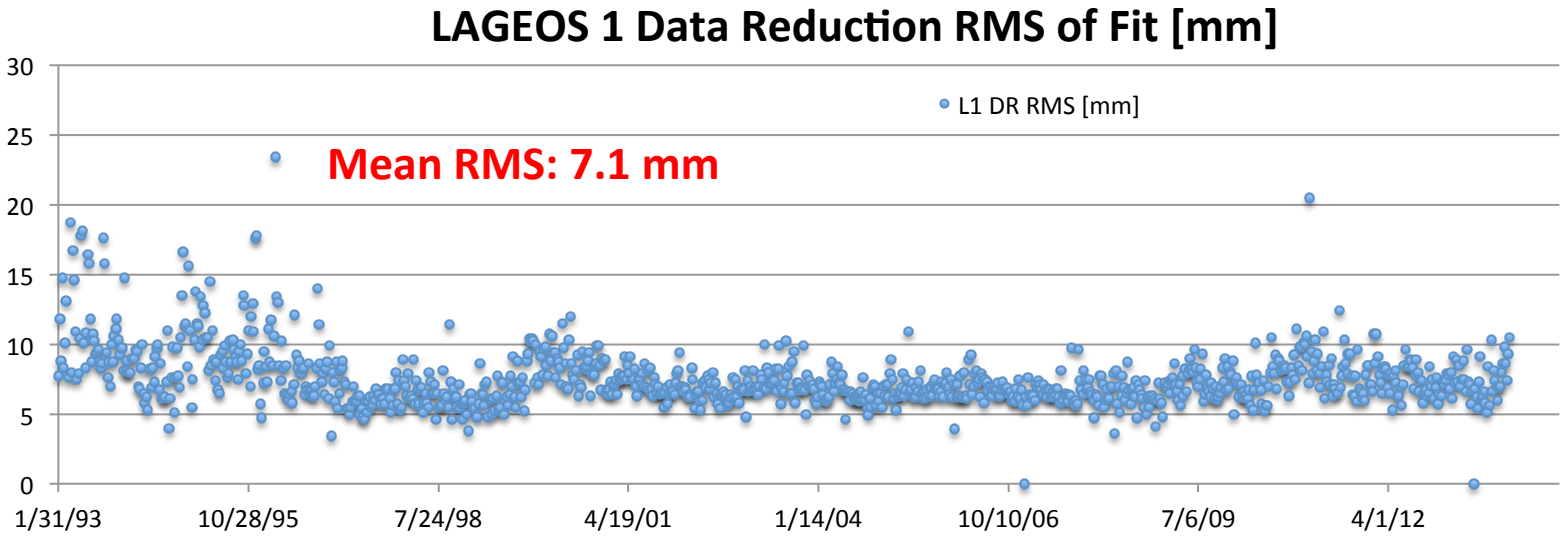


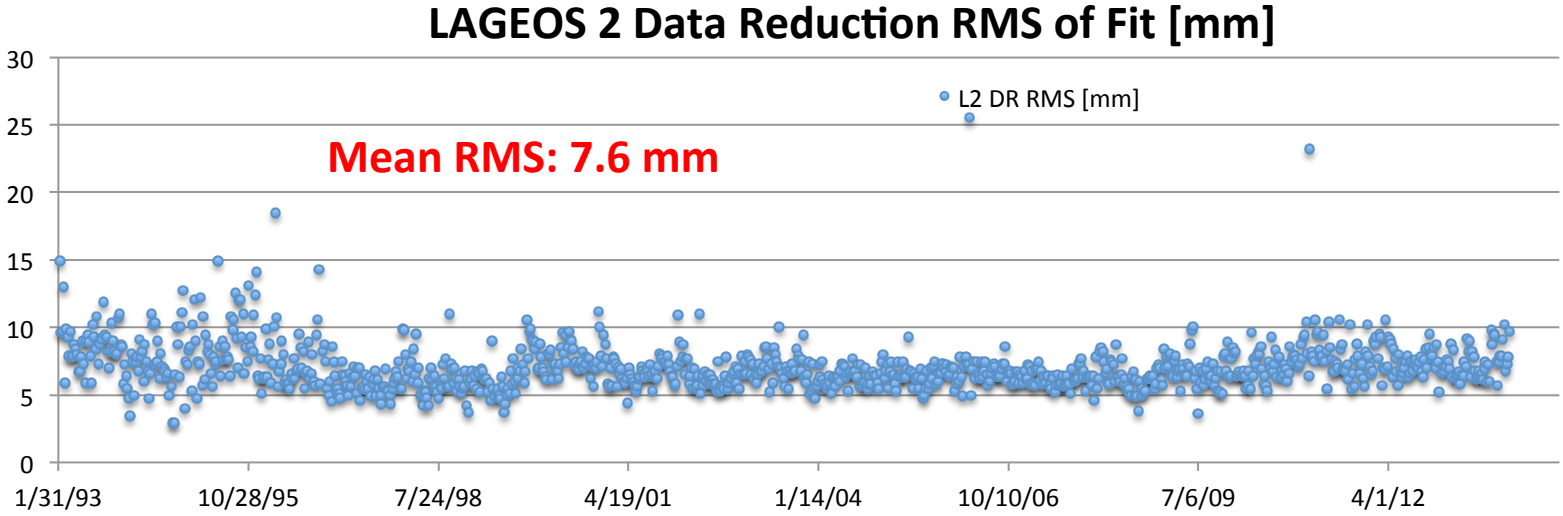

"Mean Pole" Polhode 1970 - 2020
1982 - 2011
Xp_bar_intexp [mas]
Yp_bar_intexp [mas]
250.000
200.000
150.000
100.000
50.000
0.000
-50.000
100.000
150.000
200.000
250.000
300.000
350.000
400.000
Traco of the yearly mean pole positions (1982-2011)
1982
2005
2011
70°W
(a)
(b)
Xp+YP_bar_INTEXP_1970-2020w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

Current JCET Effort for ITRF2013 Reanalysis

- New models implemented and systematic error adjustment rules strictly adhered to (based on DH file and AWG rules)
- All SLR data in the period 1993 to present re-analyzed under the new standards and normal equations formed
- V60 series of SINEX-formatted solutions delivered on 18.4.2014
  - An issue of constraints level was detected in the v60 at ASI CC
  - JCET AC reviewed the solutions and corrected the issue
  - A new series, v61, is in preparation and should be delivered by now
- The re-analysis of the 1983 to end of 1992 data set will be undertaken next and the corresponding SINEX series should be delivered by mid-May at the latest
- JCET CC is ready to combine delivered series when delivered

ITRF2013 Reanalysis Arc-fit RMS



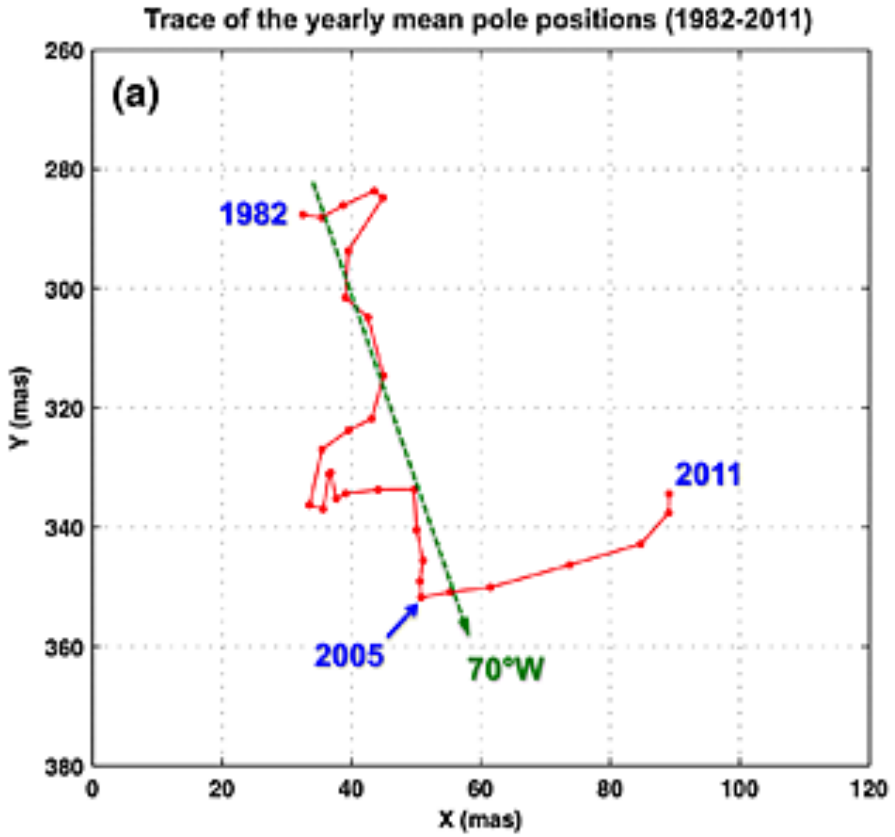


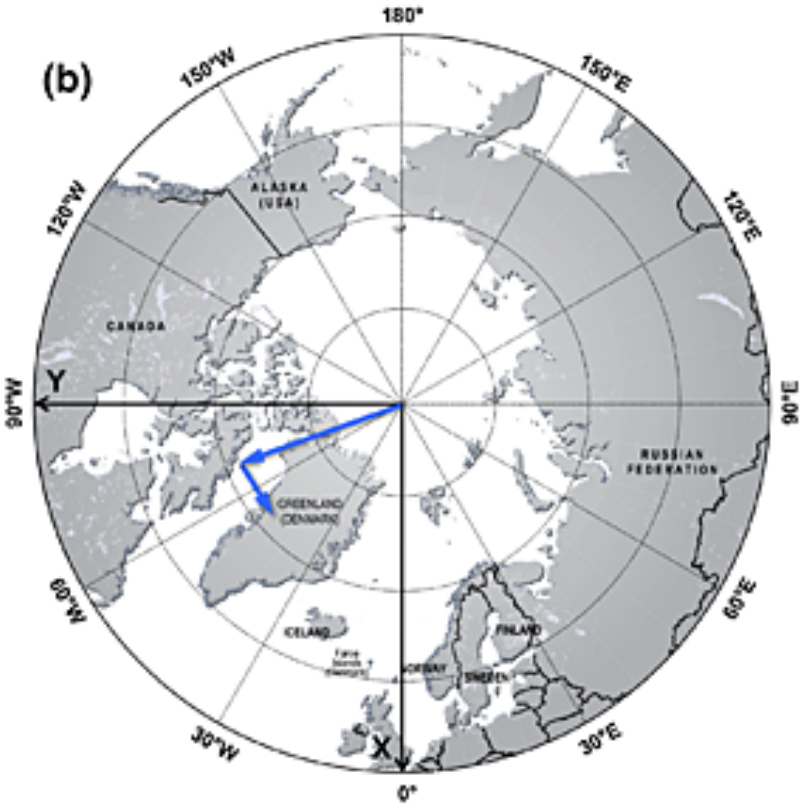
Proposed Plan for ILRS Submission

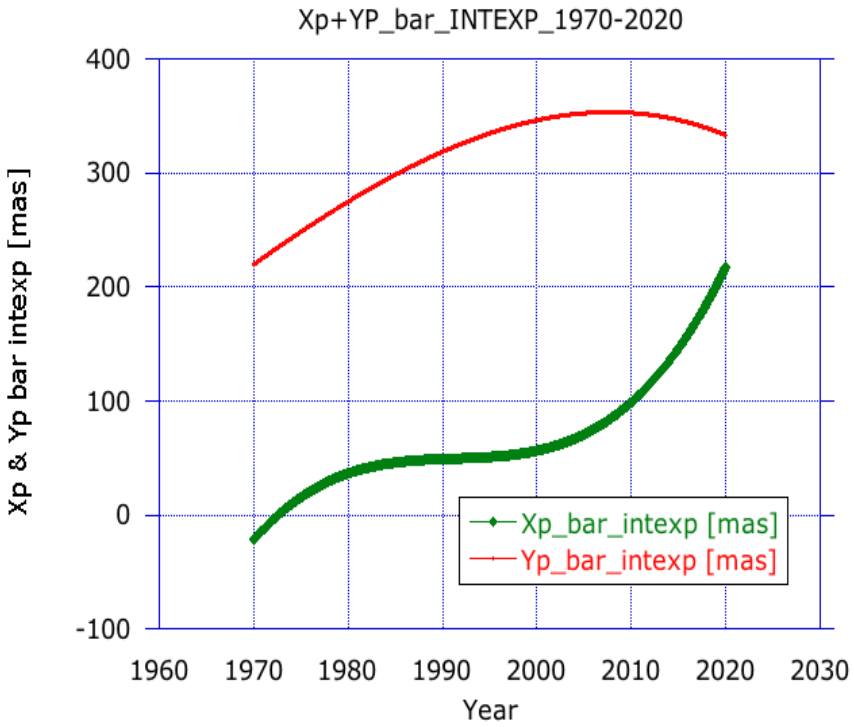
- Evaluate the 1993 – 2013 combination based on all AC deliveries, (to be completed by middle of May)
- Complete the combination process with the inclusion of the historical LAGEOS data 1983 – 1992, (by end of May)
- Deliver a preliminary ILRS combination to ITRS by early June and discuss results during the next ~one month period
- If necessary, deliver new SINEX series from ACs and a new combination series from the CCs to ITRS for the final ITRF2013 development (after we receive feedback from ITRS)

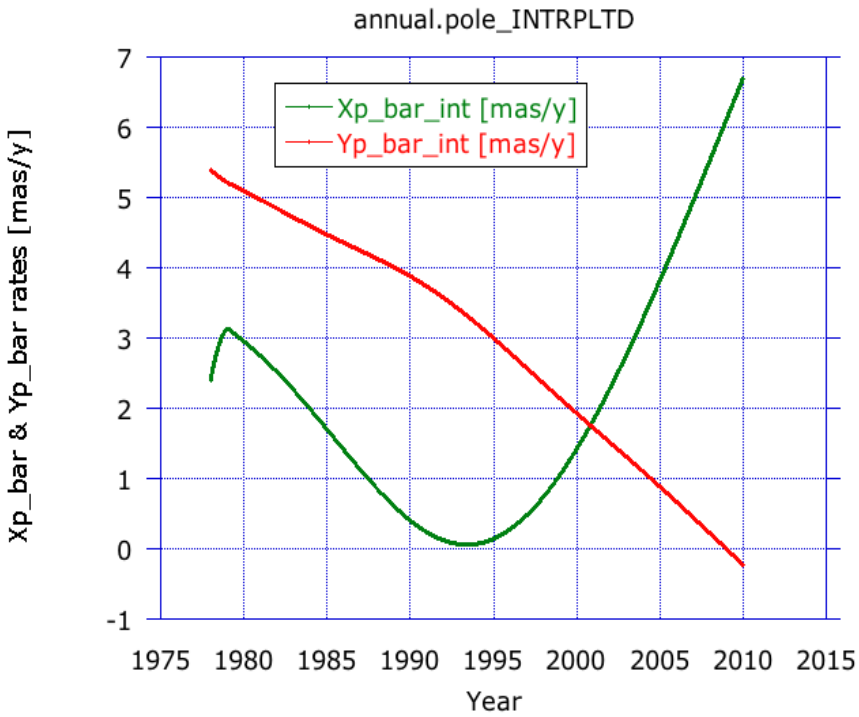
Rapid ice melting drives Earth's pole to the east

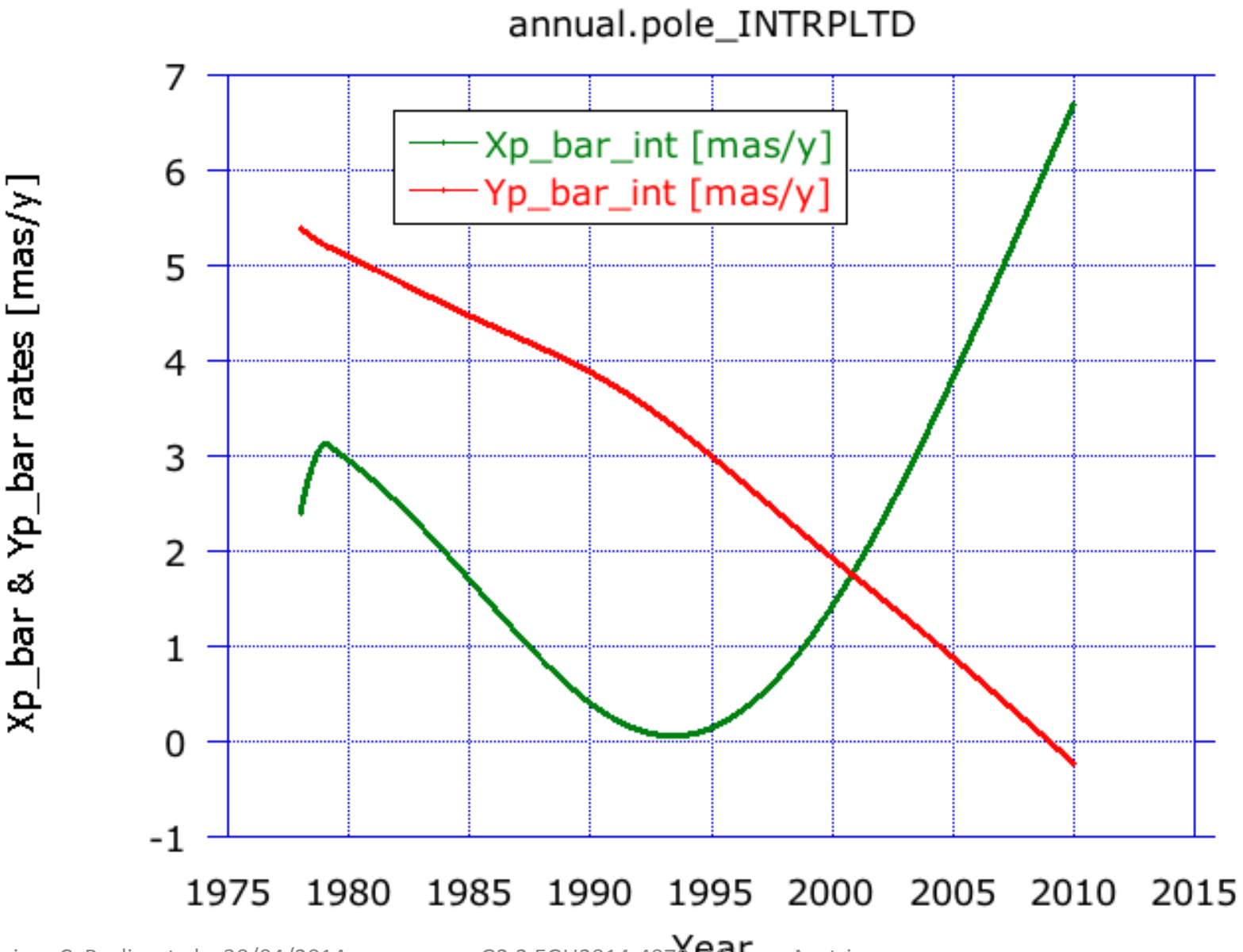
J. L. Chen[1], C. R. Wilson[1,2], J. C. Ries[1], B. D. Tapley[1]






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


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


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

International Laser Ranging Service

LLR Status Report
- 2014 -

Jürgen Müller

Institut für Erdmessung (Institute of Geodesy) and

Center of Excellence QUEST
(Quantum Engineering and Space-Time Research)

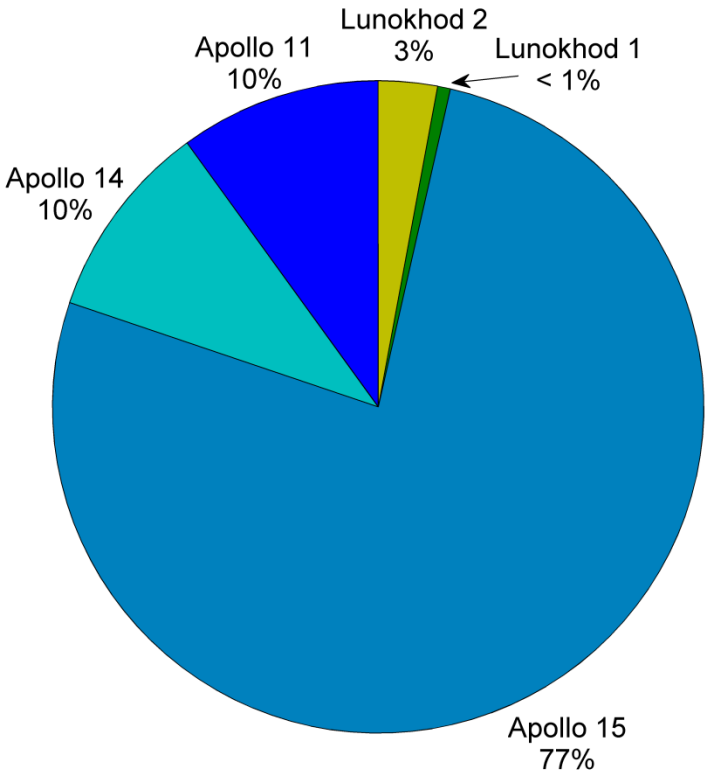
Leibniz Universität Hannover (University of Hannover)

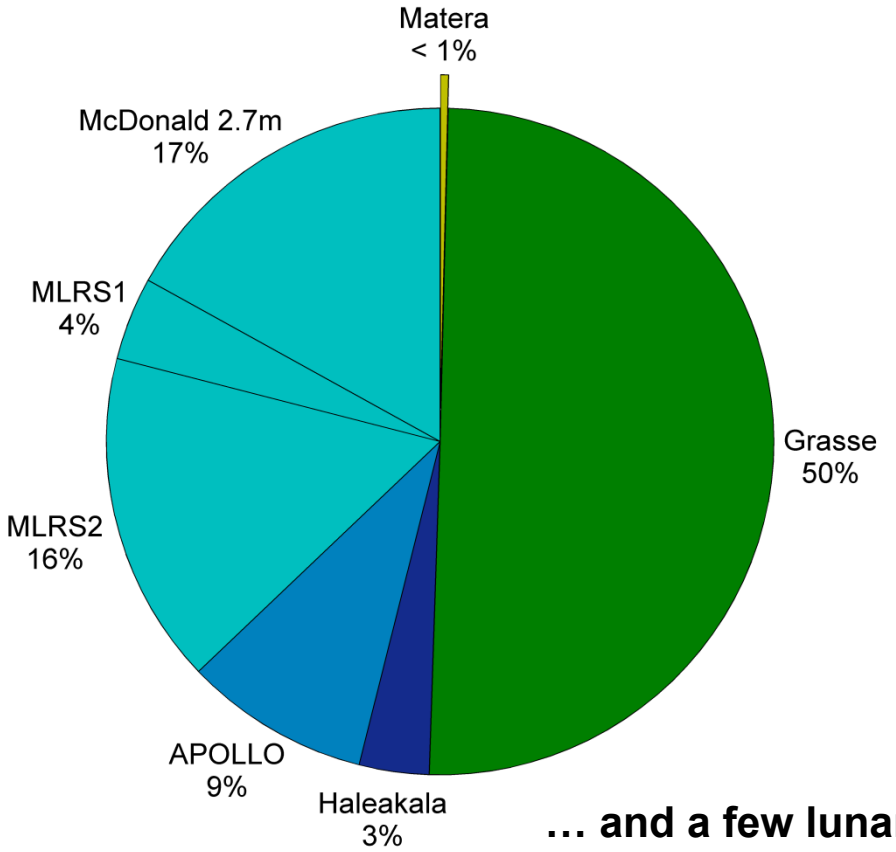
ife

Leibniz Universität Hannover

Statistics – retro-reflectors and observatories

Time span **1970-2014**





now about **20,060** LLR normal points

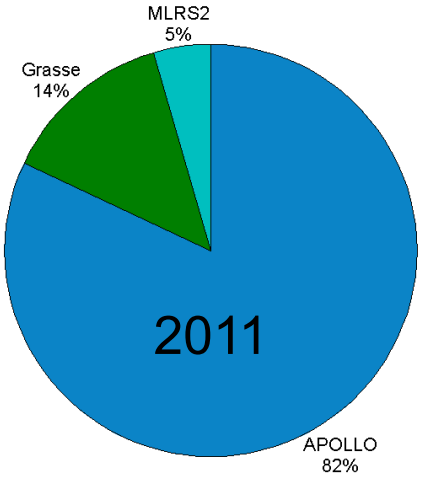
due to data screening/harmonization

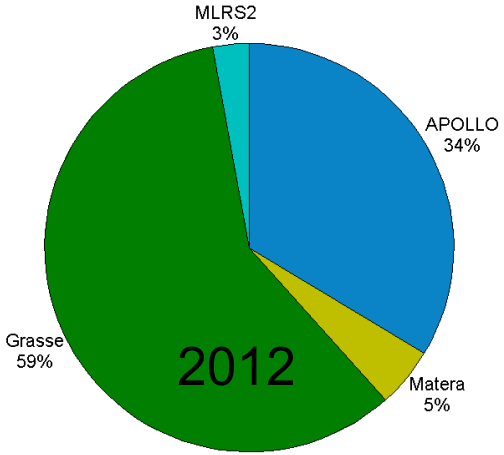
… and a few lunar tracks from

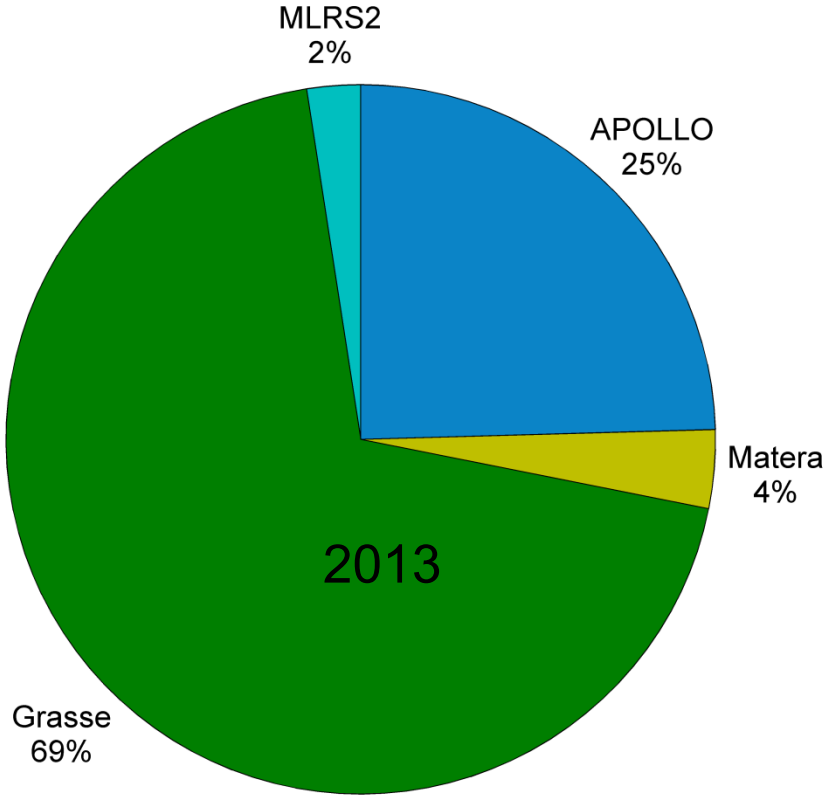
- **Orroral**
- **Wettzell**

Statistics – observatories 2013

Normal points	***2012***	**2013**
APOLLO	*201*	151
McDonald	*17*	15
Grasse	*351*	427
Matera	*28*	22
In total	***597***	**615**





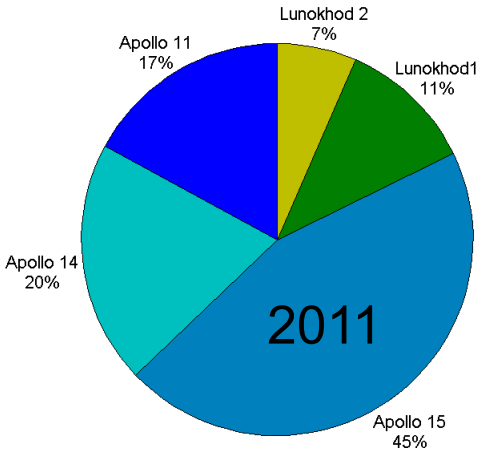


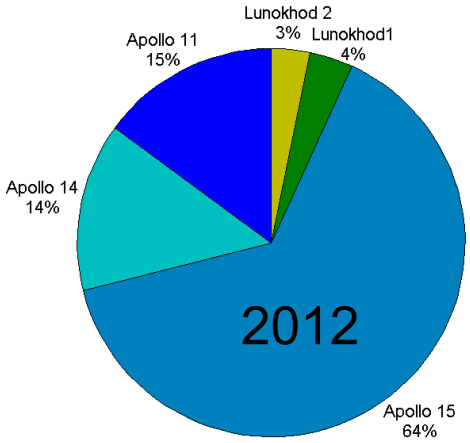
Status, perspective at the LLR sites

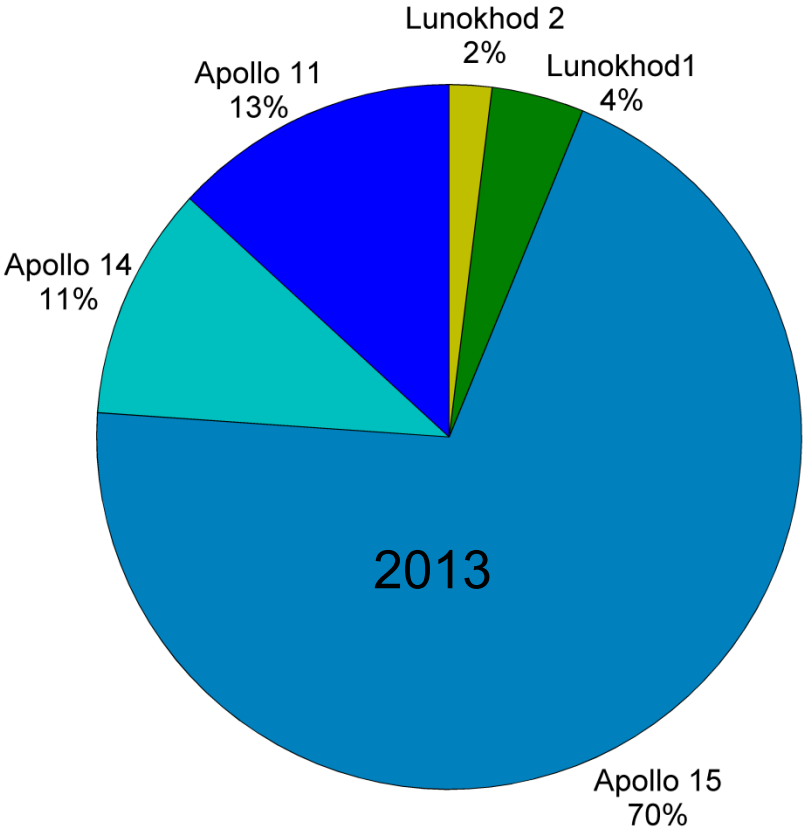
- McDonald - lunar tracking at low level
- Matera (since 2010) - lunar tracking at low level
- APOLLO - good LLR data, reduced accuracy 2011-2012 (i.e. cm instead of mm level)
- Grasse (re-start in 2009), good performance since end of 2011
- Wettzell LLR tracking is still pending

Statistics – retro-reflectors 2013

Normal points	***2012***	**2013**
Apollo 11	*89*	81
Apollo 14	*84*	66
Apollo 15	*383*	430
Lunokhod 1	*22*	26
Lunokhod 2	*19*	12
In total	***597***	**615**

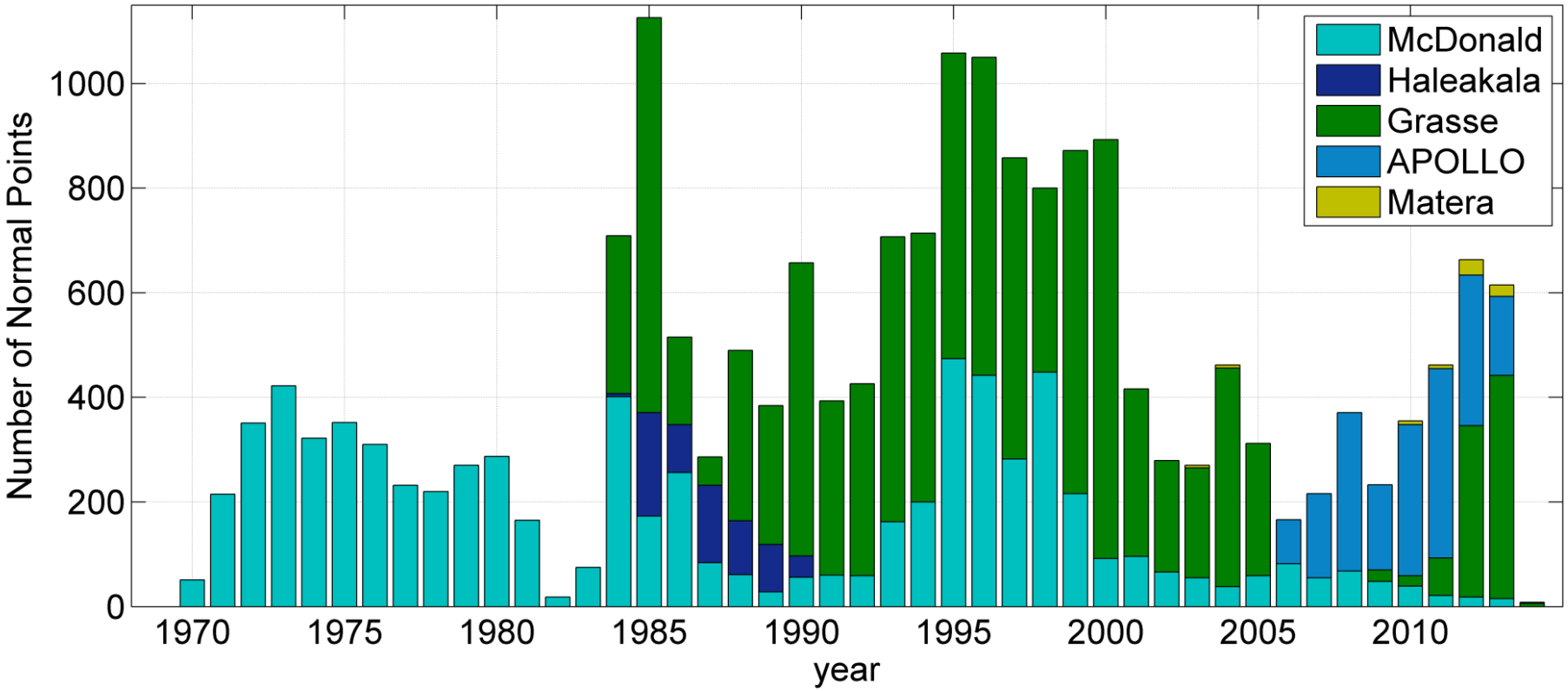






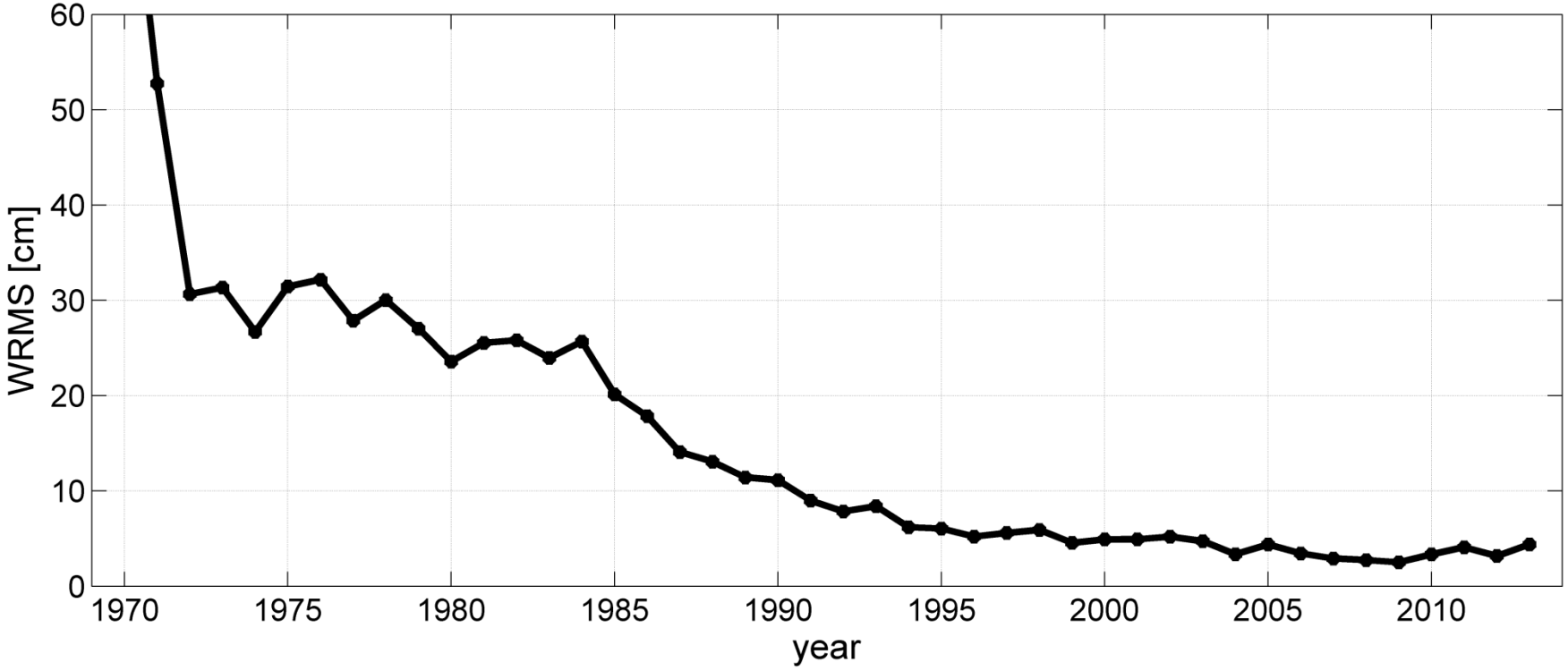
Number of normal points

1970 - 2014: ca.20,060 normal points



Weighted annual residuals

weighted residuals (observed - computed Earth-Moon distance), annually averaged



Major LLR-related activities

- Data screening, homogenization of archived LLR data: French and IfE data set prepared
- IfE LLR solution submitted for ITRF2013

LLR solution for ITRF2013

IfE LLR solution (x, y, z in m; vx, vy, vz in m/y)

Maui					
-5466006.945	-2404427.689	2242188.895	-0.008	0.056	0.018
Grasse					
4581692.108	556196.144	4389355.087	-0.017	0.019	0.021
McDonald cluster					
-1330021.384	-5328403.315	3236481.714	-0.011	0.004	-0.013
APOLLO					
-1463998.850	-5166632.764	3435012.750	-0.014	0.002	0.012
Matera					
4641978.853	1393067.486	4133249.670	-0.019	0.019	0.015

LLR solution for ITRF2013 (2)

Difference* to DTRF2008 (x, y, z in m; vx, vy, vz in m/y)

Maui

0.035	-0.098	0.010	0.006	-0.012	-0.015	(has x,y offset)

Grasse

0.062	0.010	0.013	-0.000	0.001	0.009	(slight x offset)

McDonald cluster

-0.097	0.088	-0.024	0.004	0.007	-0.009	(effect of older data?)

APOLLO

no ITRF coordinates so far!

MATERA

-0.052	0.047	-0.196	0.001	0.001	0.000	(has z offset, no Helmert fit)

*after Helmert fit

Major LLR-related activities

- Data screening, homogenization of archived LLR data: French and IfE data set prepared
- IfE LLR solution submitted for ITRF2013
- SHELLI: Proposal for a new LLR site at NTT Nasmyth (ESO)
- Simulation of impact of new LLR sites and/or reflectors

LLR-related simulations

- Arbitrary number of (new) reflectors and observatories (e.g. SHELLI), with different accuracies and data coverage
- Combination of real and simulated LLR data
- One- or two-way ranging possible
- Variance component estimation to optimally combine heterogeneous data
- Impact of new data on LLR parameters, e.g. relativity parameters – see next slide

Just started

- Further observations, e.g. VLBI transmitter on Moon + LLR for frame tie (kinematic and dynamic realization of ICRS)

Impact of more LLR data for relativity

Example time variation of gravitational constant G_dot/G [yr^{-1}]

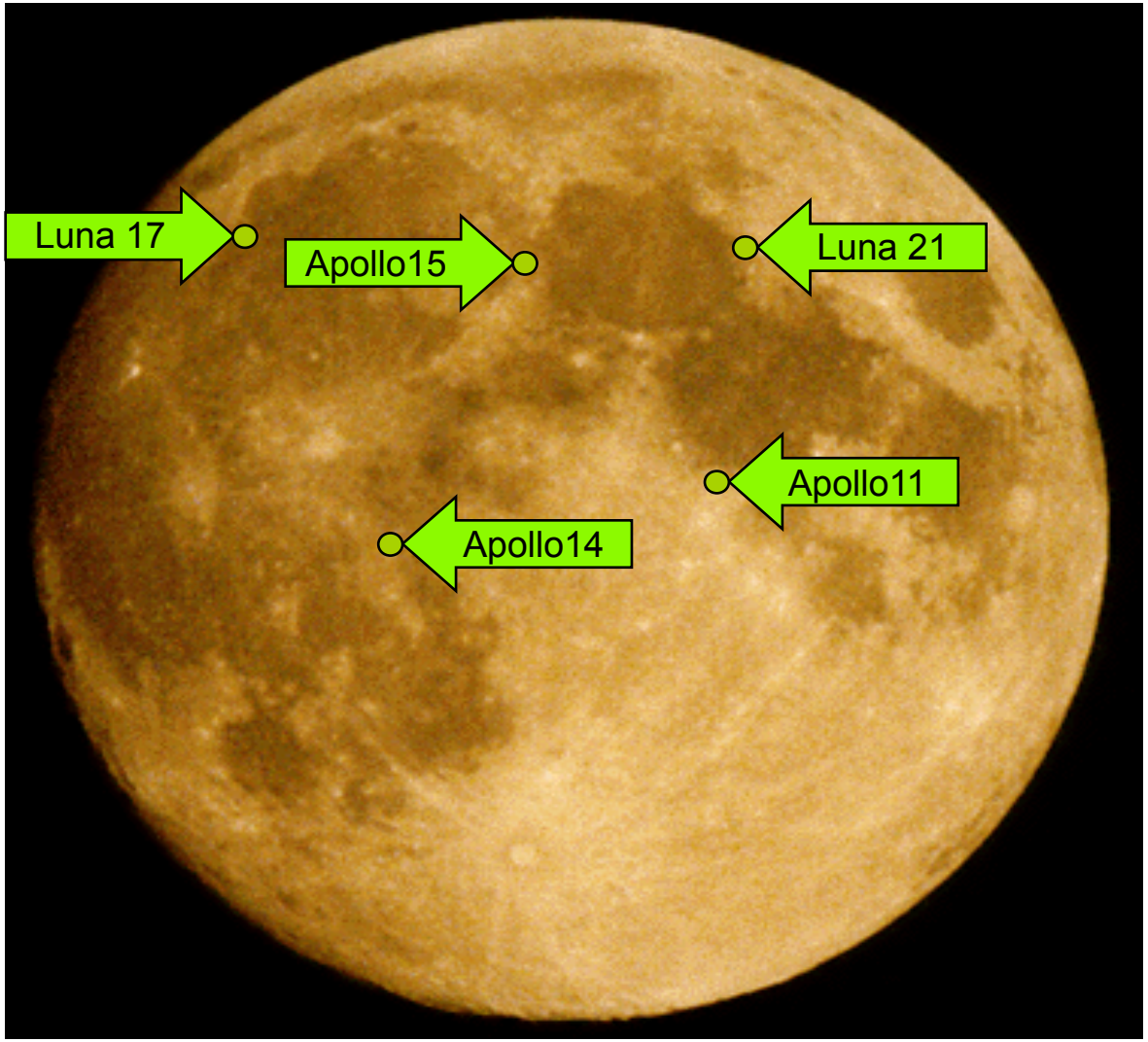
all LLR data (1970-2013) plus simulated data until end of …	current reflector distribution	plus 2 sites and 3 reflectors, reflector SpaceIL operates in the night only	now: reflector SpaceIL operates all the time	now: SpaceIL only operates in the night, Moon Express at 87°
2013 (only real LLR data)	**9.5e-14**	**-**	**-**	**-**
2016	**2.1e-14**	**1.4e-14**	**1.3e-14**	**1.4e-14**
2018	**1.2e-14**	**7.3e-15**	**6.9e-15**	**7.9e-15**
2020	**8.1e-15**	**3.6e-15**	**3.2e-15**	**4.0e-15**
2023	**5.1e-15**	**2.0e-15**	**1.8e-15**	**2.5e-15**
2026	**3.5e-15**	**1.4e-15**	**1.2e-15**	**1.7e-15**
2030	**2.3e-15**	**9.2e-16**	**8.2e-16**	**1.1e-15**

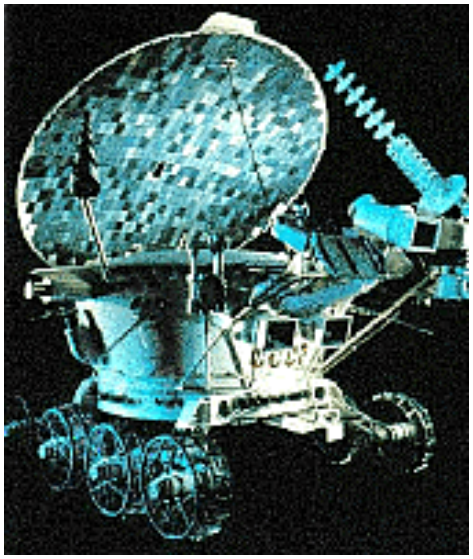
Simulation with noise (1sigma) added to simulated data:
APOLLO + old reflectors: 2.5 mm; APOLLO + new reflectors: 1 mm
other stations + old reflectors: 5 mm; other stations + new reflectors: 2 mm

Major LLR-related activities

- Data screening, homogenization of archived LLR data: French and IfE data set prepared
- IfE LLR solution submitted for ITRF2013
- SHELLI: Proposal for a new LLR site at NTT Nasmyth (ESO)
- Simulation of impact of new LLR sites and/or reflectors
- Mystery of Lunokhod 2 range data not resolved yet
- LLR part on ILRS website shall be updated
- Comparison of LLR software ongoing work between CfA (PEP)*, Paris (INPOP) and Hannover
- Many LLR-related talks (IAG, EGU, GR20 ….) and papers (CQG, IAG symposia series, Brumberg book ...) in past years

Retro-reflectors on the Moon





Lunokhod 2
at Luna 21 position,
tracked for more
than 40 years

Report from SGF Herstmonceux Analysis Centre

Graham Appleby

Jose Rodriguez

SGF Herstmonceux, UK

General

- CoM file for Ajisai compiled
- All CoM files (LAGEOS, Etalon, Ajisai) updated to include recent stations
- ILRS web updated to explain and point to the software and the three CoM tables (on EDC)

A few SATAN updates

- Switched to SOFA subroutines for precession/nutation (IAU2000)
- Use of IERS' *interp.f* subroutine for interpolating *a priori* EOPs and adding tidal/libration effects to polar motion
- Ocean pole tide effects to geopotential (C21, S21)
- Conventional mean pole IERS2010 polynomial expression
- Added geopotentials: EGM2008, GGM05S (thank you Erricos!)
- Parallelised multi-satellite solutions + GFortran optimisation flags =~100% faster runtime

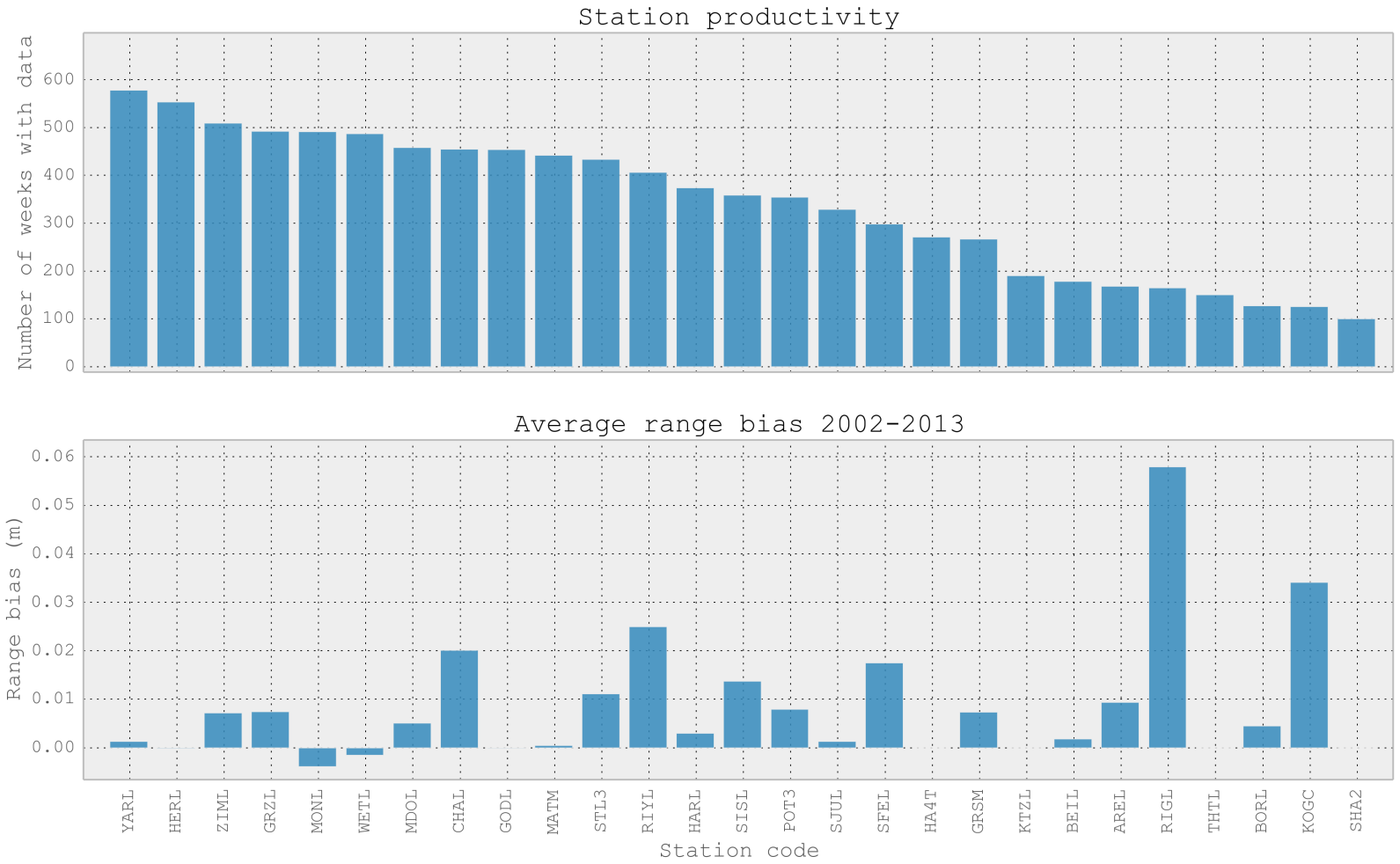
Bias Issues

- Work carried out for AGU 2012 presentation and IERS 'systematics workshop', 2013:
- Solved for weekly RB for many of the major sites along with the TRF solutions:
- Some large biases for the 'known bias' stations
- But also few-mm bias for the stations whose RB are not solved
  - E.g. YARR (7090), Graz (7839), HERL (7840)
- **Based on this preliminary work, decided**:

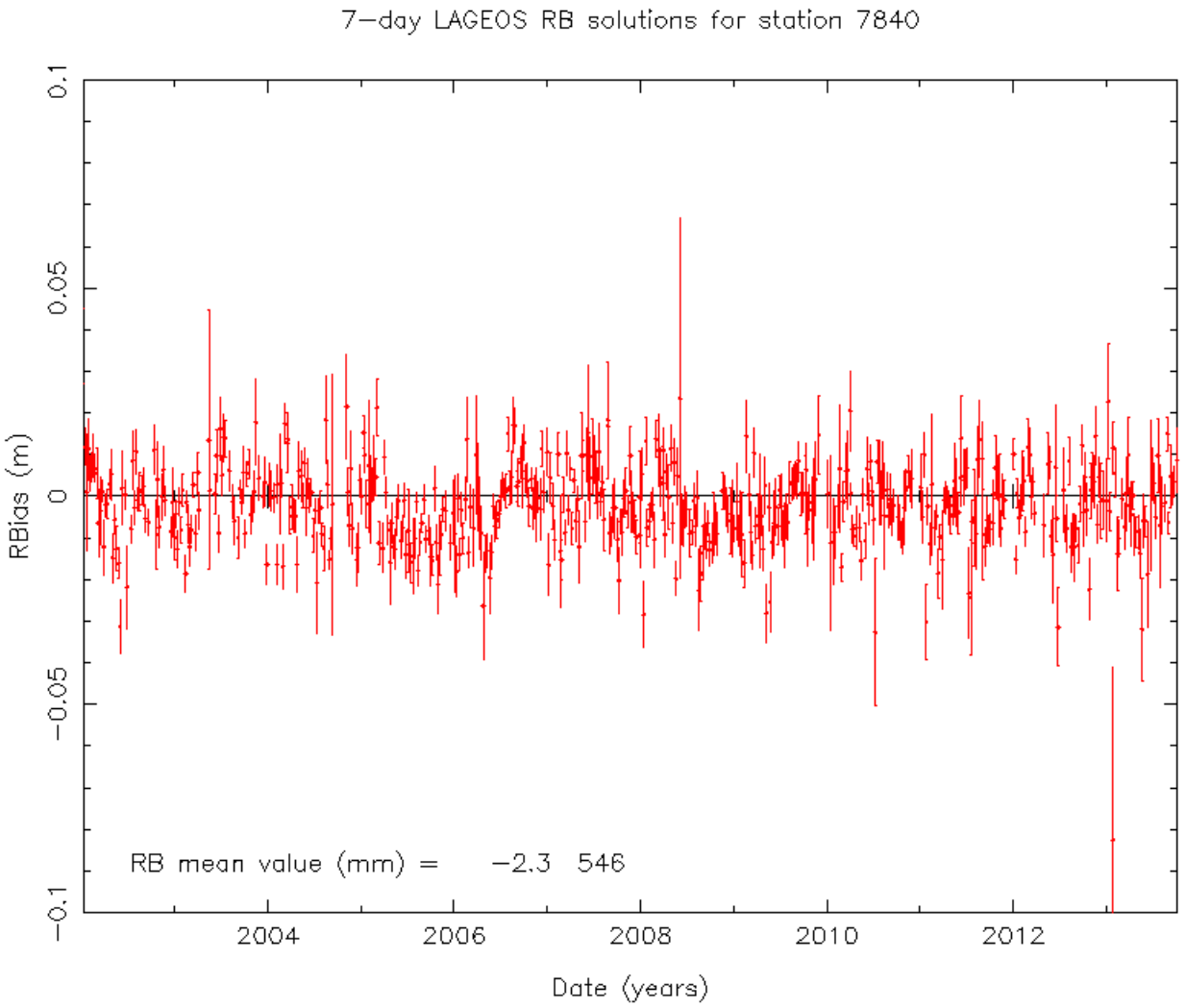
Bias Issues

- Carry out full reference frame solutions using weekly LAGEOS and LAGEOS-2 arcs
- Solved for loosely constrained station coordinates, EOPs and L1+L2 combined range bias for ALL stations (v50 SINEX)
- For comparison, as above but RB only for the AWG-approved stations (v55 SINEX)
- Weekly solutions for 2002-2013.9
  - Applied CoM from tables and ILRS data handling corrections

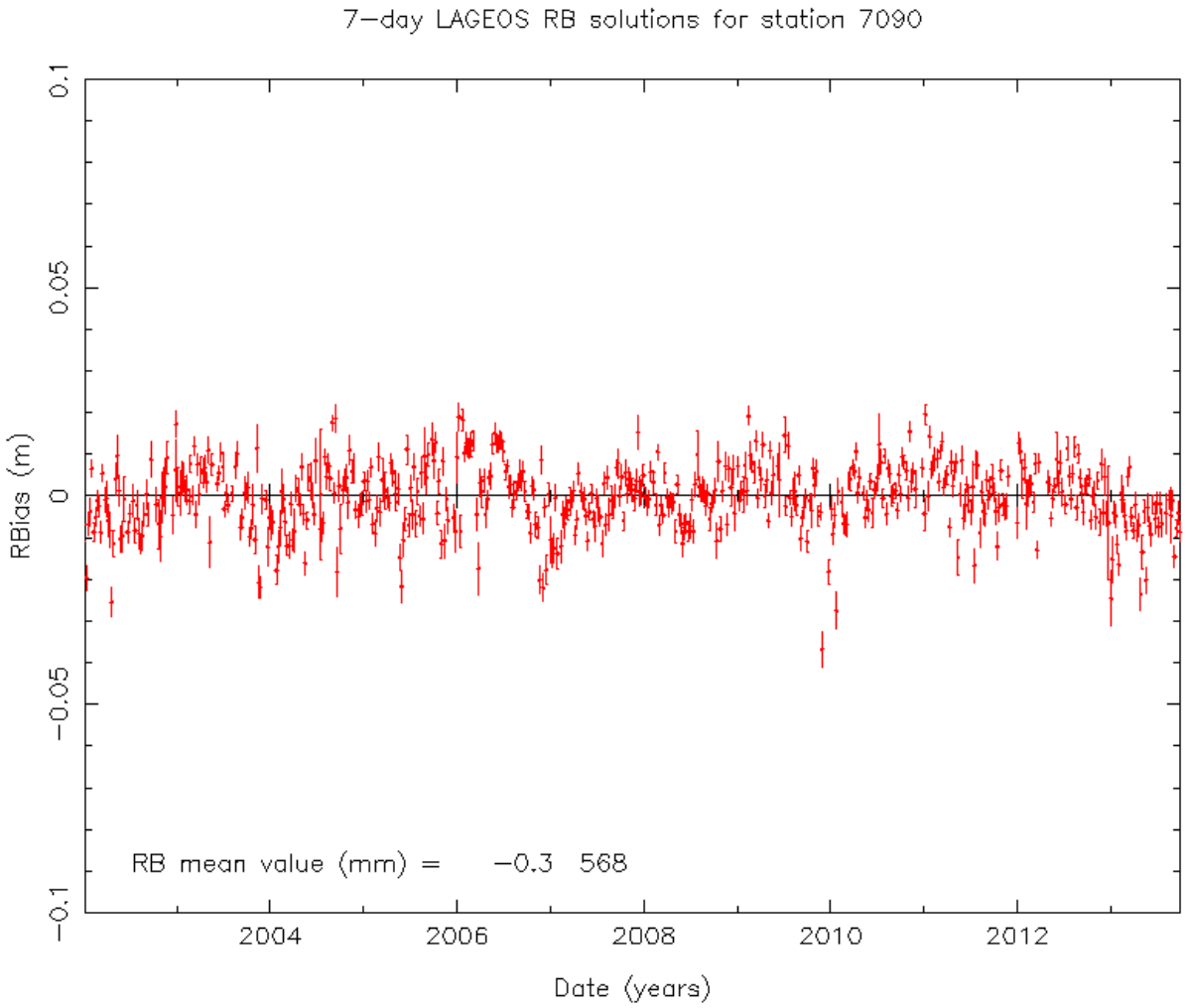
Results: Statistics 2002-2013.9



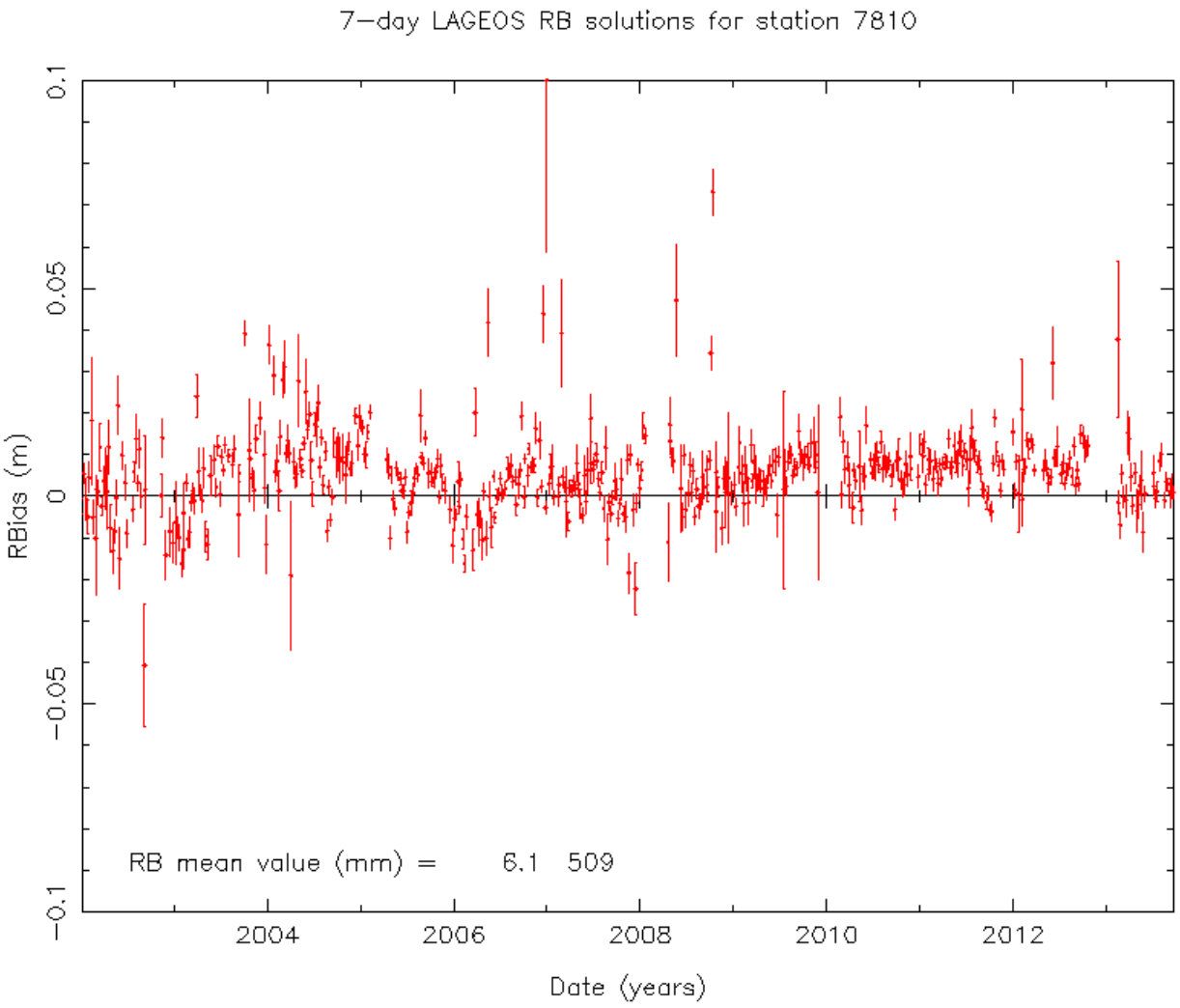
Some RB time series



Some RB time series

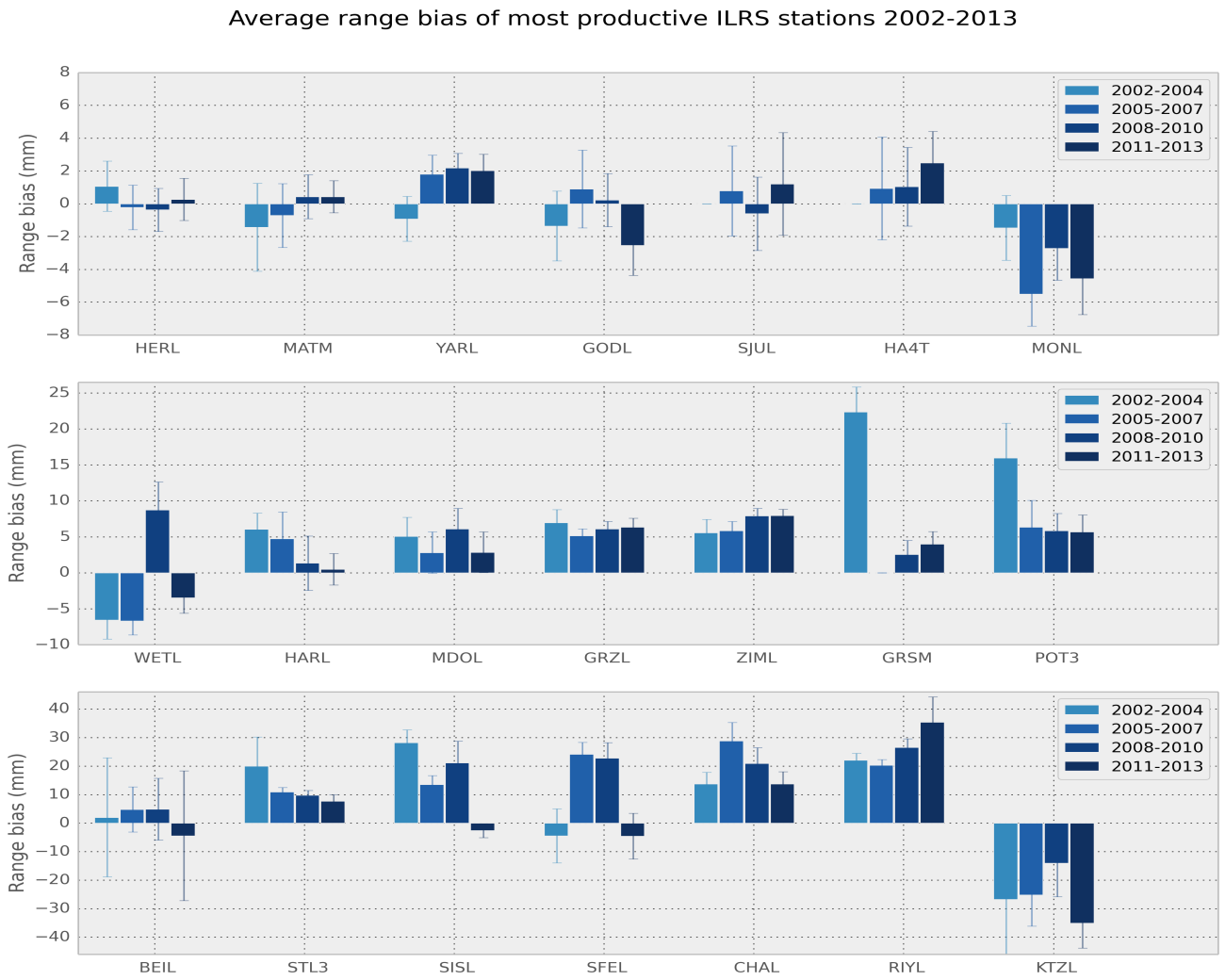


Some RB time series



Results: Statistics 2002-2013.9

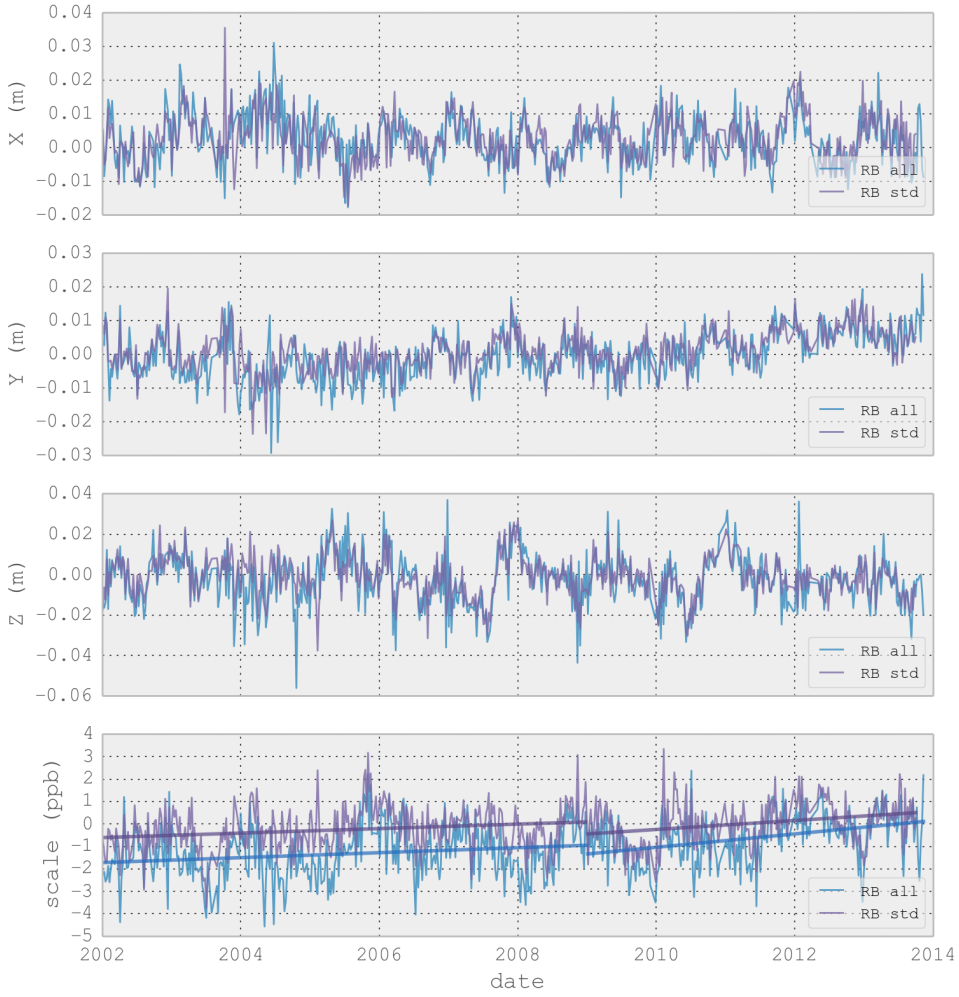
Note: RB from the ILRS 'data handling' file have been applied a-priori



Comparison of weekly solutions with SLRF2008

- Both the 'standard' (limited RB, v55) and 'experimental' (all-RB, v50) solutions have been compared to SLRF2008
- Helmert 7-parameter solutions for translation, scale (and rotations)
- O-C is (SLRF2008 – SGF v50/55 solutions)
- Time series of translation and scale are plotted:

Helmert solutions



Conclusions

- Scale: Changing the processing to include RB estimation **for all** stations:
  - Scale change by -0.90 ppb for 2002-2009.0
    - Implies ITRF2008 scale **too small** by 0.90ppb
    - ITRF2008 (Altamimi): scale 0.6ppb smaller than VLBI
  - Scale slope same for both solutions - ?
  - Different scale and slopes for 2009-2013, beyond the data period that contributed to ITRF2008
- Translations (geocentre): not a major increase in noise for the all-bias solutions