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Large-Scale Global Surface Mass Variations Inferred from GPS

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Objectives

- Surface Mass Variations
  - Load the Earth
  - Change Gravity
  - Change Earth Orientation
- Invert 3-D GPS Displacement Data for Low-Degree Surface Mass Variations
- Use a Joint Geophysical Model for Atmosphere+Oceans +Hydrology to Assess Aliasing Errors due to Neglected Terms
- Compare GPS Results with SLR and Model

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Strategy

- Data
  - Up to 200 global sites by end of 2001
  - Monthly displacement series
  - Remove linear trend for seasonal and inter-annual scales
- Inversion
  - Truncate spherical harmonic series
  - Use geophysical model to assess aliasing and total uncertainty and to guide truncation truncation
  - The estimated values do not depend on the model
- Statistics
  - Computed + Aliasing Uncertainty
  - Least squares fitting time series by seasonal cycles

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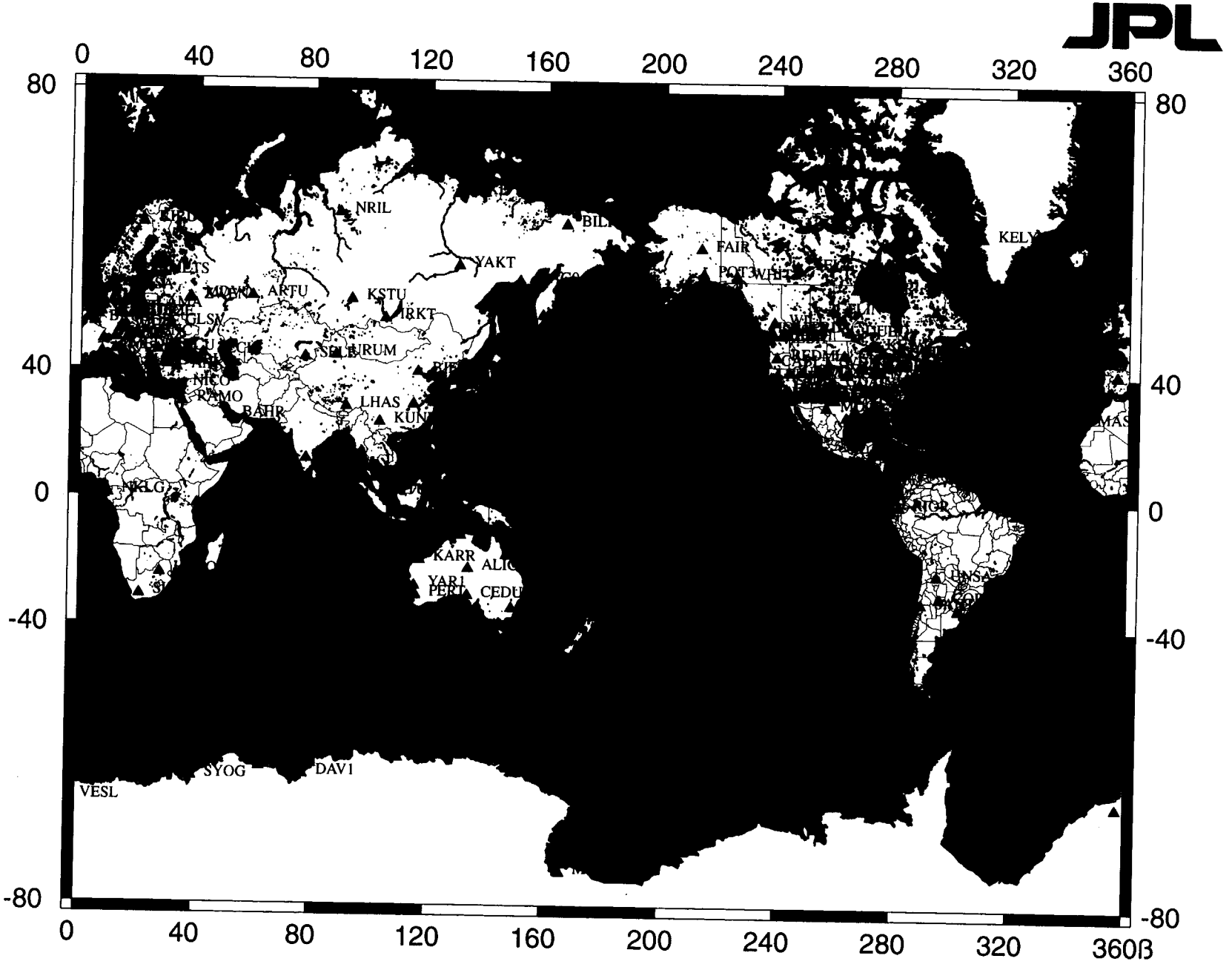
$$S = \frac{4\pi a^3}{M_E} \sum_{n=1}^{\infty} \sum_{m=0}^{n} \sum_{q=c,s} \frac{M_{nmq}}{2n+1} [h_n' Y_{nmq} \hat{e}_r + l_n' \partial_\vartheta Y_{nmq} \hat{e}_\vartheta + \frac{1}{\sin\theta} \partial_\varphi Y_{nmq} \hat{e}_\varphi$$

$$Y = H_x X + H_c C + \Delta$$

$$\Sigma = (H_x^T W H_x)^{-1} + S_{xc} \Sigma_c S_{xc}^T$$



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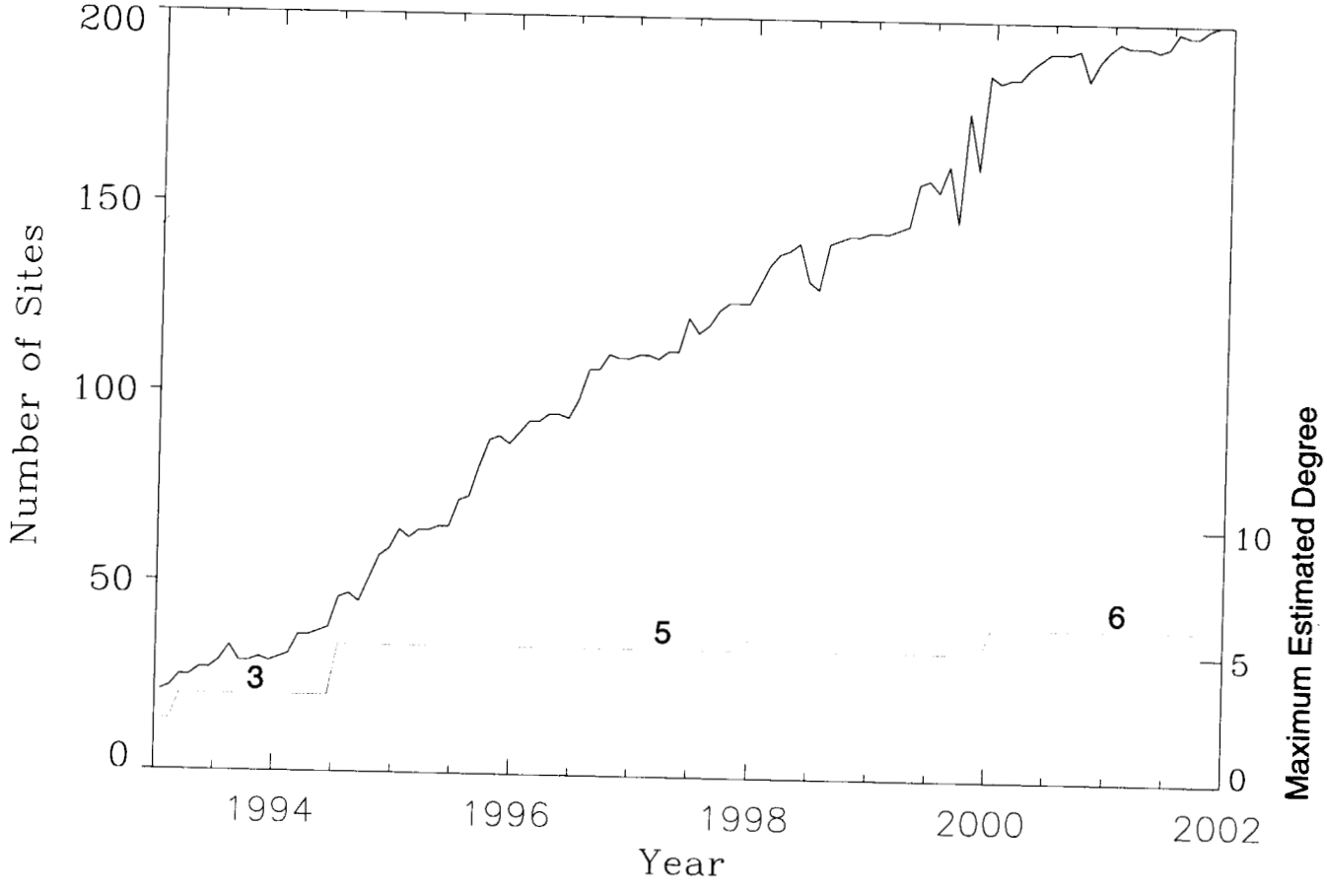
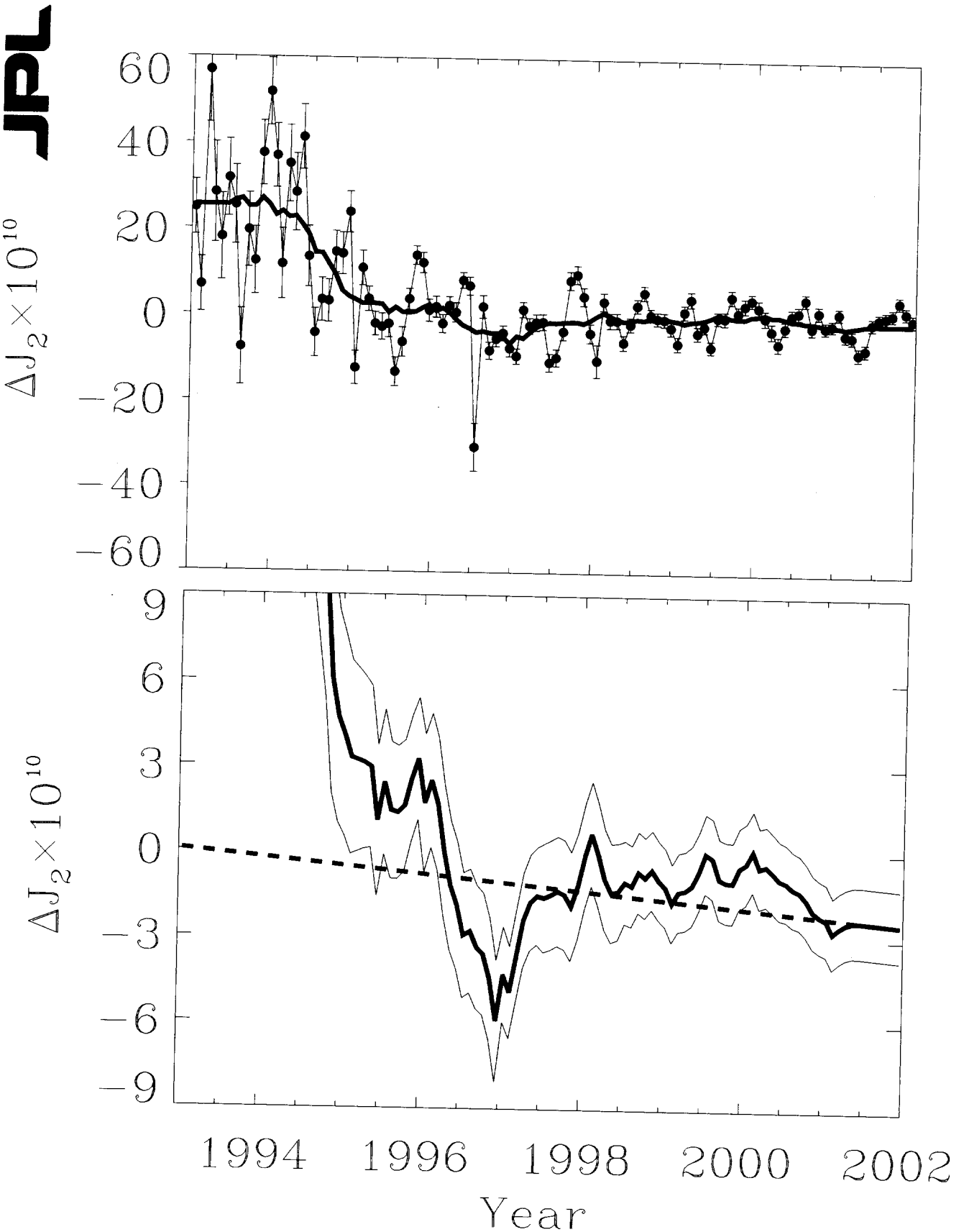

200
150
100
50
0
Number of Sites
1994
1996
1998
2000
2002
Year
10
5
0
Maximum Estimated Degree
3
5
6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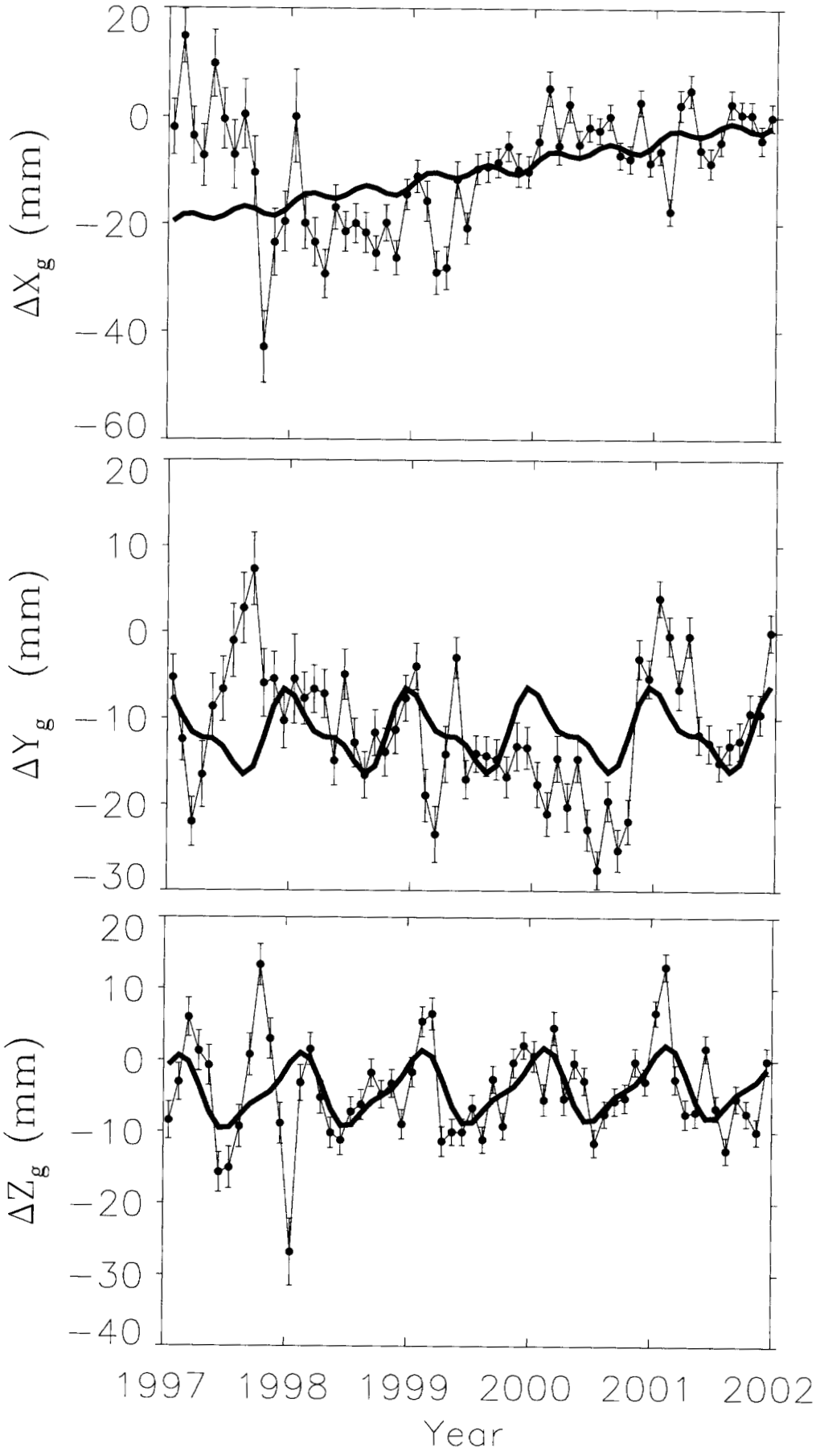
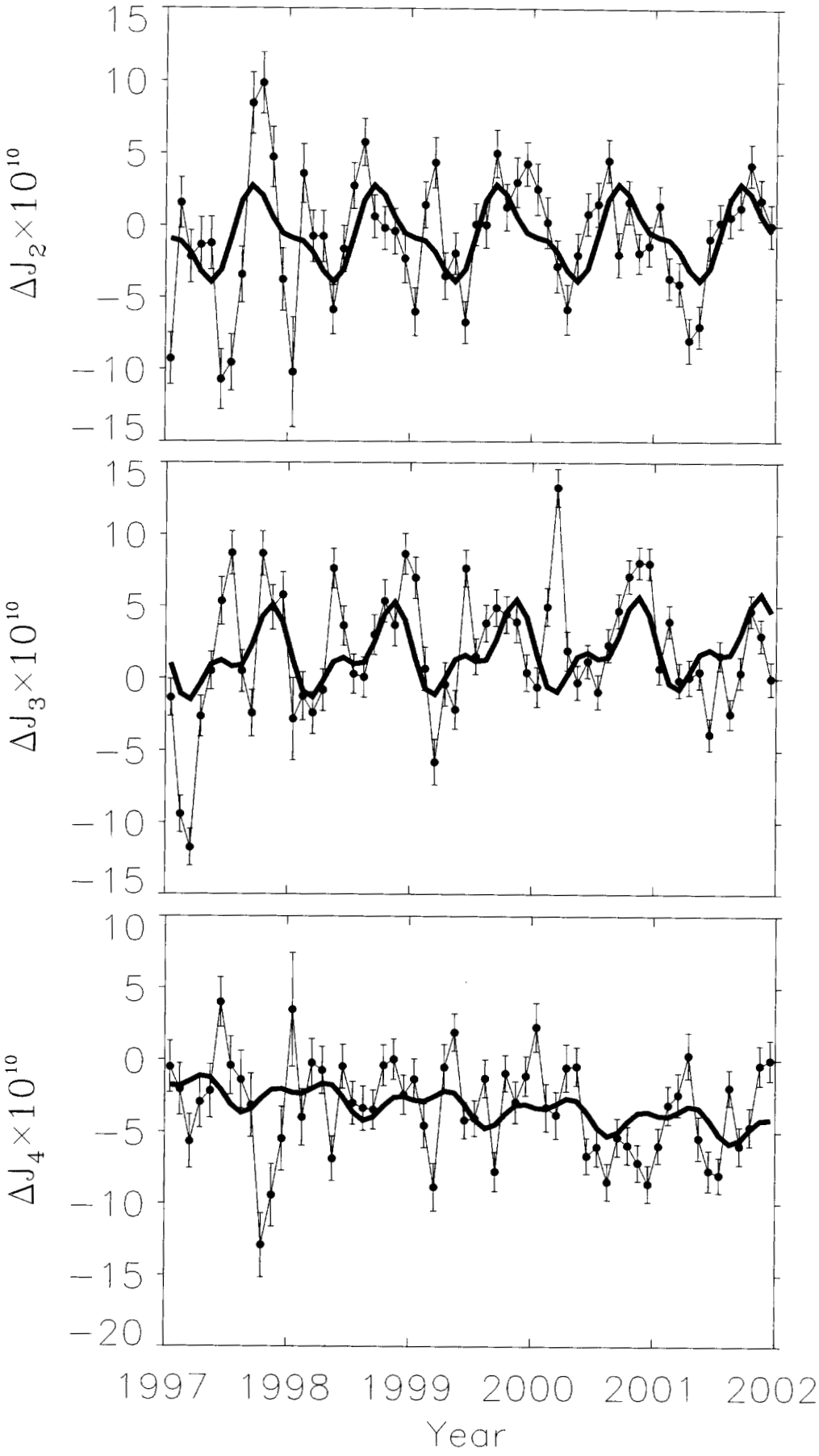
60
40
20
0
−20
−40
−60
$\Delta J_2 \times 10^{10}$
9
6
3
0
−3
−6
−9
$\Delta J_2 \times 10^{10}$
1994
1996
1998
2000
2002
Year


20
0
−20
−40
−60
ΔX_g (mm)
20
10
0
−10
−20
−30
ΔY_g (mm)
20
10
0
−10
−20
−30
−40
ΔZ_g (mm)
1997
1998
1999
2000
2001
2002
Year


15
10
5
0
−5
−10
−15
$\Delta J_2 \times 10^{10}$
15
10
5
0
−5
−10
−15
$\Delta J_3 \times 10^{10}$
10
5
0
−5
−10
−15
−20
$\Delta J_4 \times 10^{10}$
1997
1998
1999
2000
2001
2002
Year

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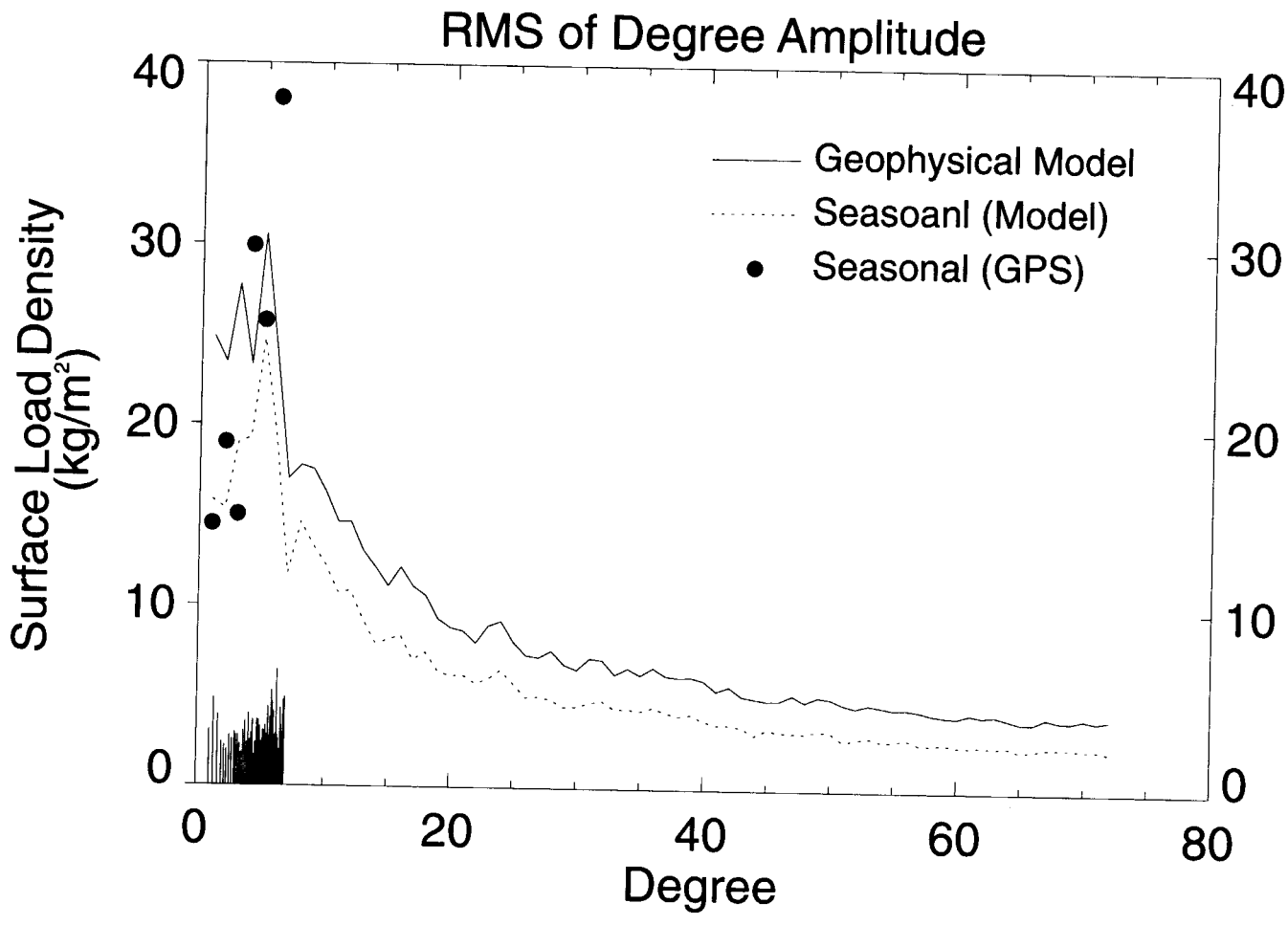
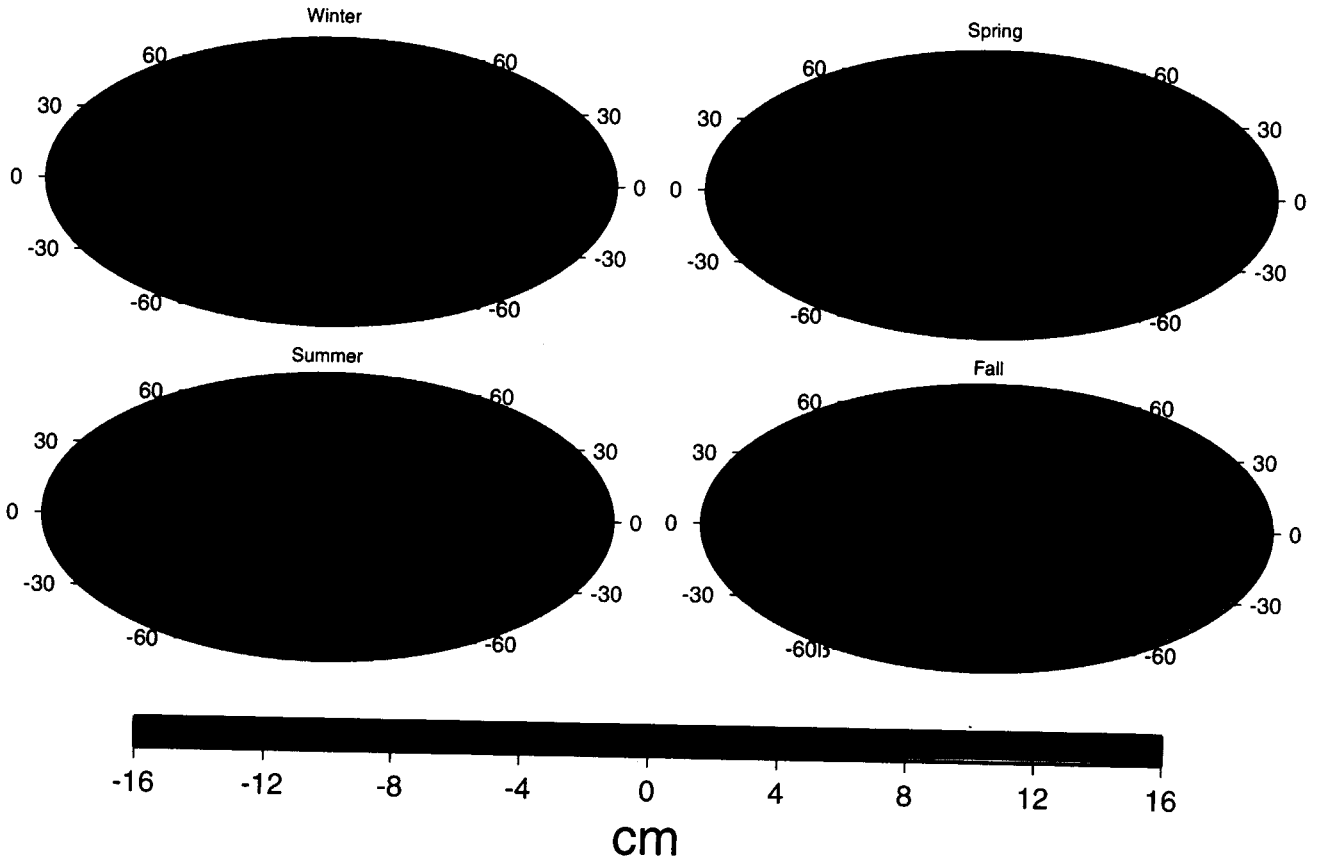

RMS of Degree Amplitude
Geophysical Model
Seasoanl (Model)
Seasonal (GPS)
Surface Load Density (kg/m²)
Degree
0
10
20
30
40
0
20
40
60
80

GPS Inverted



Geophysical model Prediction

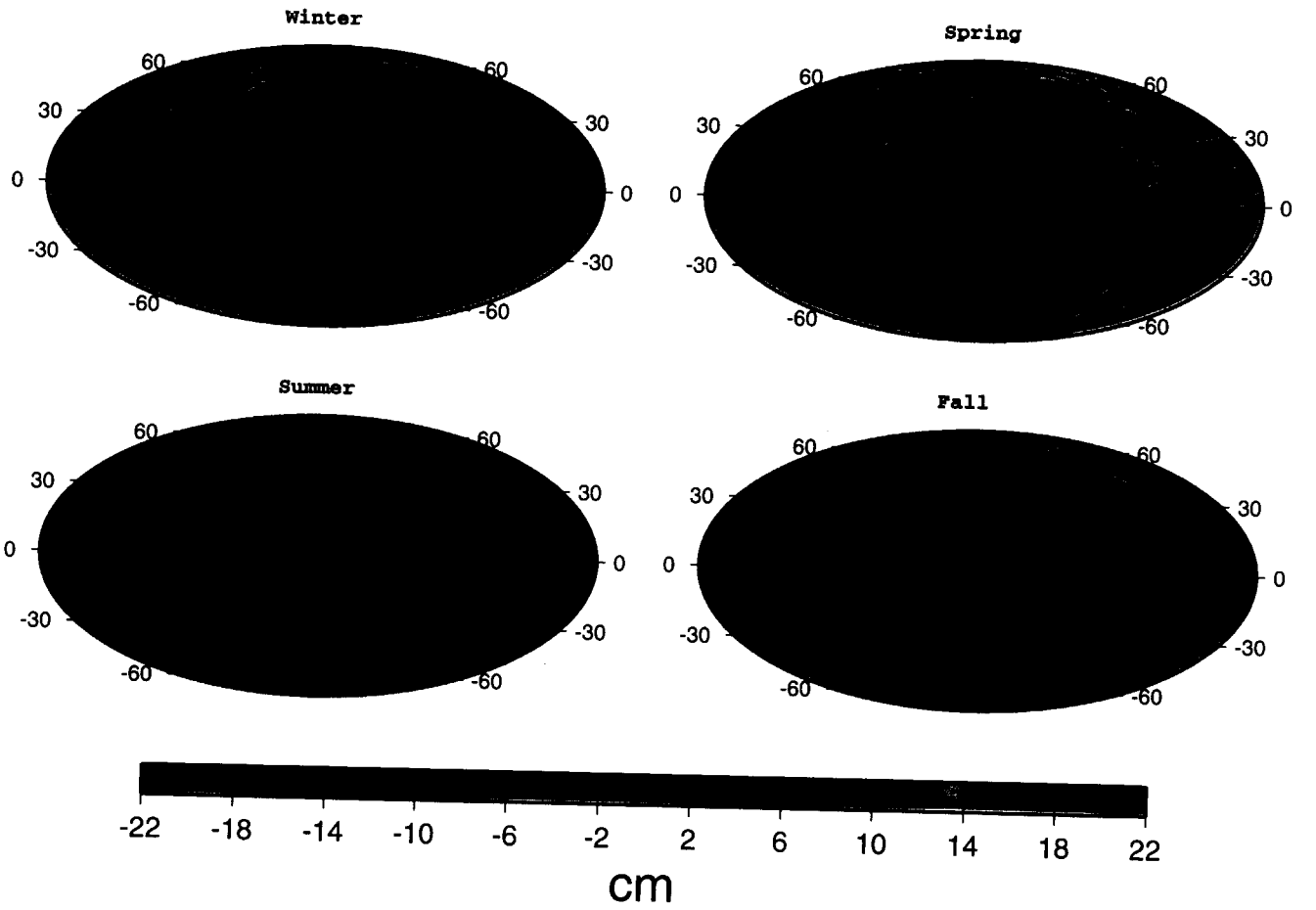


Table 1. SLR and GPS Estimated Geocenter and Zonal Gravity Variations

Δ	A^a		ϕ^a		A^{sa}		ϕ^{sa}	
	SLR	GPS	SLR	GPS	SLR	GPS	SLR	GPS
X_g	2.1 ± 0.5^a	0.7 ± 1.5	48^a	119 ± 131	1.1^b	1.2 ± 1.5	145^b	47 ± 37
Y_g	2.0 ± 0.5^a	3.8 ± 1.2	327^a	16 ± 20	0.8^b	1.9 ± 1.2	120^b	160 ± 20
Z_g	3.5 ± 1.5^a	4.5 ± 1.0	43^a	27 ± 13	0.4^b	1.6 ± 1.0	39^b	65 ± 18
$J_2{}^c$	1.3^d	2.6 ± 0.6	223	287 ± 14	0.6	1.2 ± 0.6	72	63 ± 15
J_3	2.2	2.2 ± 0.8	19	294 ± 19	1.0	1.6 ± 0.7	40	142 ± 14
J_4	1.1	0.8 ± 0.6	22	65 ± 38	0.4	0.6 ± 0.6	148	135 ± 27
J_5	1.1	2.0 ± 0.8	211	98 ± 20	0.7	0.9 ± 0.7	148	114 ± 24
J_6	0.3	2.0 ± 1.0	23	348 ± 32	0.2	1.2 ± 1.0	93	58 ± 23

The annual (a) and semiannual (sa) variations are modeled as $\Delta = Acos[\omega(t - \phi)]$. Geocenter components ($X_g$, Y_g, and Z_g) are in units of mm. Zonal gravity coefficients (J_n) are in units of 10^{-10}. t and ϕ are time and phase (in days) measured from January 1. ϕ is also equivalent to the peak time of the variation cycle under this convention.

[a]Bouille et al., [2000]

[b]Eanes et al., [1997]

[c]All SLR zonal gravity results are from Cheng and Tapley, [1999]

[d]An annual J_2 amplitude of 3.2×10^{-10} has also been reported by Cox and Chao, [2002]

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Summary

- GPS agrees with SLR on geocenter and zonal harmonics surprisingly well
- Significant n>1 and non-zonal surface mass variations are also found
- Recovery over Northern continents is better than over oceans and some Southern continents due to data coverage
- Improvement will be expected by incorporating ocean bottom pressure model