A FEW DECADES OF SLR DATA FOR THE LONG WAVELENGHTS OF THE EARTH'S GRAVITY FIELD

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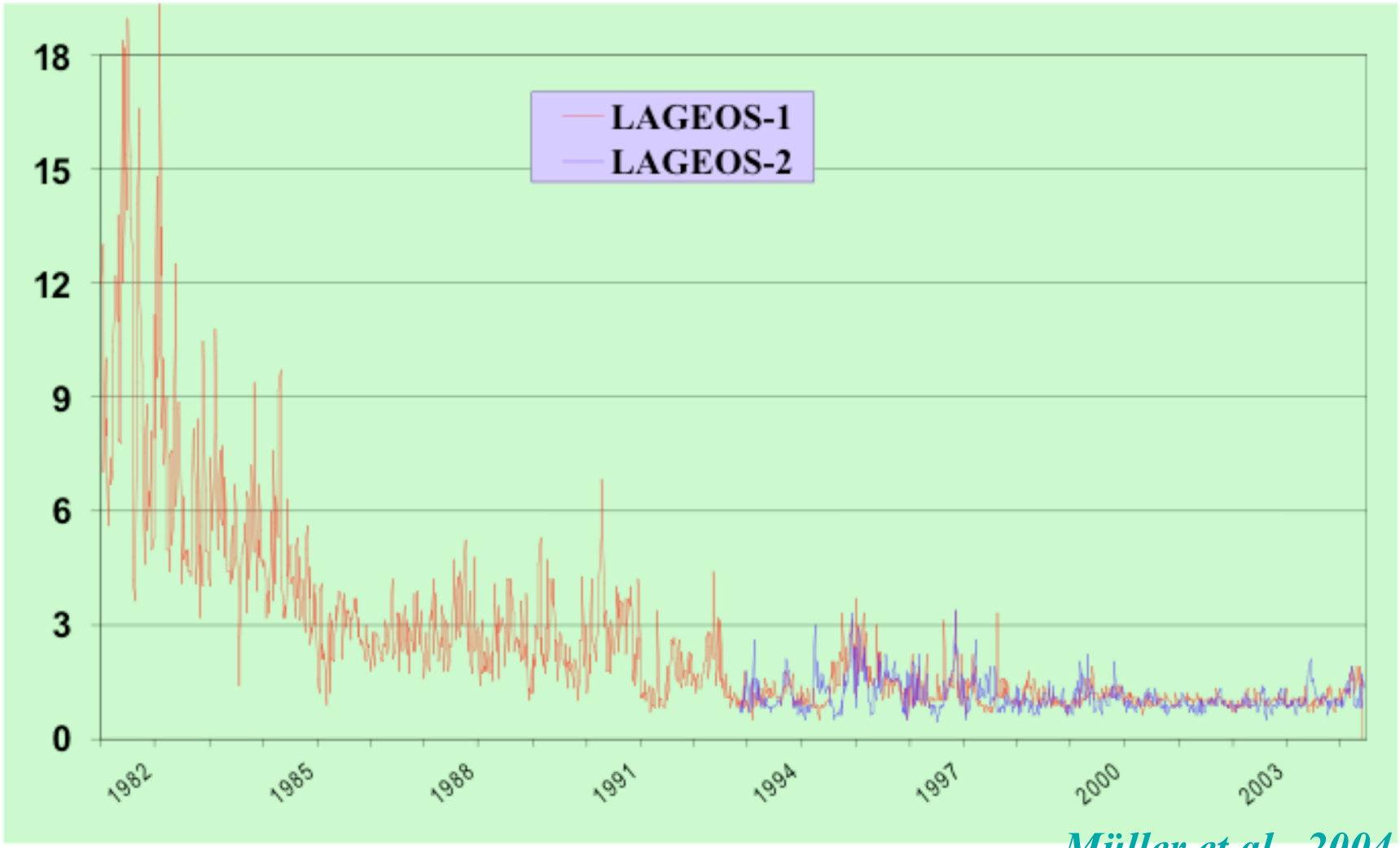
SLR among other geodetic technics

©	LLR	VLBI	SLR	GPS/ GALILEO	DORIS
Celestial frame		***			
Solar system tie	***	*			
Terrestrial tie					
Precession-Nutation	**	***	*	*	
Universal Time	*	***			
Earth Rotation					
Length of Day		***	*	**	
Polar motion		***	**	***	*
Terrestrial frame					
Network homogeneity		*	*	**	***
Center of mass (GM)			***	*	*
Center of figure		**			
Tectonic motion		***	**	***	***
Densification			*	***	**
Orbitography: high satellites					
GPS/GALILEO –like			*	***	
LAGEOS, ETALON -like			***		
Orbitography: low satellites					
TOPEX/Poséïdon, Jason-1, Jason-2			**	***	***
ERS, ENVISAT – like			**	***	***
CHAMP, GRACE –like			*	***	
Gravity field					
Long wavelengths			***	**	*
Short wavelengths			**	***	**

Residuals analysis

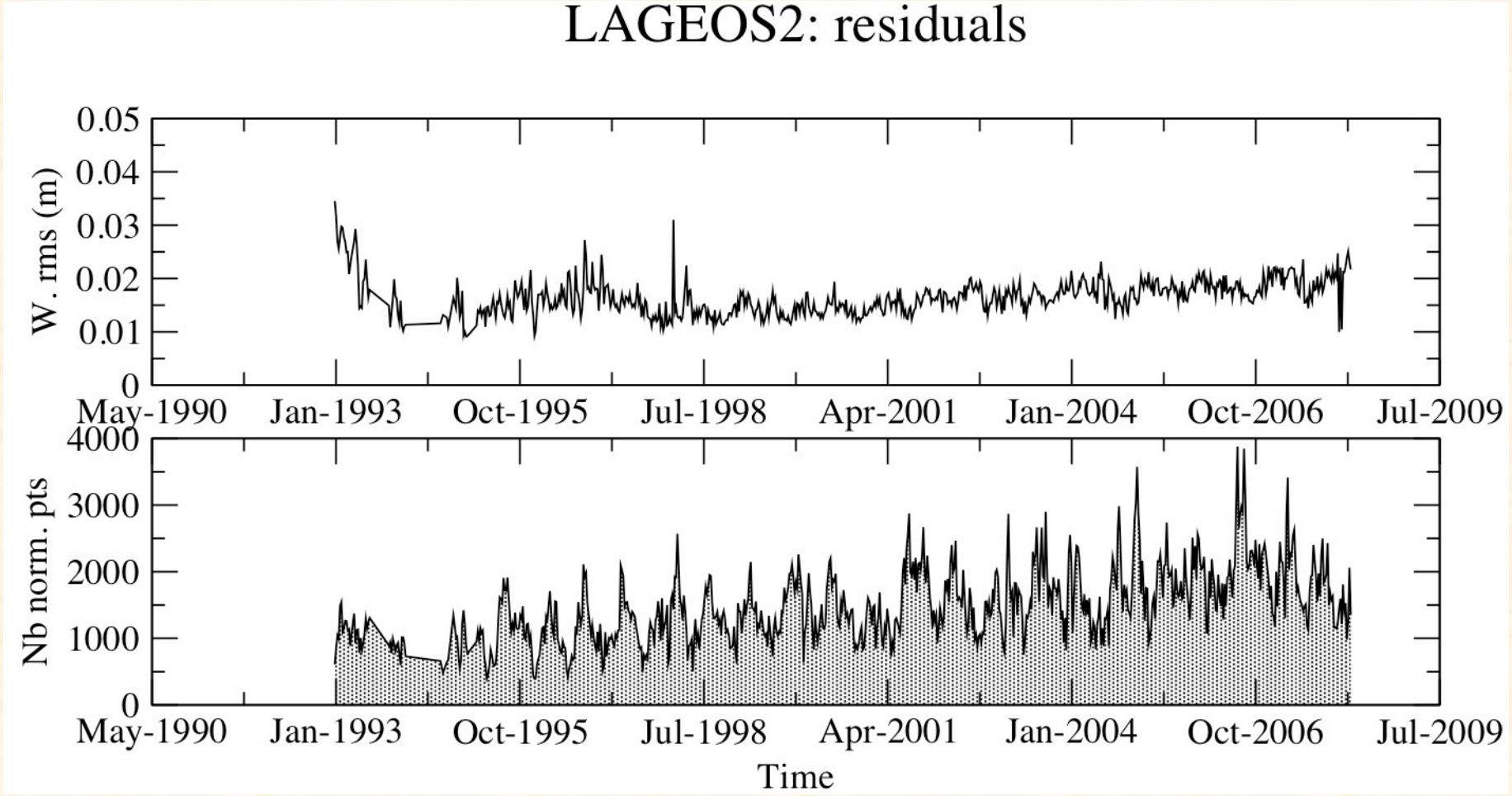
Weekly Orbital Fit [cm]



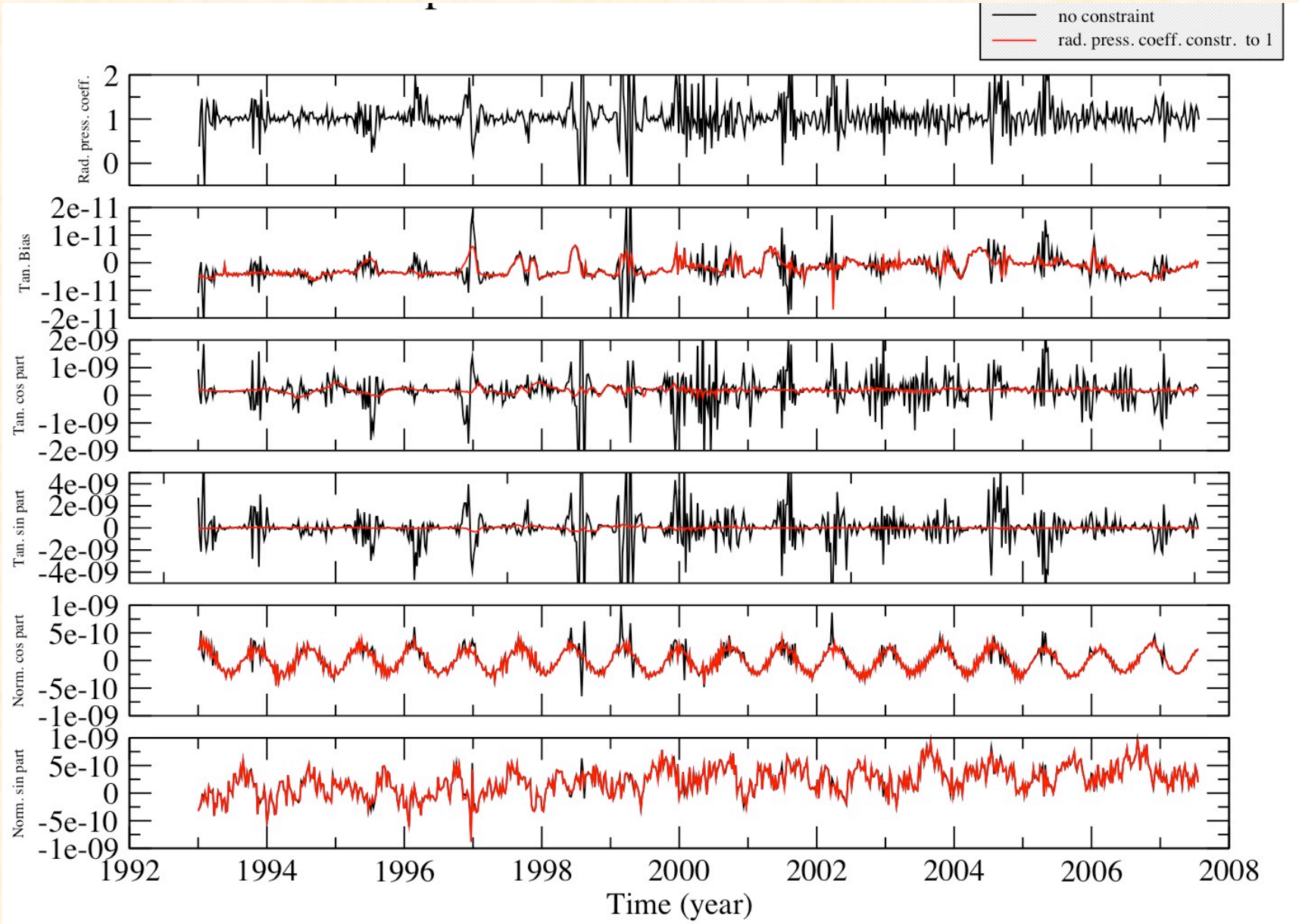
Müller et al., 2004

Our own analysis

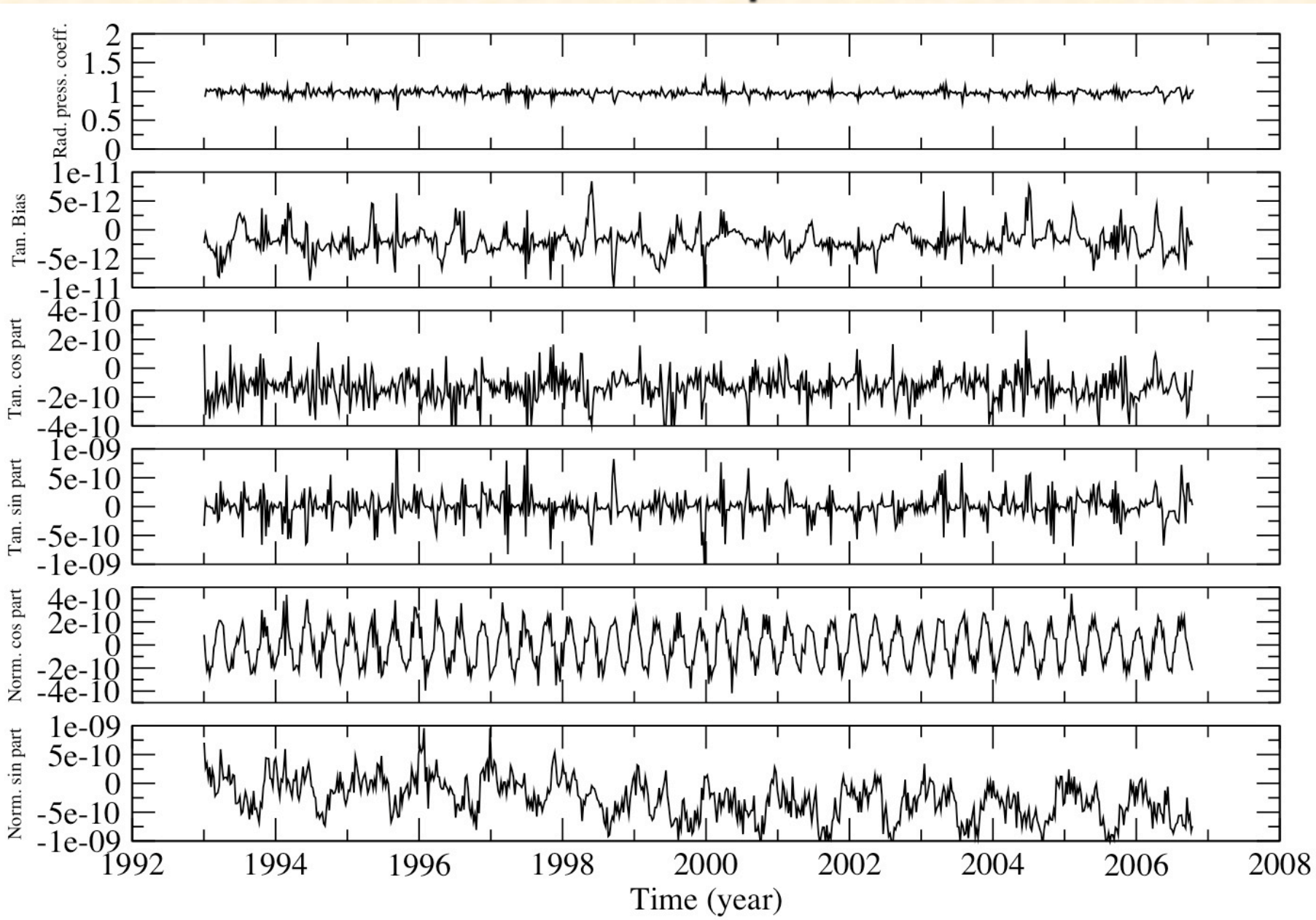
- LAGEOS modelling

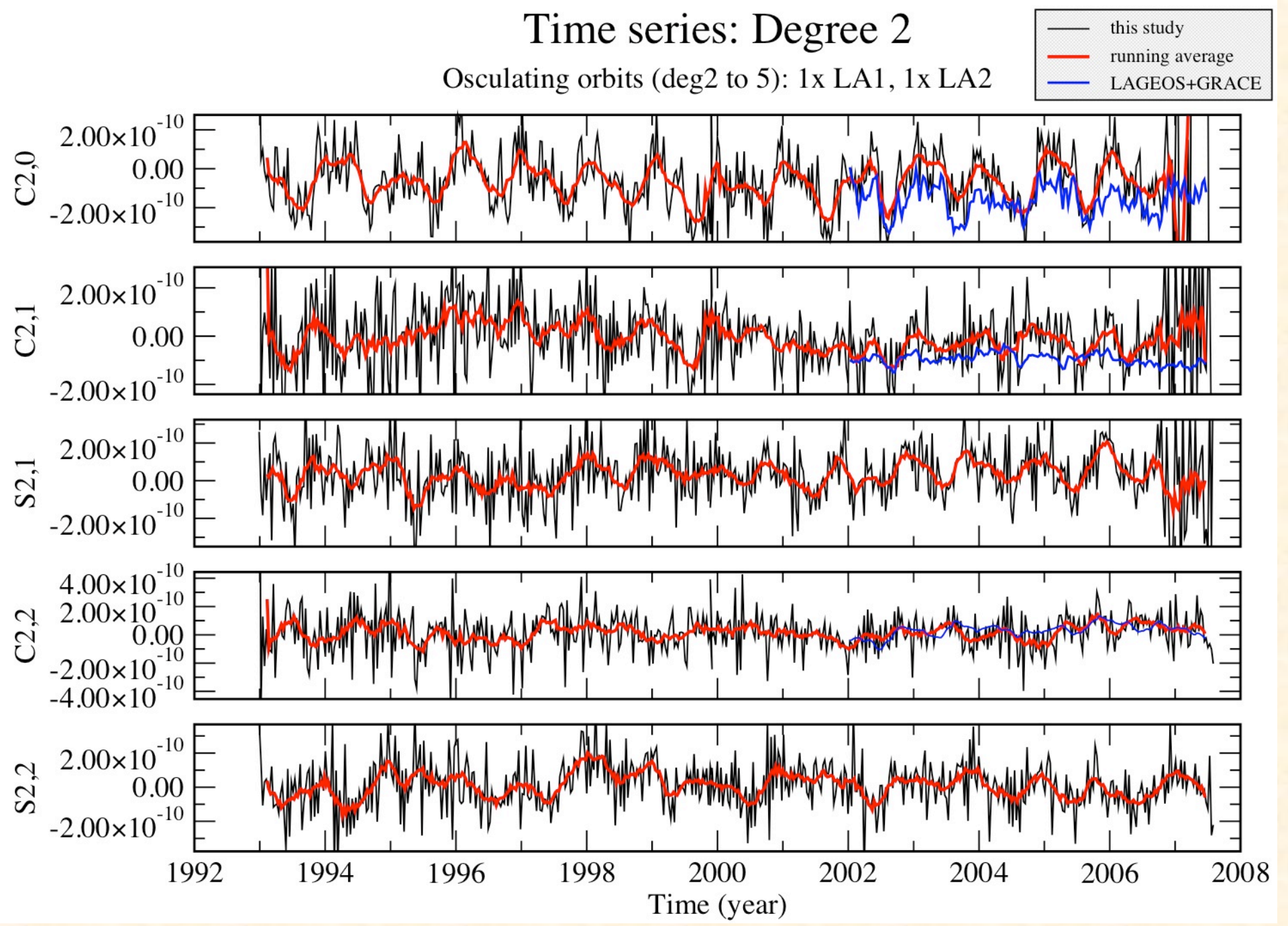


LA1: time series of empirical coefficients

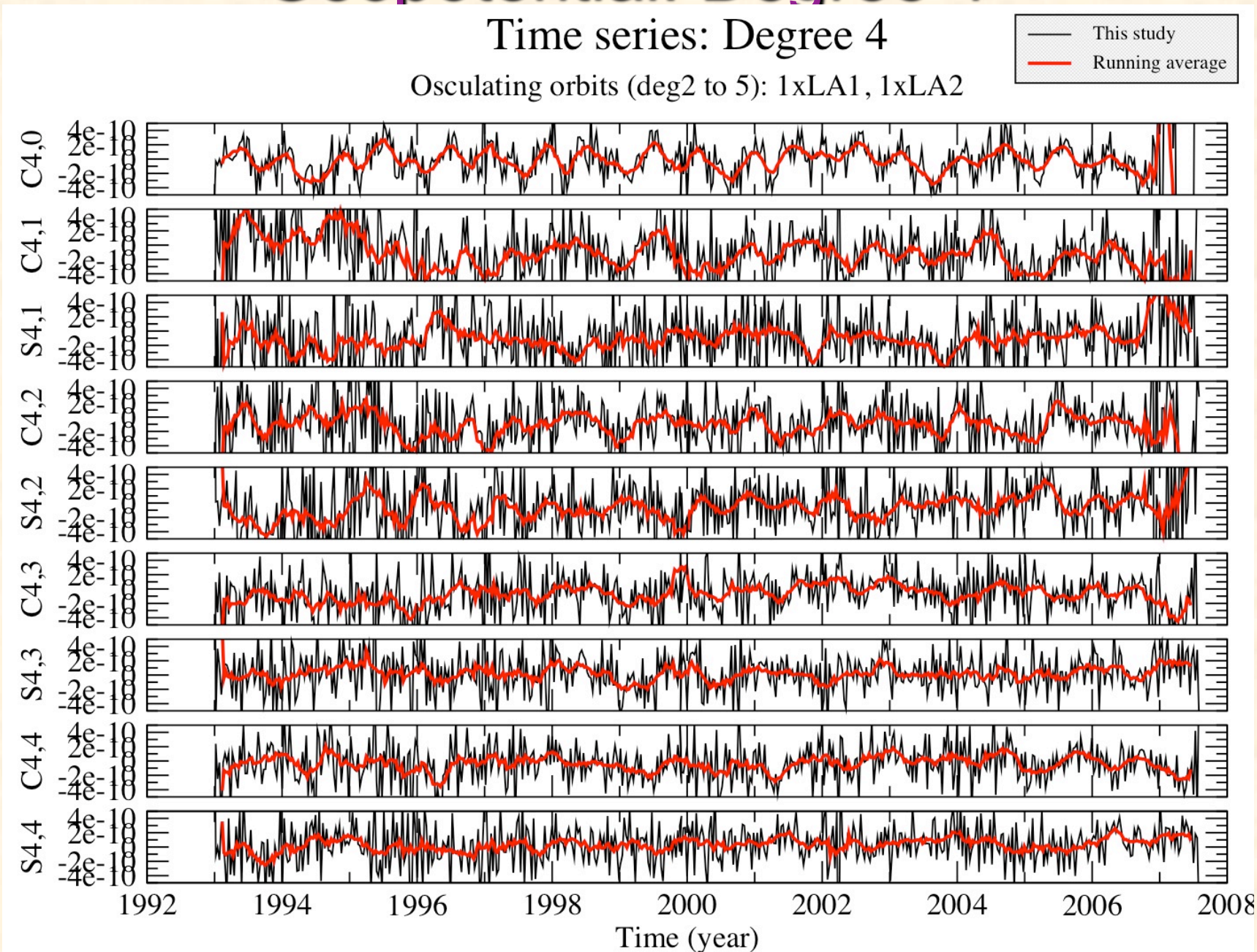


LA2: time series of empirical coefficients

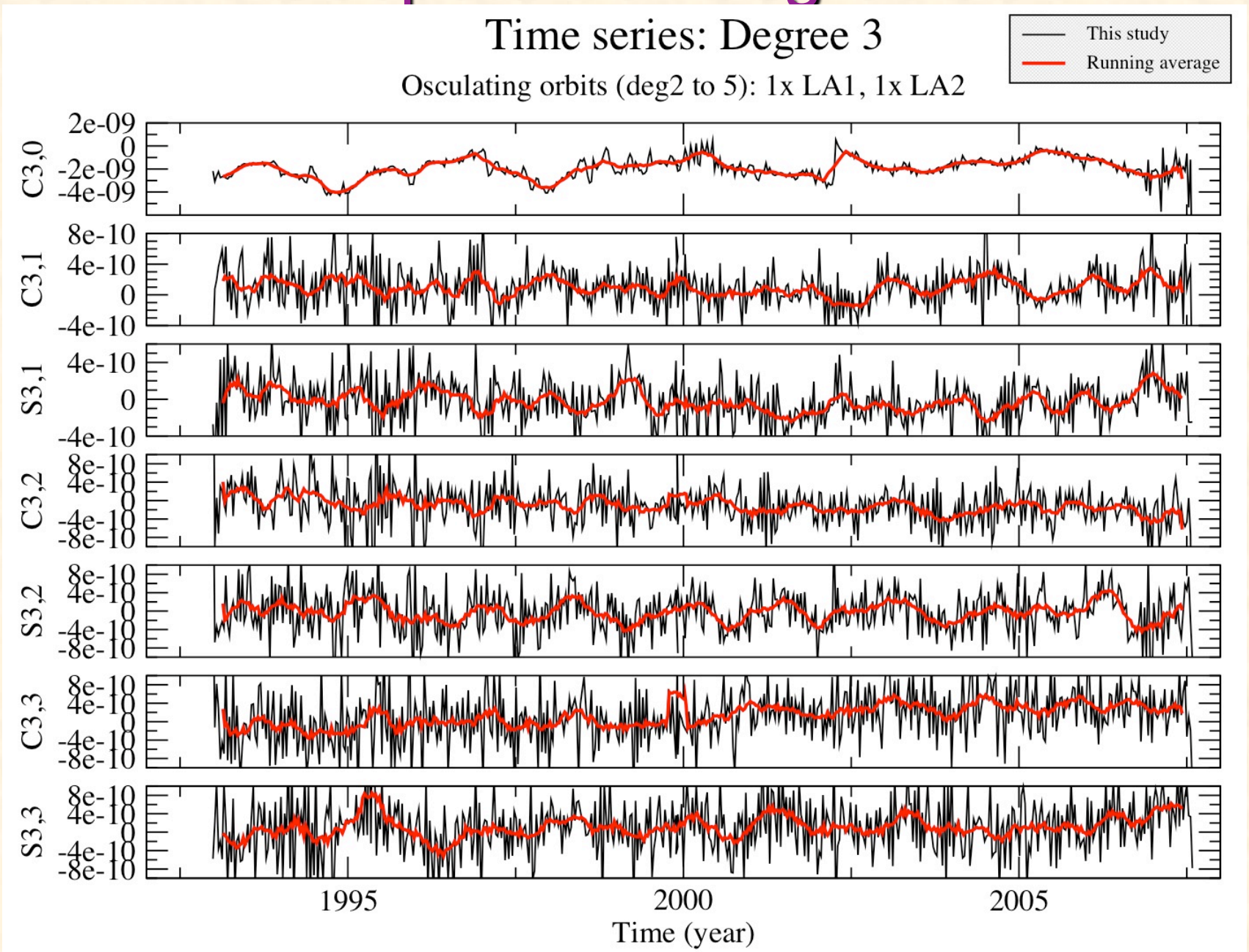



Time series: Degree 2
Osculating orbits (deg2 to 5): 1x LA1, 1x LA2
this study
running average
LAGEOS+GRACE
C2,0
C2,1
S2,1
C2,2
S2,2
2.00×10-10
0.00
-2.00×10-10
4.00×10-10
-4.00×10-10
1992
1994
1996
1998
2000
2002
2004
2006
2008
Time (year)

Geopotential: Degree 4

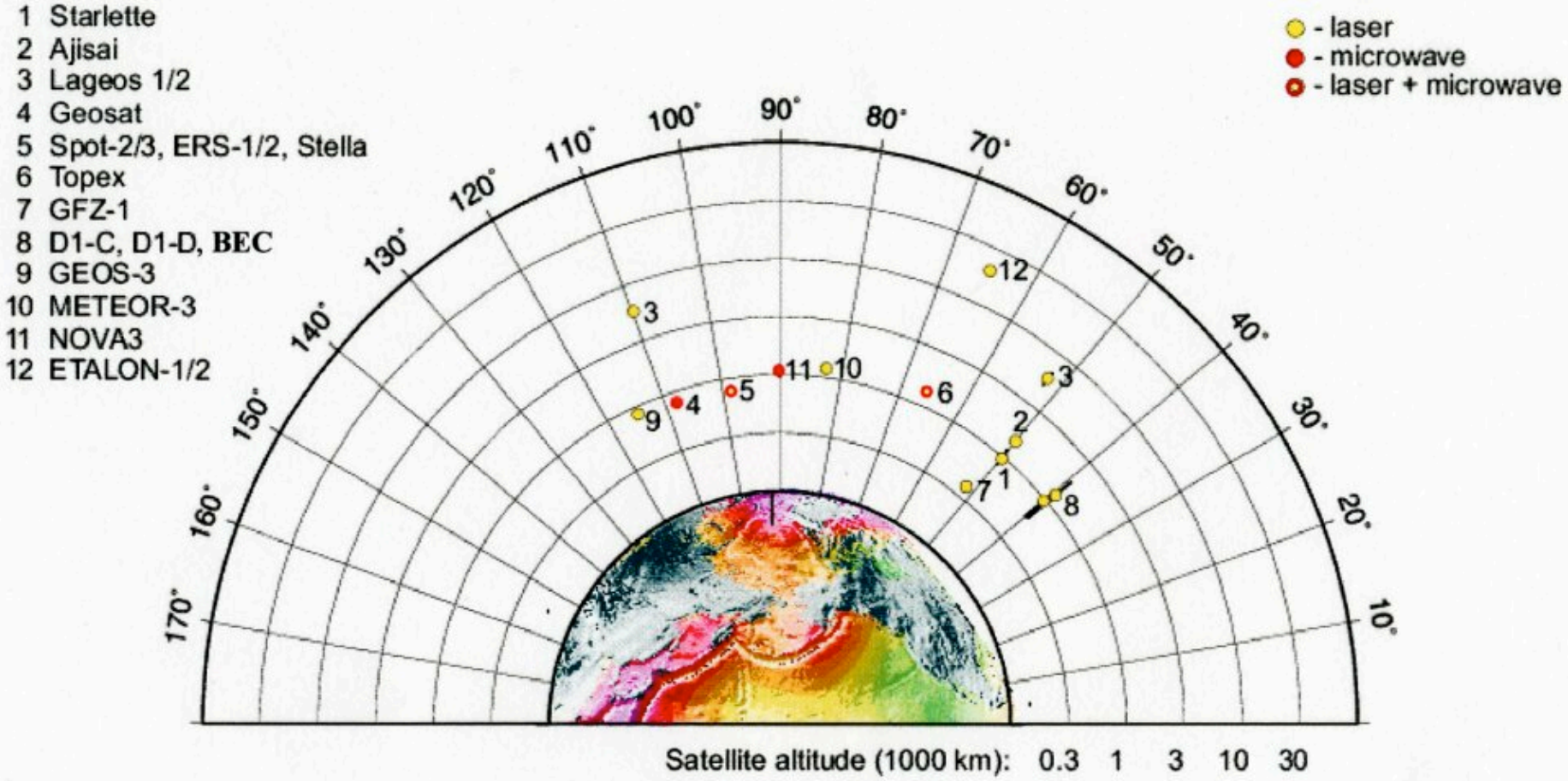


Geopotential: degree 3



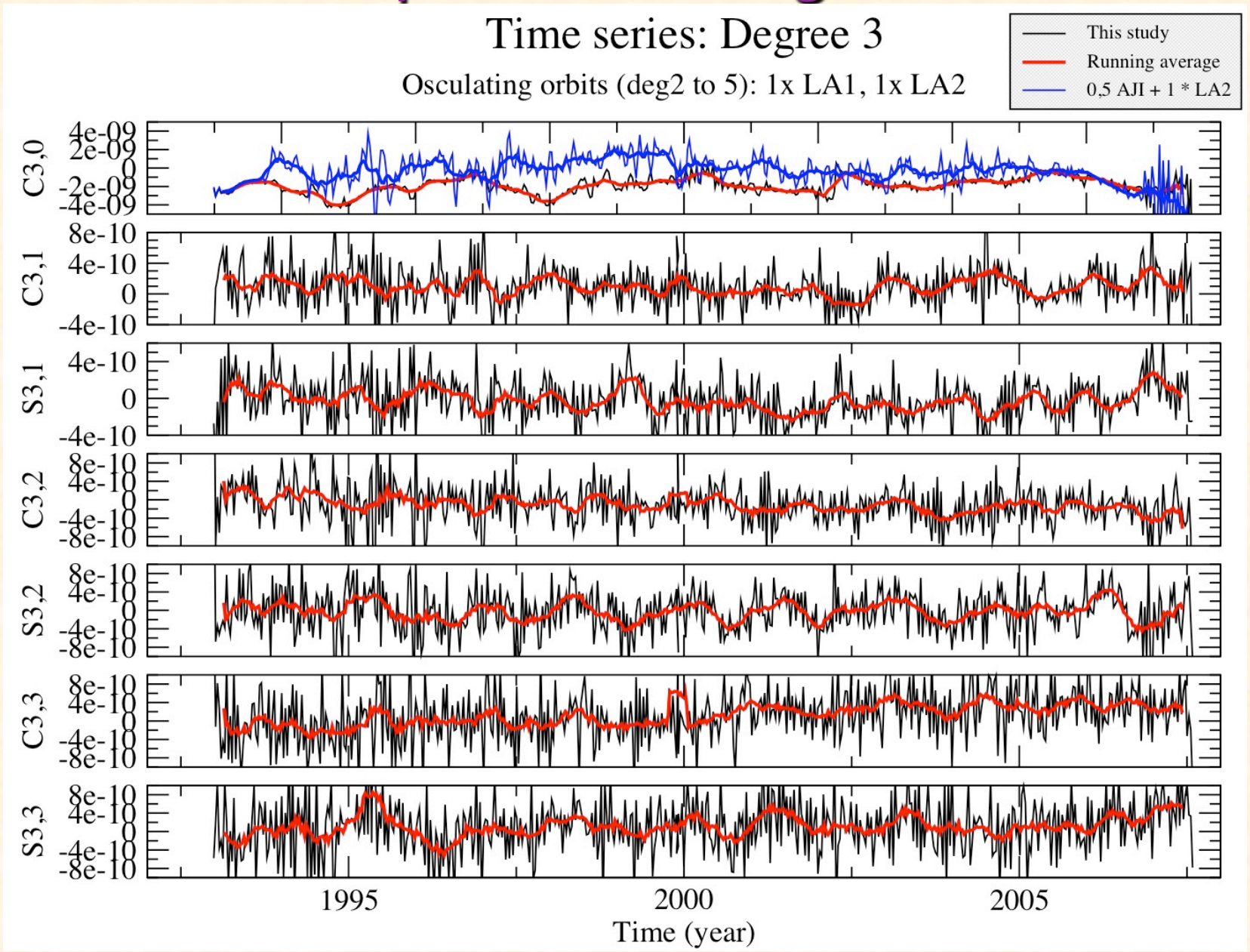
A constellation of geodetic satellites

Limited observation accuracy ⟹ *Various dynamical configurations, determination of specific sets of harmonics*

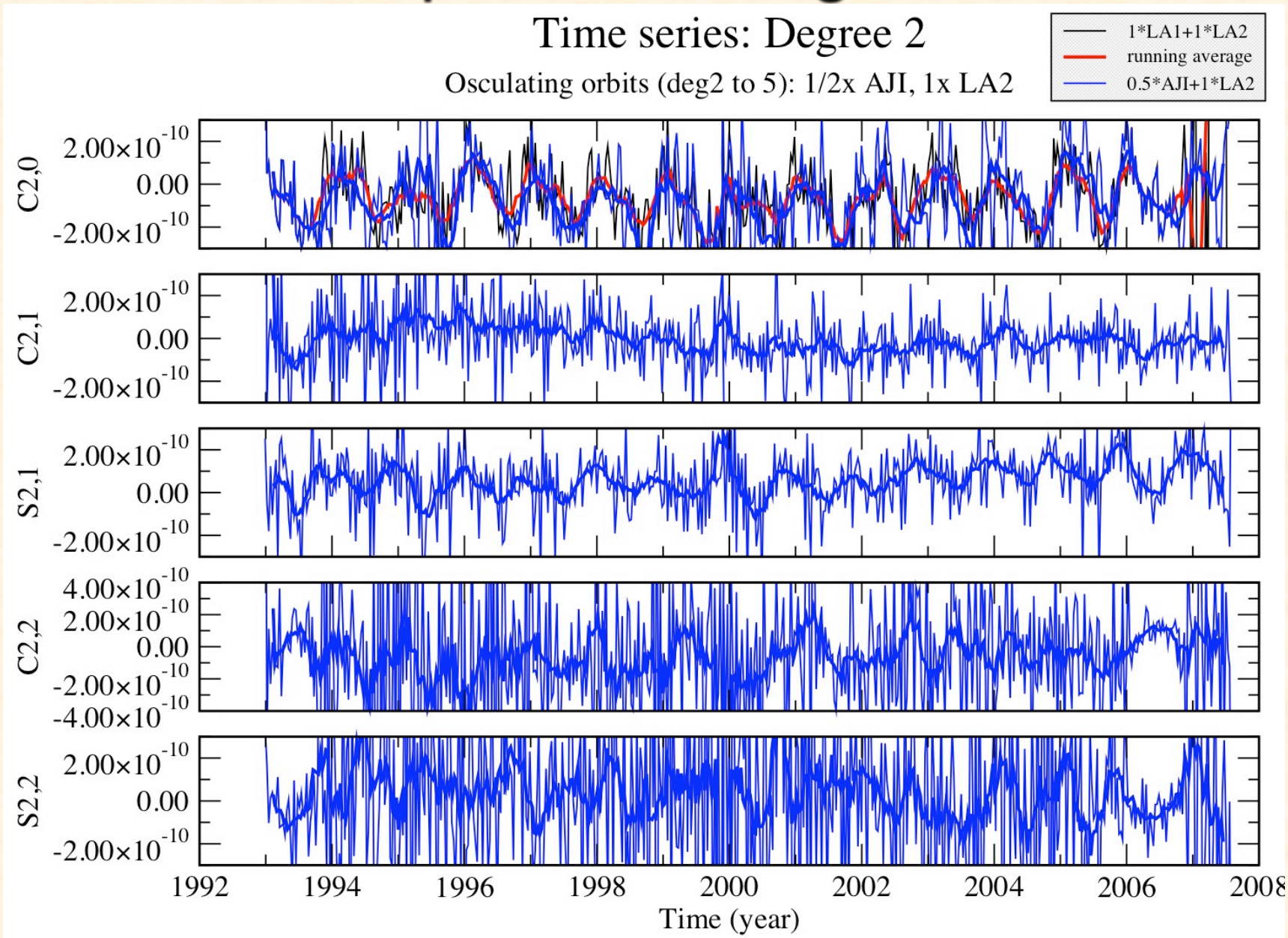


Satellites, orbits and tracking data employed for GRIM5-S1 global gravity field recovery

Geopotential: degree 3



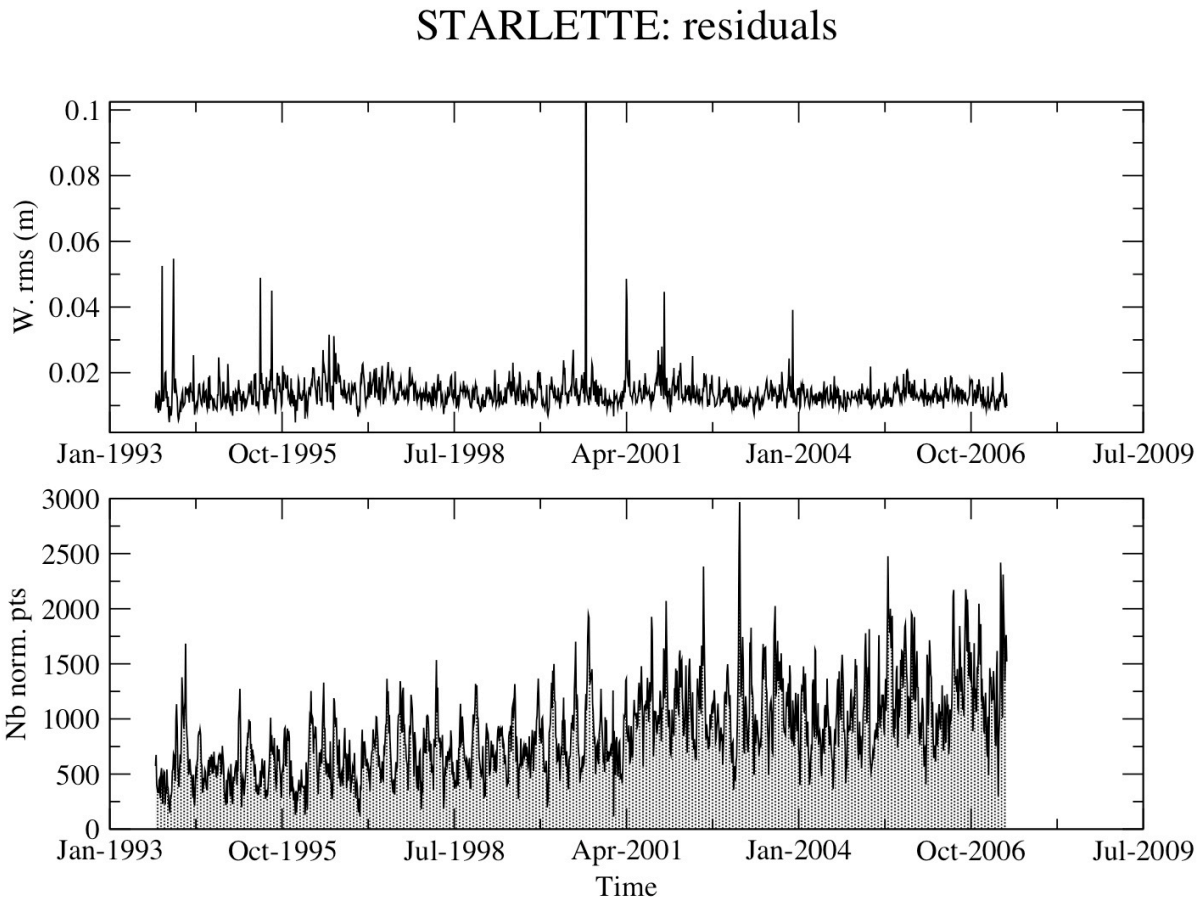
Geopotential: degree 2

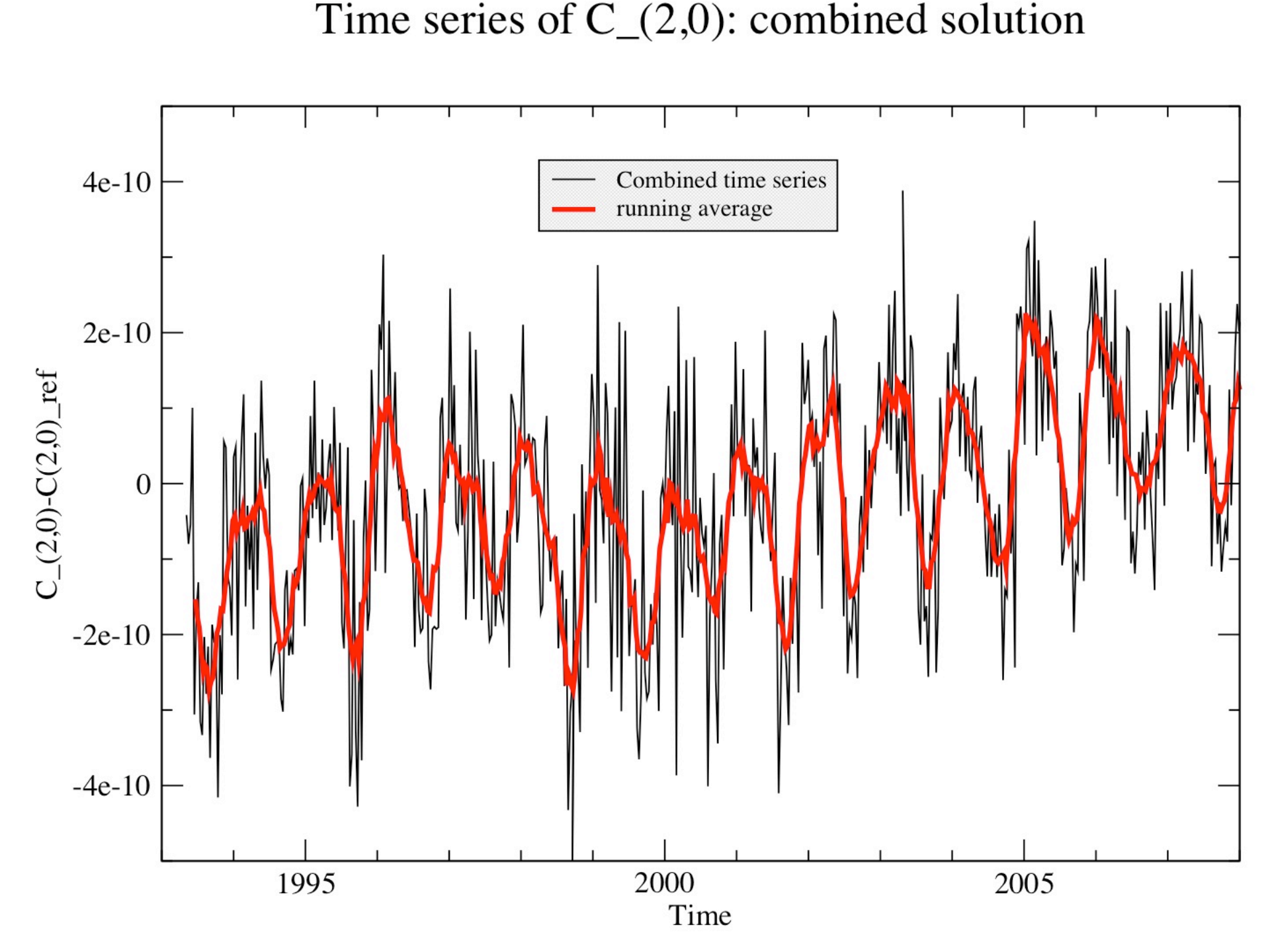


A combined solution

- Several satellites, weighted wrt the level of residuals (Helmert method)
  - LA1: 0,9
  - LA2: 1,2
  - ET1: 3,3
  - AJI: 0,18
  - STA: 1,4

- Time series of coefficients




Time series of C_(2,0): combined solution
Combined time series
running average
4e-10
2e-10
0
-2e-10
-4e-10
C_(2,0)-C(2,0)_ref
1995
2000
2005
Time

Temporal variations over long time scales ?

©	GRIM5-C1	Cheng & Tapley, 2004	This study (osc. motion)	This study (mean motion)
J2dot	$3.05\ 10^{-11}$ / yr	$2.75\ 10^{-11}$ / yr	from $2.61\ 10^{-11}$ /yr to $4.42\ 10^{-11}$ /yr	…
J4dot	$3.67\ 10^{-11}$ /yr		$4{,}41\ 10^{-11}$ /yr	…
J3dot	$7.45\ 10^{-12}$ /yr		∅	∅

- Post glacial rebound:
  - J_{2n}dot : affect ascending node
  - J_{2n+1}dot : affect eccentricity vector
  - Tesseral terms: do not perturbe orbits over long time scales
- Other origins:
  - Oceanic tides: 18.6 year tide, 9.3 year tide
  - Interannual events: El Nino, other mass transfer(atmosphere…)
- Methodology
  - Orbital model valid on long timescales
  - Inversion strategy suitable to detect small but cumulative effects

    Few parameters adjusted,

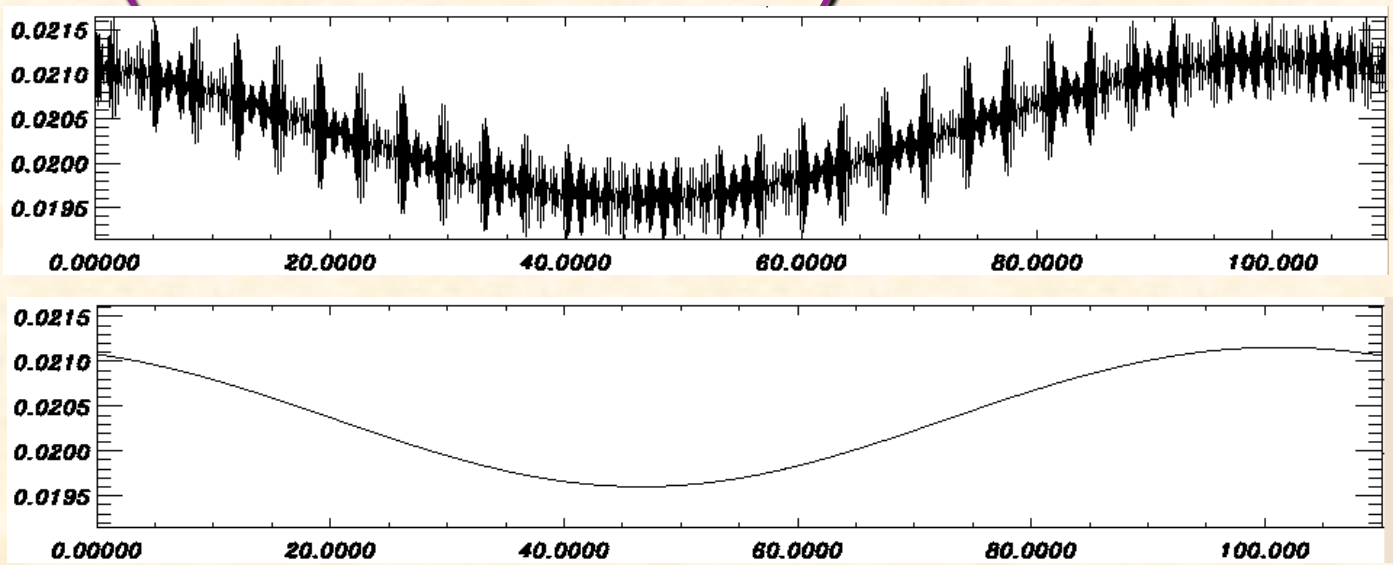
Long term orbital dynamics (*CODIOR* model)

Osculating motion

$$\frac{d\mathbf{E}}{dt} = SM(\mathbf{E}, \Sigma)$$
$$\mathbf{E}(t_0) =$$

Long Period terms

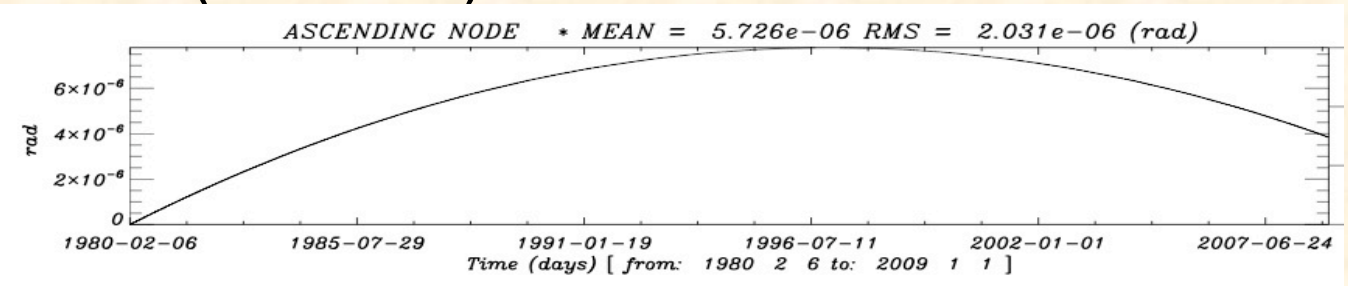
$$\frac{d\mathbf{E}'}{dt} = SM'(\mathbf{E}', \Sigma)$$



- Mean equations of motion obtained with an analytical averaging (5th order in J_2), which are integrated in a numerical way
  - J_2^5, coupling effects $J_2 J_n$ up to *n=40*
  - Tesseral resonant terms (1st order)
  - Luni-solar effects up to degree 3, and coupling effects with J_2
  - Radiation pressure, shadow effects (numerical averaging)
  - Development in power series of the eccentricity (up to e^{12} for J_2)

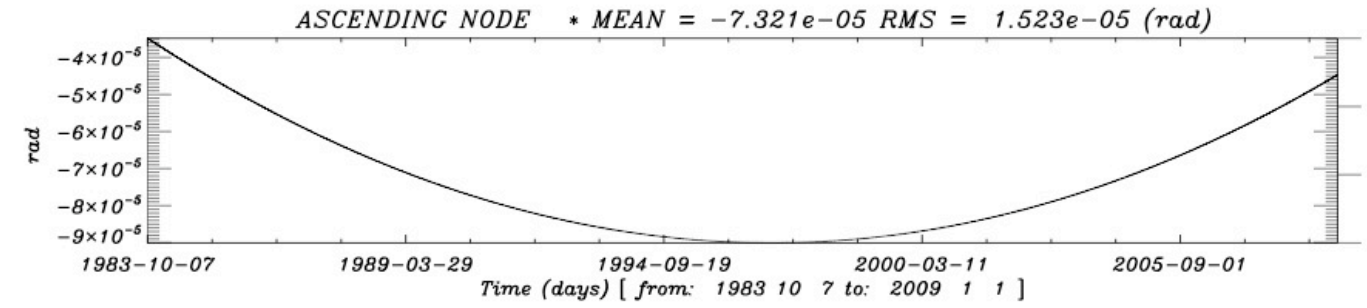
Post-glacial rebound:
signal to be expected on the node

- LAGEOS1 (6000 km):



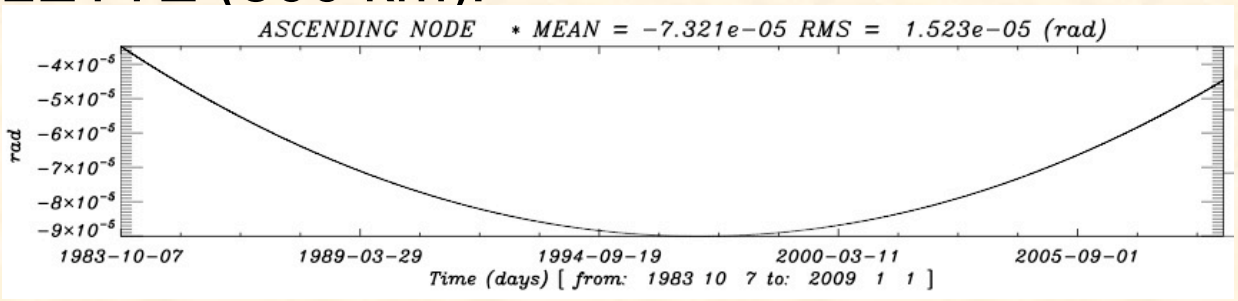
100m

- AJISAI (1200km):



280m

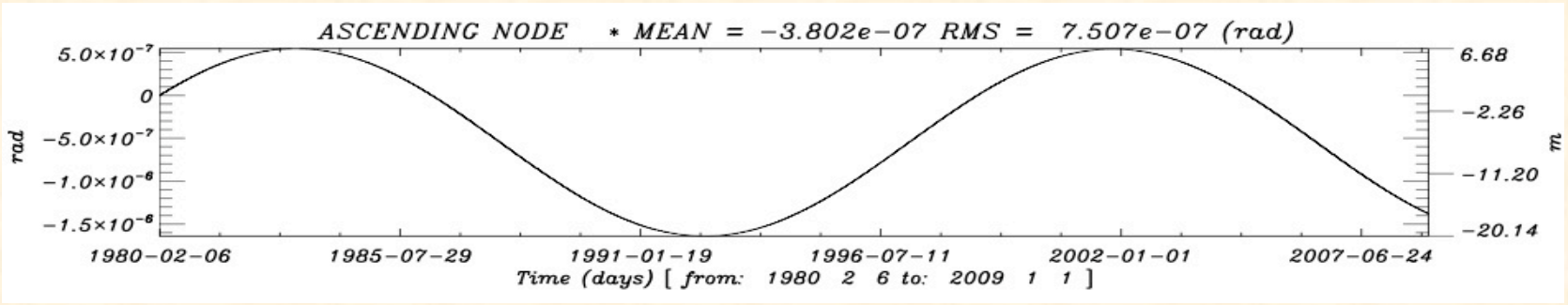
- STARLETTE (800 km):



400m

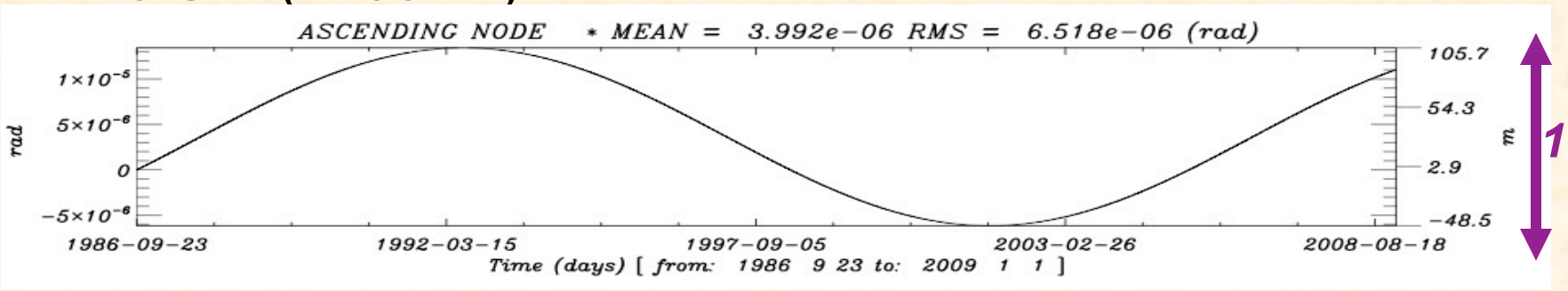
18.6 year tide:
signal to be expected on the node

- LAGEOS1 (6000 km):



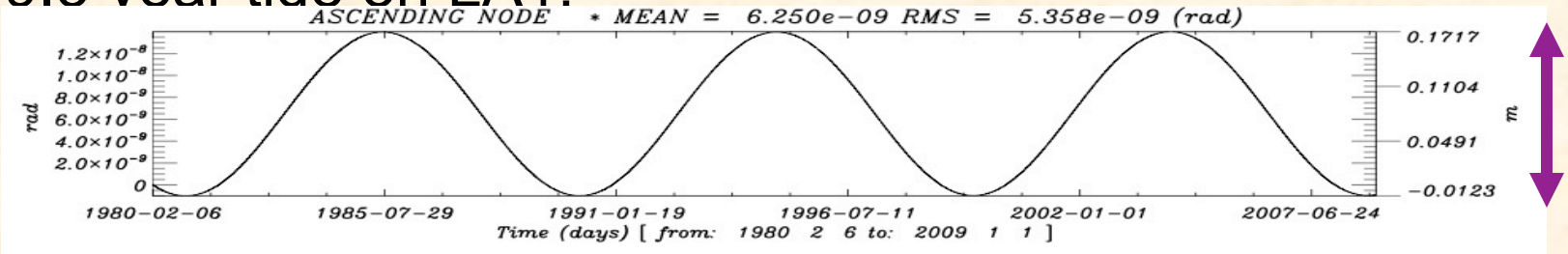
26m

- AJISAI (1200km):



150m

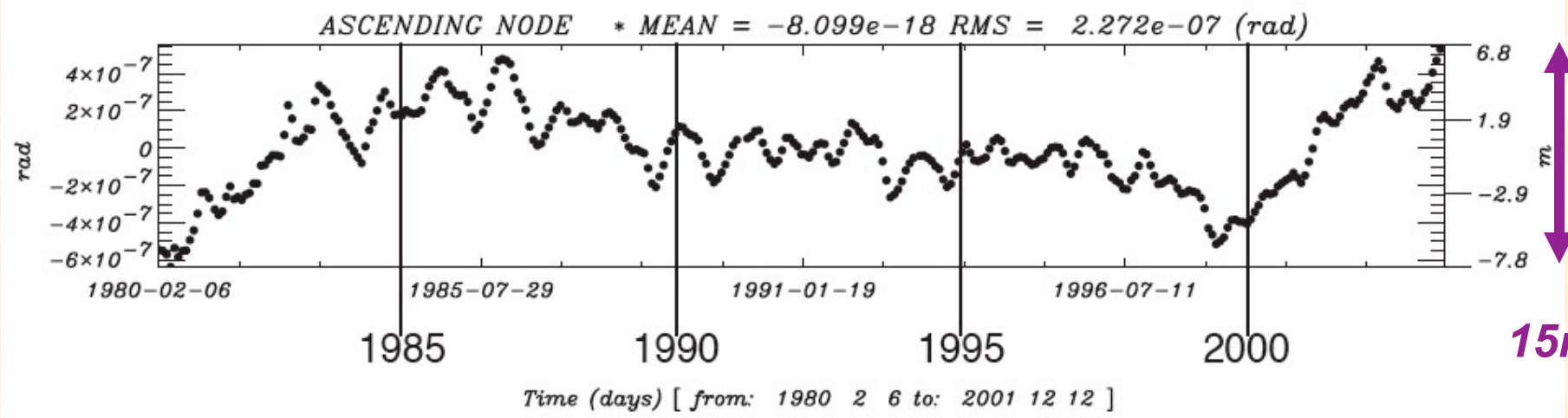
- 9.3 year tide on LA1:



20cm

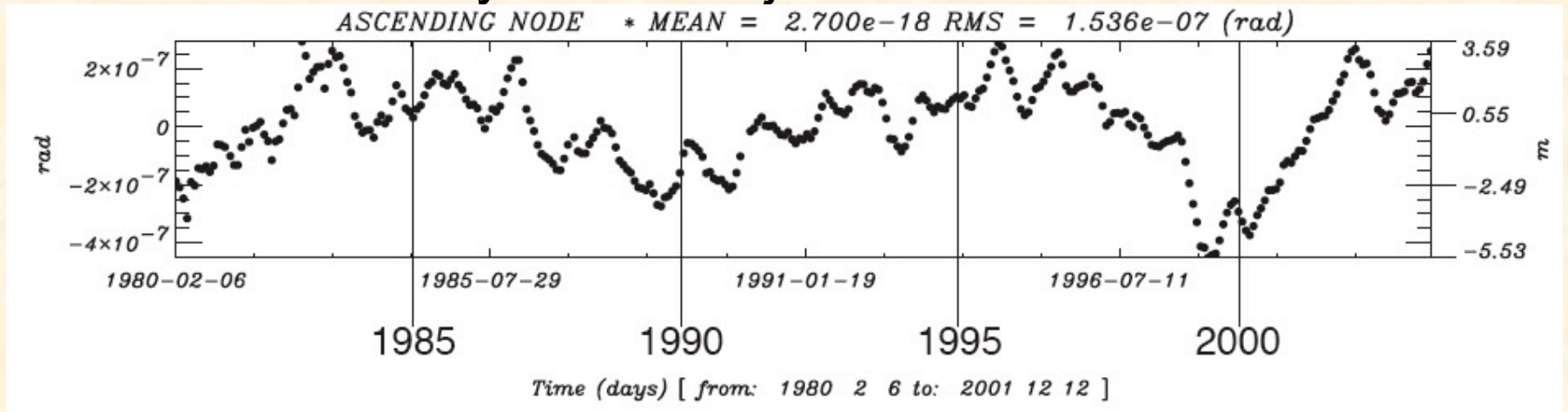
Post-fit residuals long term analysis: LAGEOS-1

- No geodynamical parameter adjusted



15m

- J2dot and 18.6 year tide adjusted:



Adjusted values

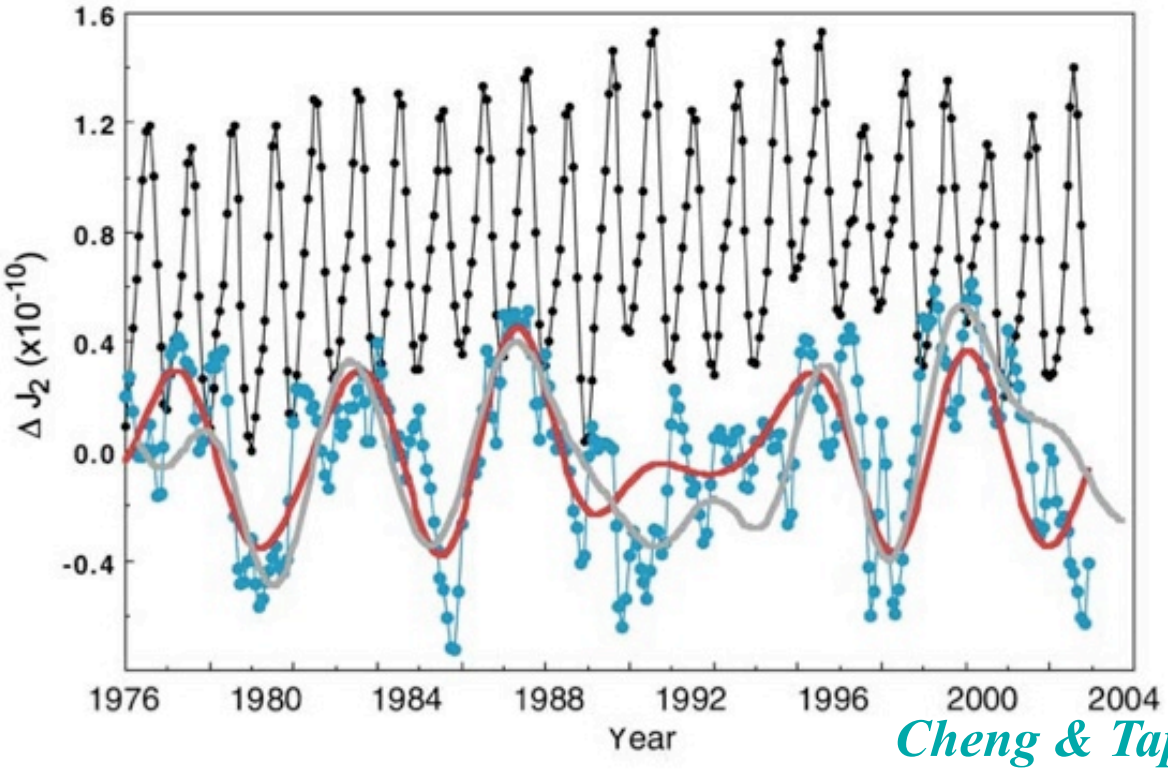
Arc	Period of the arc	$C_{2,0}$	$\dot{C}_{2,0}$ $year^{-1}$
1	1980-1996	$-0,108262643\ 10^{-2} \pm 0,1\ 10^{-9}$	$2,72\ 10^{-11} \pm 0,1\ 10^{-10}$
2	1980-2002	$-0,108262636\ 10^{-2} \pm 0,4\ 10^{-10}$	$2,70\ 10^{-11} \pm 0,9\ 10^{-12}$
3	1980-2002	$-0,108262636\ 10^{-2} \pm 0,4\ 10^{-10}$	$2,83\ 10^{-11} \pm 0,7\ 10^{-12}$

Arc	Period of the arc	18.6 year tide				9.3 year tide			
		Ampl. *cm*	Phase *deg*	C *cm*	S *cm*	Ampl. *cm*	Phase *deg*	C *cm*	S *cm*
1	1980-1996	1,60	81	$1,58 \pm 0,1$	$0,27 \pm 0,5$	0,25	−7	$0,03 \pm 0,09$	$-0,25 \pm 0,2$
2	1980-2002	1,45	77	$1,41 \pm 0,05$	$0,34 \pm 0,03$	0,49	−50	$0,37 \pm 0,05$	$-0,32 \pm 0,04$
3	1980-2002	1,50	78	$1,47 \pm 0,04$	$0,31 \pm 0,03$	-	-	-	-

- Aims:
  - Accuracy AND exactness of each coefficient: Characterizing mass transfer, decorrelation of estimations
  - Global modelling of the system Earth: gravity field,reference frame
- Analysis:
  - No influence of the « 1998 event »
  - The 9.3 year tide can not be adjusted in a realistic way

Conclusions

-
-
-



Cheng & Tapley., 2004

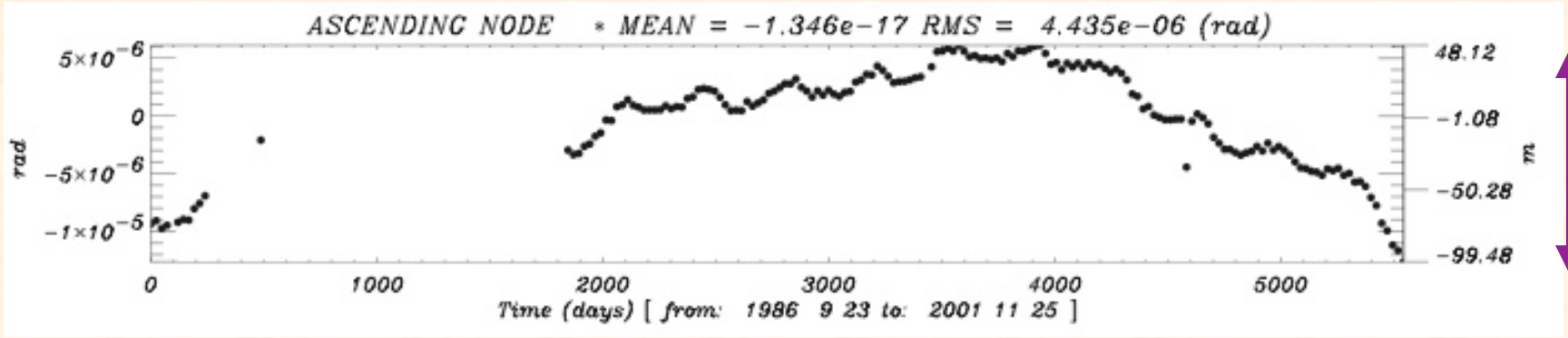
Figure 5. Variations in J_2 over tropical (blue circles) and extratropical areas (black circles) induced by soil moisture changes, the global soil-moisture-induced interannual variation in J_2 (red line), compared with the SOI (gray line) warm phase (<0) and cold phase (>0).

  - Earth rotation, polar motion

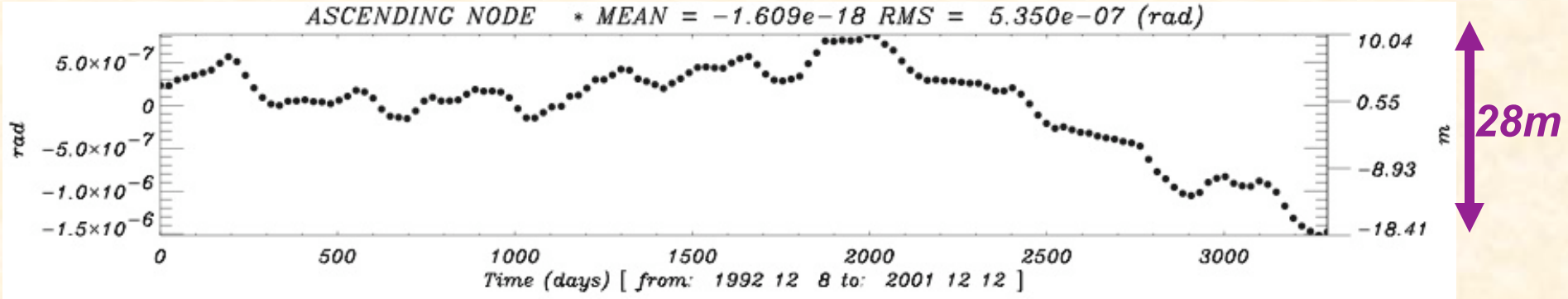

Thank you for your attention !

Post-fit residuals long term analysis: AJISAI, LAGEOS-2

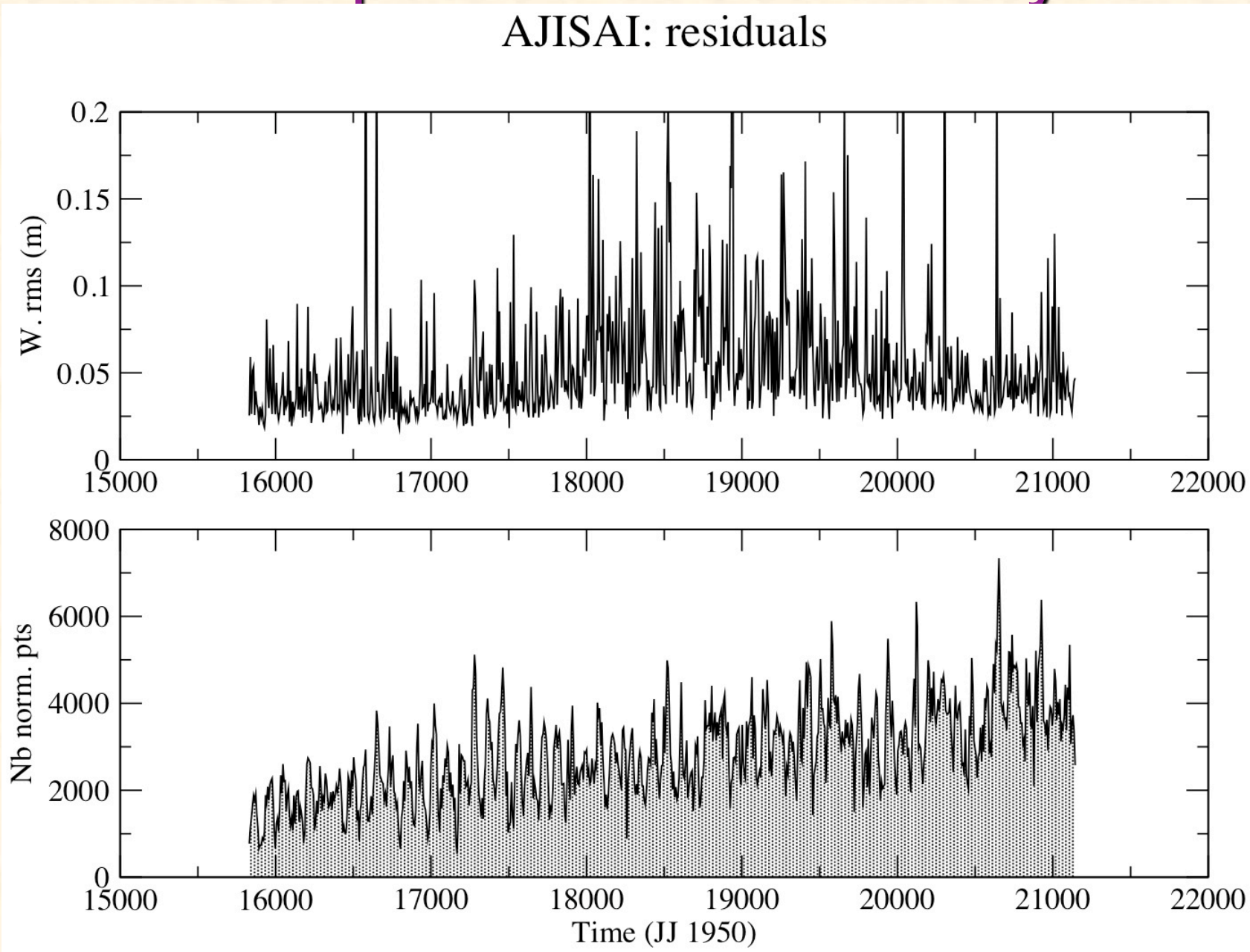
- AJISAI: No geodynamical parameter adjusted



- LAGEOS2: No geodynamical parameter adjusted



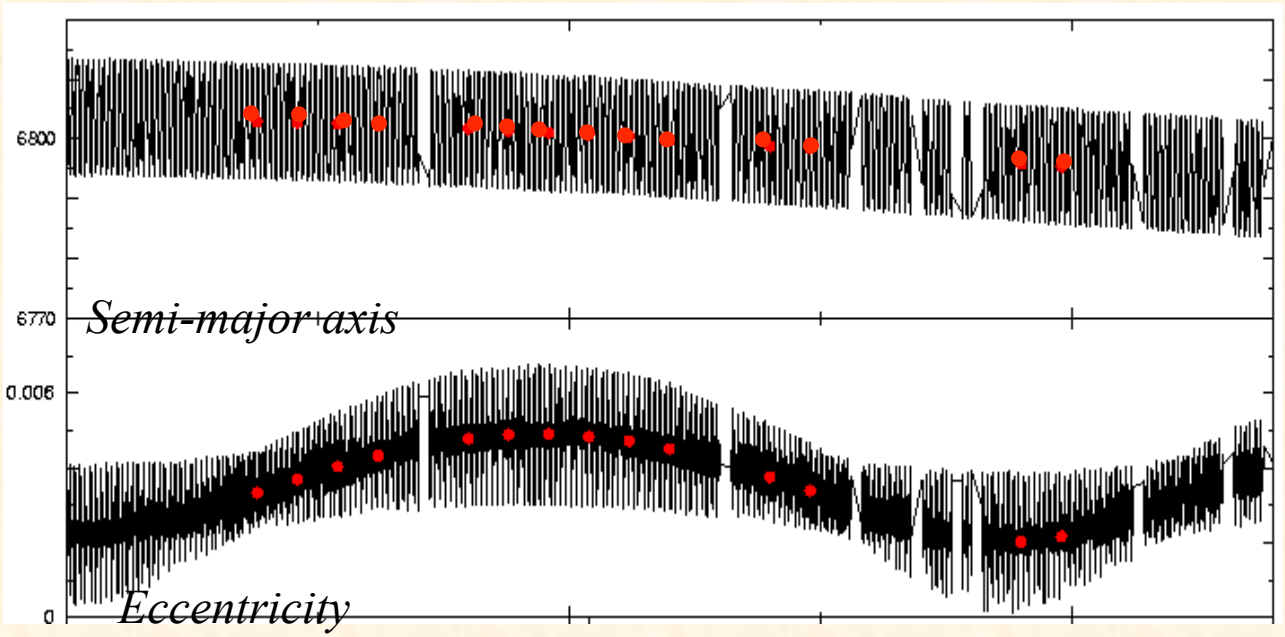
AJISAI: post-fit residuals analysis



Mean Observed Elements

Osculating elements

Mean Observed elements



• Analytical filtering

$$\Delta a = \quad \Delta\Omega =$$

$$\Delta e = \quad \Delta\omega =$$

$$\Delta i = \quad \Delta M =$$

$$\overline{E}(t) =$$

$$E(t) - \Delta E(t)$$

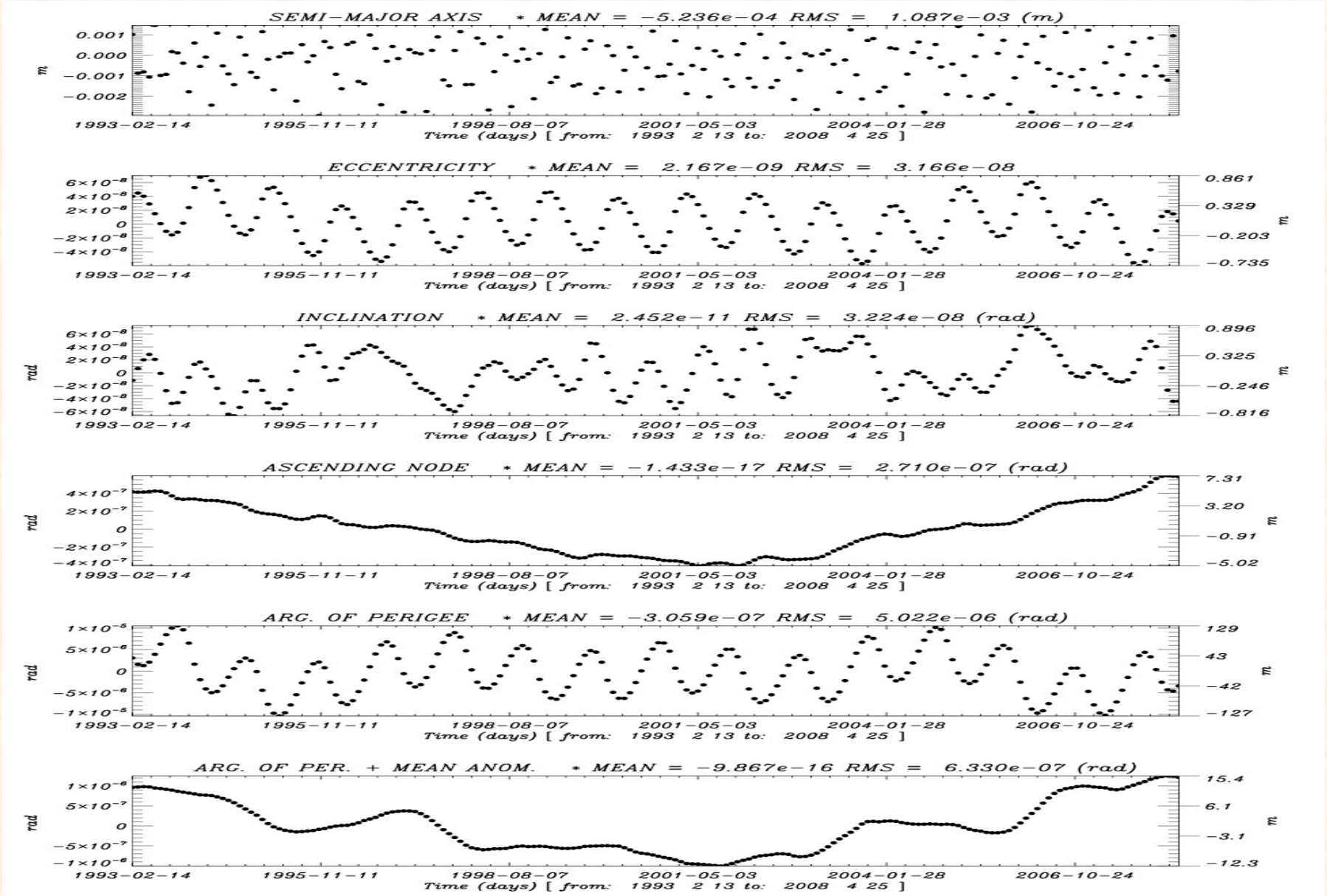
• Numerical step: *filtering of residual short periodic terms*

MOE are built from osculating orbits once for all:

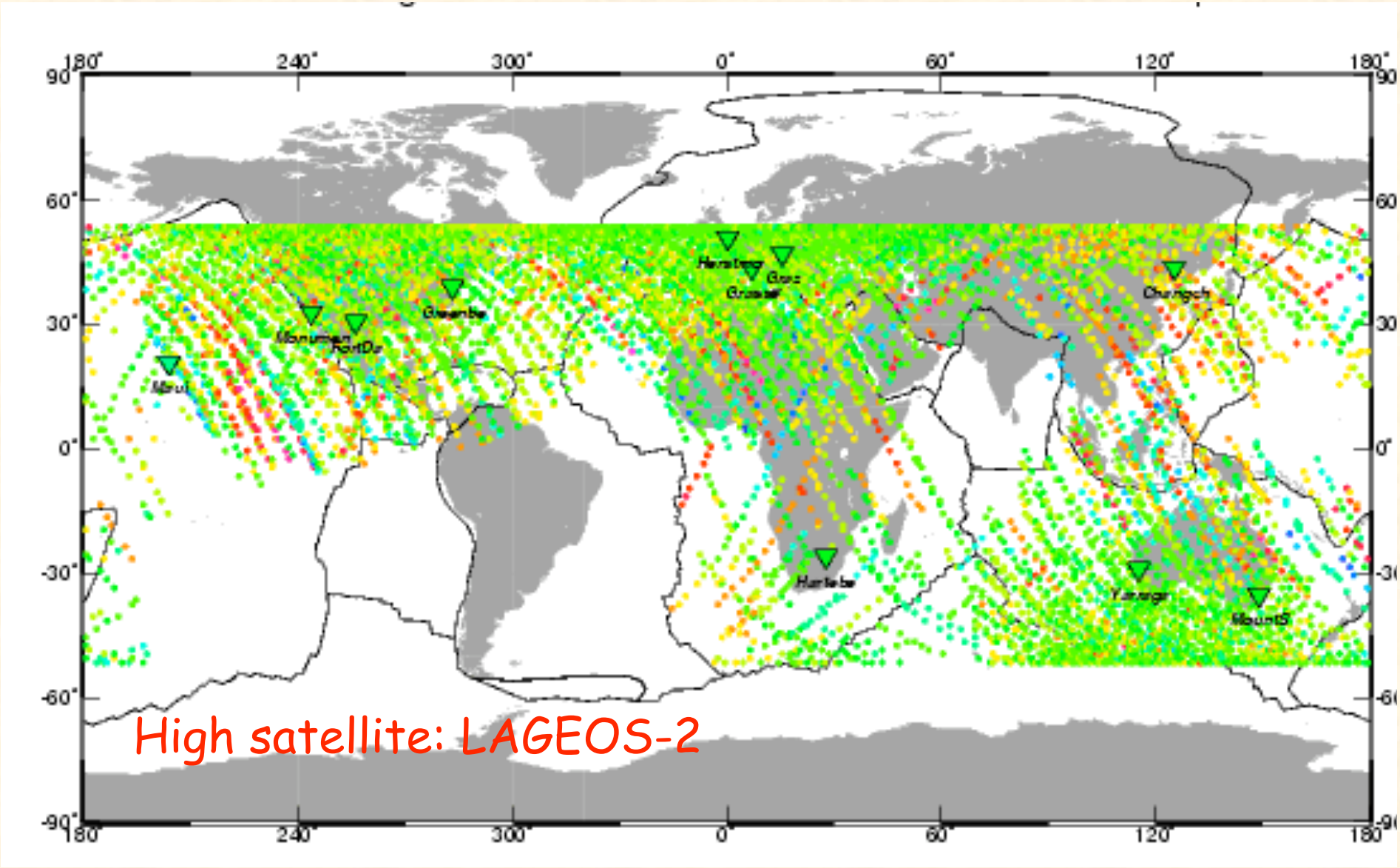
- in our database: LA1 (feb1980), LA2 (dec 1992), AJI (sept 1986), STA (dec 1983), STE (nov 1993), T/P (mar 1994), CHAMP (2001)

- scheduled: ET1, ET2, GPS34, and others…

Consistency of the method: *results of a simulation*



ILRS network and satellite tracking



Impact on the LAGEOS-1 satellite

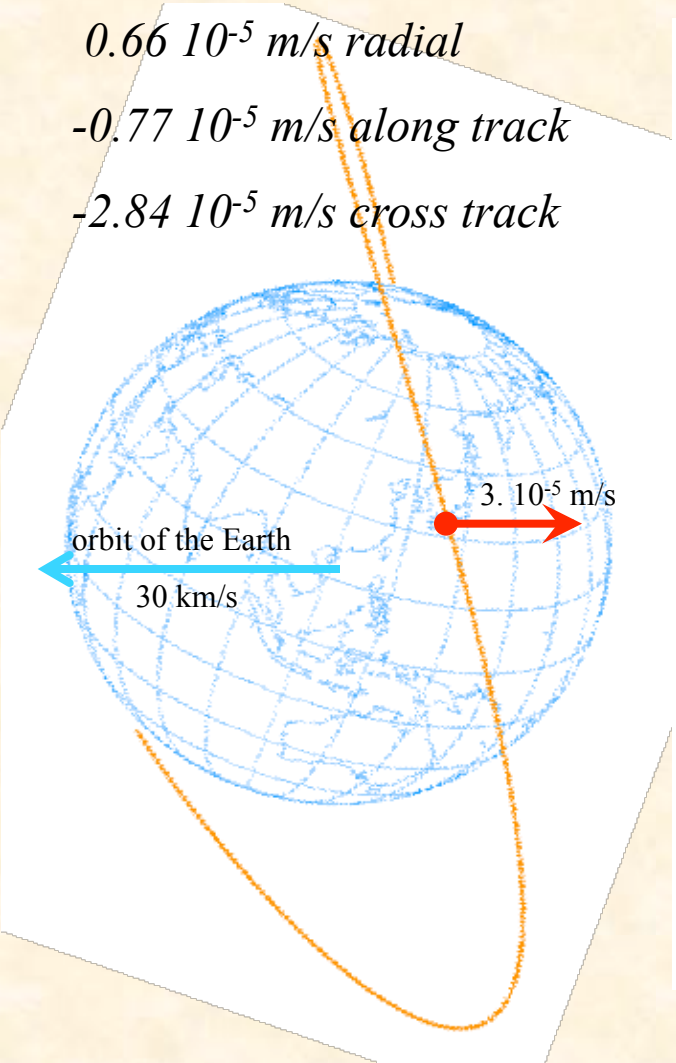
on April 5th, 2002, at 3:19:11 IAT above the Pacific ocean; lat. : 23°, long : 141°

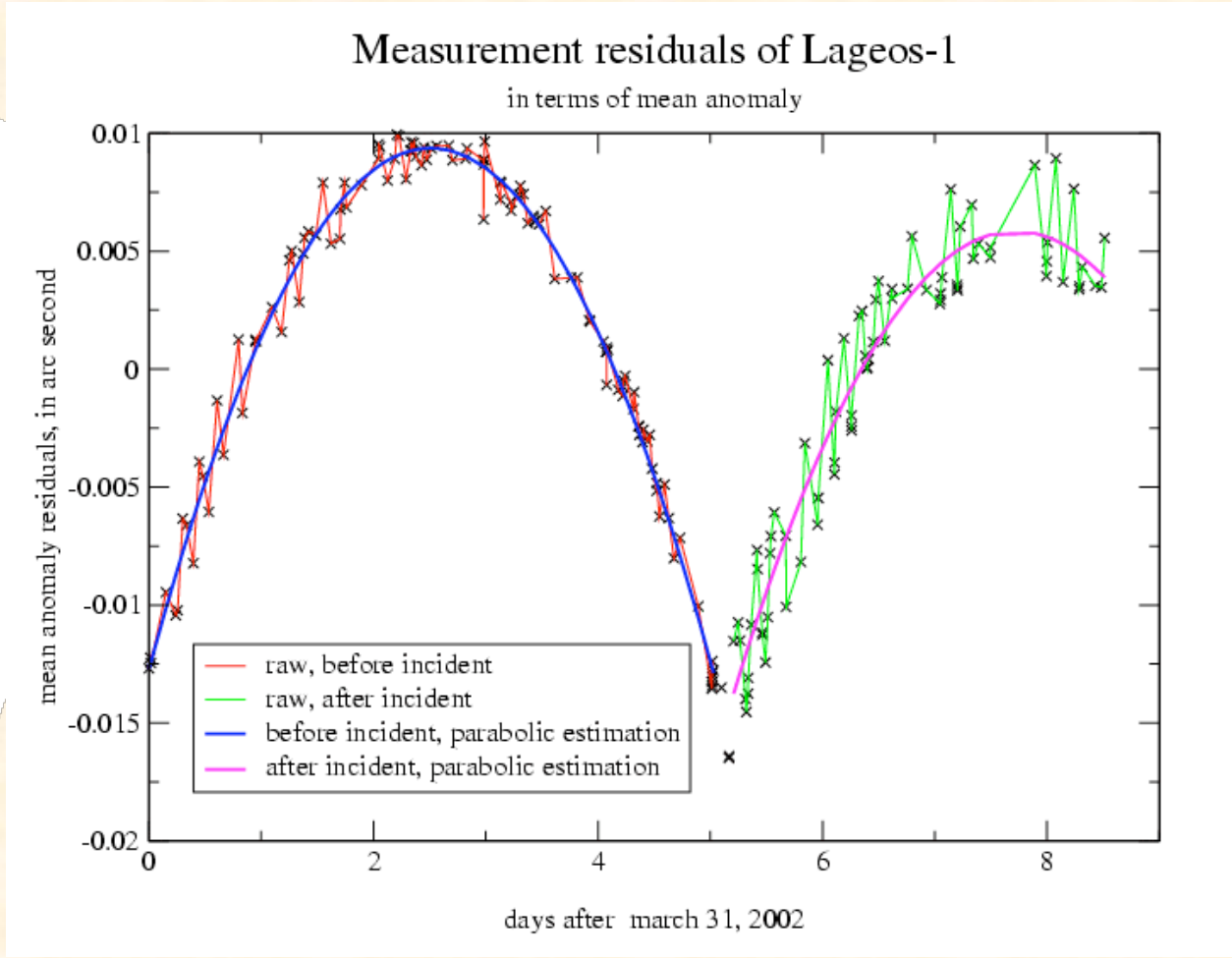
Impulse (given by some mg space particle ???):

0.66 10^{-5} m/s radial

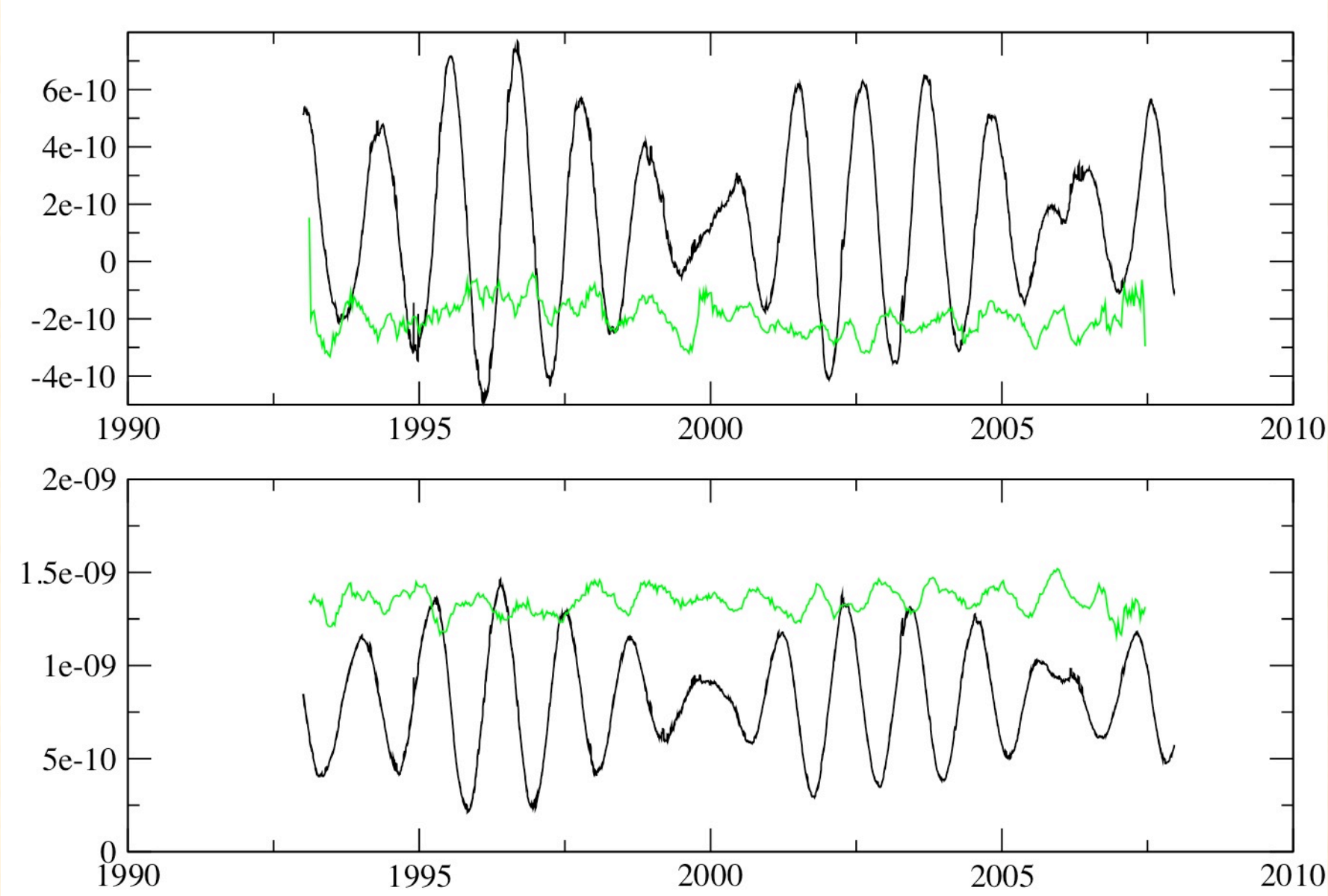
-0.77 10^{-5} m/s along track

-2.84 10^{-5} m/s cross track

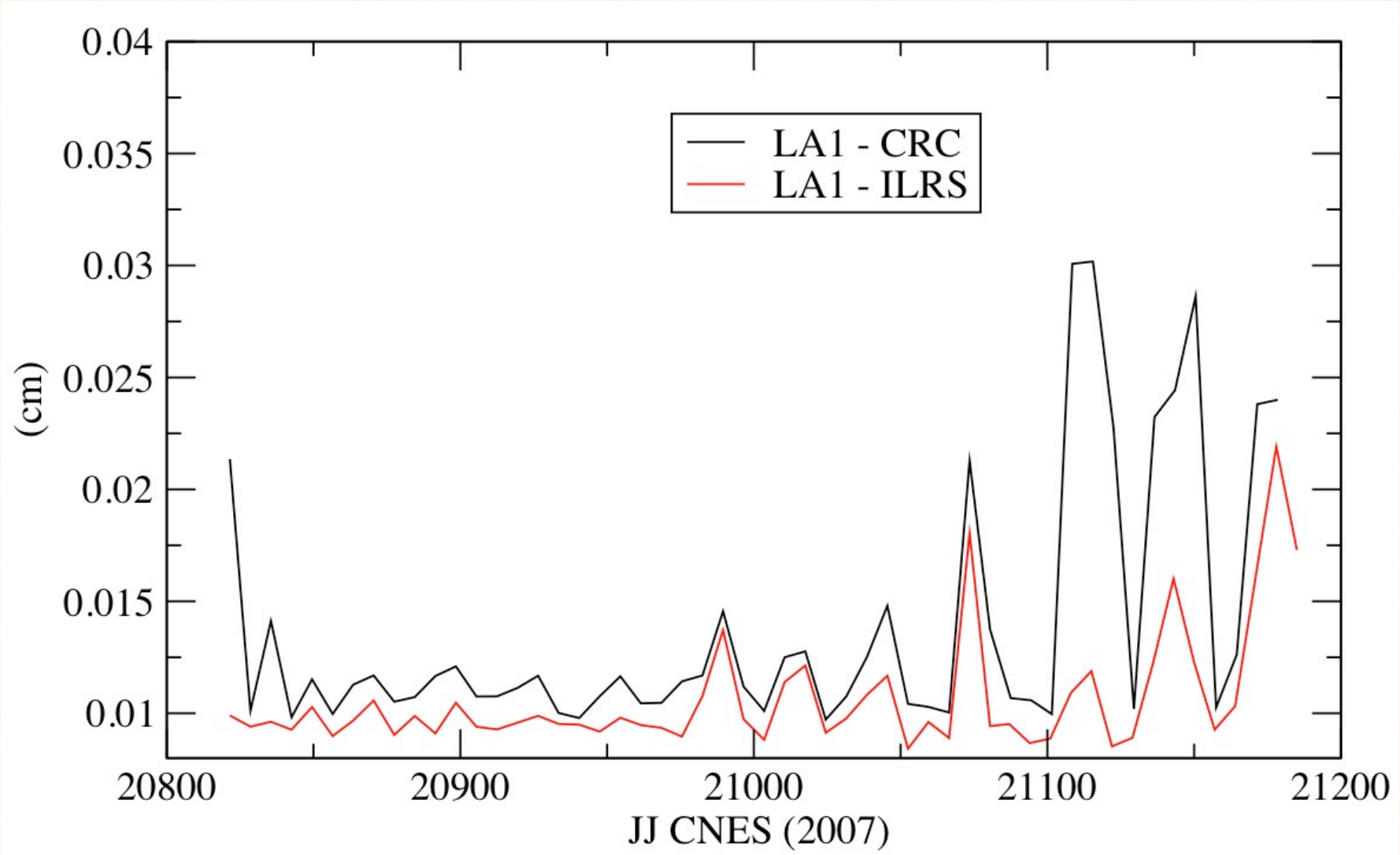




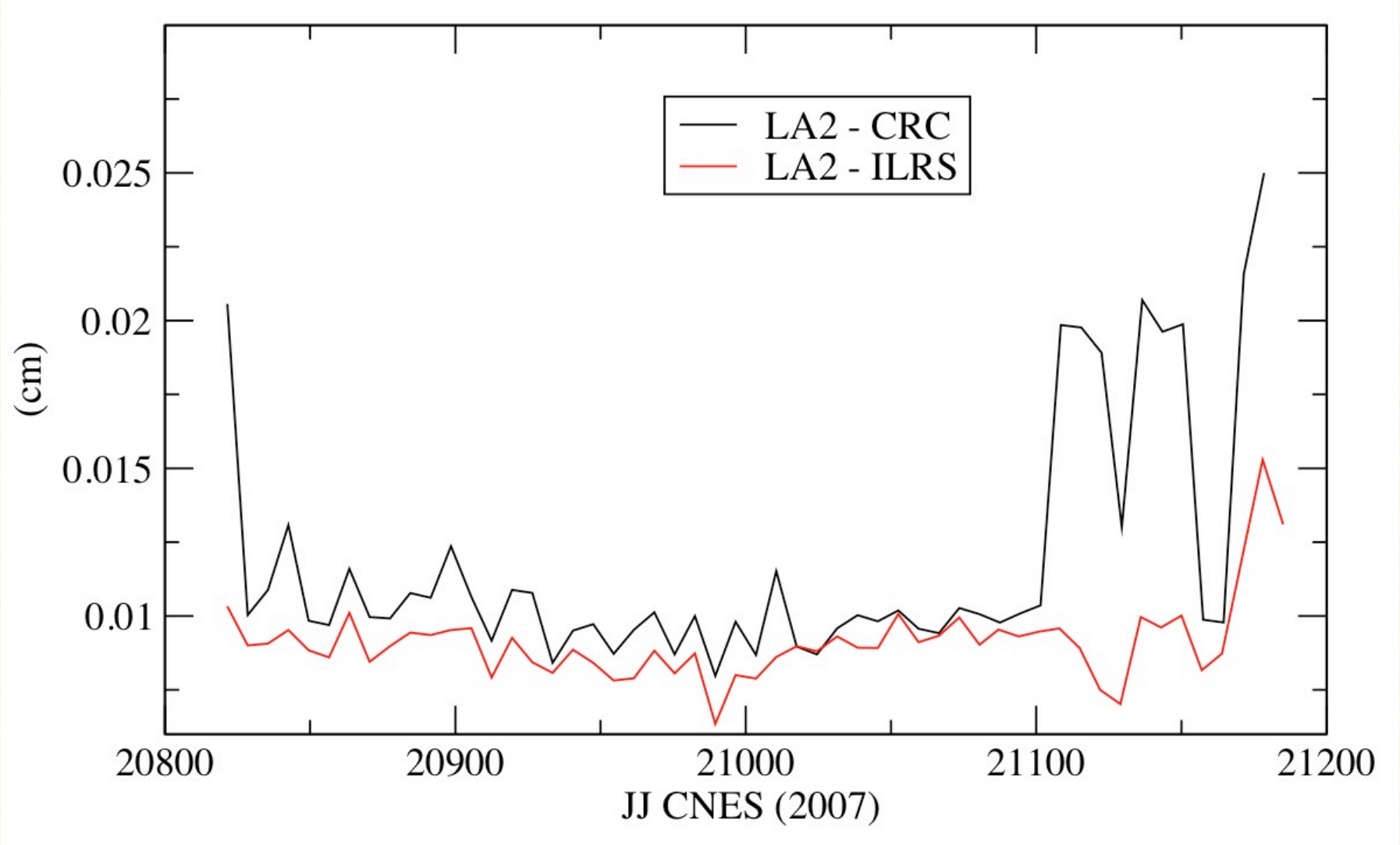
Comparison :
polar motion, and C_{21} S_{21}



LAGEOS-1: weekly *post-fit residuals*



LAGEOS-2: weekly *post-fit residuals*



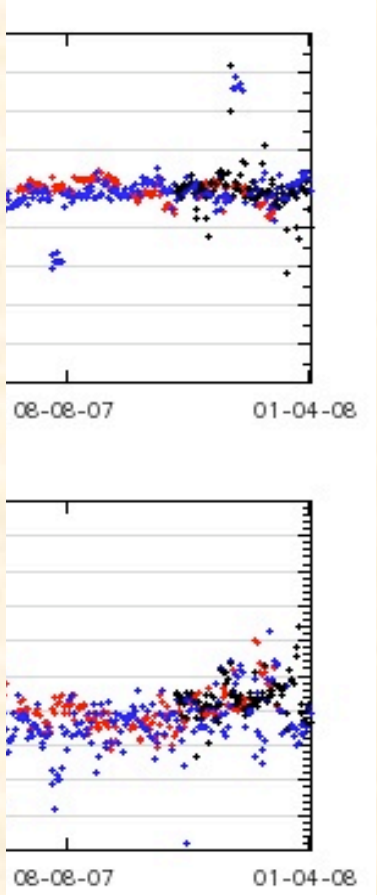
LAGEOS-1, -2: *Orbital modelling*

- ILRS
  - Week n-1
  - Albedo: Stephens model
  - No atmospheric loading for the gravity field (DEPSTA = 0)
  - No atmospheric loading for the stations (fes2002 = 0)
  - Daily polar motion a priori
  - Empirical coefficients: BT, BTC, BTS, BNC, BNS

- CRC
  - Week n-3
  - Polar motion a priori: C04
  - DEPSTA = 1, fes2002 = 1
  - Albedo : Grids
  - Empirical coefficients: BT, BTC, BTS, BNC, BNS

ILRS operational products

EOP: Res wrt c04 (2006-2008)

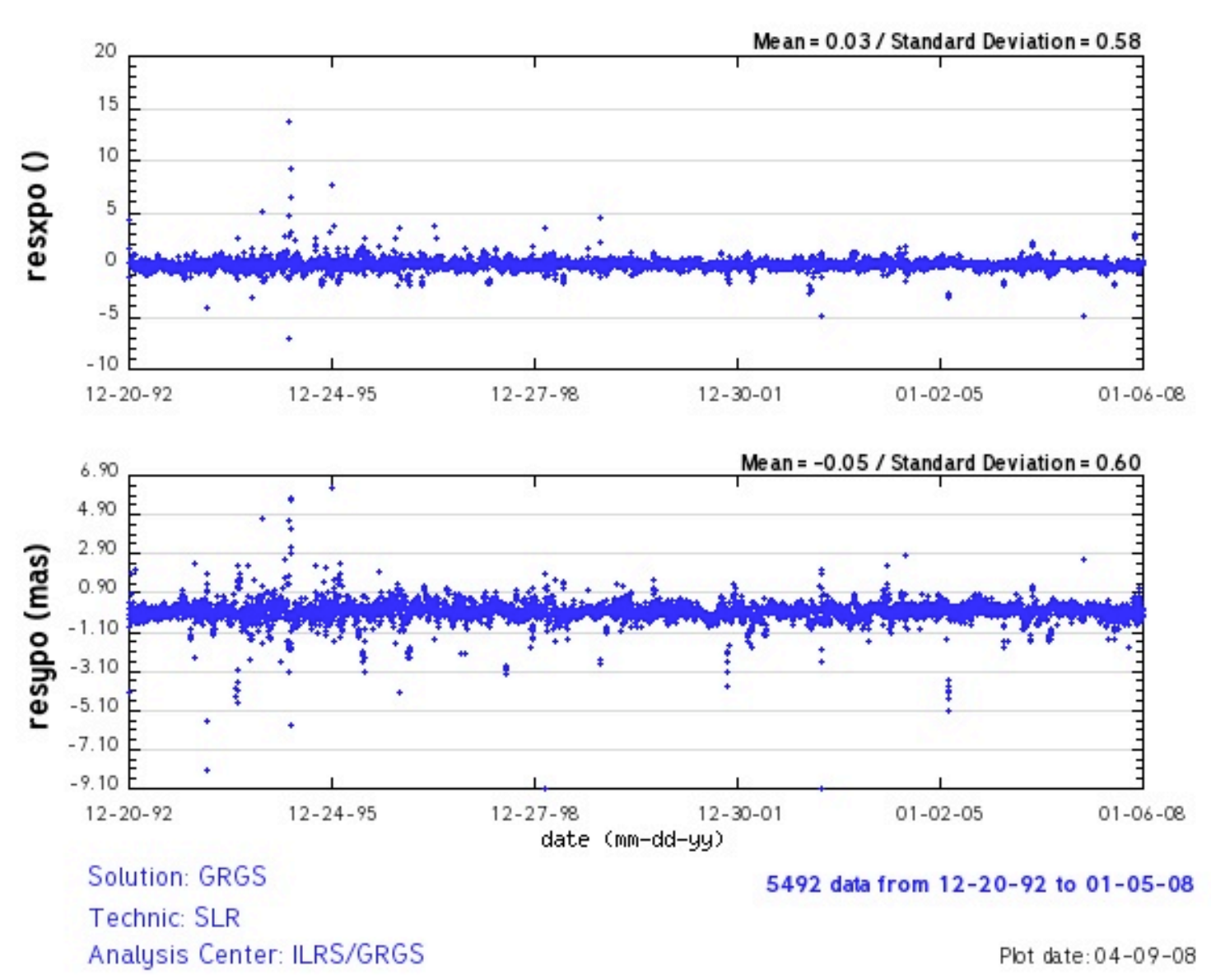


	X(mas)	Y (mas)
CRC	0,00 ± 0,20	0,00 ± 0,20
ILRS	0,01 ± 0,39	0,02 ± 0,40

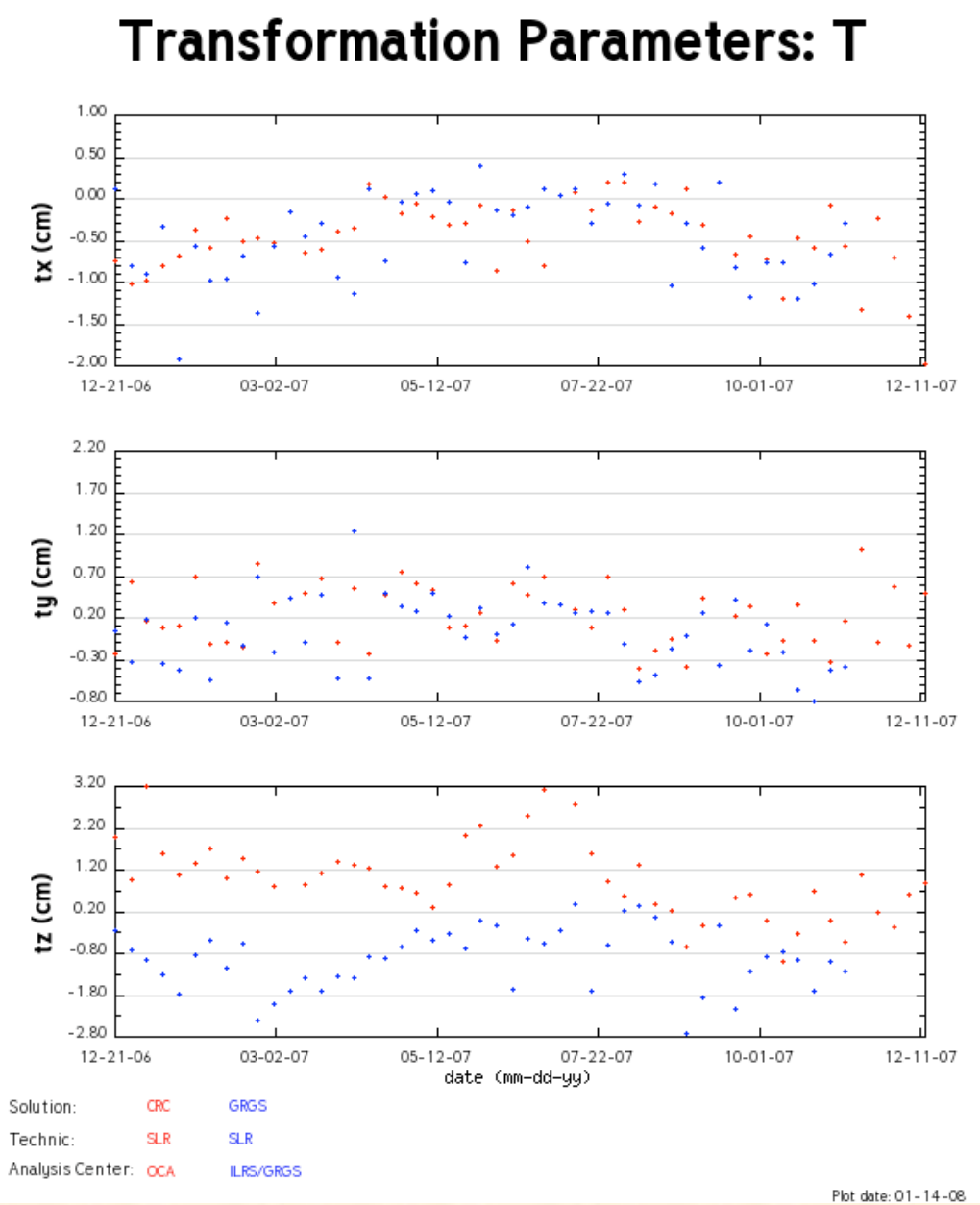
Solution:	CRC	GRGS	ILRSB
Technic:	SLR	SLR	SLR
Analysis Center:	OCA	ILRS/GRGS	ILRS/DGFI

ILRS operational products

EOP: Res wrt c04 (1993-2008)



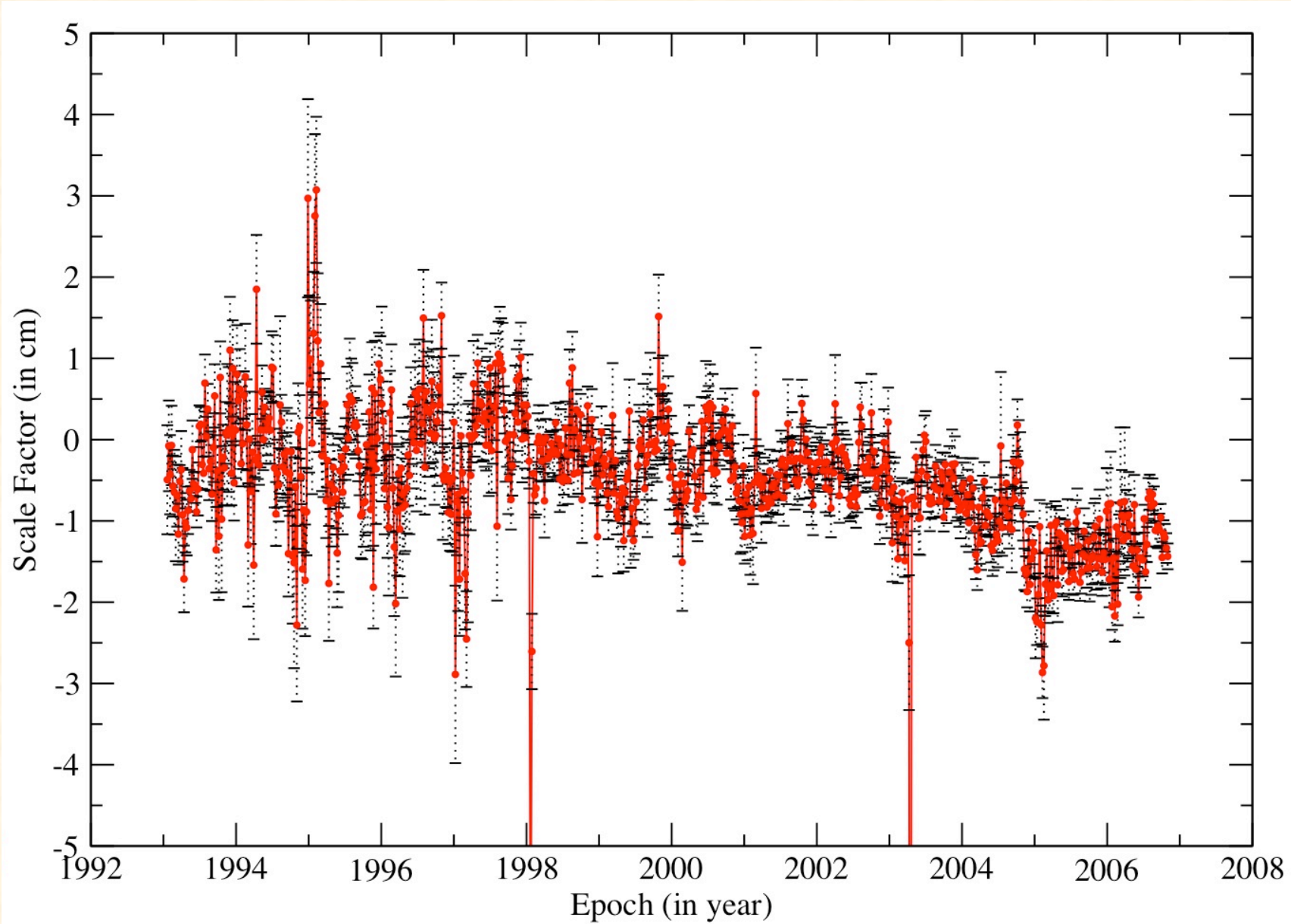
Reference frame



	CRC	ILRS
Tx (cm)	-0,47 ± 0,44	-0,46 ± 0,52
Ty (cm)	0,23 ± 0,36	0,09 ± 0,42
Tz (cm)	0,98 ± 0,90	-0,93 ± 0,73

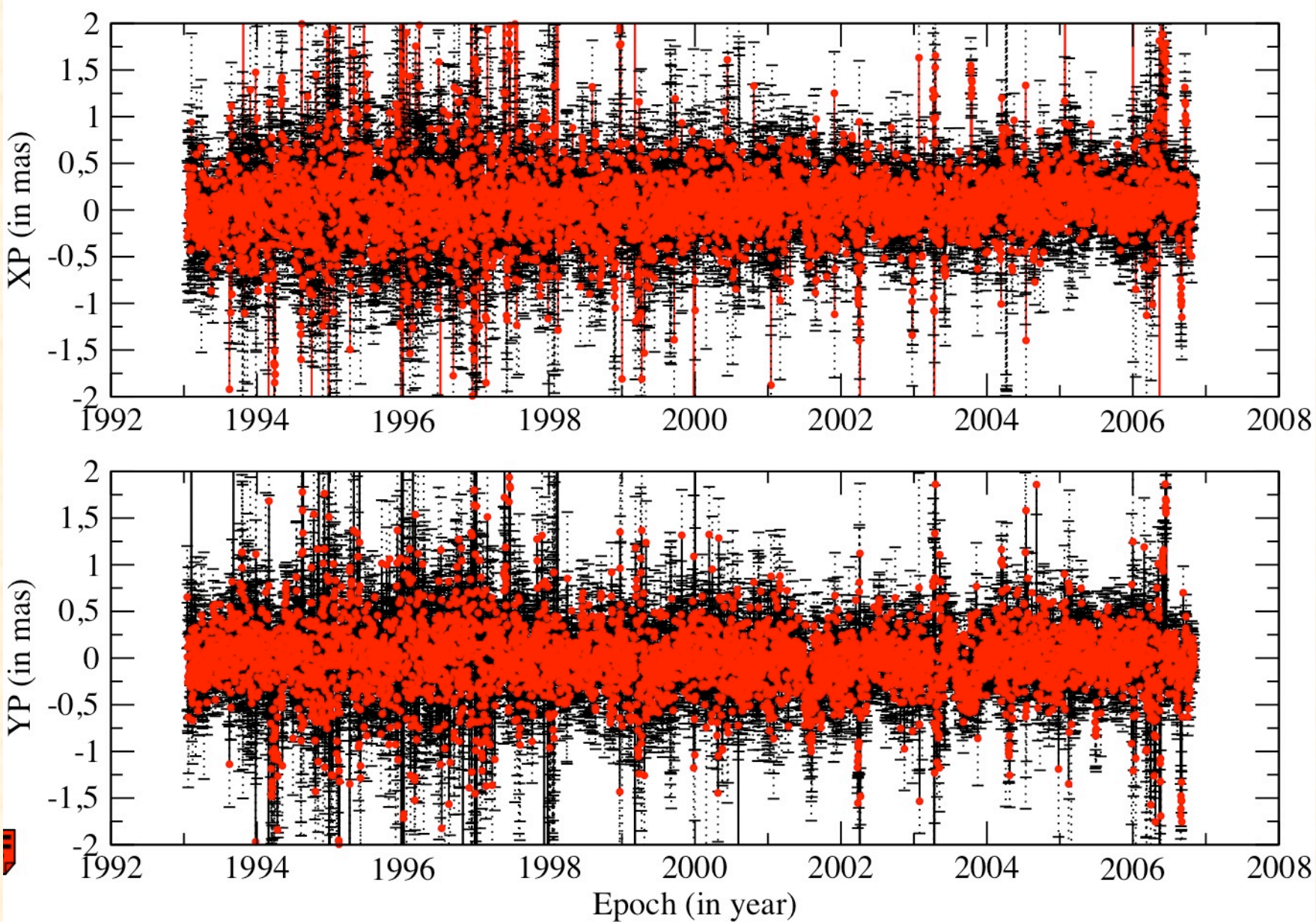
Post-fit reference frame: 1993-2007

scale factor



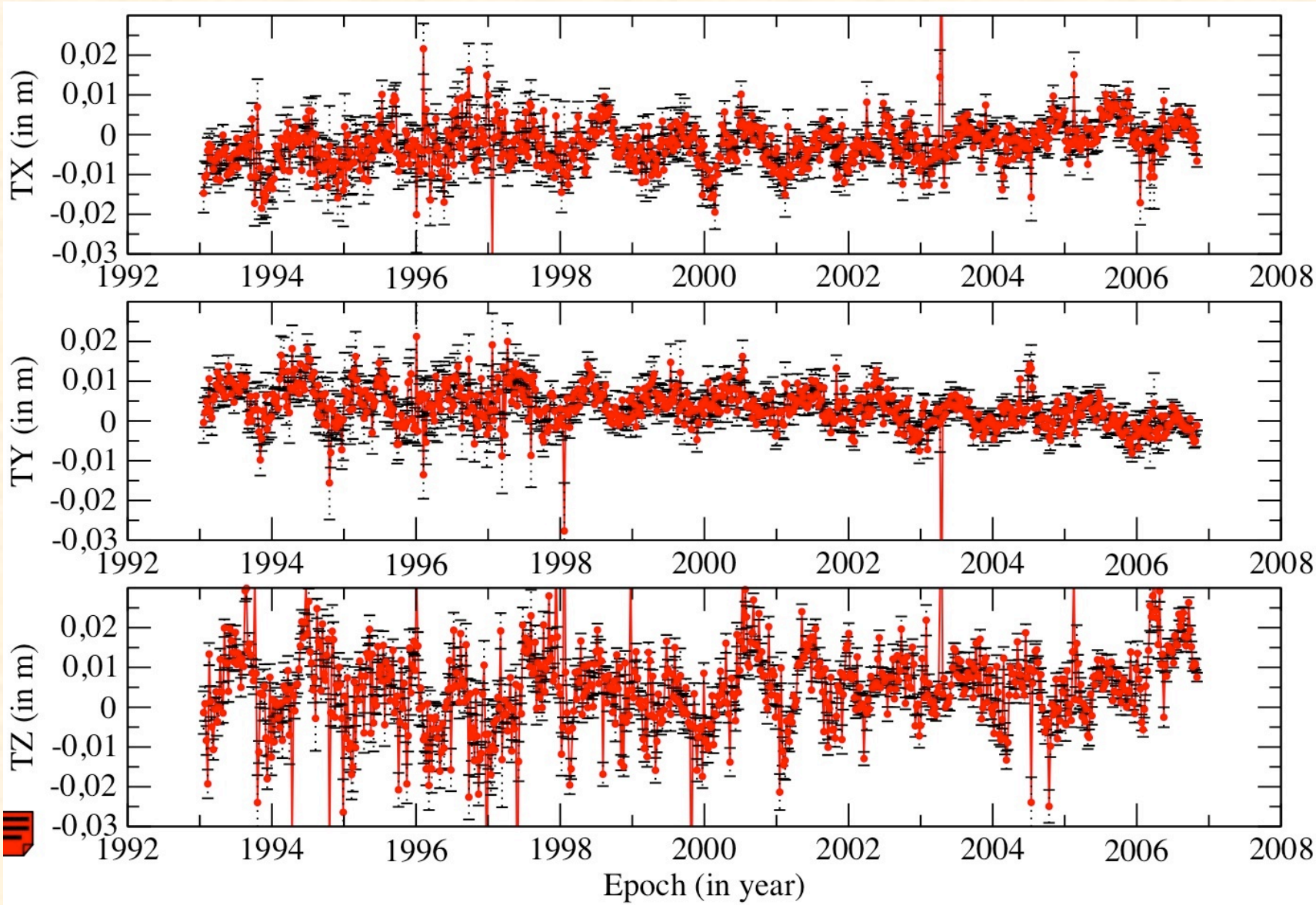
Post-fit reference frame: 1993-2007

polar motion (res wrt C04)



Post-fit reference frame: 1993-2007

transformation parameters



Post-fit reference frame: 1993-2007 *results*

	mean	rms
Xp (mas)	0,053	0,287
Yp (mas)	-0,028	0,288

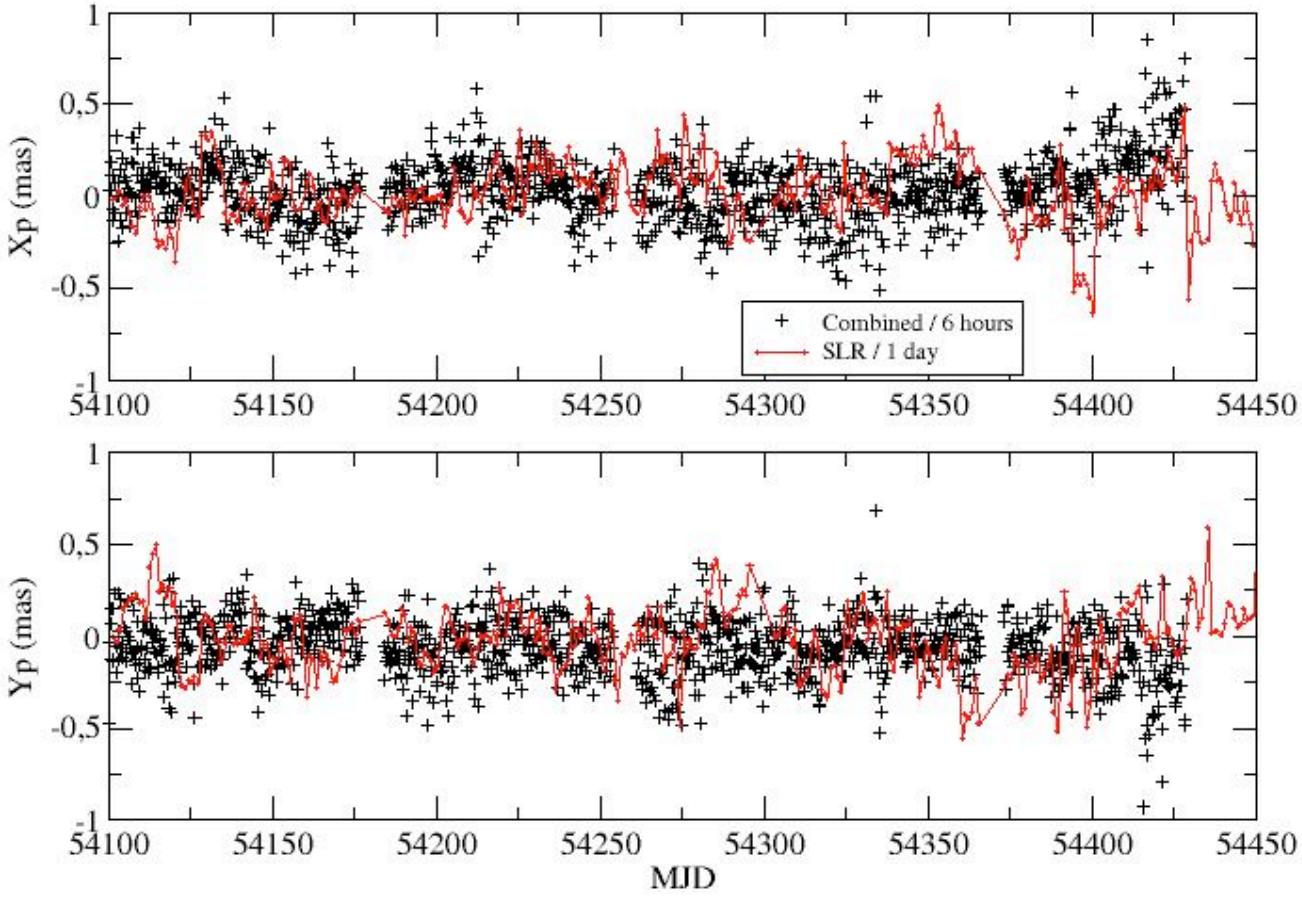
	mean	rms
D (mm)	-3,8	4,16

	mean	rms
Tx (mm)	-1,99	4,96
Ty (mm)	2,97	4,5
Tz (mm)	6,55	8,77

Inversion LA1 - LA2

- CRC
  - Empirical Orbital parameters
    Re-estimated under constraint
  - Stacking LA1-LA2
  - Contraints:
    pole : ± 1m
    stations à ± 1m
  - Deriving SINEX file + projection ITRF 05
- ILRS
  - MATLO : dynamical strategy (same parameters as orbit modelling)
  - Bias : ILRS strategy :
    No estimated bias, except for 4 stations, other bias only applied (ASI list)

Comparaison sol. SLR, sol. combinée / C04



Time series: Degree 2

Osculating orbits: LA1, LA2