Gravity Model Comparisons and Orbit Determination Analyses with DORIS data

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Objective:

- Compare gravity models and OD performance for ENVISAT, JASON and Topex/Poseidon.

Outline:

- Summary of models tested.
- Review Force and Satellite specific modelling.
- Satellite specific OD Results:
  - ENVISAT
  - JASON
  - Topex/Poseidon
- JASON DORIS residuals from GPS orbits.
- Gravity model predicted error.
- Conclusions & Questions.

Summary of Gravity Models (mean fields)

Model	Description
JGM3 (70x70; *1994*)	Tuned with TOPEX/GPS Tracking data
EGM96 (70x70; 360x360; *1996*)	New tracking data, surface data & altimetry
GRIM5C1 (120x120)	GRGS/GFZ: Pre-champ combination model
DGME04 (70x70) (*~1997*)	DEOS: EGM96-Tuned with ERS crossovers
EIGEN1S (115x115) ¶ (*Dec, 2001*)	CHAMP (~88 days) + other satellites.
EIGEN2 (140x140) ¶ (*2003*)	CHAMP-only, ~six months.
EIGEN3p (140x140) (*Oct, 2003*)	CHAMP-only, ~three years.
GGM01S (120x120) (*July, 2003*)	CSR: GRACE-only, ~111 days of Grace data
GGM01C (200x200) (*July, 2003*)	GGM01S combination model
EIGEN-GRACE01S, (140x140) (*Fall 2003*)	GFZ: ~39-days of GRACE data
GRACE-EIGEN02, 66days, (120x120) *(Dec 2003)*	GFZ: ~66 days of GRACE data: (aug2002 + aug2003)
GRACE-EIGEN02,111days (150x150) (*Feb 2004)*	GFZ: ~ 111 days of GRACE data: (aug2002-aug2003)
GRACE-JPL-MEAN, APR-NOV2003 (120x120) (*Jan. 2004*)	JPL: ~191 days of GRACE data: (apr 2003 – nov 2003)
PGS7772P24 (99x99) *(April 2003)*	GSFC: CHAMP-only (~87 days)
PGS7777B (110x110) (*Oct, 2003*)	GSFC: CHAMP + Other satellites (e.g., GFO, Envisat, TOPEX, Jason….)
PGS7779E (110x110) (*Dec, 2003*)	GSFC: PGS7777B + 3 days GRACE

¶ Complete only for select degrees & orders.

Combination models (satellite tracking data, altimetry & surface gravity) are shown in red.

All other models are satellite-only.

Summary of Gravity Models (time-varying or monthly fields)

CSR: 2002: APR-MAY; AUG; NOV.
2003: FEB: MAR; APR; APR-MAY;
JUL; AUG: SEPT;
OCT.

GFZ: 2002: AUG;
2003: AUG.

JPL: JUL; AUG; SEPT; OCT.

All models are to 120x120 and include only GRACE data in the indicated month.

CSR/JPL fields are 'inclusive' of the permanent tide; GFZ fields are 'exclusive' of the permanent tide.

Modeling for Orbit tests

- Gravity fields to 90x90, except JGM3, EGM96, DGME04 (70x70).
- Use appropriate GM, Ae, & time-varying field for each gravity model (C20-dot, C21-dot, S21-dot, C30-dot, C40-dot).
- Tides held fixed at pgs7751q2 (GOT99.2 overwritten with resonant tides from post-EGM96 solution).
- ITRF2000 station coordinates.
- Atmospheric drag: MSIS 86.
- Ephemerides: DE403 & DE410.
- All other modeling as per conventions used for TOPEX POD processing.

Satellite specific Modeling

- Panel (nonconservative force model):
  - TOPEX: (Repro2, *Marshall et al.,* 1995).
  - ENVISAT: (Info from CNES + corrections to ERS attitude model from Eelco Doornbos).
  - JASON: (Info. From CNES).
- Empirical once per revolution accelerations adjusted along & cross-track once/day.
- Atmospheric drag: Cd's adjusted 1/8-hrs (sometimes 1/6-hrs on ENVISAT).
- SLR data weight: 10 cm; DORIS data weight: 0.20 cm/s. (select SLR stations downweighted as per TOPEX conventions).
- For JASON: In gravity tests, data for some SAA DORIS stations are systematically excluded: LIBB, SANB; AREB; ASDB; CACB; KRUB; EASB; HBKB; HELB.
- For combined SLR/DORIS arcs, adjust DORIS timing bias.

Envisat tests (description)

SLR+DORIS:

- 20 arcs, April 04, 2003 - July 11, 2003.
- Arclength: 2-7 days (average ~5 days).
- 449, 567 DORIS observations.
- 21,657 SLR observations.

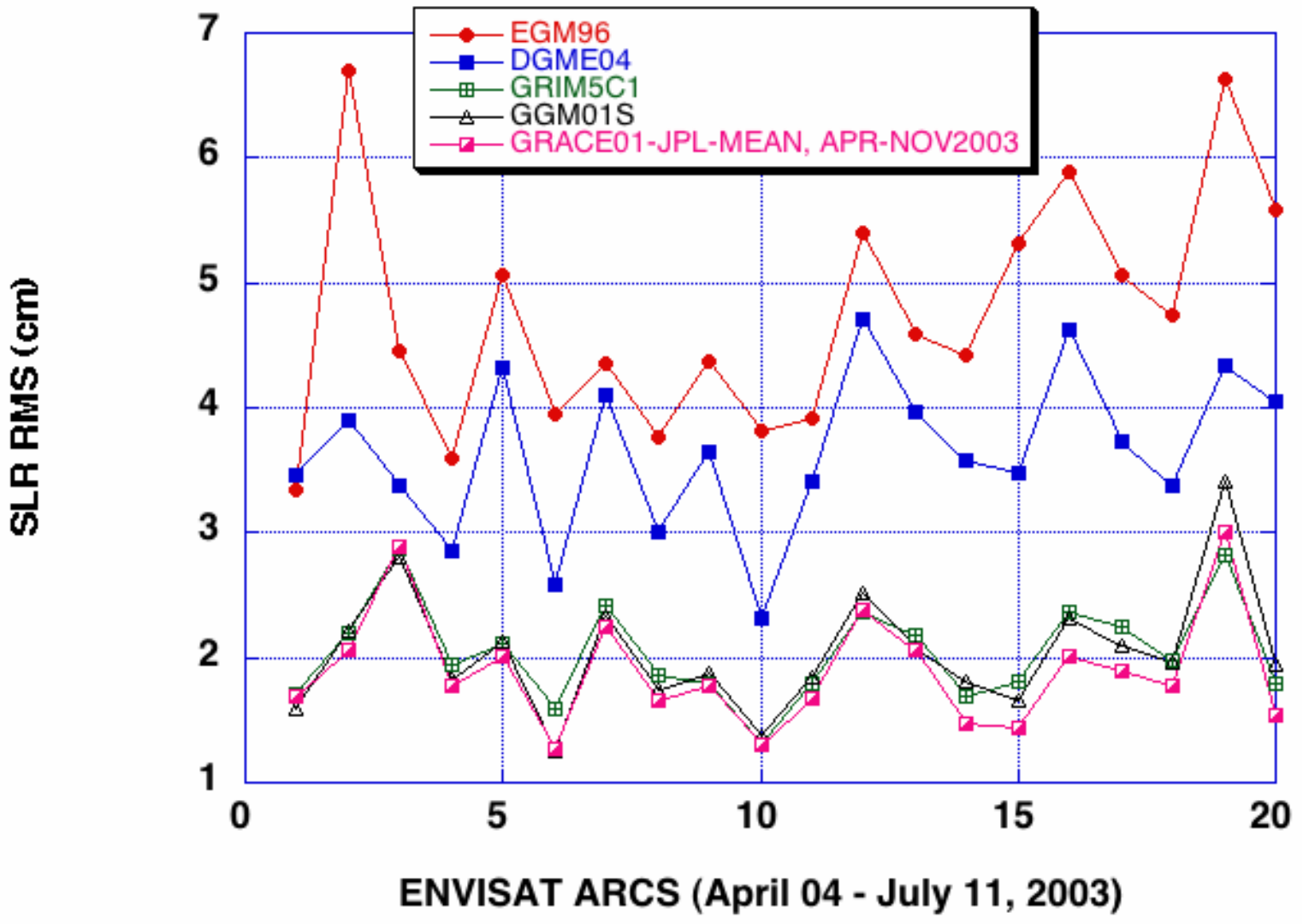
DORIS-only:

- 51 arcs, July 09, 2002 - July 11, 2003.
- Arclength: 2-7 days (average ~5 days).
- 1,150,264 DORIS observations.
- 43,658 SLR observations (*Independent*).

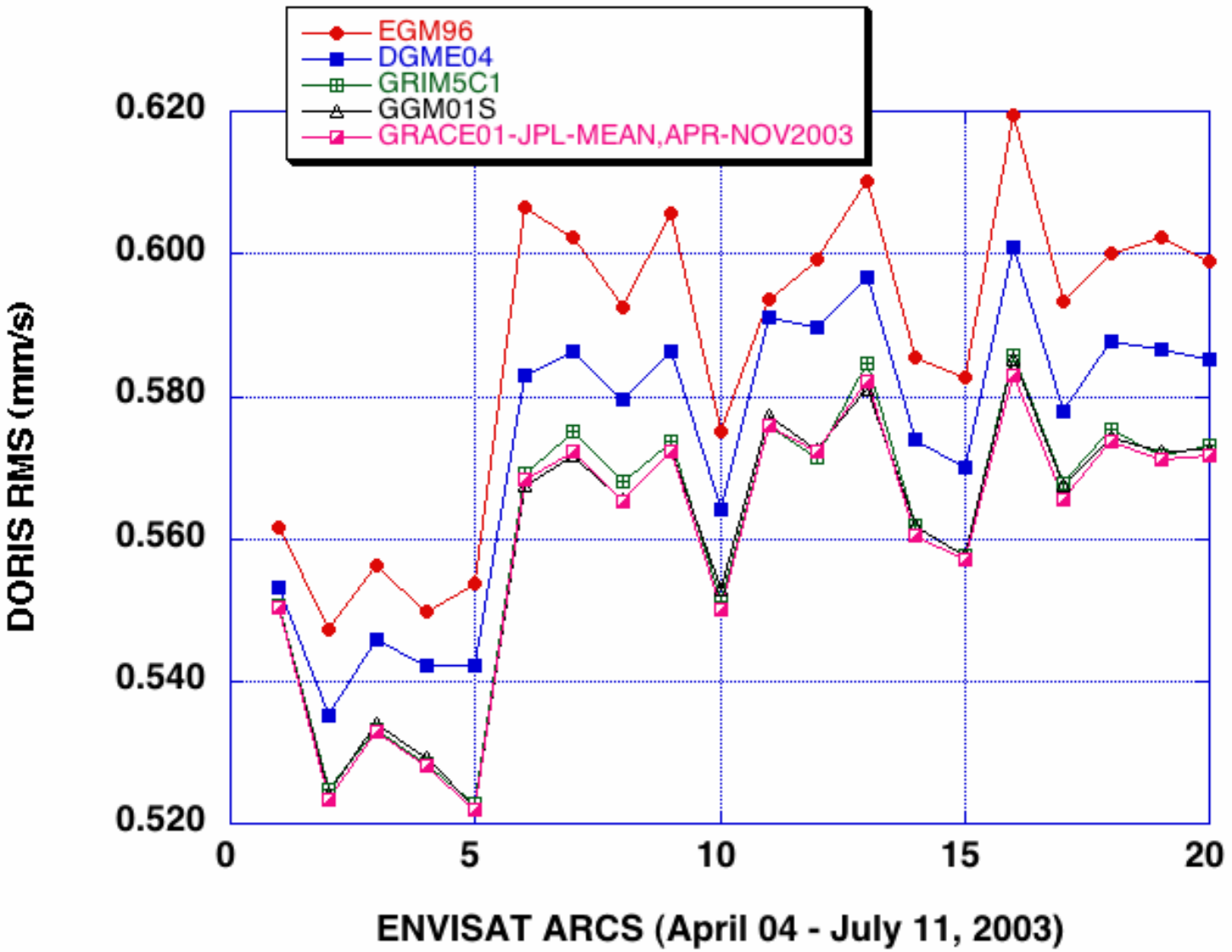
Envisat SLR/DORIS gravity test summary

Model	Doris (mm/s)	SLR(cm)
EGM96	0.587	4.75
GRIM5C1	0.561	2.05
DGME04	0.574	3.64
EIGEN1S	0.577	**5.95**
EIGEN2	**0.625**	5.53
EIGEN3p	0.584	5.90
PGS7772P24	0.579	3.49
PGS7777B	0.561	2.02
GGM01S	0.561	2.04
GGM01C	0.562	2.05
EIGEN_GRACE01S	0.560	1.97
GRACE01-EIGEN02-66day	0.561	2.45
GRACE01-EIGEN02-111day	0.560	1.92
GRACE01-JPL-MEAN APR-NOV 2003	**0.560**	**1.90**
GRACE: CSR, APRMAY2002	0.562	2.64
GRACE: CSR, AUG2002	0.562	2.57
GRACE: GFZ, AUG2002	0.562	2.66
GRACE: CSR, JUL2003	0.561	2.01
GRACE: JPL, JUL2003	0.560	1.91
GRACE: CSR AUG2003	0.562	2.49
GRACE: GFZ AUG2003	0.562	2.66
GRACE: JPL AUG2003	0.560	2.44
GRACE: CSR, OCT2003	0.561	2.08
GRACE: JPL, OCT2003	0.561	2.05

Envisat SLR RMS for SLR/DORIS Test Arcs



Envisat DORIS RMS for SLR/DORIS Test Arcs

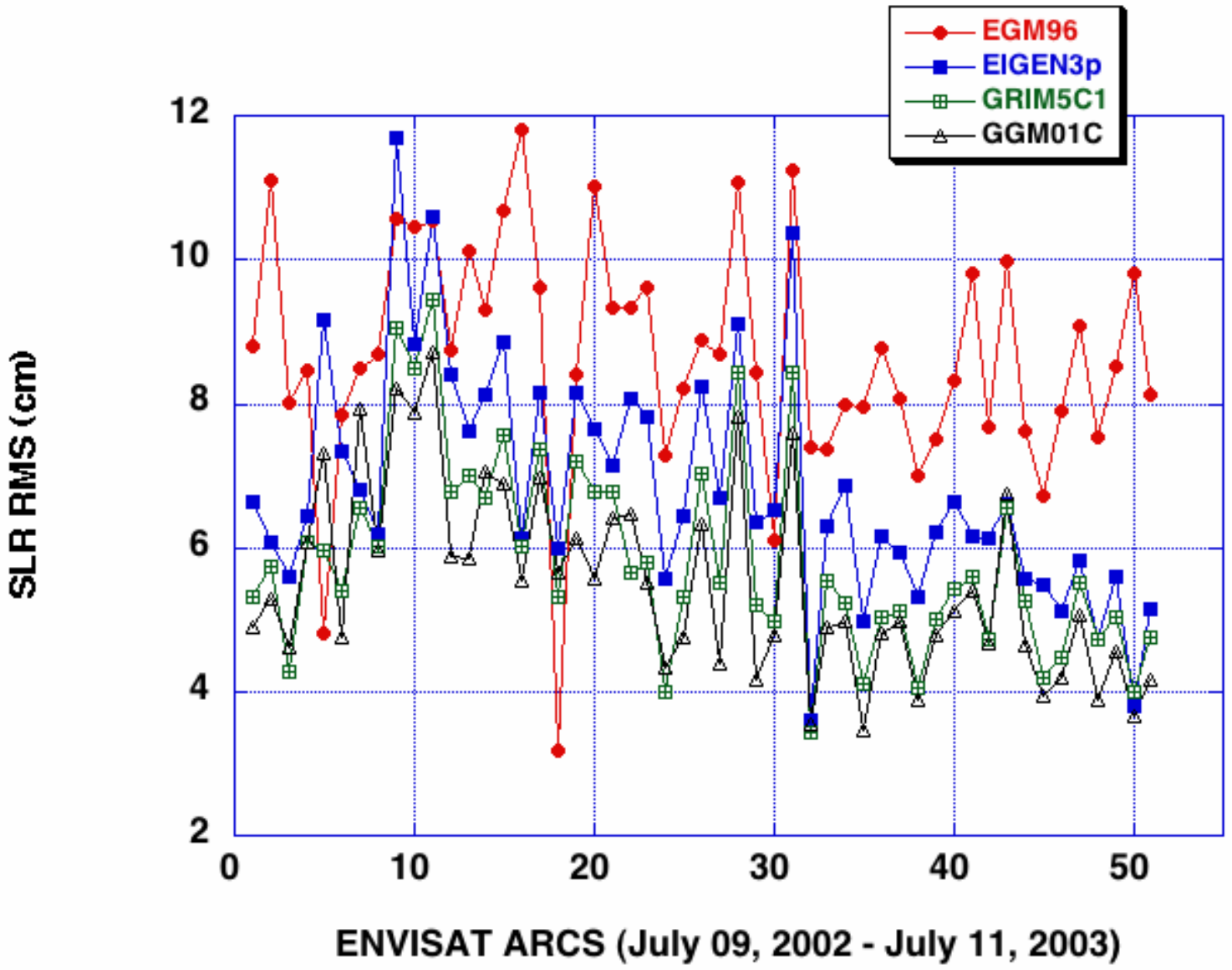


Envisat DORIS-only gravity test summary

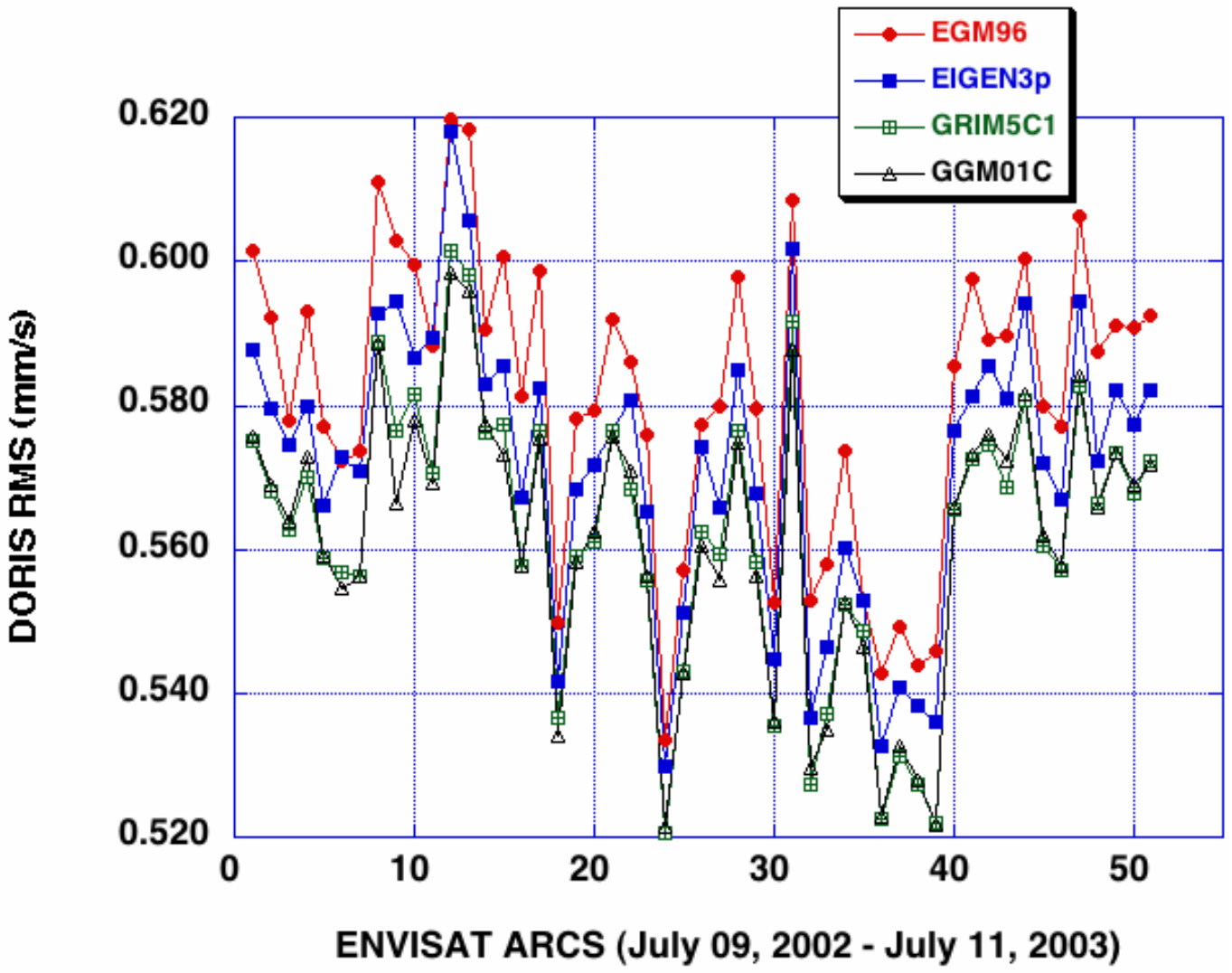
Model	Doris (mm/s)	SLR (cm)
JGM3	**0.600**	**9.86**
EGM96	0.581	8.67
GRIM5C1	0.562	5.84
DGME04	0.572	7.51
EIGEN1S	0.566	6.18
EIGEN2	**0.611**	**8.97**
EIGEN3p	0.572	6.84
PGS7772P24	0.582	7.34
PGS7777B	0.562	5.71
PGS7779E	0.565	5.92
GGM01S	0.562	5.98
GGM01C	**0.562**	**5.51**
EIGEN_GRACE01S	0.563	5.96
GRACE01-EIGEN02-66day	0.564	6.15
GRACE01-EIGEN02-111day	0.563	5.91
GRACE01-JPL-MEAN APR-NOV 2003	0.562	5.76
GRACE: CSR, JUL2003	0.563	5.90
GRACE: JPL, JUL2003	0.564	5.89
GRACE: CSR AUG2003	0.563	6.07
GRACE: JPL AUG2003	0.563	5.82
GRACE: CSR, OCT2003	0.563	6.02
GRACE: JPL, OCT2003	0.562	5.80

NB: SLR data are independent

Envisat *(Independent)* SLR RMS for DORIS-only Test Arcs



Envisat DORIS RMS for DORIS-only Test Arcs



Jason-1 tests (description)

SLR+DORIS:

- 42 arcs, March 25, 2002 - June 24, 2003.
- Arclength (cycle): ~10 days.
- Average no. of observations/arc:

  DORIS: 87000-103000

  SLR: 2900- 8000.

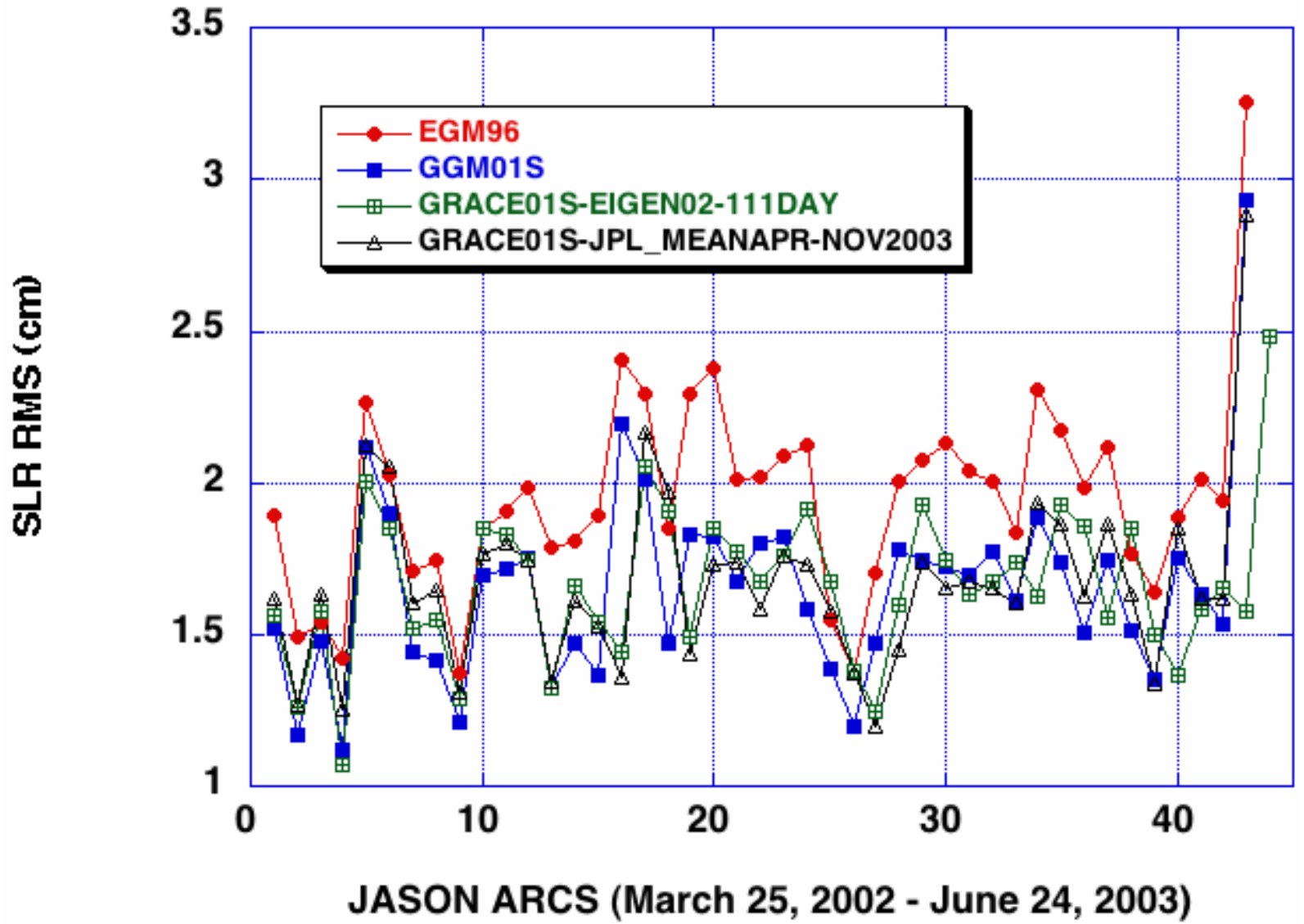
  XOVER *(Independent)* : 2000-5000

JASON SLR/DORIS gravity test summary

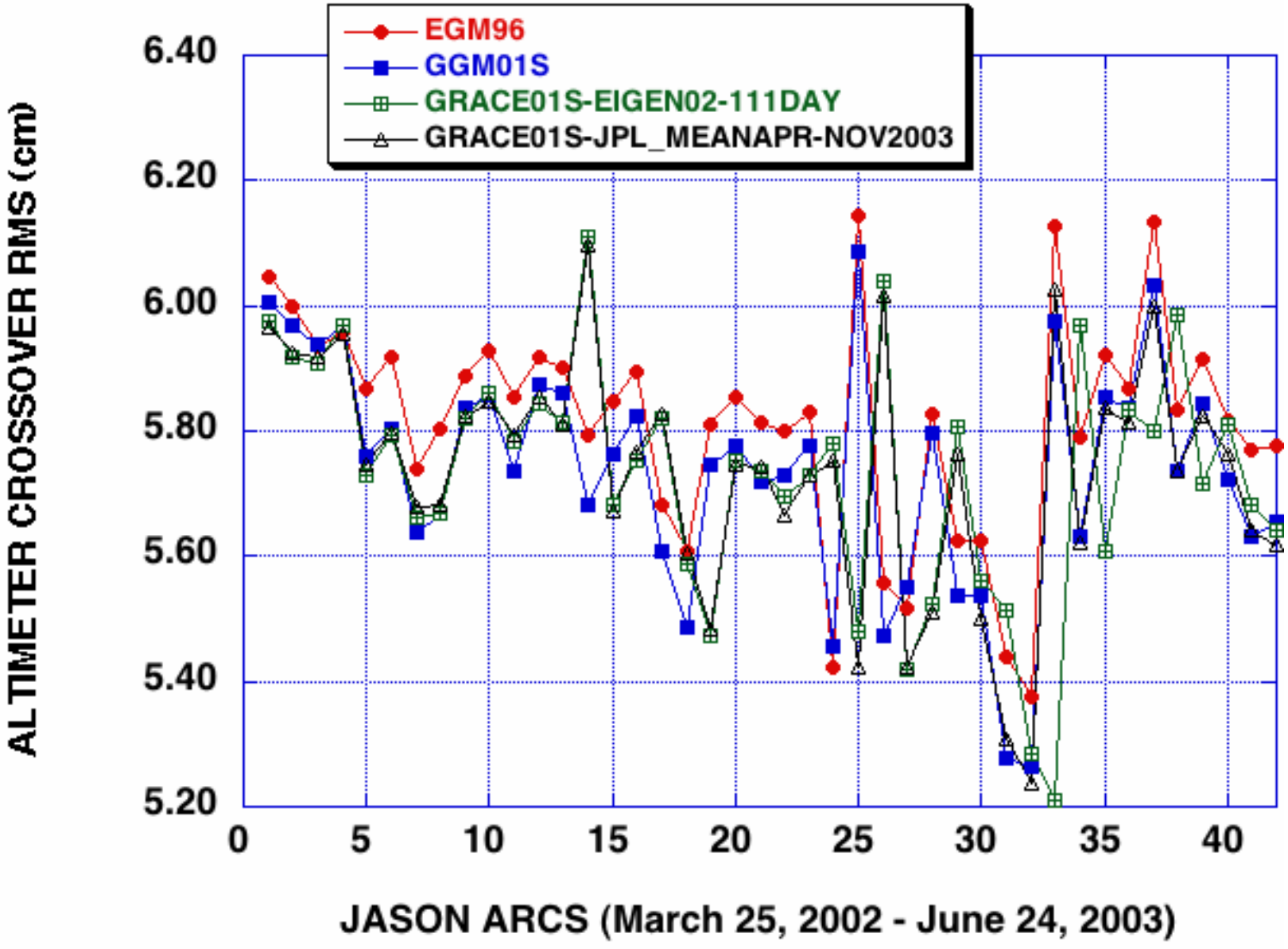
(Crossovers are independent)

Model	Doris (mm/s)	SLR (cm)	Crossover (cm)
EGM96	0.412	**1.96**	**5.822**
EIGEN3p	0.411	1.73	5.765
PGS7777B	0.411	1.71	5.801
GGM01S	0.411	**1.65**	5.749
GGM01C	0.411	1.75	5.745
EIGEN_GRACE01S	0.411	1.67	5.738
GRACE01-EIGEN02-66day	0.412	1.96	5.765
GRACE01-EIGEN02-111day	0.411	1.66	**5.730**
GRACE01-JPL-MEAN APR-NOV 2003	0.411	1.67	5.737
GRACE: CSR, APRMAY2002	0.412	2.02	5.774
GRACE: CSR, AUG2002	0.412	1.96	5.781
GRACE: CSR, JUL2003	0.407	1.64	5.737
GRACE: CSR AUG2003	0.412	1.98	5.770
GRACE: GFZ AUG2003	0.412	2.01	5.773
GRACE: JPL AUG2003	0.411	1.70	5.744

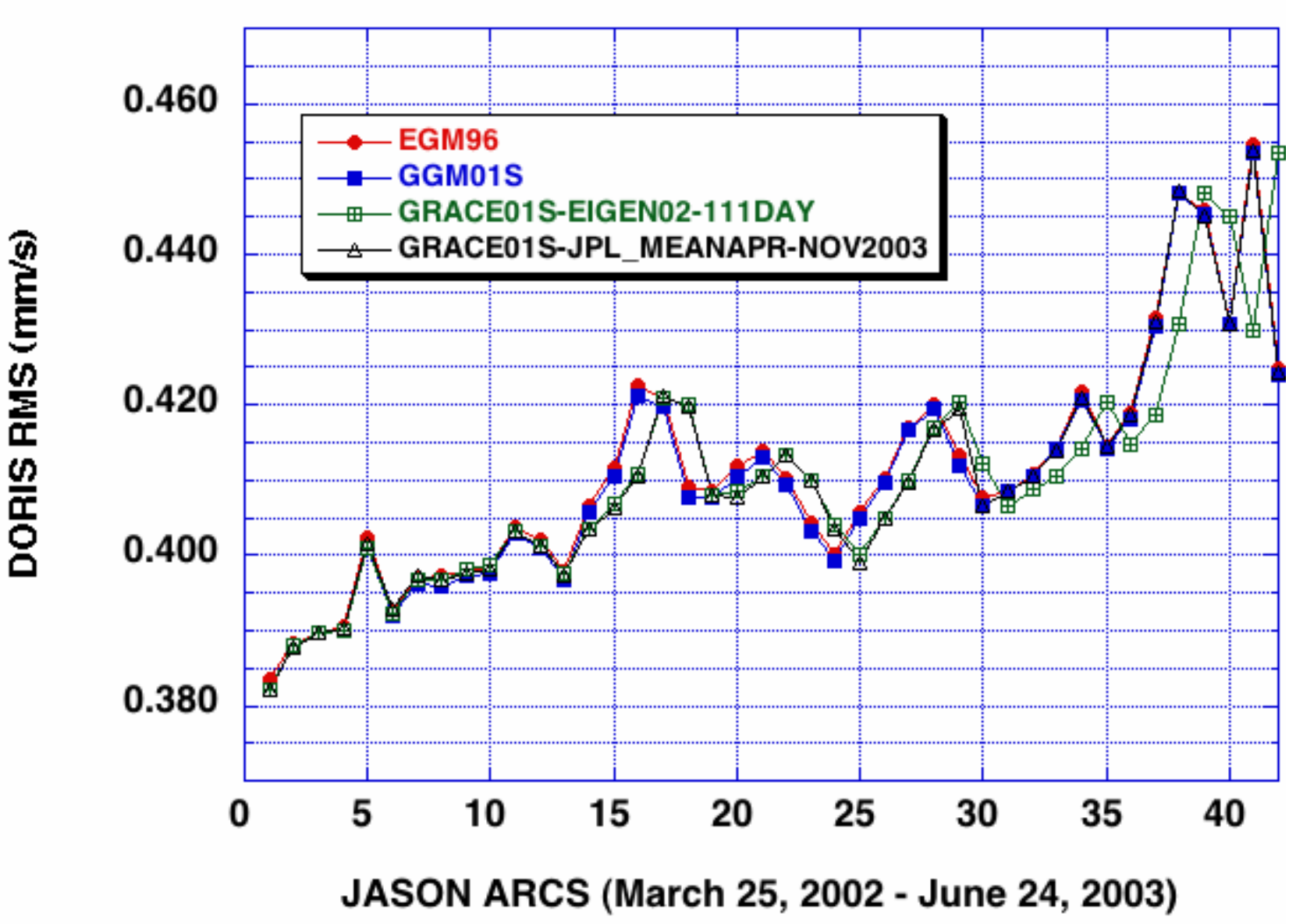
SLR RMS for JASON SLR/DORIS ARCS



Independent Crossover RMS for JASON SLR/DORIS ARCS



DORIS RMS for JASON SLR/DORIS ARCS



TOPEX tests (description)

DORIS-only:

- 18 arcs, Jan. 01 -- June 15, 1997.
- Arclength: 7 days.
- 780,717 DORIS observations.
- 56,546 SLR observations (*Independent*).

DORIS-only:

- 20 arcs, Jan 06 -- July 11, 2002.
- Arclength: 7 days.
- DORIS observations.
- SLR observations (*Independent*).

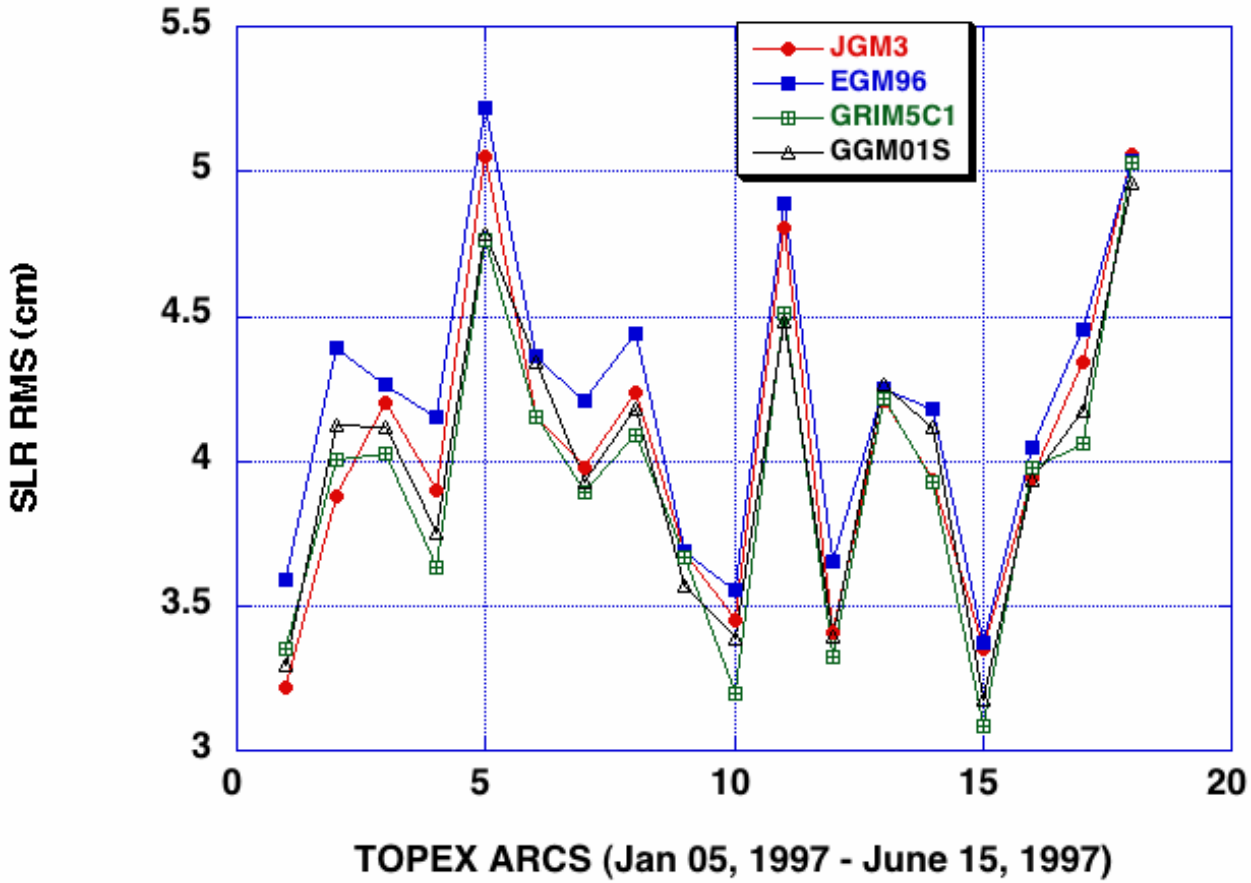
TOPEX DORIS-only gravity test summary (1997)

Model	Doris (mm/s)	SLR(cm)
JGM3	0.556	4.09
EGM96	0.556	**4.25**
GRIM5C1	0.556	**3.97**
EIGEN3p	0.556	**4.25**
GGM01C	0.556	4.18
GGM01S	0.556	4.04
GRACE01-EIGEN02-66day	0.556	4.08
GRACE01-EIGEN02-111day	0.556	4.13
GRACE01-JPL-MEAN-APRNOV2003	0.556	4.15
GRACE01-CSR-JUL2003	0.556	4.09
GRACE01-CSR-AUG2003	0.556	4.15
GRACE01-GFZ-AUG2003	0.556	4.11
GRACE01-JPL-AUG2003	0.556	4.17

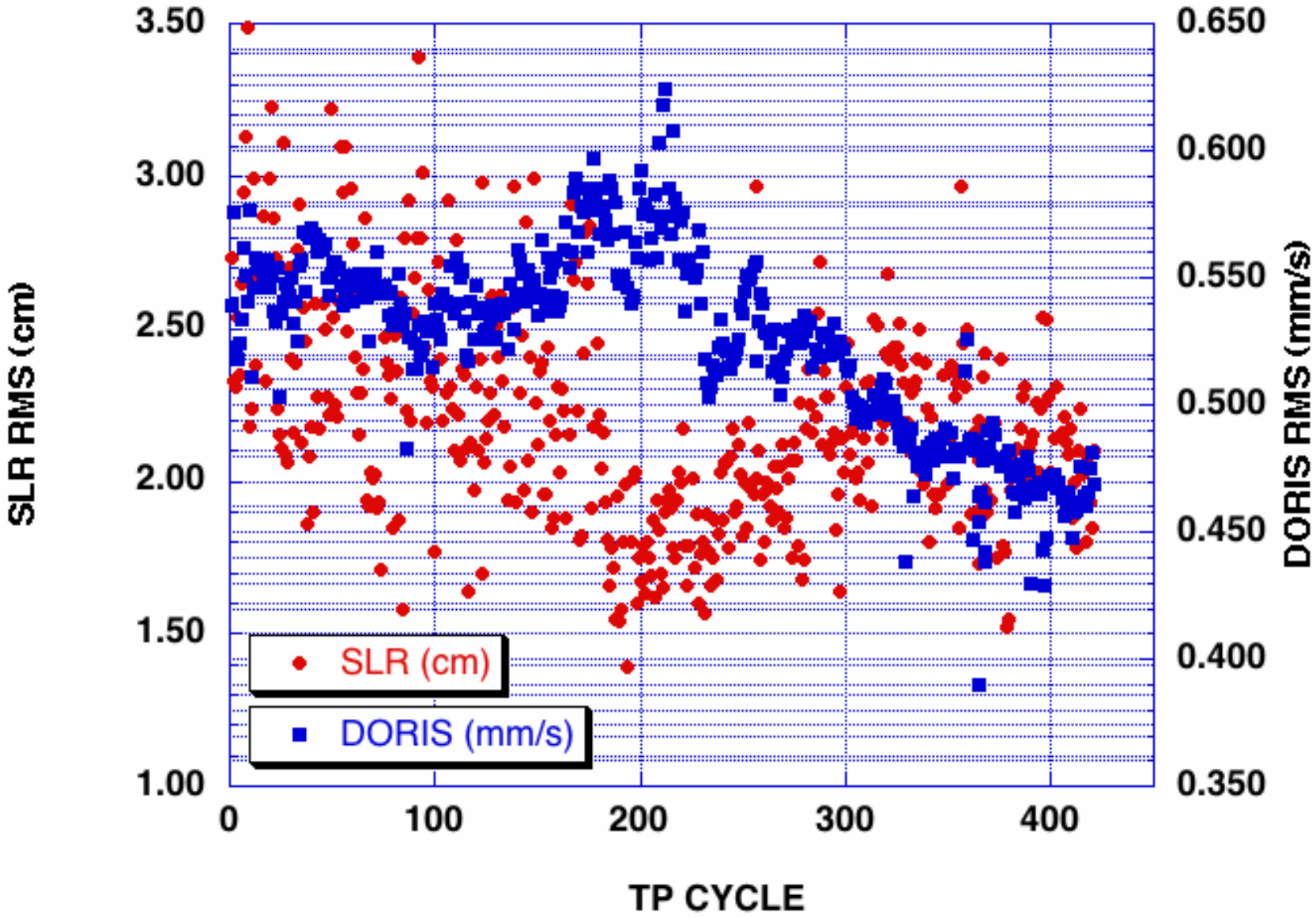
TOPEX DORIS-only gravity test summary (2002)

Model	Doris (mm/s)	SLR(cm)
JGM3	**0.488**	**4.04**
GGM01S	0.488	3.87
GRACE01-EIGEN02-111day	0.488	3.89
GRACE01-JPL-MEAN APR-NOV 2003	**0.488**	**3.85**

TOPEX *(Independent)* SLR RMS for DORIS-only Test Arcs in 1997



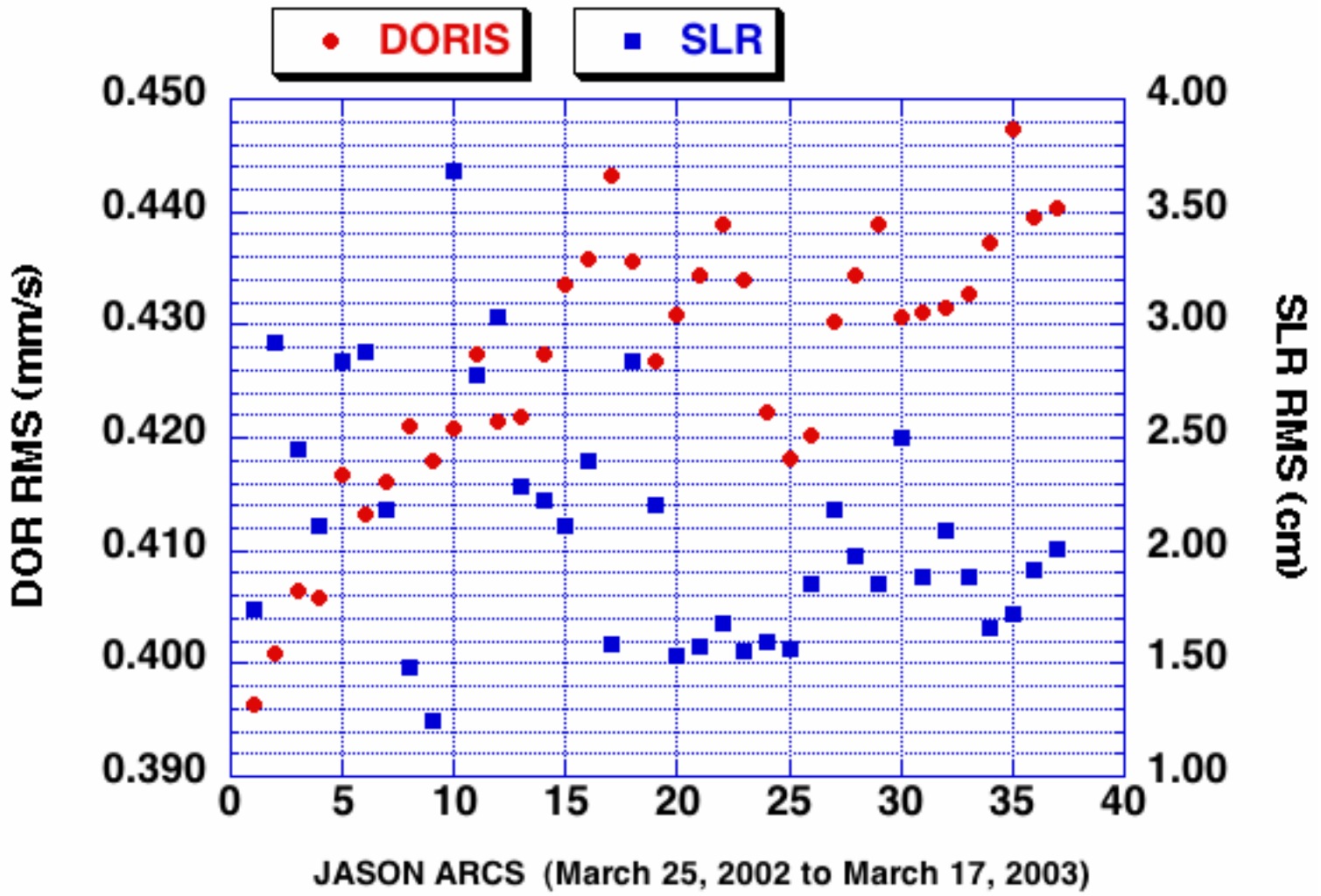
TOPEX POD SLR & DORIS FITS
vs. TP CYCLE



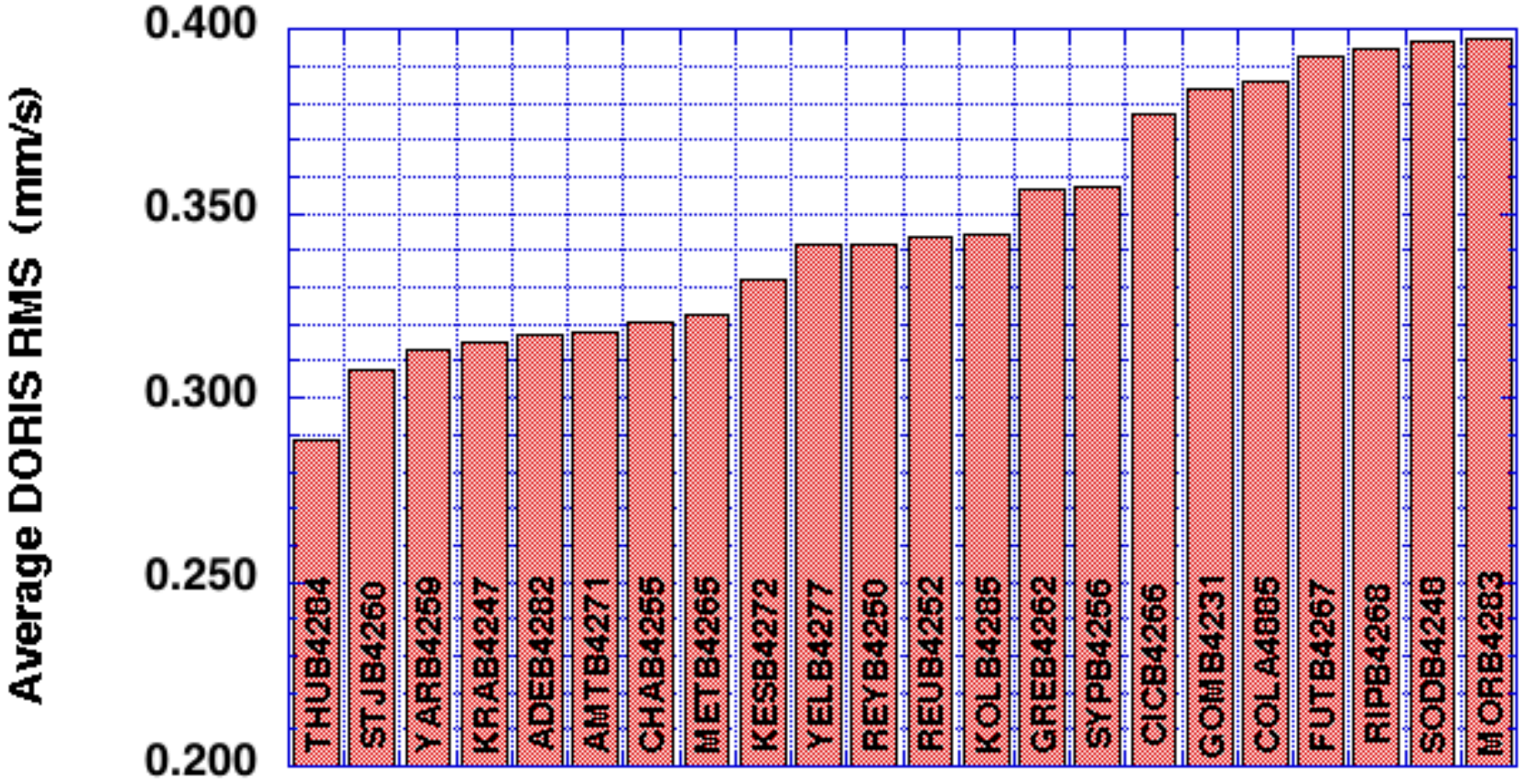
DORIS STATION RMS from GPS ORBITS

- GPS orbits computed from JASON in 30-hr arcs using GEODYN.
- Parameterization uses a reduced dynamic approach and JASON/GPS Phase antenna Map as described in *Luthcke et al.* [2003].
- Middle sections of GPS-derived JASON orbits are stitched together for each JASON cycle.
- The SLR & DORIS residuals are computed with the orbit held fixed to the GPS-derived trajectory.
- The advantage is we can examine & compare SLR & DORIS residuals without any concern that the dynamics of a SLR/DORIS orbit might contaminate the results.

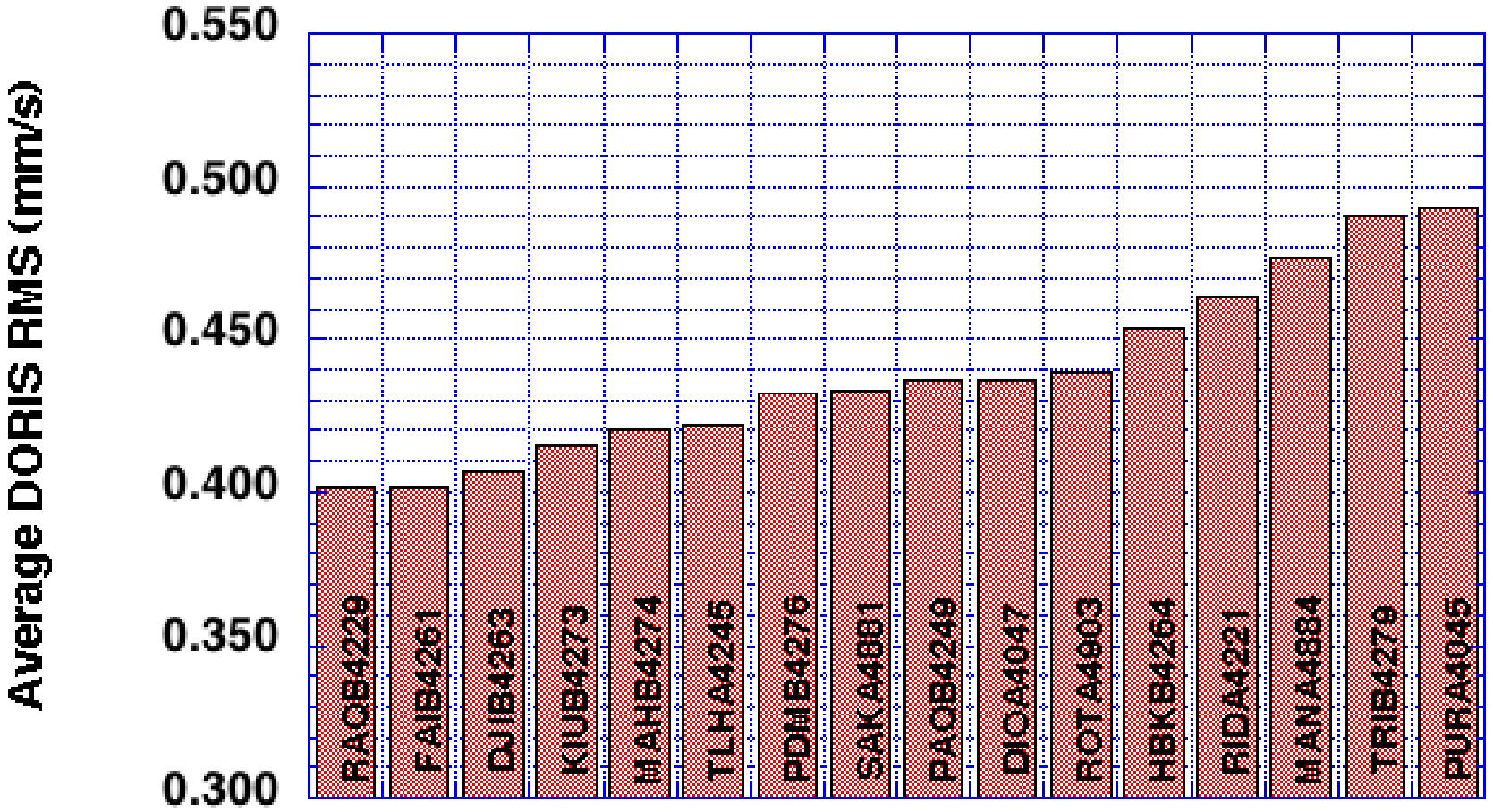
SLR/DORIS RMS from GSFC GPS reduced dynamic orbits



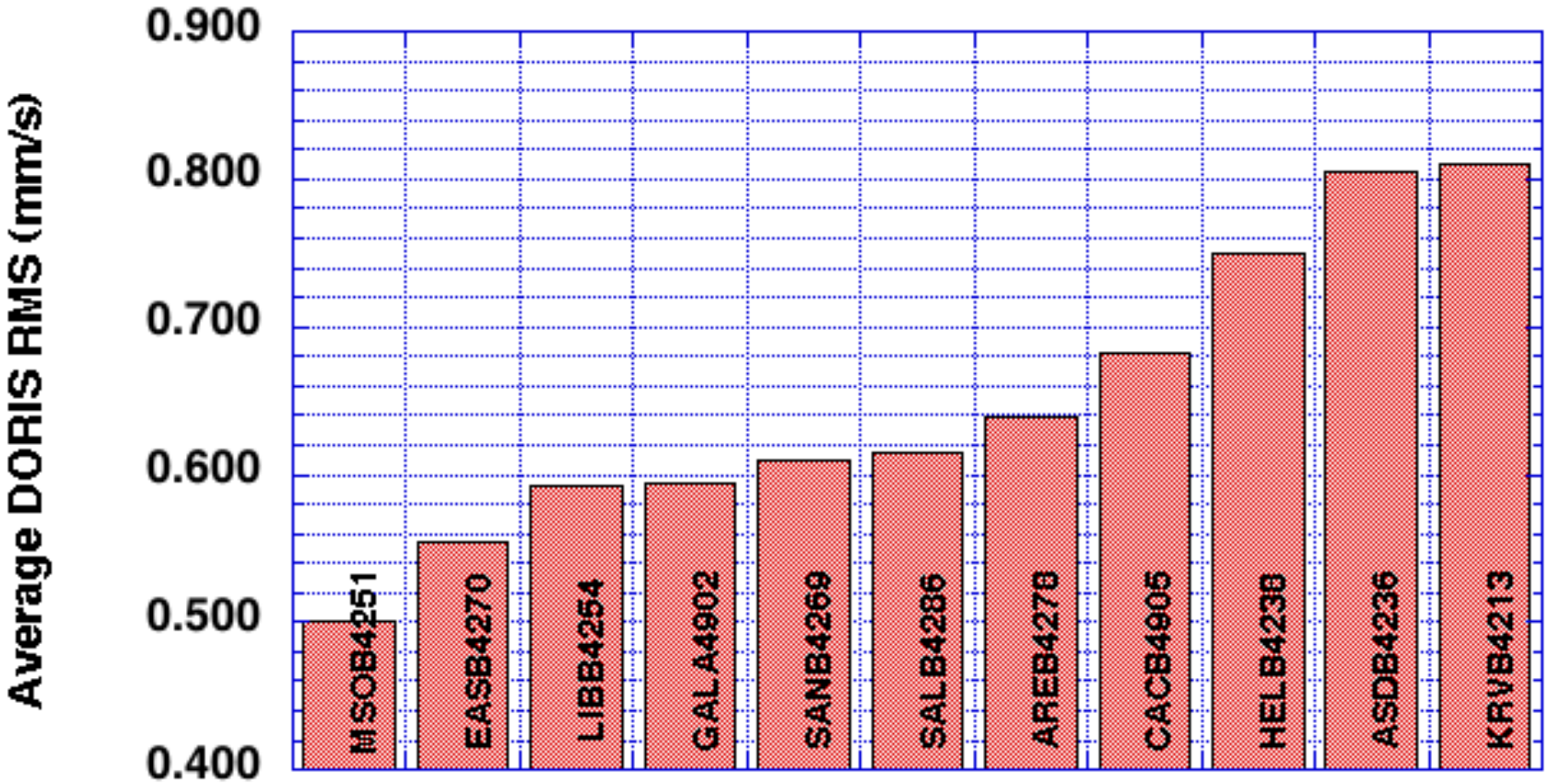
Average DORIS RMS for JASON Cycles from
March 25, 2002 to March 27, 2003. (< 0.40 mm/s)
(*Independent RMS Computed from GSFC GPS RED-DYN orbits)*



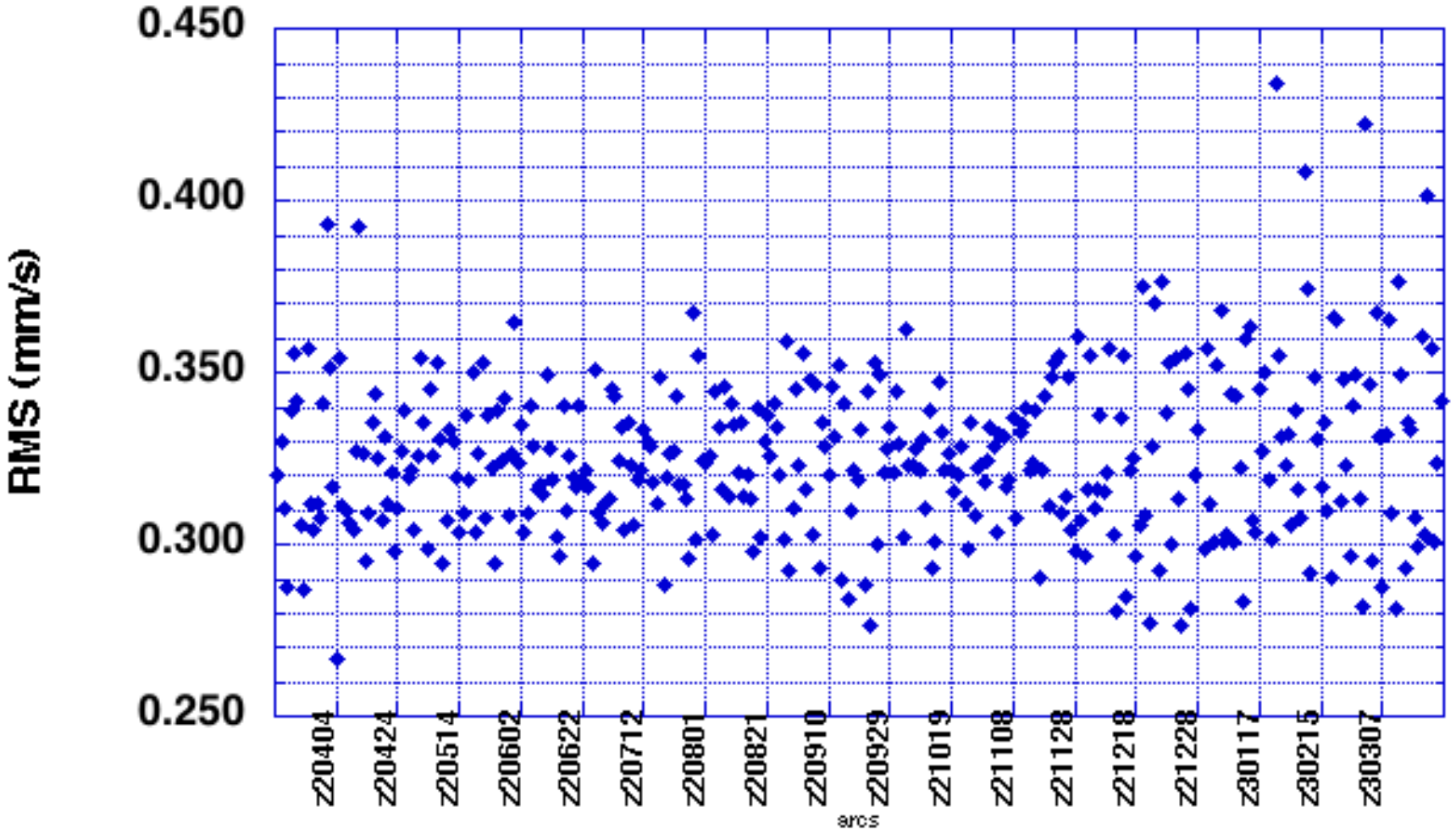
Average DORIS RMS for JASON Cycles from
March 25, 2002 to March 27, 2003. (0.40 < RMS < 0.50 mm/s)
(*Independent RMS Computed from GSFC GPS RED-DYN orbits)*



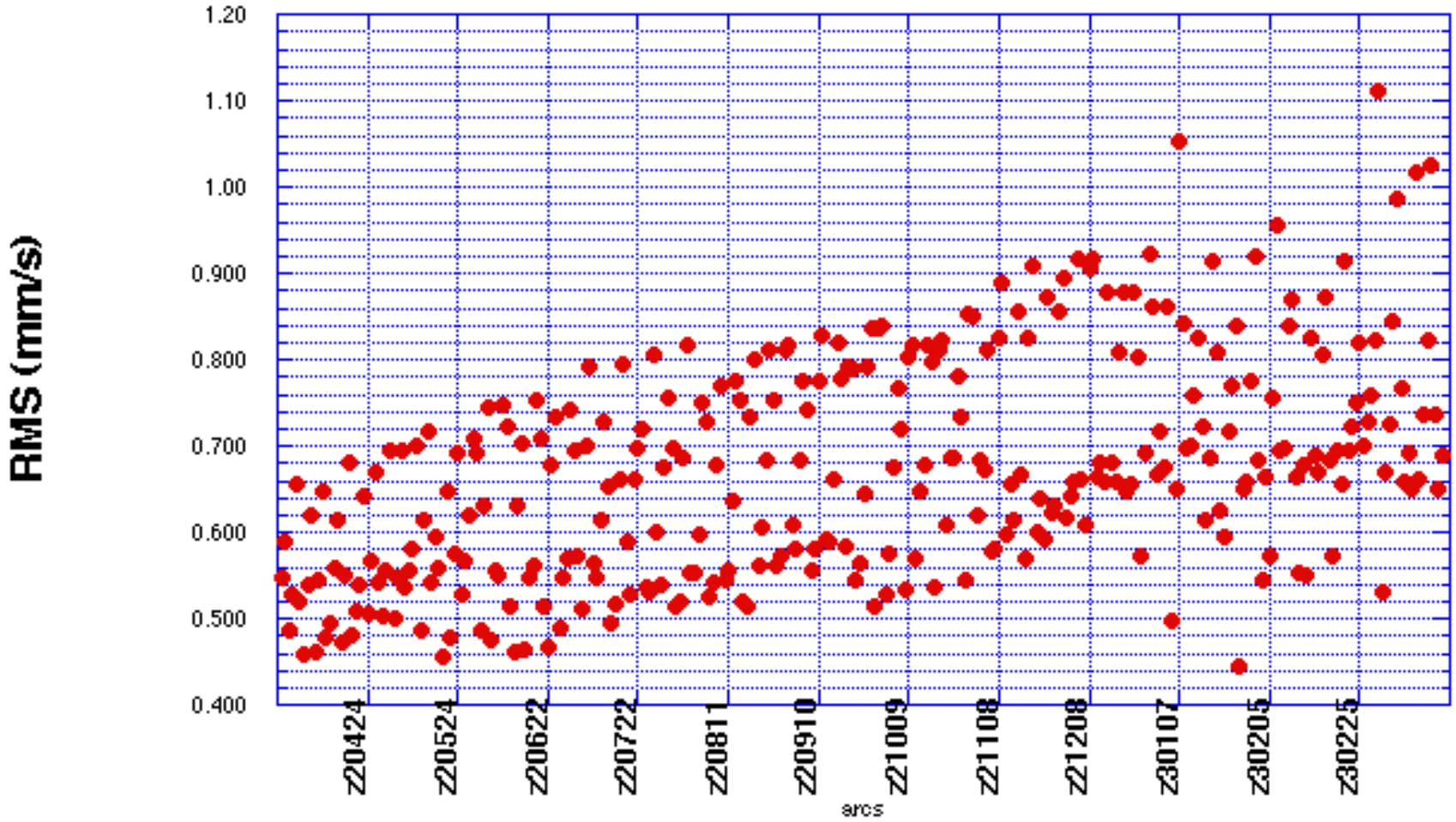
Average DORIS RMS for JASON Cycles from
March 25, 2002 to March 27, 2003. (> 0.50 mm/s)
(*Independent RMS Computed from GSFC GPS RED-DYN orbits)*

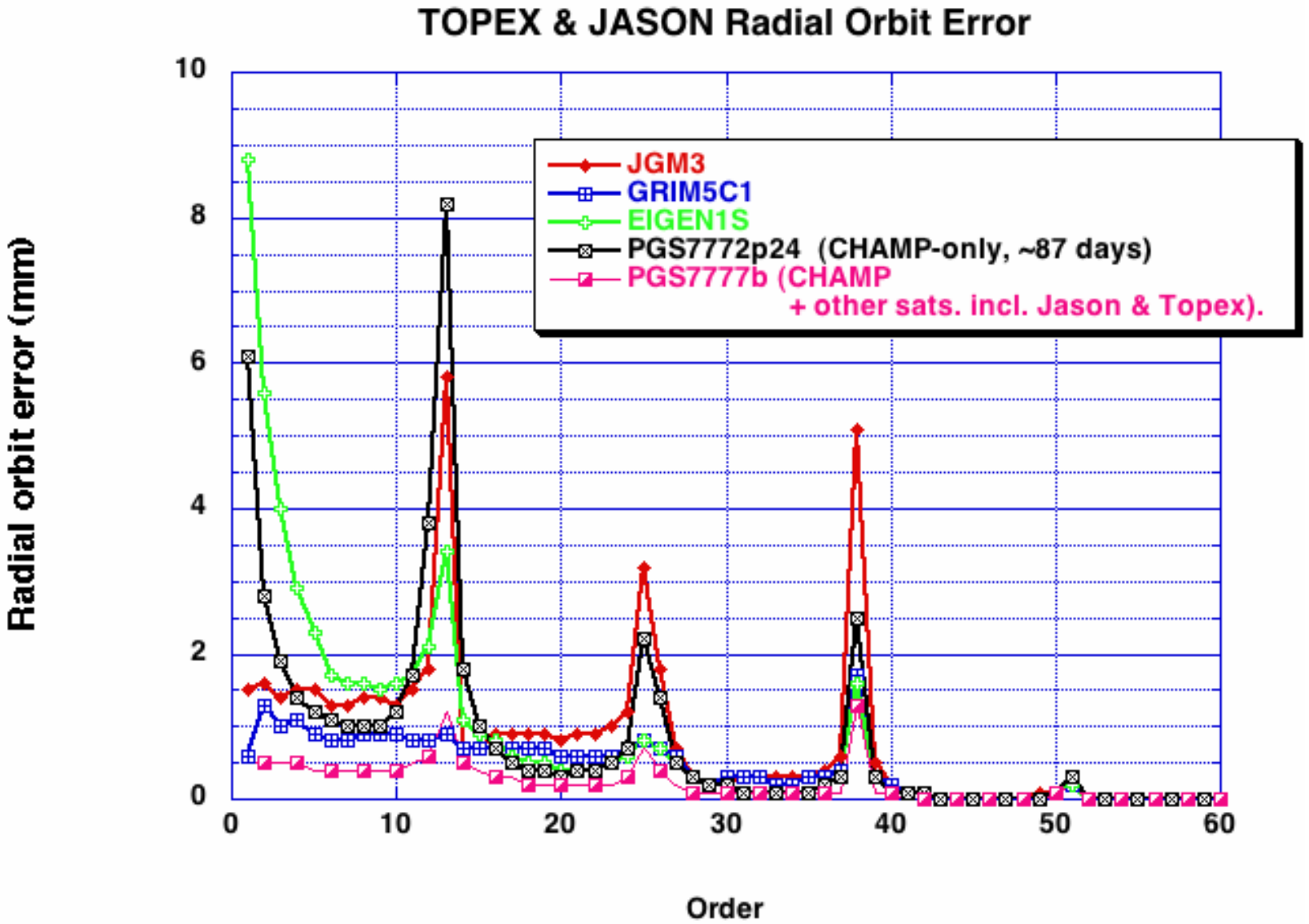


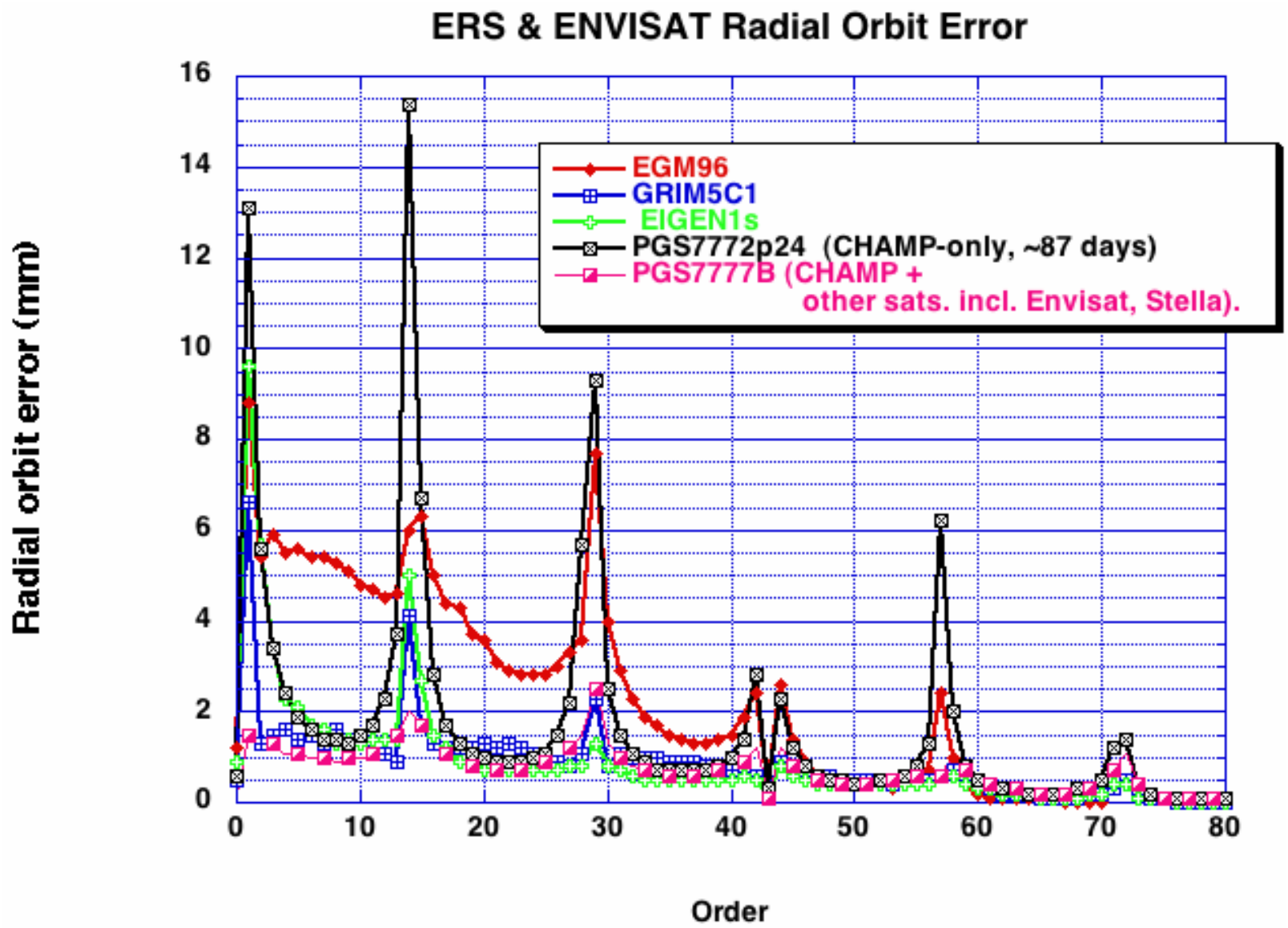
DORIS RMS for JASON (Ten "better" stations: YARB, STJB, KESB, KRAB, CHAB, AMTB, REYB, METB, YELB, REUB (*Independent RMS Computed from GSFC GPS RED-DYN orbits)*



DORIS RMS for JASON (Ten "worst" stations: SALB, CACB, EASB, AREB, GALA, LIBB, SANB, HELB, KRVB, ASDB (*Independent RMS Computed from GSFC GPS RED-DYN orbits)*




TOPEX & JASON Radial Orbit Error
Radial orbit error (mm)
Order
JGM3
GRIM5C1
EIGEN1S
PGS7772p24 (CHAMP-only, ~87 days)
PGS7777b (CHAMP
+ other sats. incl. Jason & Topex).
0
2
4
6
8
10
0
10
20
30
40
50
60


ERS & ENVISAT Radial Orbit Error
Radial orbit error (mm)
Order
EGM96
GRIM5C1
EIGEN1s
PGS7772p24 (CHAMP-only, ~87 days)
PGS7777B (CHAMP +
other sats. incl. Envisat, Stella).
0
2
4
6
8
10
12
14
16
0
10
20
30
40
50
60
70
80

Gravity Model Error Predicted from Error Covariances

Model	Radial (cm)	Along-track (cm)	Cross-track (cm)	Total (cm)
EGM96S	5.13	28.05	31.45	44.25
EGM96	2.87	18.24	13.19	22.70
JGM3	3.68	39.86	34.73	53.00
GRIM5C1	1.15	2.61	2.12	3.55
EIGEN1S ¶	1.45	7.03	2.67	7.66
EIGEN3p §	0.84	7.83	3.49	8.62
PGS7772p24 §	2.77	20.56	18.17	27.58
PGS7777b¶	0.83	3.06	4.52	5.52
GRACE models	????????	????????	???????	??????

ERS/ENVISAT

§ CHAMP-only model.
¶ CHAMP multisatellite model.
• 10-day cutoff in perturbations:
• Assume near circular orbit at 776.3 km altitude, 98.5° inclination.

Model	Radial (cm)	Along-track (cm)	Cross-track (cm)	Total (cm)
EGM96S	1.47	31.46	2.16	31.57
EGM96	0.88	9.98	1.34	10.11
JGM3	1.05	23.54	1.31	23.60
GRIM5C1	0.44	10.54	0.87	10.59
EIGEN1S ¶	1.33	11.28	1.88	11.51
EIGEN3p §	0.60	6.23	1.25	6.38
PGS7772p24 §	1.27	14.52	1.34	14.63
PGS7777b¶	0.28	6.67	0.43	6.69
GRACE models	????????	????????	???????	??????

T/P & JASON

§ CHAMP-only model.
¶ CHAMP multisatellite model.
• 10-day cutoff in perturbations:
• Assume near circular orbit at 1336 km altitude, 66° inclination.

Summary & Conclusions

- New mean fields from GRACE have better fits than previous generation of geopotential models (JGM3, EGM96, DGME04).
- GRACE solutions with more data tend to do better (e.g., 111-days is better than 39 days or 66 days & 191 days better than the 111-day model).
- The GRACE monthly fields have OD performance comparable to or better than the older generation of geopotential models.
- Caveat: Of the "older" models, GRIM5C1 is the only model that has performance close to that of the GRACE models. This is because the model models the ERS/SPOT orbit quite well.
- ENVISAT is a better "test" satellite than TOPEX/JASON for purposes of testing geopotential models.SLR fits for ENVISAT orbits now at 2 cm.
- The POD System on TOPEX (SLR & DORIS) has improved with age due to upgrade of tracking networks.
- JASON: Equatorial stations or those proximate to the SAA have biggest degradation. Even stations "further" away show higher scatter with time.

Questions

- Is 3.5 to 4.0 cm (*Indep SLR fit)* the best we can do on DORIS-only orbits for TOPEX & JASON? Why?
- Is 5 cm (*Indep SLR fit)* the best we can do on DORIS-only orbits for ENVISAT? Why?
- The tests on JASON show the value of having a single satellite with tracking from SLR/DORIS & GPS. Can we insist that NPOESS also include DORIS (only GPS & SLR are baselined at present)?
- Can we obtain DORIS data for other low-altitude satellites? (for testing).
- Can the current DORIS receiver on JASON be trusted for any geodetic work (positioning, EOP, time-variable gravity)?
- Can we obtain the error covariances for the new mean field GRACE gravity models?