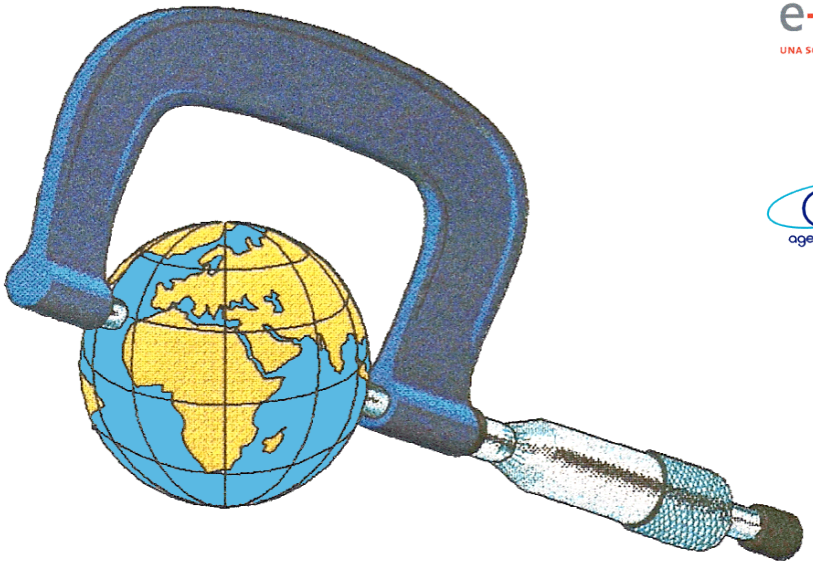
The ASI/CGS contribution to the ITRF maintenance: the ILRSA solution



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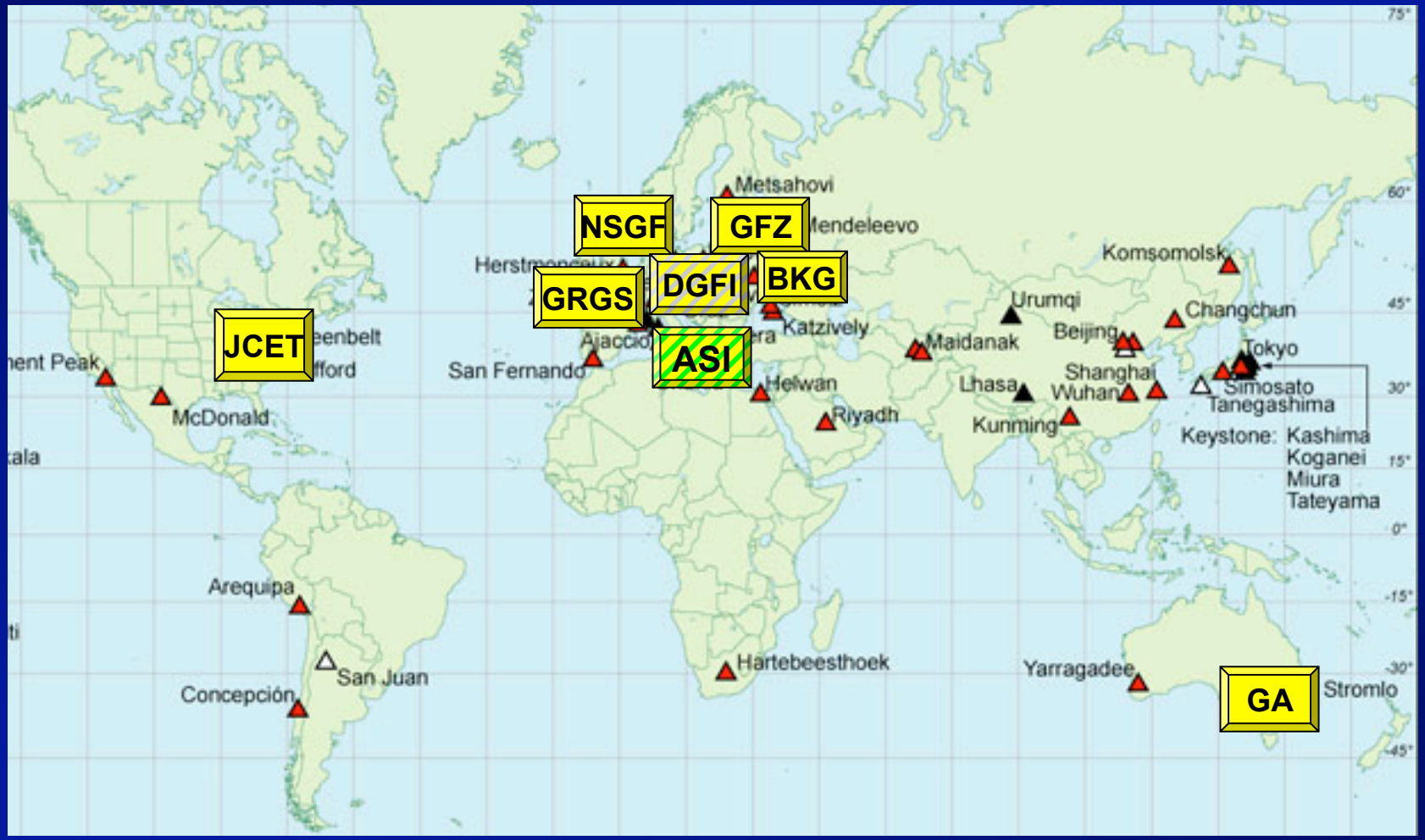
International Technical Laser Workshop on SLR Tracking of GNSS Constellation, Metsovo, Greece, 14 – 18 September, 2009

The ILRS Analysis&Combination Centers

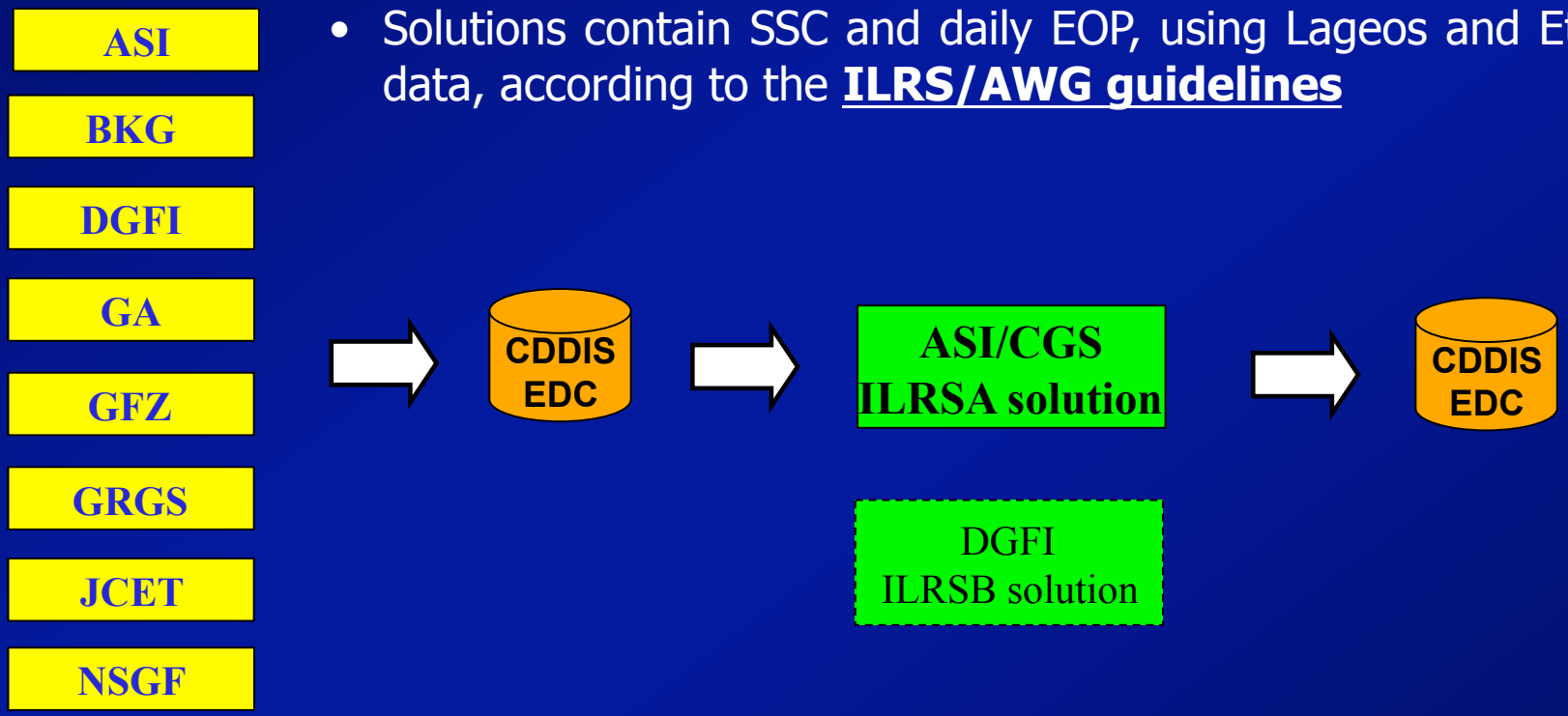


ILRS Data Analysis Products

- ILRS is producing weekly, since 2004, a 7-day arc combined solution with a minimum latency of 4 days, providing daily EOPs and weekly site coordinates, based on the contributions of up to 8 AC's
- The time series for ITRF2005, covering 1993-2005, has been generated by ASI/CGS as ILRS official Combination Center under the same strategy
- at present, ASI/CGS has provided the official ILRS contribution, covering 1983-2008, to the new ITRF2008 in construction

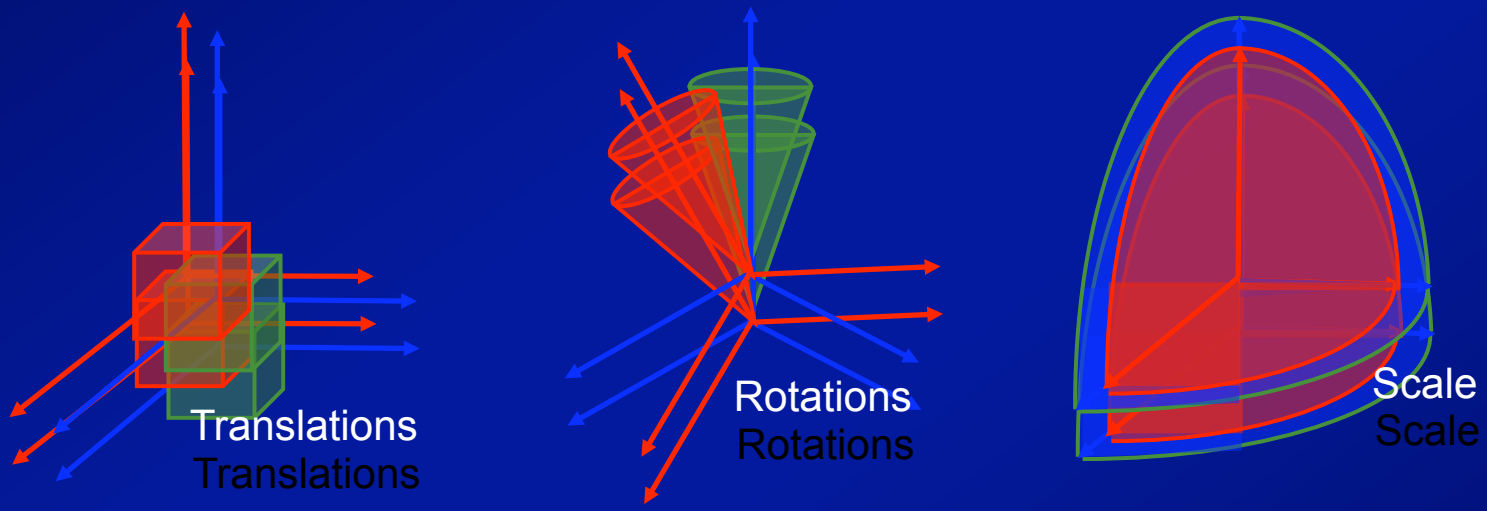
The ILRS processing flow

- The official ILRS analysis centers (ACs) weekly solutions are combined by the two combination centers (CCs)
- Solutions contain SSC and daily EOP, using Lageos and Etalon data, according to the **ILRS/AWG guidelines**



The ILRSA combination approach

The ASI-CGS combination procedure is based on the direct combination of loose constrained solutions (*"Methodology for global geodetic time series estimation: A new tool for geodynamics"*, Davies and Blewitt, 2000).



The combination is performed along the lines of the iterative **Weighted Least Square** technique: each contributing solution plays the role of a '**pseudo-observation**' whose residuals with respect to the combined solution must be minimized; each solution is stacked using its full covariance matrix rescaled by a factor to reach convergence and to balance the contributions; for each combination step proper editing criteria are applied

The quality of the final product

The final combined product quality is affected by different factors, such as:

data analysis

- Conventions adopted
- Application/estimation of system biases
- Satellite Center of Mass correction
- Data coverage
- SW
- Hidden constraints

combination

- Balance in the contribution of all the ACs solutions
- Outlier editing, which affects the iterative computation of the solution scaling factors in the combination process

The quality of the final product

Remarks

- At AC level, the **"coherence"** of the input solutions is a critical factor impacting the quality of the final combined products since the inconsistencies (different application/estimation of system bias, existence of hidden constraints not traceable in the SINEX file, different conventions applied,…) might not be removed in the combination step. In particular, different treatment of station biases may cause incorrect and not physically interpretable coordinates estimation in the combined solution. This issue implies a preliminary discussion and agreement, at the **AC** level, of **common standard and policies in the data analysis**

- At CC level, the combination procedure must include a proper **outlier editing method** to remove residual specific problems in the input solutions and a proper **looseness control** to guarantee the necessary looseness level of the final solution

ILRS range bias information sources

Engineering bias report from CDDIS database and from the stations through SLRMail

Rapid, daily bias analysis report from the ILRS ACs

Bias time series estimated from a multi-year solution

The aim is the definition of:

- **bias to be applied**
- **sites requiring bias estimation**
  (to be kept at minimum)
- **unrecoverable data to be edited**

ILRS AWG recommendations

Lists of data editing and corrections (october 2007; REVISED 090118)

Those lists have been proposed by ASI at the AWG meeting in Grasse (september 2007) and accepted by the ILRS/AWG for the generation of the ILRS official products.

LIST OF DATA TO BE DELETED

Site No.	Wav	Core NonCore in V50	Solve ?	Model ?	bias in sol V50	SOLUTION PROPOSAL	Source
1863	G	NC	NO	NO	--	data before 1994.0	
1873	G	NC	NO	NO	--	data before 1995.0	
1884	G	NC	NO	NO	1993.0 ->	data before august 1994	
1893	G	NC	NO	NO	--	data before 1998.0	CDDIS
7112	G	NC	NO	NO	--	data before 1985.0	
7123	G	NC	NO	YES	--	data from 25 to 30 august, 1988 (3 m bias) data on may 12, 1993 (> 500 meter bias)	
7236	G	NC	NO	NO	--	data after 1998.0 (a few acquisitions)	
7237	G	NC	NO	NO	--	data before 1996.0	
7249	G	NC	NO	NO	--	data before 1999.0	
7355	G	NC	NO	NO	--	use only data in 2003	
7510	G	NC	NO	NO		data from 920623 to 920930 to be deleted	CDDIS
7585	G	NC	NO	NO		data from 920623 to 920930 to be deleted	CDDIS
7810	B	C	NO	YES	--	data from dec 18, 1996 to dec 29, 1997	
7811	G	NC	NO	YES	1993.0 -1994.0	data before 1993:202	CDDIS
7820	G	NC	NO	NO	--	data before 2000:291	CDDIS
7824	G	NC	NO	NO	--	data before 1996	
7831	G	NC	NO	YES	--	data before 1984	
7832	G	C	NO	NO	__	data before 1998	
7835	G	NC	NO	YES	--	data before oct 1988	
7837	G	C	NO	NO	__	data before 1990	
7841	G	NC	NO	NO	--	data before feb 19, 2004	

LIST OF SITES WITH BIAS ESTIMATION

Site No.	Wav	Core NonCore in V50	Solve ?	Model ?	bias in sol V50	SOLUTION PROPOSAL
1864	G	NC	YES	NO	1993.0 ->	bias to be estimated over all the period
1868	G	NC	YES	NO	1993.0 ->	bias to be estimated over all the period
1953	G	NC	YES	NO	--	bias to be estimated over all the period
7548	G	NC	YES	NO	--	bias to be estimated over all the period
7308	G	NC	YES	NO	--	bias to be estimated over all the period
7548	G	NC	YES	NO	--	bias to be estimated over all the period
7810	I	C	YES	NO	--	bias to be estimated over all the period
7845	G	NC	YES	NO	--	bias to be estimated over all the period (bad for EOP referencing)

LIST OF SITES WITH RANGE BIAS APPLICATION

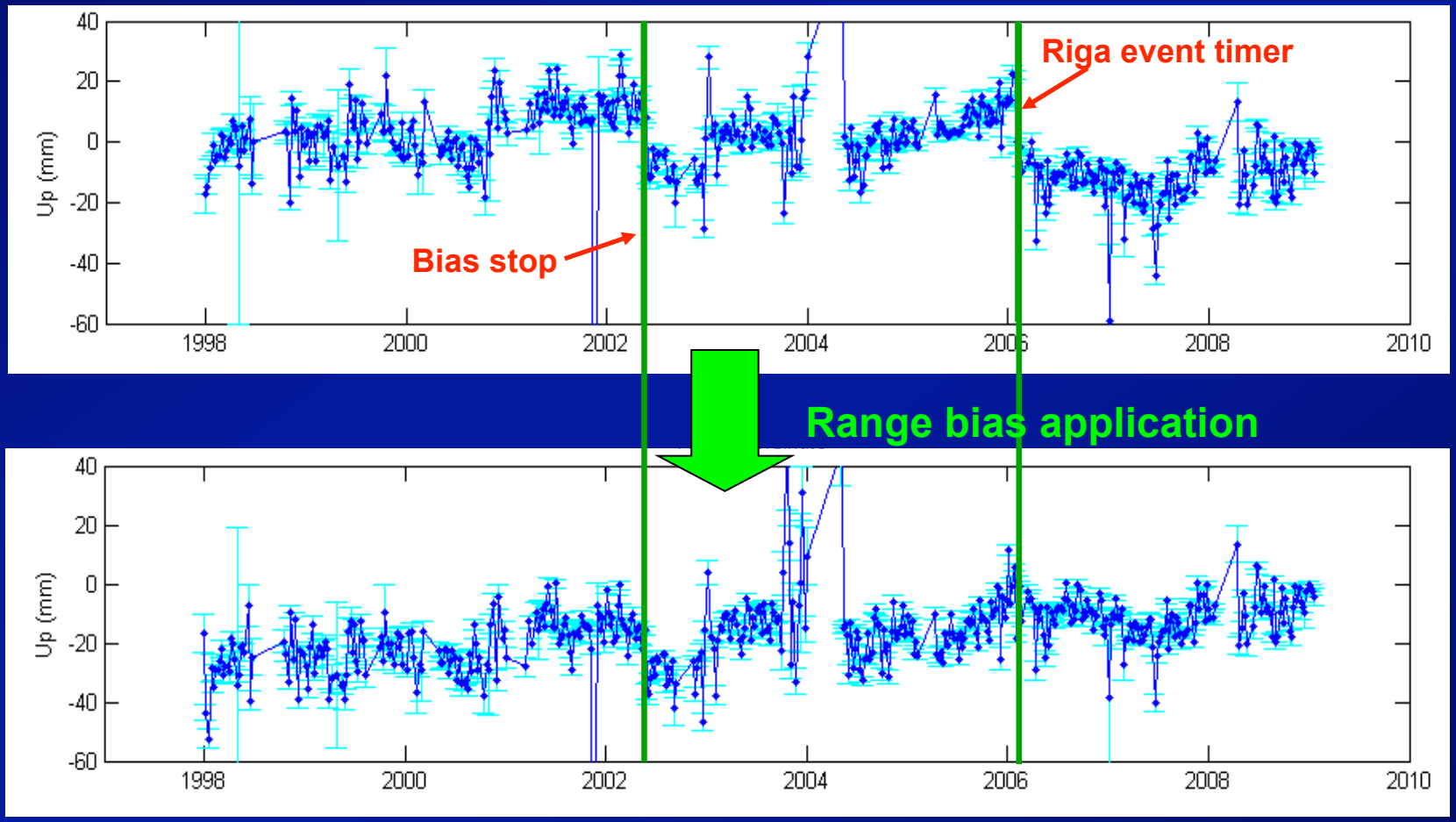
The range correction should be subtracted from the data and is one-way

Site No.	Wav	Core NonCore in V50	Solve?	Model?	bias in sol V50	SOLUTION PROPOSAL			Bias Source
						Start Date	End Date	Correction	
1873	G	C	NO	YES	__	1995	2000	-270 mm	Analysis
7080	G	C	NO	YES	__	Jan 1, 1988	Dec 15, 1989	-40 mm	Analysis
						April 4, 1990	Jan 31, 1993	25 mm	CDDIS
								Correction to be added to the pressure values	
						March 6, 1995	Jan 26, 1996	2.1 mB	CDDIS
						Jan 26, 1996	April 25, 1996	10.3 mB	CDDIS
						April 25, 1996	May 8, 1996	9.7 mB	CDDIS
7109	G	NC	NO	YES		Jan 9, 1997	Jan 18, 1997	164.9 mm	CDDIS
7110	G	C	NO	YES	__	jan 01, 1984	may 15, 1984	30 mm	Analysis
						oct 27, 1987	jan 25, 1988	30 mm	Analysis
						Aug 27, 1996	Oct 3, 1996	163,6 mm	CDDIS
7122	G	NC	NO	YES		May 1984	Mar 15, 1987	30 mm	Analysis
7123	G	NC	NO	YES		July 14, 1987	Oct 9, 1987	-30 mm	CDDIS
7210	G	NC	NO	YES	1993 -2005	1983.0	sep 12, 1987	25 mm	Analysis
						sep 12, 1987	jan 21, 1994	-37 mm	Analysis
						jan 21, 1994	2000	-11 mm	Analysis
7237	G	NC	NO	YES		1996.0	1998.0	20 mm	Analysis
						1998.0	June 24, 2002	-20 mm	Analysis
7512	G	NC	NO	YES		Mar 1992	May 1992	-30 mm	Analysis
7517	G	NC	NO	YES		june 1992	august 1992	-94 mm	Analysis
7525	G	NC	NO	YES		march 1992	June 1992	11 mm	CDDIS
7544	G	NC	NO	YES		sept 1992	Dec 1992	-85 mm	Analysis
7545	G	NC	NO	YES		Oct 1993	Mar 1994	15 mm	Analysis
7580	G	NC	NO	YES		Nov 1992	Jan 1993	68 mm	Analysis
7587	G	NC	NO	YES		Aug 1992	Oct 1992	30 mm	Analysis
7810	B	C	NO	YES	__	May 24, 1988	Sept 30 1989	50 mm	Analysis
						Jan 1998	May 29, 2002	-26 mm	Analysis
						May 29, 2002	Dec 28, 2004	-20 mm	Analysis
						Dec 28, 2004	Feb 6, 2006	-26 mm	Analysis
7811	G	NC	NO	YES	1993 -1994	jul 20, 1993	may 19, 1998	-50 mm	Analysis
						may 19, 1998	mar 28, 2003	-35 mm	Analysis
7831	G	NC	NO	YES		1987	June 1990	+85 microsec	CDDIS
7834	G	NC	NO	YES		Mar 11, 1985	Jul 18, 1986	-30 mm	Analysis
7835	G	NC	NO	YES	1993 - 1998	sep, 1991	Sept 9, 1997	25 mm	Analysis
7836	G	NC	NO	YES		Jan 1, 1994	Oct 12, 1994	18.45 mm	CDDIS
7839	G	C	NO	YES	93.0 to 09/96	1983	Sept 28, 1996	-22 mm	Analysis
~~7840~~ *	~~G~~	~~C~~	~~NO~~	~~YES~~	~~__~~	~~jan 1984~~	~~dec 1984~~	~~30 mm~~	~~Analysis~~
						~~Sep 15, 1988~~	~~Dec 1992~~	~~Bias drift~~	~~Analysis~~
						~~Oct 1, 1994~~	~~Feb 1, 2002~~	~~-2.5 mm~~	~~Appleby~~
						~~Feb 1, 2002~~	~~Feb 10, 2007~~	~~5.5 mm~~	~~Appleby~~
8834	G	C	NO	YES	1993 - 1997	1990	Nov 1, 1992	-35 mm	CDDIS
						Nov 1, 1992	April 15, 1996	40 mm	Analysis
						April 15, 1996	Oct 13,2000	5 mm	Analysis

* **Consult new (separate) table of corrections for 7840**

Zimmerwald: the new time series

Zimmerwald height before and after the bias application



ILRSA outlier editing strategy

In the ILRSA combination procedure a rigorous editing has been included: any estimated parameter in the incoming solutions being neither SSC nor EOP (e.g. range bias, ...) has been **rigorously pre-eliminated** before the combination step *("Combination of solutions for geodetic and geodynamic applications....",* E. Brockmann, PhD thesis, AIUB).

The same technique has been used to eliminate discrepancies w.r.t. the ILRS AWG recommendations in the contributing solutions :

1. too weak SSC estimates (<10 NP)
2. SSC estimates outside the data selection periods

and discrepancies w.r.t. the adopted reference values

3. too bad SSC estimates, outside 0.3m (0.5) w.r.t. ITRF2005 in at least one coordinate after (before) 1997.0
4. too bad EOP estimates, outside 1.5mas/0.5ms (2.0mas/1.0ms) w.r.t USNO finals.data after (before) 1997.0

and finally, in the combination step,

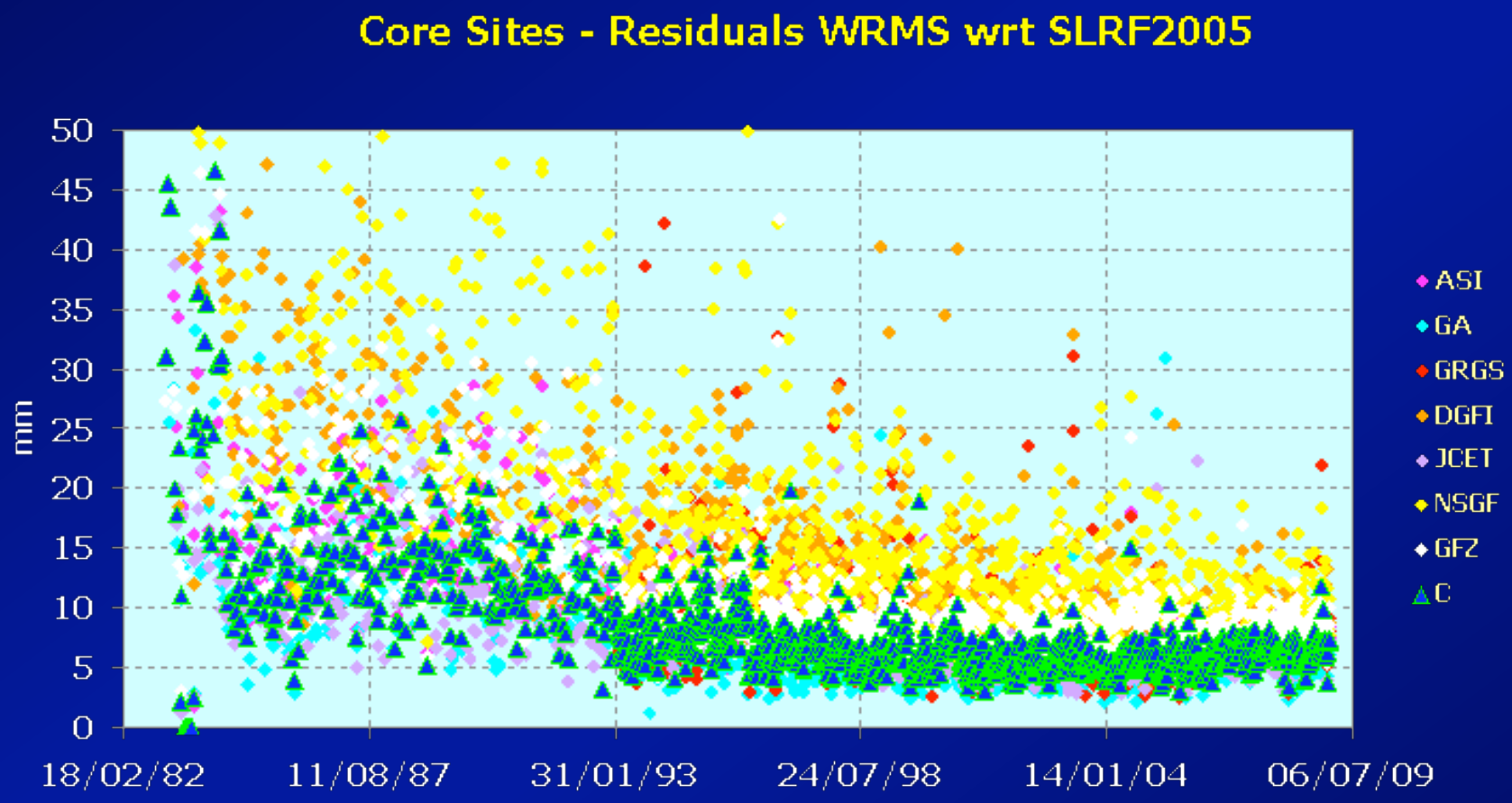
5. outliers with respect to combined solution following a 5σ criterion

ILRSA solution basic facts

- 7 ACs have submitted several versions of their SLR SSC/EOP 7/15-day arc solutions covering the period 1983 – 2008 during Spring/Summer 2009
- ILRSA has been issued in its final version on August 10th, after two preliminary versions (v20, v23)
- for all the AC solutions, bias/dataset as well as looseness level has been checked vs the ILRS AWG recommendations; corrections have been performed by the ILRSA CC and/or requested to the ACs. The table below lists the coverage % of actually used solutions

AC	Version	Issue Date	% Coverage 1983-1992	% Coverage 1993-2008
ASI	V23	19/05/09	88,84%	95,92%
DGFI	V23/V24	27/05/09	88,84%	91,49%
GA	V22	19/05/09	69,42%	90,89%
GFZ	V23	19/05/09	86,36%	95,56%
GRGS	V24	03/06/09	-	96,04%
JCET	V23	24/05/09	88,02%	92,69%
NSGF	V23	13/07/09	85,54%	95,08%

ILRSA solution overall quality

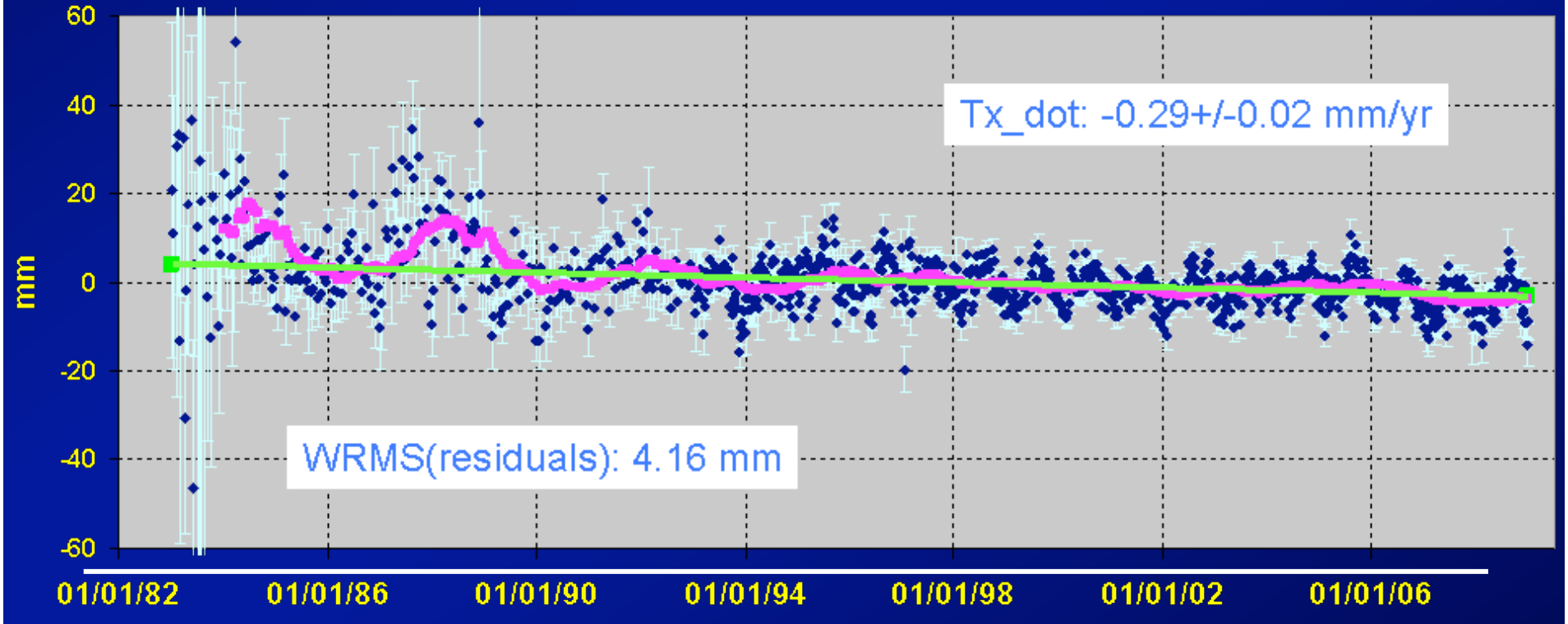


mm	ASI	GA	GRGS	GFZ	DGFI	JCET	NSGF	C
All Sites	13+/-8	8+/-6	15+/-9	16+/-9	26+/-30	11+/-7	22+/-12	13+/-18
Core Sites	10+/-6	7+/-4	8+/-4	11+/-7	16+/-20	8+/-5	17+/-10	8+/-6

ILRSA solution Reference Frame stability

The following slides show the complete time series of the estimated Helmert Parameters (Translations and Scale) for ILRSA v24 solutions vs SLRF2005, on the same scale

Tx



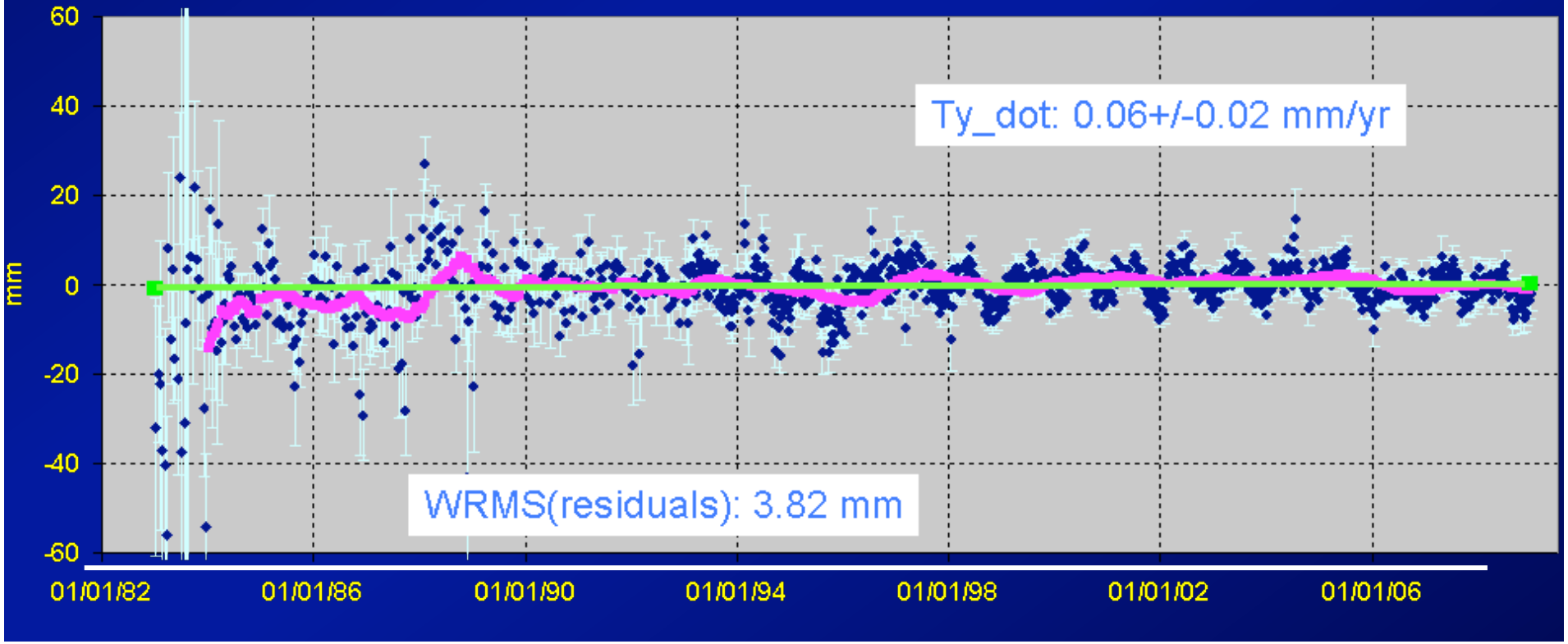
ILRSA solution Reference Frame stability

- Initial (<1993) estimates are weak and noisy; it depends on the data strength and geographical distribution

- Secular and periodic trends are visible in the time series, to be evaluated to assess the origin and scale stability.
  - a linear fit (green line) has been estimated rigorously on each parameter time series; the results impact on the long term stability evaluation
  - as indicated by the purple line, (running mean over a 1-yr period), a dominant annual term is visible.

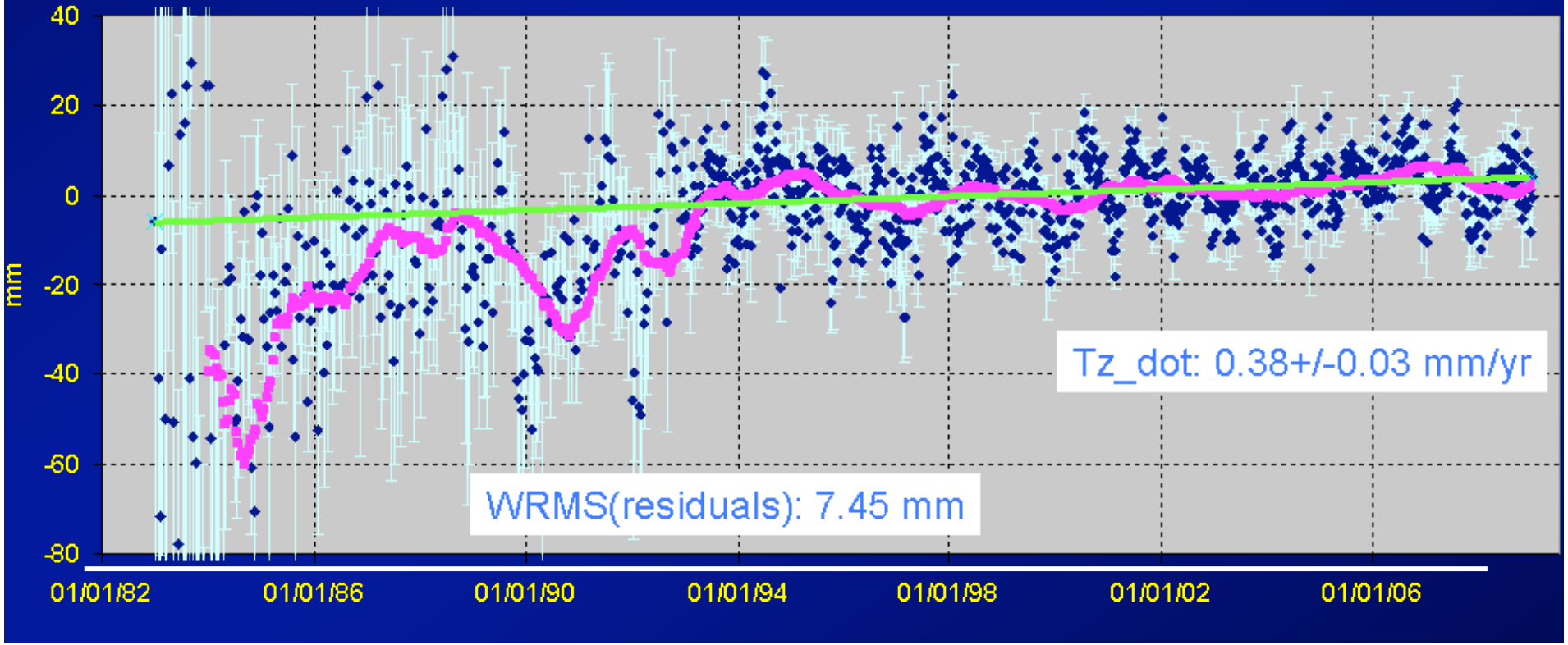
ILRSA solution Reference Frame stability

Ty



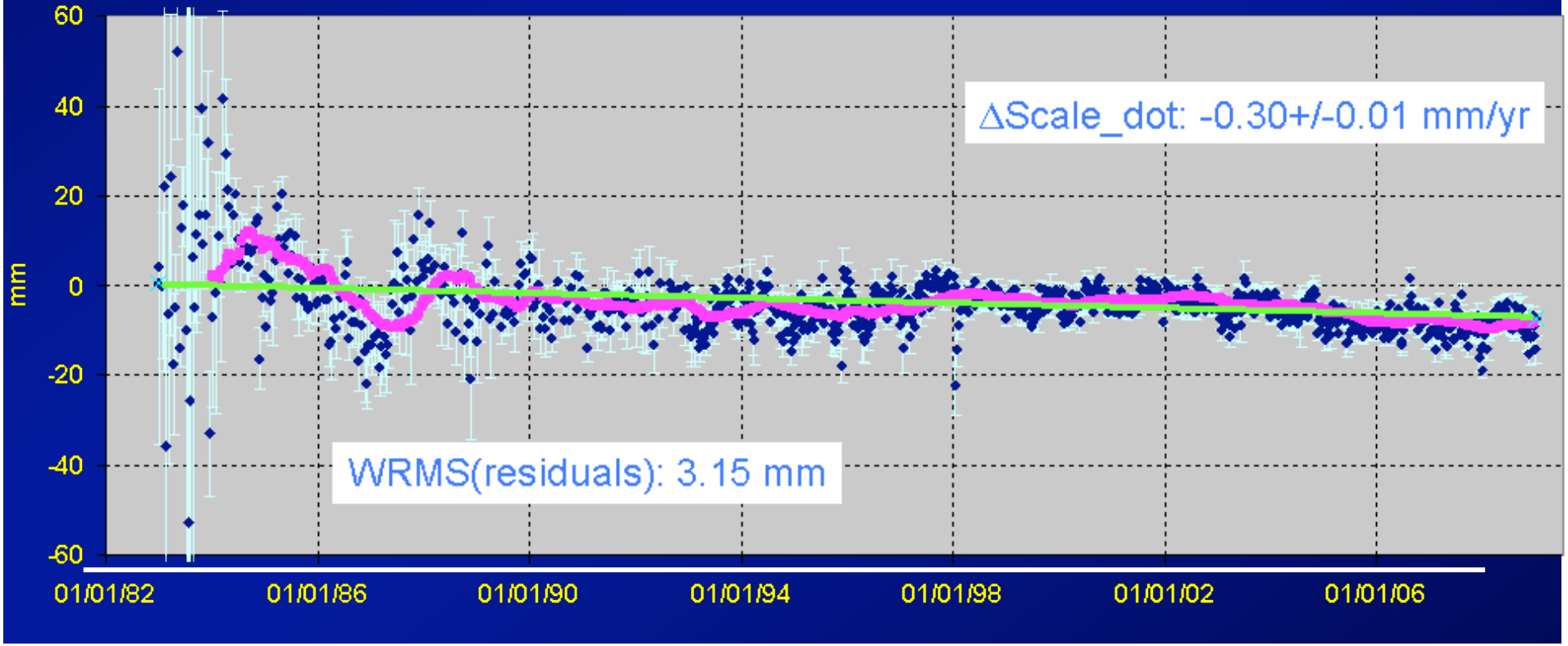
ILRSA solution Reference Frame stability

Tz



ILRSA solution Reference Frame stability

Δ Scale



ILRSA solution Reference Frame stability

From ITRF2008 development presentation by Z. Altamimi (IAG 2009)

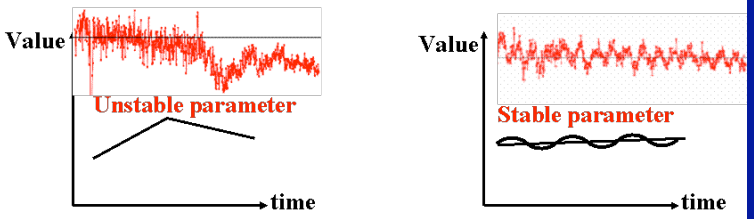
ITRF and Science Requirement

- Long-term stable ITRF: 0.1 mm/yr

  ==> Stable: linear behaviour of the TRF parameters, i.e. with no discontinuity :

  – Origin Components: 0.1 mm/yr

  – Scale 0.01 ppb/yr (0.06 mm/yr)



But stability also means TRF site position predictabilty

- Ty shows the stablest behavior, with a slope << 0.1 mm/yr and a WRMS of the residuals < 4mm.
- Tx shows a clear slope of -0.3 mm/yr, with a residual WRMS of the order of 4mm
- Tz, affected by the unevenly data distribution in the the two emispheres, highly remarkable especially in the initial SLR years, indicates a slope of almost 0.4 mm/yr with a residual WRMS of almost 8 mm
- Δ_scale shows a very clear slope of -0.3 mm/yr with a residual WRMS of 3mm

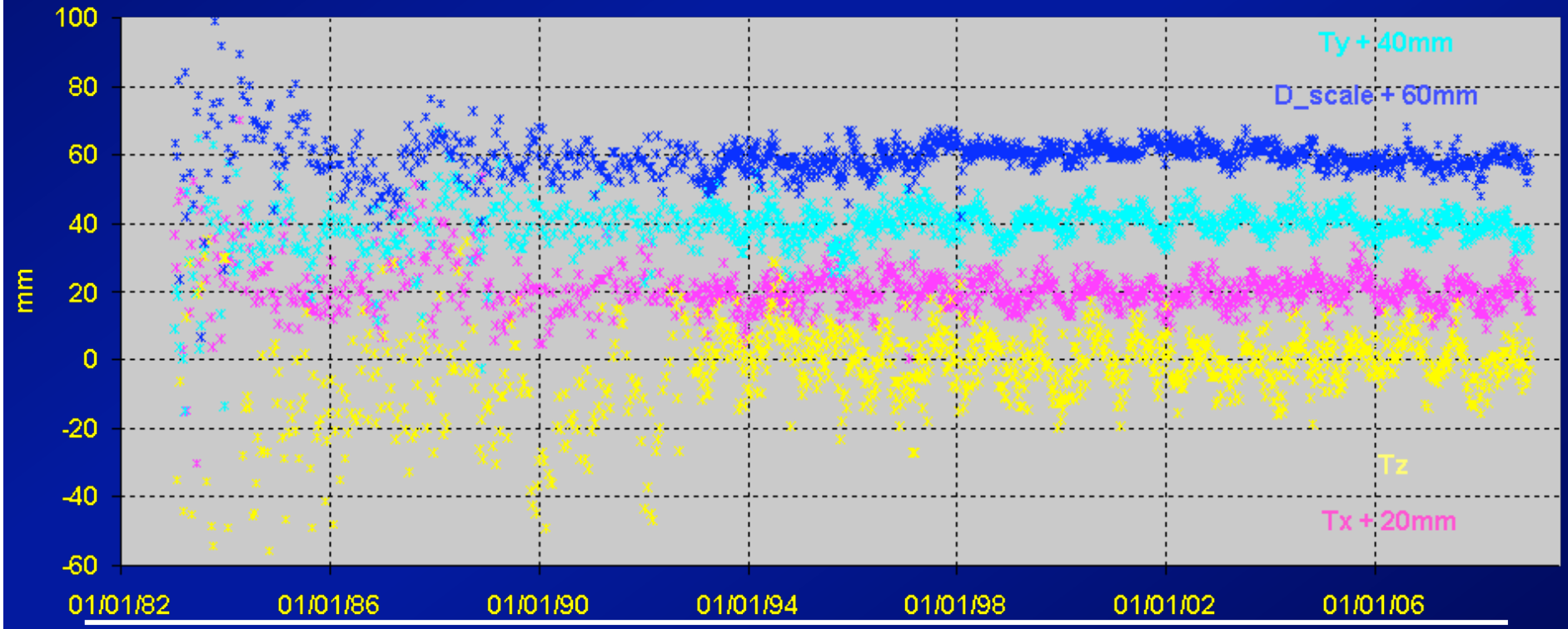
ILRSA solution Reference Frame stability

Contributing Solutions

Tx	Tx_dot mm/yr	σ_Tx_dot mm/yr	WRMS (res) mm	Ty	Ty_dot mm/yr	σ_Ty_dot mm/yr	WRMS (res) mm
asi	-0,35	0,02	5,37	asi	-0,12	0,02	4,50
dgfi	-0,57	0,03	6,27	dgfi	0,09	0,03	5,78
ga	0,05	0,02	4,18	ga	0,17	0,02	4,29
gfz	-0,49	0,03	5,46	gfz	0,11	0,02	4,98
grgs	-0,32	0,03	4,50	grgs	0,04	0,03	3,71
jcet	-0,18	0,02	4,19	jcet	0,10	0,02	3,99
nsgf	-0,41	0,03	6,70	nsgf	-0,08	0,03	7,26
C	**-0,29**	**0,02**	**4,16**	C	**0,06**	**0,02**	**3,82**
Tz	**Tz_dot mm/yr**	**σ_Tz_dot mm/yr**	**WRMS (res) mm**	**D_Sc**	**D_Sc_dot mm/yr**	**σ_D_Sc_dot mm/yr**	**WRMS (res) mm**
asi	0,24	0,06	10,38	asi	-0,31	0,02	4,26
dgfi	0,88	0,08	13,07	dgfi	-0,48	0,03	4,98
ga	0,83	0,04	8,58	ga	-0,22	0,01	3,64
gfz	0,36	0,06	10,89	gfz	-0,08	0,03	4,71
grgs	0,06	0,02	7,11	grgs	-0,46	0,02	3,34
jcet	0,25	0,04	8,32	jcet	-0,23	0,01	2,88
nsgf	0,11	0,08	14,06	nsgf	-0,62	0,03	6,00
C	**0,38**	**0,03**	**7,45**	C	**-0,30**	**0,01**	**3,15**

ILRSA solution Reference Frame stability

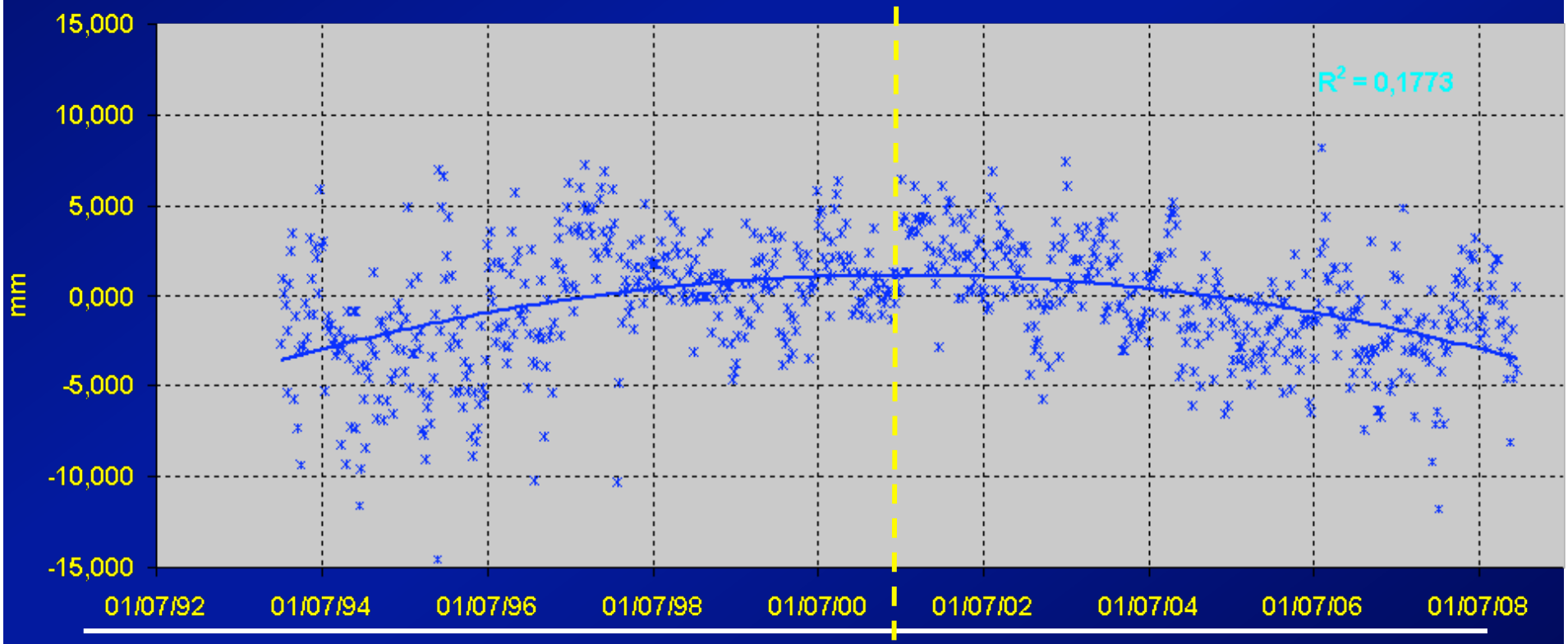
- The following plot shows the Helmert parameter residuals w.r.t. the linear fit. Periodic trends of small amplitude are visible in all the time series, in a clearer way since 1993 onwards.



ILRSA solution Reference Frame stability

Δ_Scale

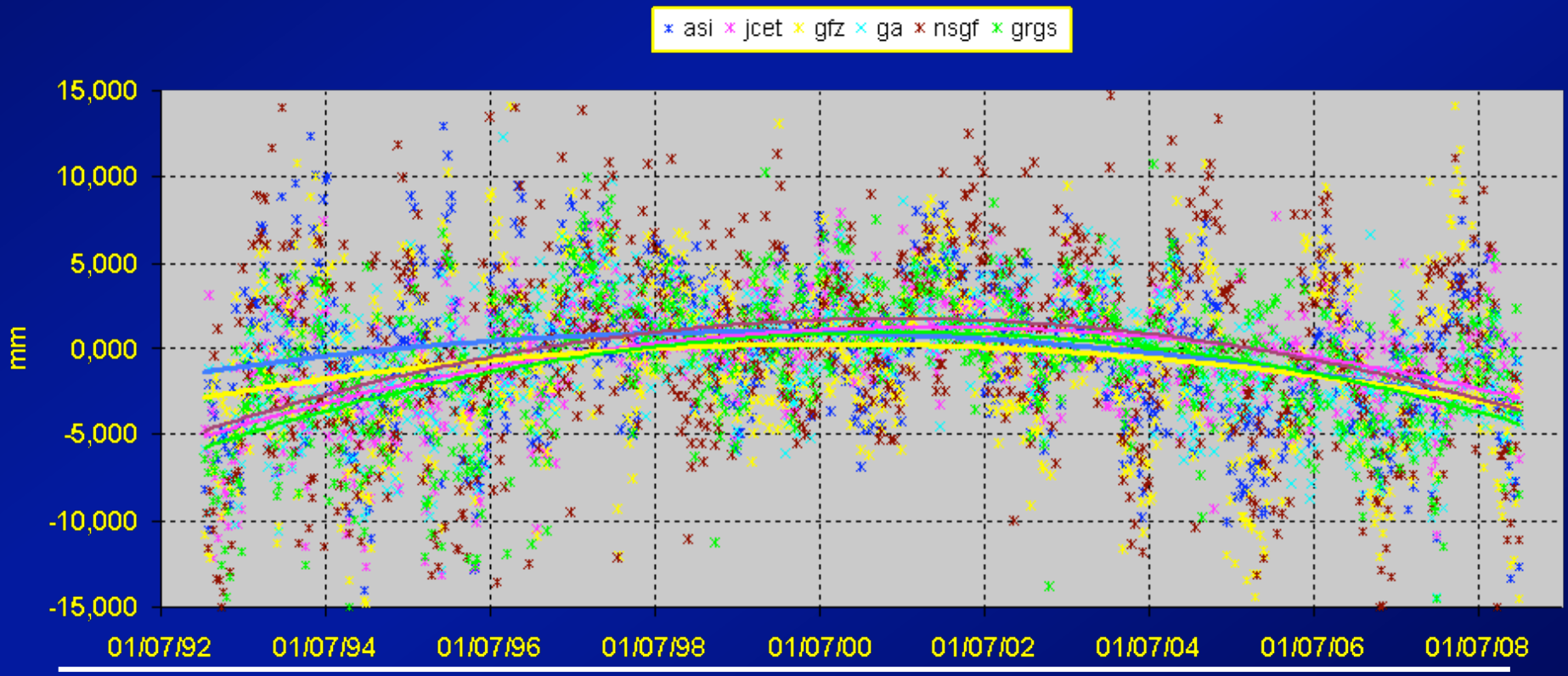
- The scale shows, besides the annual periodicity, a long periodic residual component, in the plot below modelled as a 2-order polynomial on the 1993-2008 years.



ILRSA solution Reference Frame stability

Δ_Scale

- The same trend appears in the contributing solutions



Conclusions 1/2

- The analysis of the entire data span 1983-2008 for the ILRS contribution to ITRF2008 has required a big effort for both ACs and CCs (conventions adopted, application/estimation of system biases, data editing, treatment of hidden constraints); the final official ILRS combined solution, ILRSA v24, has been issued publicly on August 10th
- The ILRSA v24 solution shows an overall coherence of all the final AC contributing solutions
- Close cooperation with the inter-technique Combination Centers has been fundamental

Conclusions 2/2

- The latest ILRS contribution to the next ITRF clearly shows the benefit of the work done as far as the TRF is concerned:
  - 8mm WRMS of the Core Site residual w.r.t. SLRF2005
  - Very neat Helmert parameter time series, allowing to detect small secular and periodic components
  - Long term stabler scale, with low residual WRMS (3mm); small residual non linear trend to be investigated
  - a very stable behavior of the Tx and Ty Helmert translations (4mm residual WRMS)
  - Tz noisier, as expected