

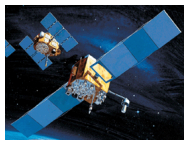
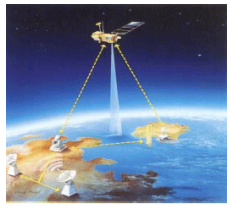
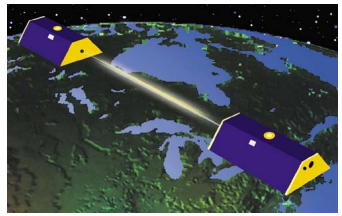

Consistency and Complementarity among Gravity, Deformation, and Ocean model in the Global Inverse Framework

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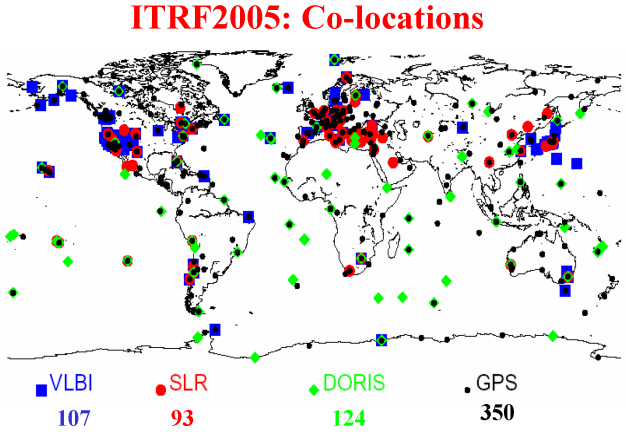
Geocenter Motion Determination Methods

$$\vec{S}_{cm} - \vec{S}_{cf} = \frac{4\pi}{3}\frac{R_e^3}{M_e}\rho_w\left(1 - \frac{h_1' + 2l_1'}{3}\right)(M_{11c}\hat{e}_x + M_{11s}\hat{e}_y + M_{10c}\hat{e}_z)$$

- **Direct Satellite Determinatio**
  - In the CM frame
  - SLR
  - GPS

$$\vec{S}_{cm} - \vec{S}_{cn} = -\frac{1}{N}\sum_i \vec{S}_i = -T$$

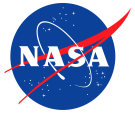


- **Inverse Solution of**
  - GPS
  - Ocean Bottom Pressure (OBP)
  - GRACE

$$G(\theta,\phi,t) = \sum_{nmq} G_{nmq}(\theta,\phi,p..)M_{nmq}(t)$$

Comparison of Solutions For Annual Geocenter Motion

Data	ΔX_g		ΔY_g		ΔZ_g		Ref
	Amp mm	Phase day	Amp mm	Phase day	Amp mm	Phase day	
SLR (L1/L2)	2.2	60	3.2	303	2.8	46	*Eanes97*
SLR	2.1± 0.5	48	2.0± 0.5	327	3.5±1.5	43	*Bouille00*
GPS	0.7±1.5	119±131	3.8±1.2	16±20	4.5±1.0	27 ±13	*Wu.. 03*
GPS+OBP	1.6±0.7	27± 21	1.9±0.4	326±11	5.2± 0.5	23 ± 5	*Wu.. 06*
GPS+OBP+GRACE	1.8±0.4	46±15	2.5±0.3	329±5	3.9±0.4	28 ± 5	*Wu..06*
GPS+OBP+GRACE	1.8±0.1	49 ± 4	2.7±0.1	329±2	4.2±0.2	31 ± 3	*2002-2009*



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n=1 Mass and Geocenter Results

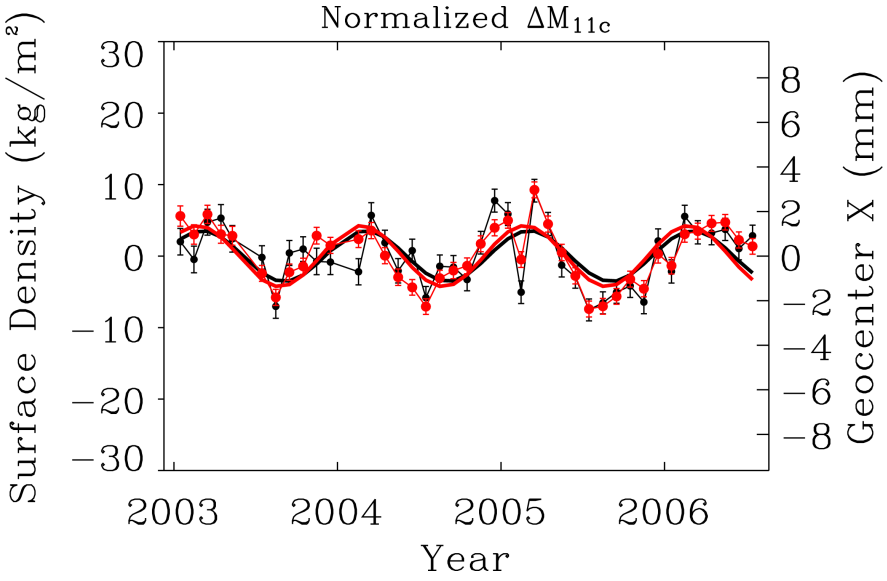
From GPS+OBP

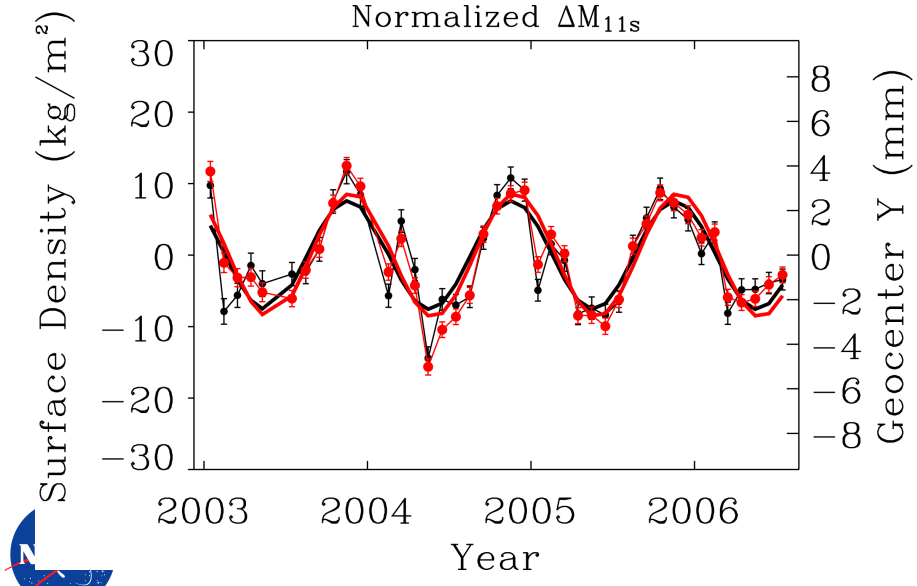
$X^a = 1.9 \pm 0.3$ mm

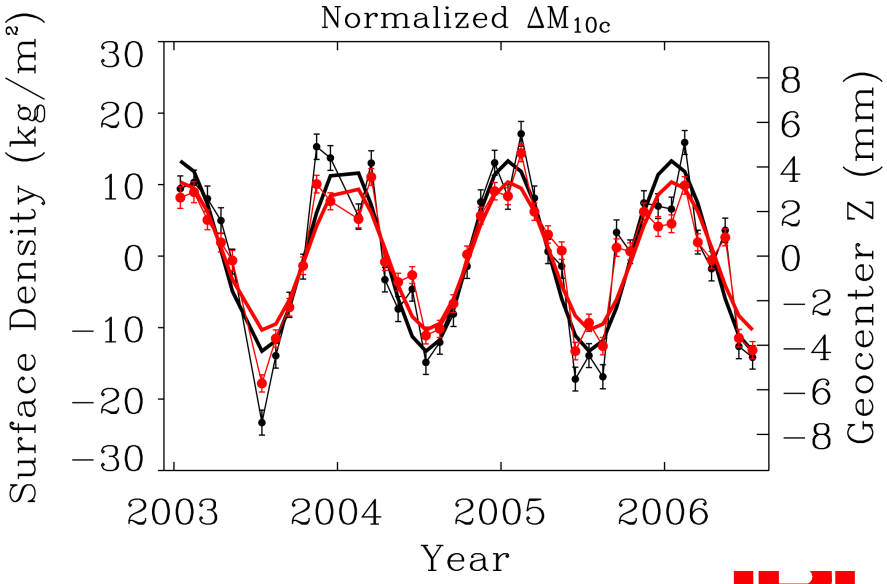
$Y^a = 3.0 \pm 0.4$ mm

$Z^a = 3.6 \pm 0.3$ mm

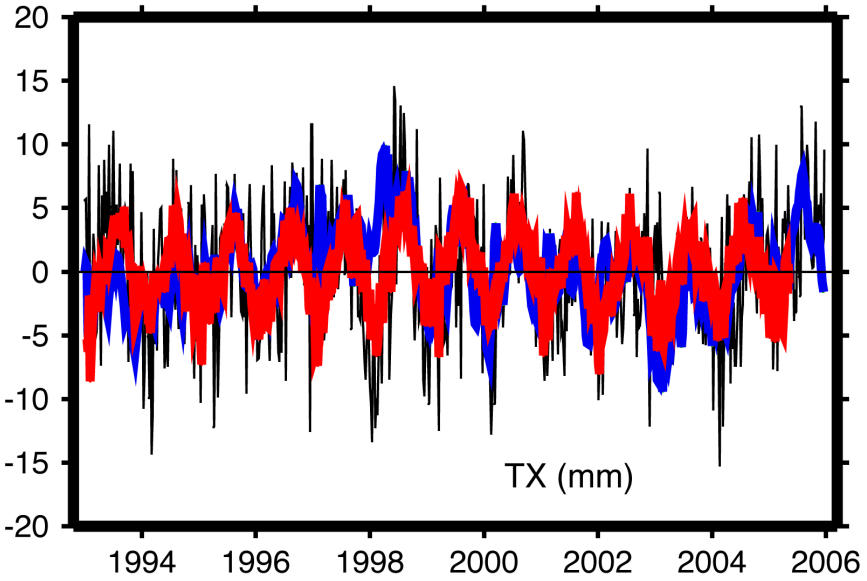
From GPS+OBP+GRACE

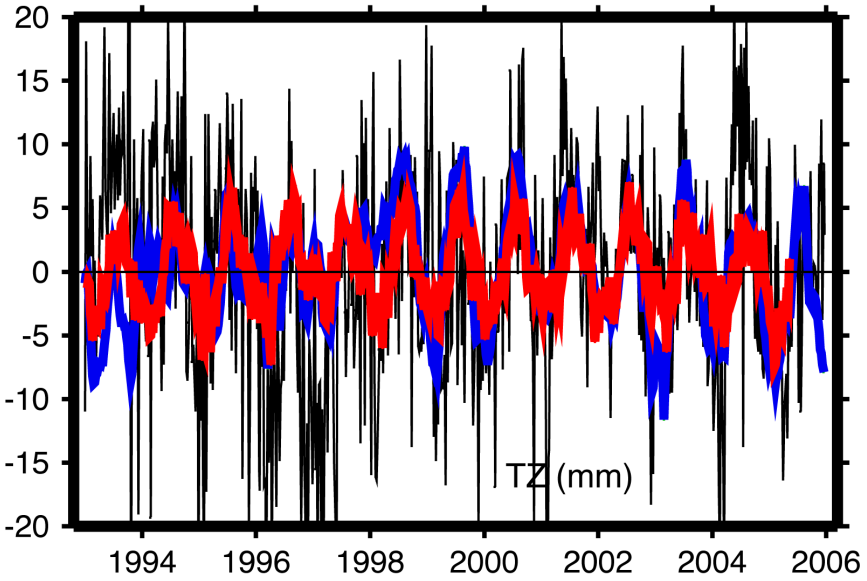






Compare with SLR and Hydrological Mode





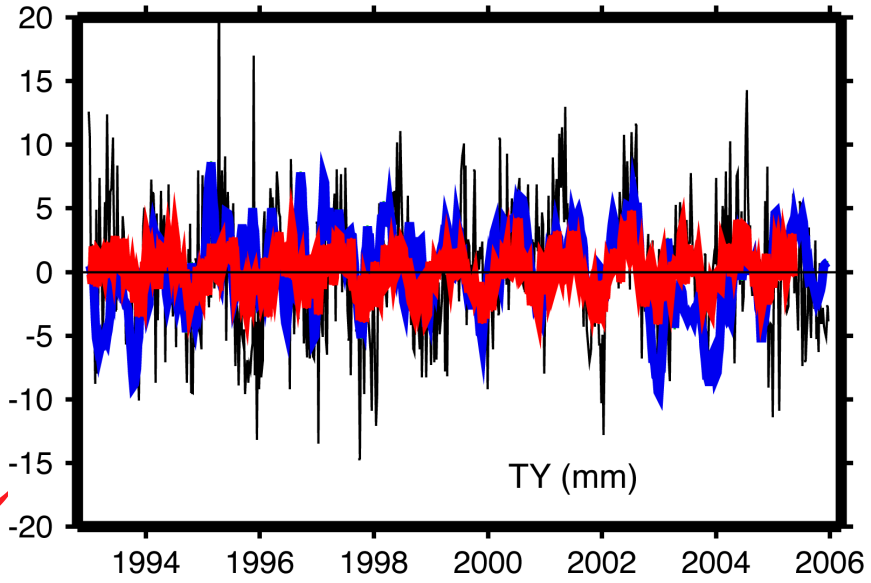
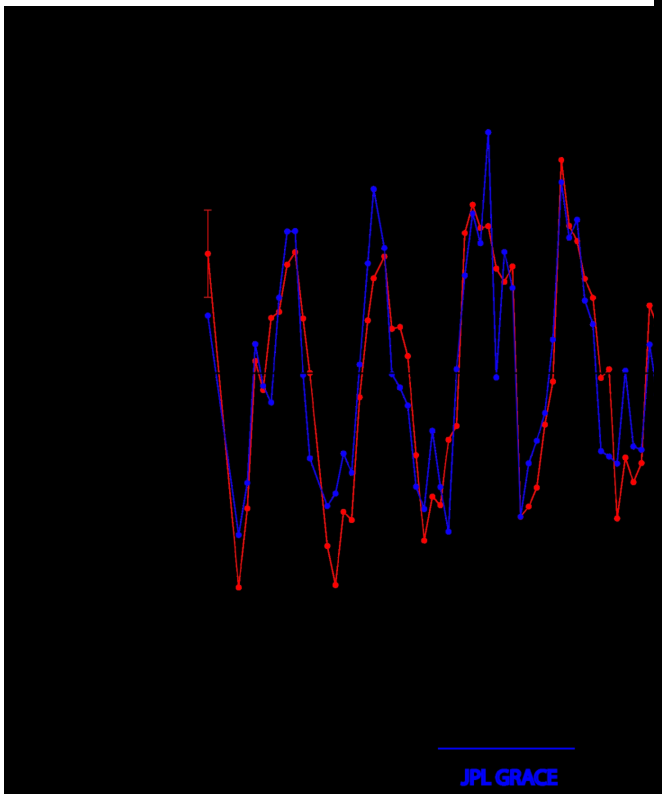
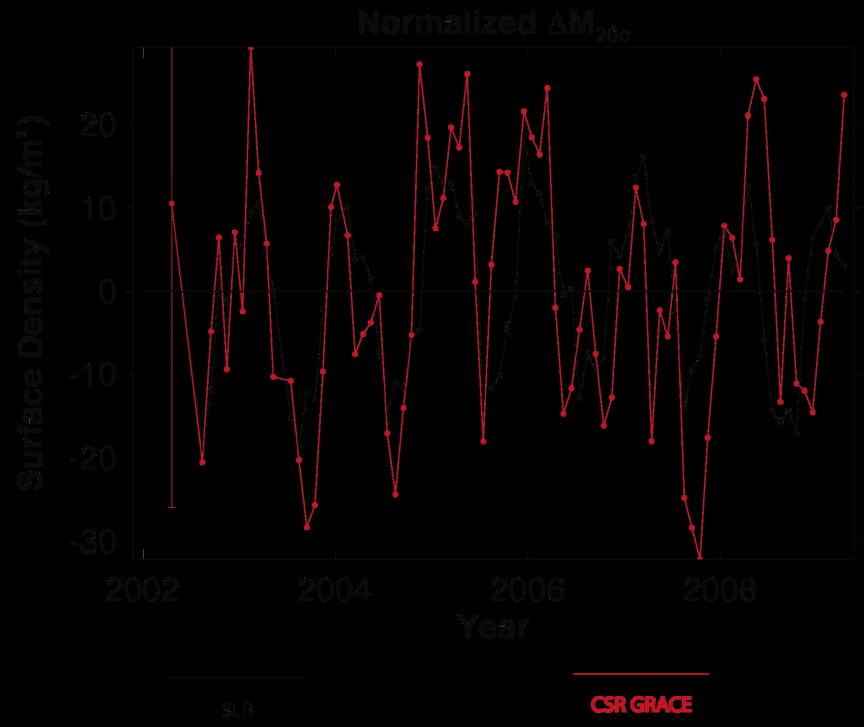


Figure by Xavier Collilieux

- **SLR from ITRF2005 Altamimi**
- **AOW Mass Model from van Da**
- **GPS/OBP Inversion**

C20 Surface Density from GPS/OBP, SLR, GRACE





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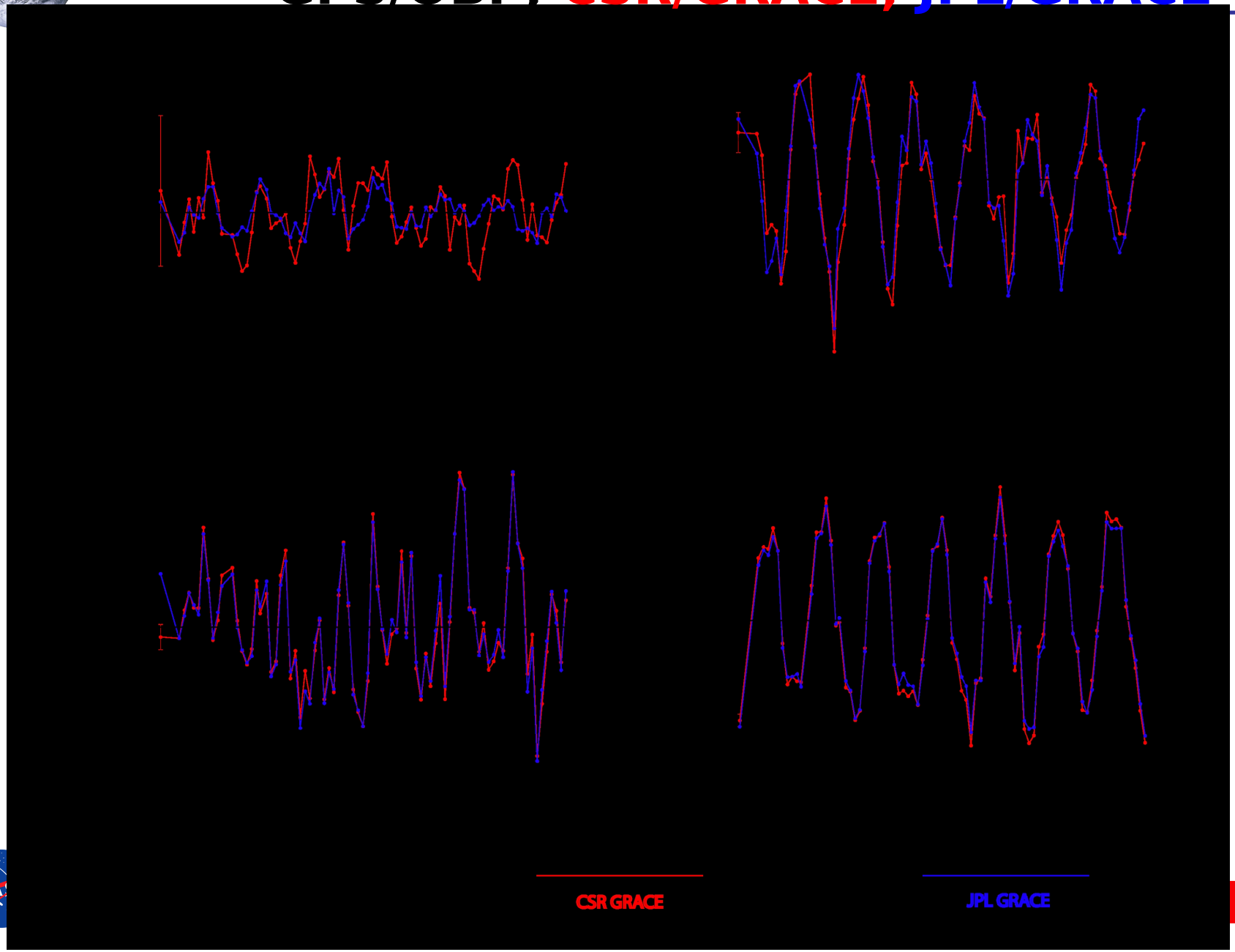
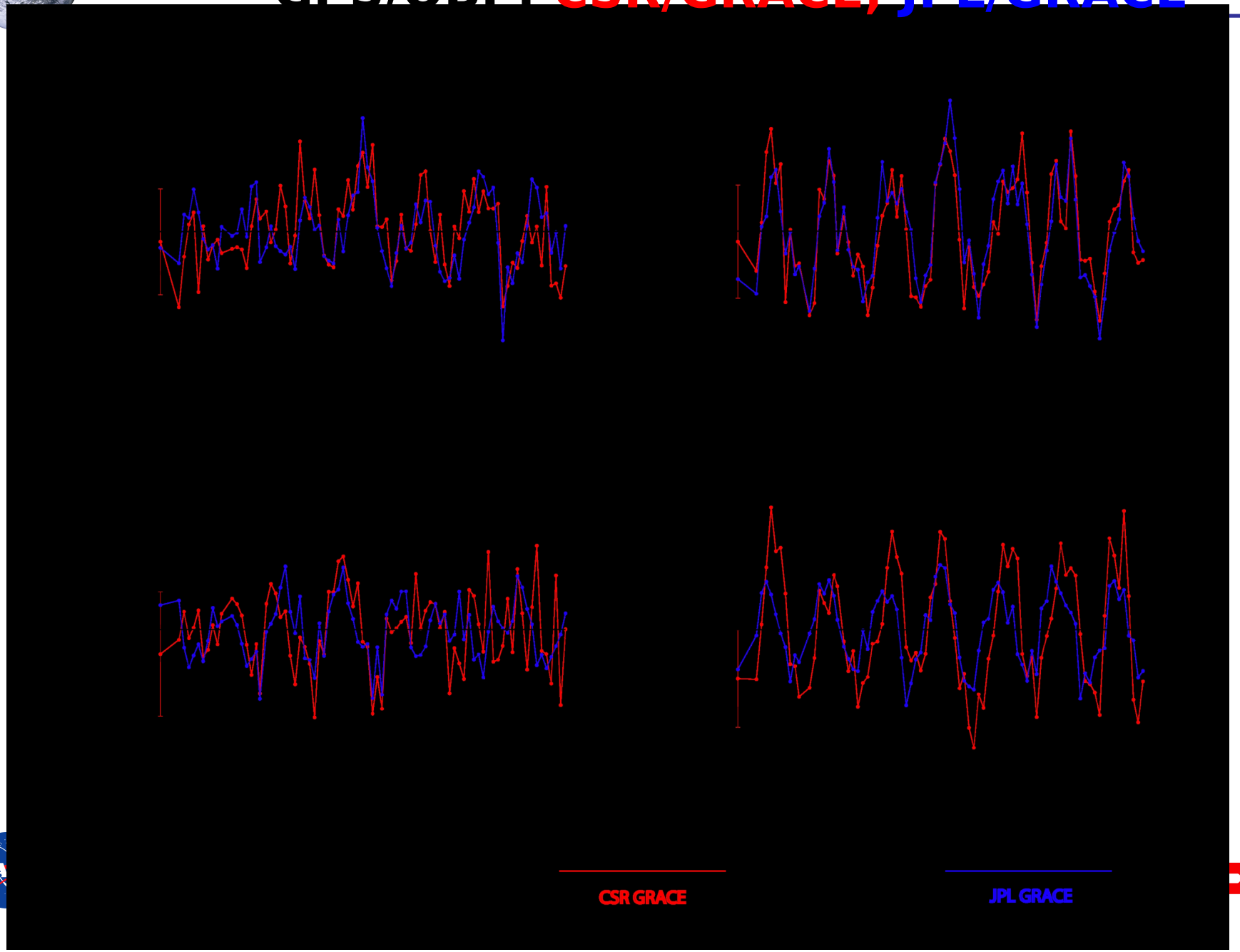
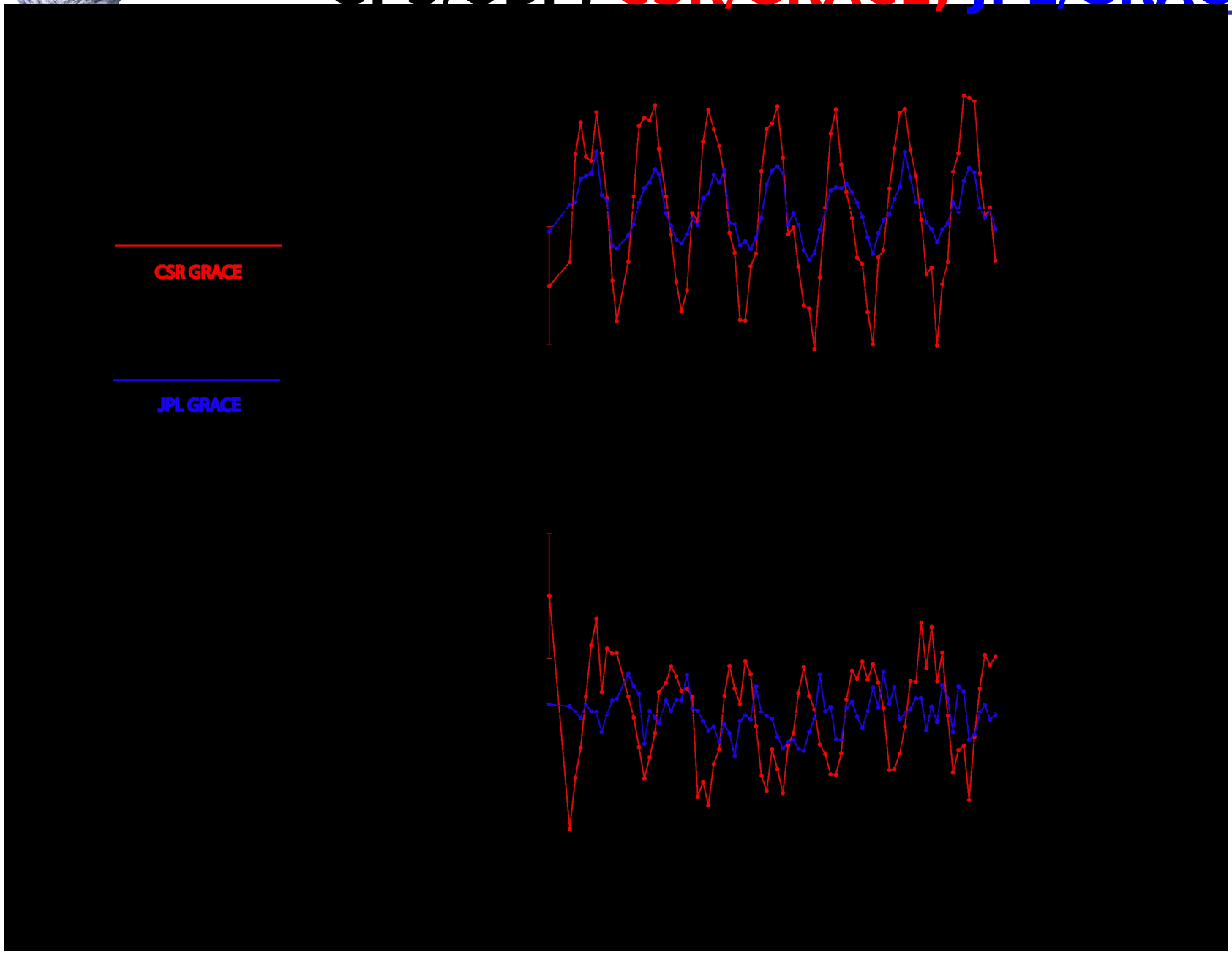
Zonal Surface Density from GPS/OBP, CSR/GRACE, JPL/GRACE



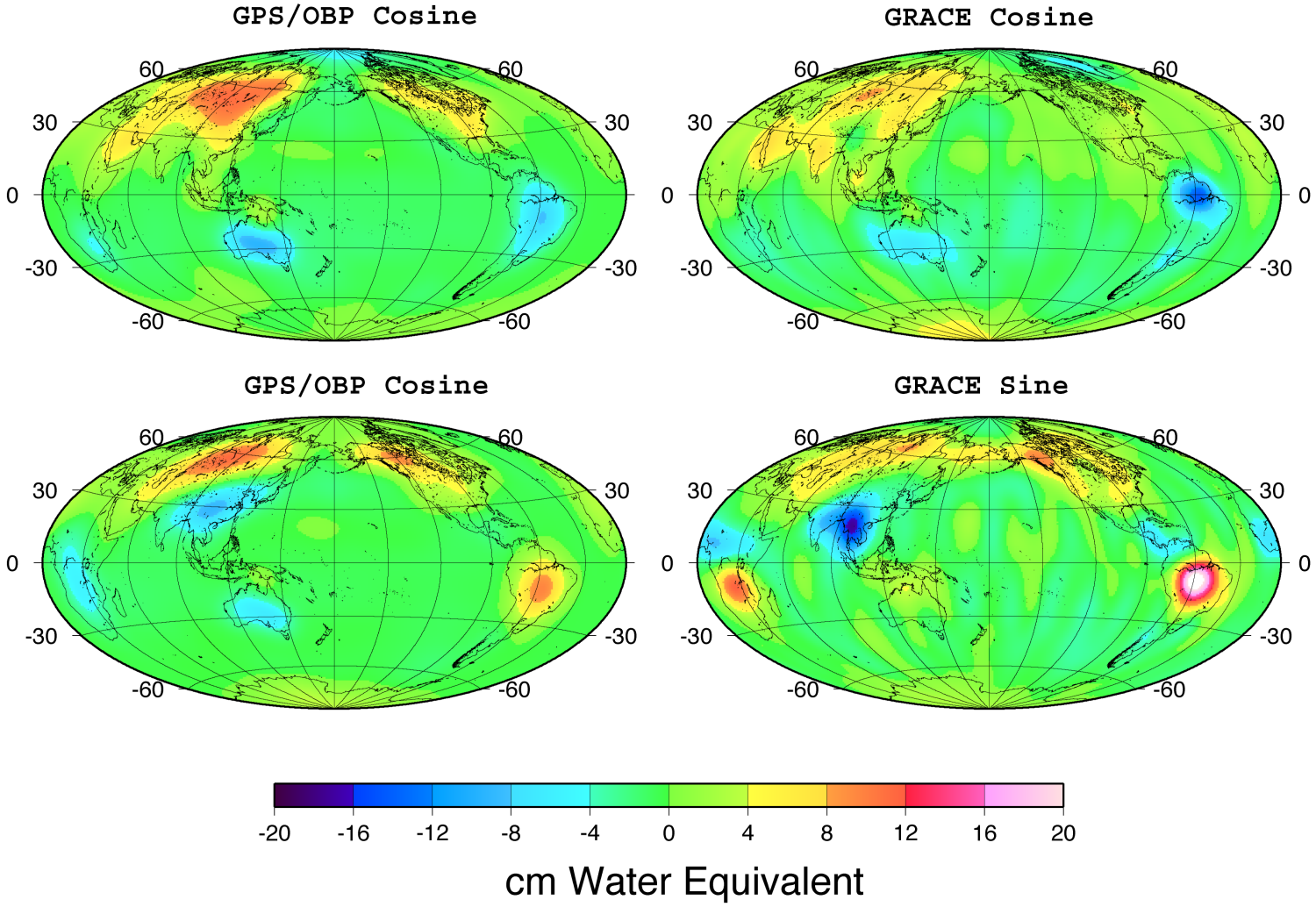
Degree-2 Surface Density from GPS/OBP, CSR/GRACE, JPL/GRACE



Degree-3 Sectorial Surface Density from GPS/OBP, CSR/GRACE, JPL/GRACE



Compare GPS/OBP and GRACE Annual Variations (2004-2005)



351 Day GPS Draconitic Harmonic error ?

Secular Changes

- Multiple data types to separate present-day surface mass trend (PDMT) and GIA
- Gravity trend ⇔ X Surface velocity because of GIA
- Few redundancies and many holes in spatiotemporal data coverage

€

- Inverse determination of geocenter velocity using relative GPS velocity, GRACE, ocean bottom pressure model to <0.1 mm/yr
- ITRF origin stability is at 0.3 mm/yr level

NASA

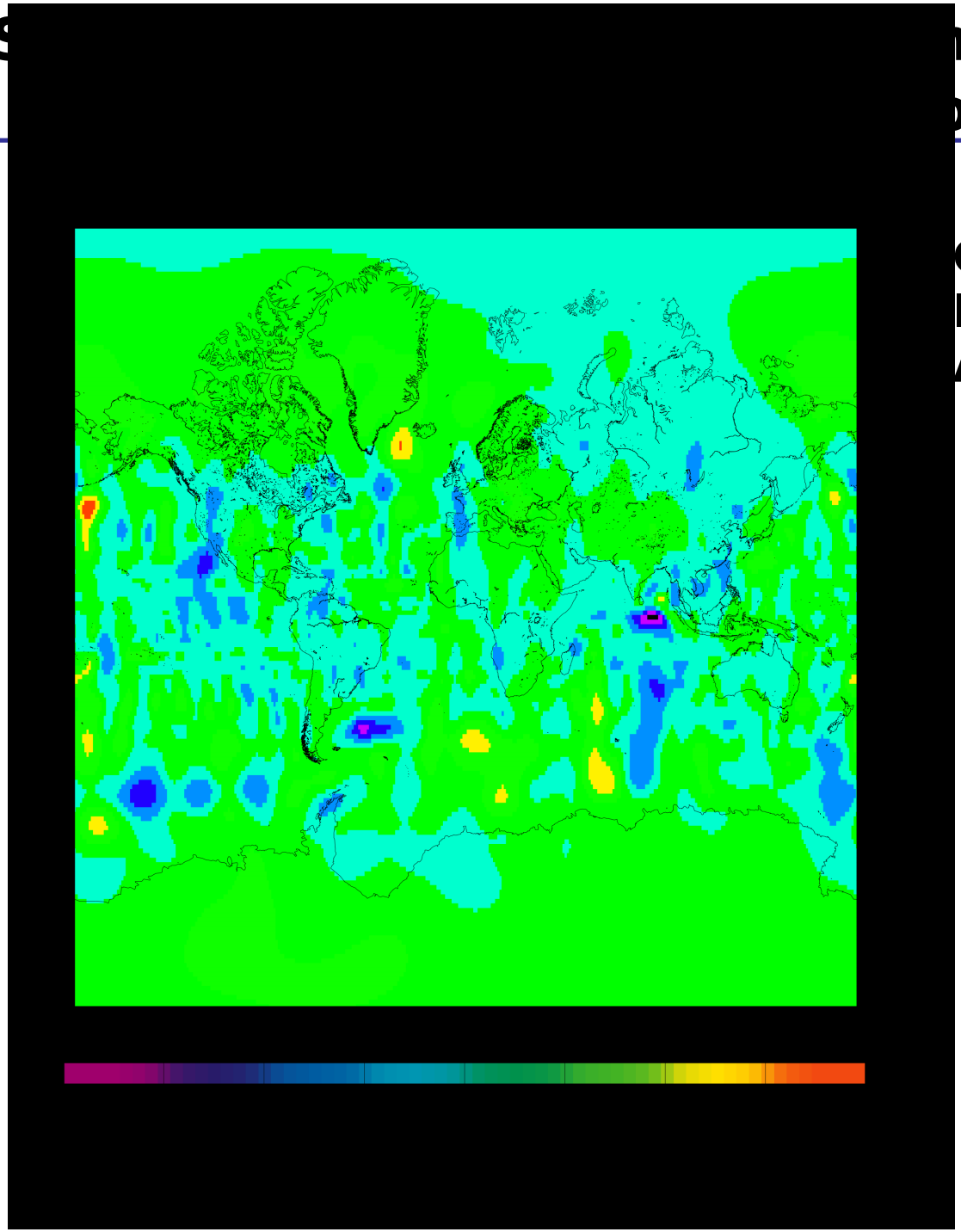
JPL

Polar Wander and C21/S21 Rates

$$\dot{C}_{21} = \sqrt{3}\,C_{20}\,\dot{X}_p, \qquad \dot{S}_{21} = -\sqrt{3}\,C_{20}\,\dot{Y}_p$$

Data	C21 rate	S_{21} rate	Ref
Mean Pole	-20×10^{-12}	4.3×10^{-12}	
GRACE (CSR)	-15×10^{-12}	4.4×10^{-12}	
SLR	-9.3×10^{-12}	5.8×10^{-12}	*Cheng 2009*

S[illegible]ne Simultaneous
[illegible]on

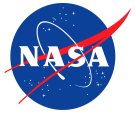


GRACE/GPS/OBP
Inversion with
A Priori GIA model

300-km Gaussian
Filtered

Model Atmospheric Mass Change in Gt/y

Models	Greenland	Alaska/ Yukon	Antarctica	Oceans	Remaining Land	Total
NCEP Reanalysis-2	4	-6	-31	32	-106	-100
ECMWF Operational	-4	-7	14	-64	-146	-200



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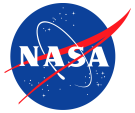
Summary and Conclusion

- Mostly consistent low-degree surface mass coefficients at sub-secular time scales but errors are still large
- Geocenter velocity due to PDMT and GIA determined to uncertainties better than 0.1 mm/yr; ITRF origin stability at 0.3 mm/yr
- Draconitic GPS harmonic errors contaminating annual signal, orbit error?
- GIA model errors still a major concern for GRACE results
- GRACE non-steric mean sea level determination subject to a large atmospheric model error



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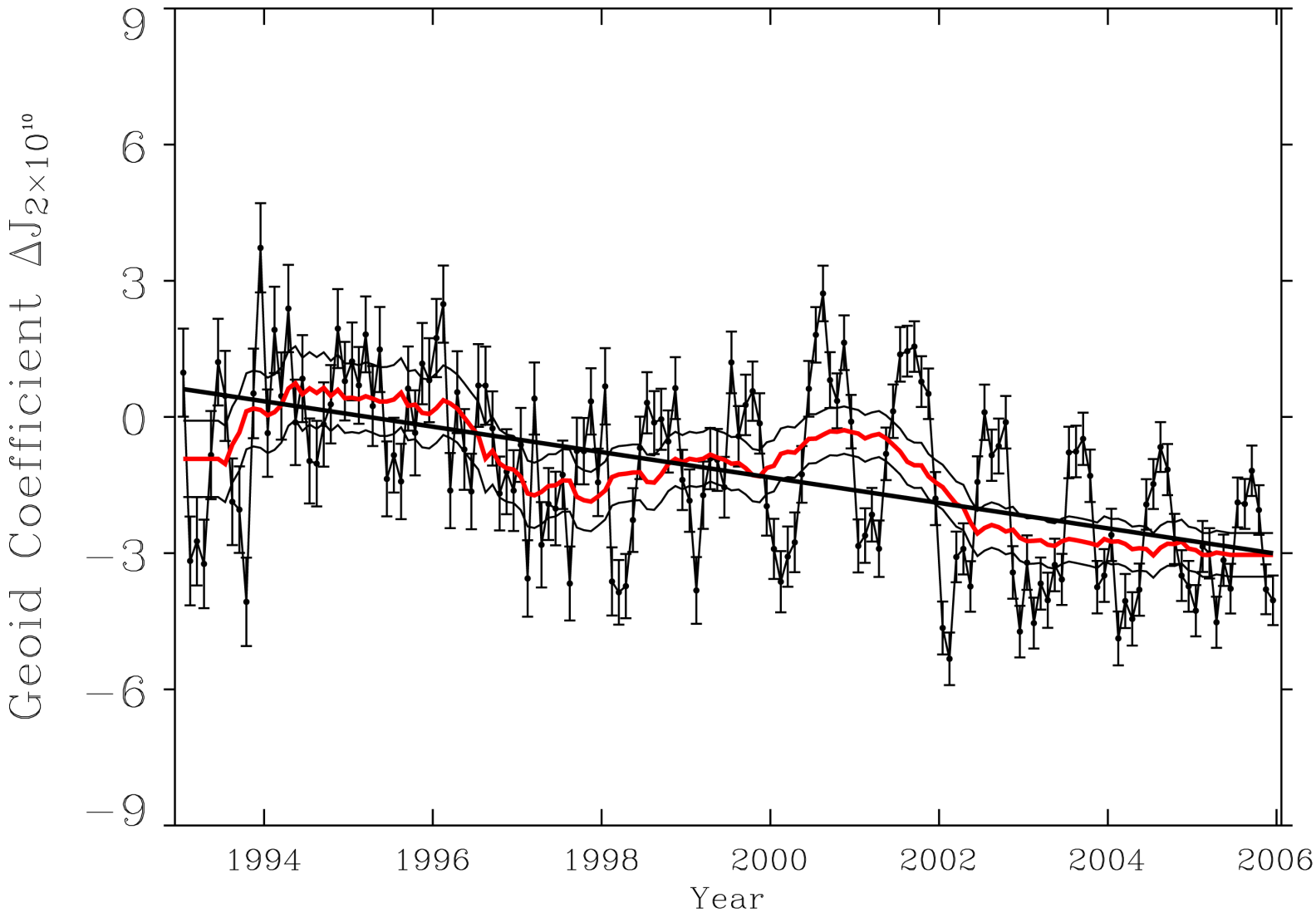
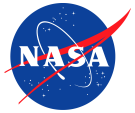
J2 Time series





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Degree-4 Surface Density from GPS/OBP, CSR/GRACE, JPL/GRACE