GGOS Unified Analysis Workshop

Seasonal Geocenter Motion from Space Geodesy and Models

J. C. Ries

Center for Space Research
The University of Texas at Austin

16-17 September 2011
Zurich, Switzerland

Geocenter Motion Definition

IERS2010 Conventions:

C) *Geocentric positions*

The ITRF origin should be considered as the mean Earth center of mass, averaged over the time span of the SLR observations used and modeled as a secular (linear) function of time. If an instantaneous geocentric position $\vec{X}$ is required, it should be computed as

$$\vec{X} = \vec{X}_{ITRF} - \vec{O}_G, \qquad (4.16)$$

where $\vec{O}_G$ represents the geocenter motion in ITRF (vector from the ITRF origin to the instantaneous center of mass) $<^2>$.

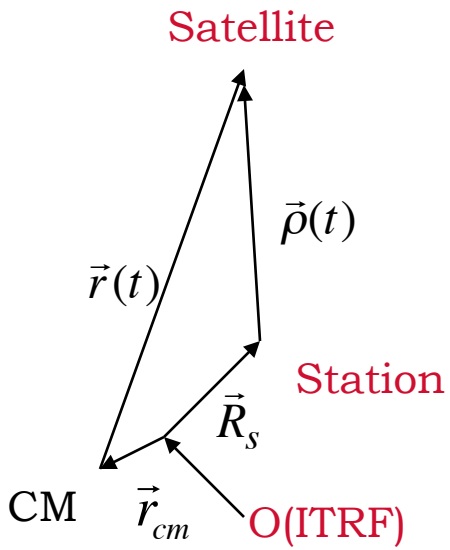
By definition, ITRF does not include seasonal variations between the mean and instantaneous center of mass; these must be included as a correction

$$\vec{R}_s(t) = \vec{R}_{so} + (t - t_o)\vec{V}_s + \Delta\vec{R}_s(t) \ (tides, \ ocean \ loading, pole \ tides, \ etc.)$$

IERS conventions include tidally coherent geocenter motion, but not non-tidal; non-tidal variations dominate the annual geocenter motion.

‘Dynamical’ Approach to Determine Geocenter Motion

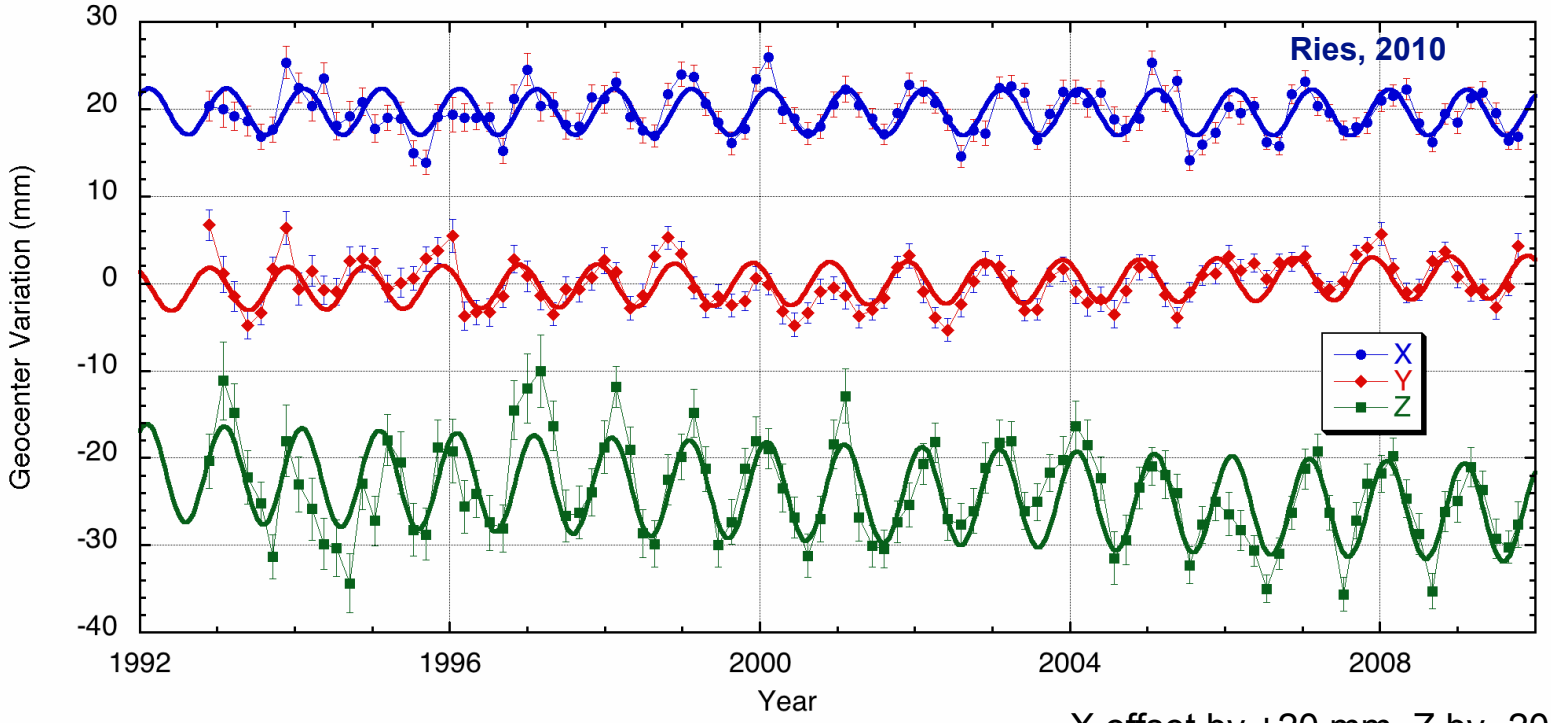
- Satellites orbit about the center of mass of the entire Earth system (solid Earth, oceans and atmosphere).
- Geocenter motion vector $\vec{r}_{cm}$ can be estimated simultaneously with the orbit.
- This is identical to estimating degree-1 gravity harmonics (as long as a Coriolis-type correction is included to account for the fact that the geocentric frame origin is no longer an inertial point [Kar, 1997]).
- Degree-1 mass redistribution and geocenter motion tend to be used interchangeably.



$$\vec{r}_{cm} = a_e(C_{11}, S_{11}, C_{10})$$

Geocenter Motion from SLR (1)

60-day estimates of geocenter from LAGEOS-1/2 SLRF2005/LPOD2005 station coordinates

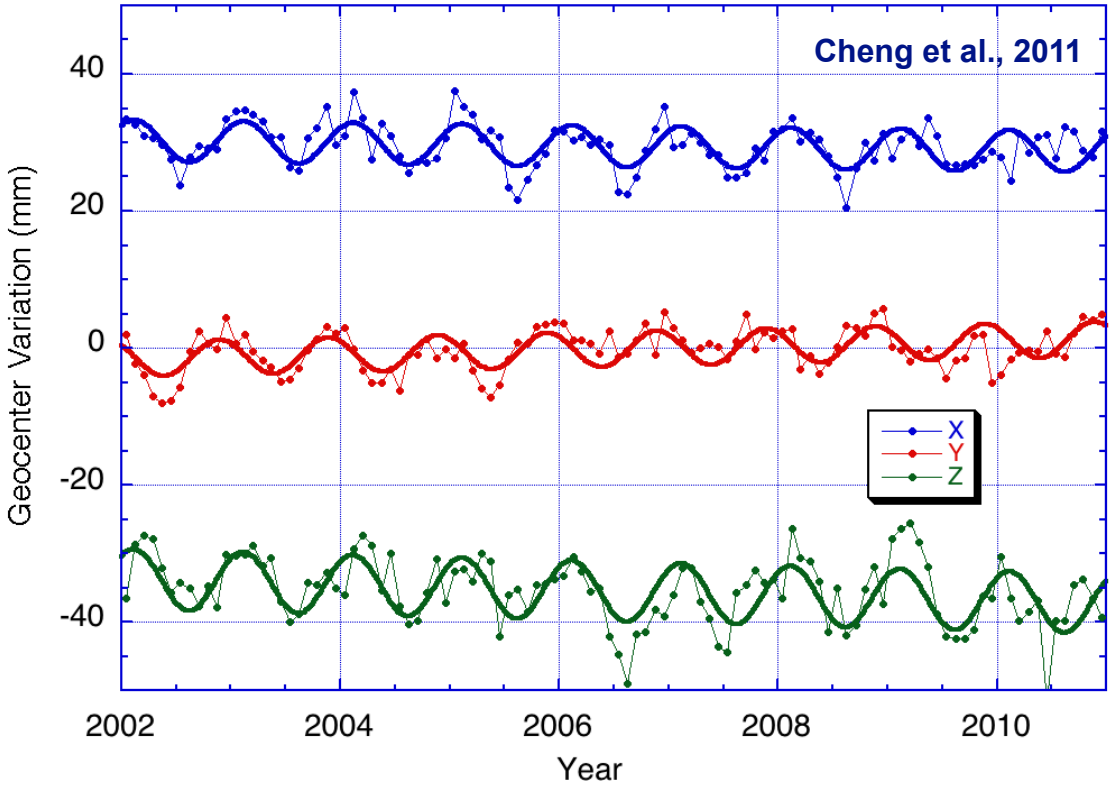


X offset by +20 mm, Z by -20 mm

X (amp)	X (phase)	Y (amp)	Y (phase)	Z (amp)	Z (phase)	Reference (comments) (phase is in degrees)
2.7	42	2.5	324	5.5	36	Ries, 2010 (60-day solutions; 1993-2010)
1.9	33	2.5	323	4.4	14	Ries, 2010 (30-day solutions; 1993-2010, est. biases w 5 mm sigma)

Geocenter Motion from SLR (2)

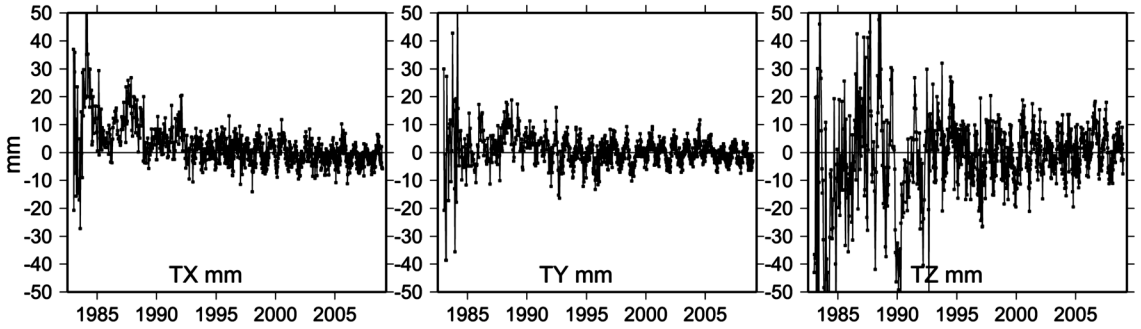
Monthly estimates of geocenter from 5 satellites
SLRF2005/LPOD2005, AOD applied, estimate monthly 5x5 gravity field



X (amp)	X (phase)	Y (amp)	Y (phase)	Z (amp)	Z (phase)	Reference (comments) (phase is in degrees)
2.7	35	2.8	309	5.2	25	Cheng et al., 2011 (weekly solutions, estimating 5x5 gravity, 1993-2010)
3.0	43	2.6	321	4.4	42	Cheng et al., 2011 (monthly solutions, estimating 5x5 gravity, 2002-2010)

‘Kinematic’ Approach

Stack time series of loosely-constrained frame estimates



Altamimi et al., 2010

Fig. 4 Weekly translation components of the SLR ILRS solution with respect to ITRF2008, in millimeter along the *X*, *Y* and *Z*-axes: *left*, *middle* and *right*, respectively

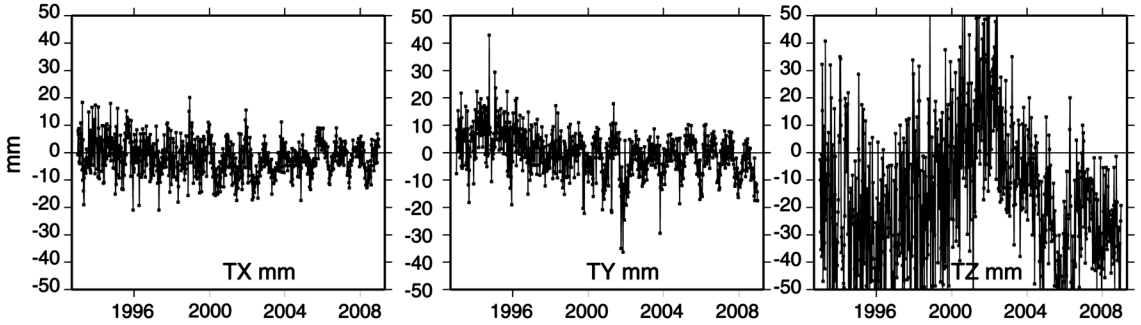
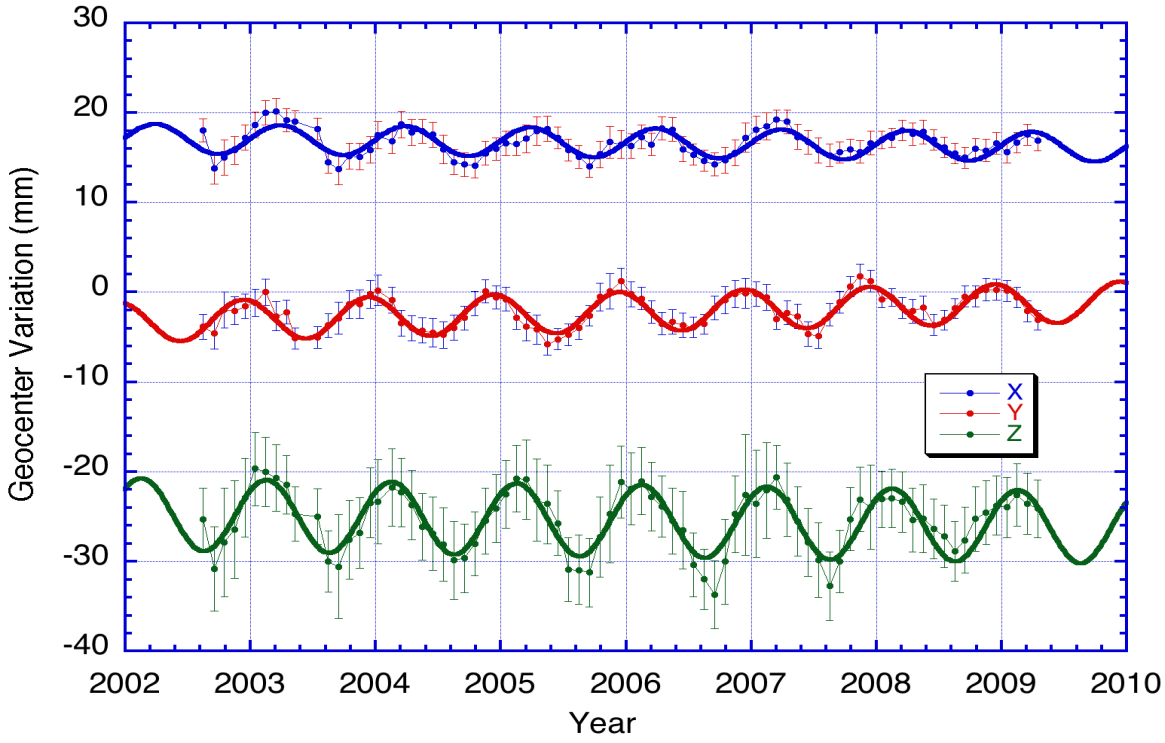


Fig. 5 Weekly translation components of the DORIS IDS-3 solution with respect to ITRF2008, in millimeter along the *X*, *Y* and *Z*-axes: *left*, *middle* and *right*, respectively

X (amp)	X (phase)	Y (amp)	Y (phase)	Z (amp)	Z (phase)	Reference (comments) (phase is in degrees)
2.6	42	3.1	315	5.5	22	Altamimi et al., 2010 (ILRS contribution to ITRF2008)

‘Global Inversion’ Approach

Estimate degree-1 deformation from GPS, using other information (GRACE, Ocean bottom pressure, etc.) to remove load signal above degree 1

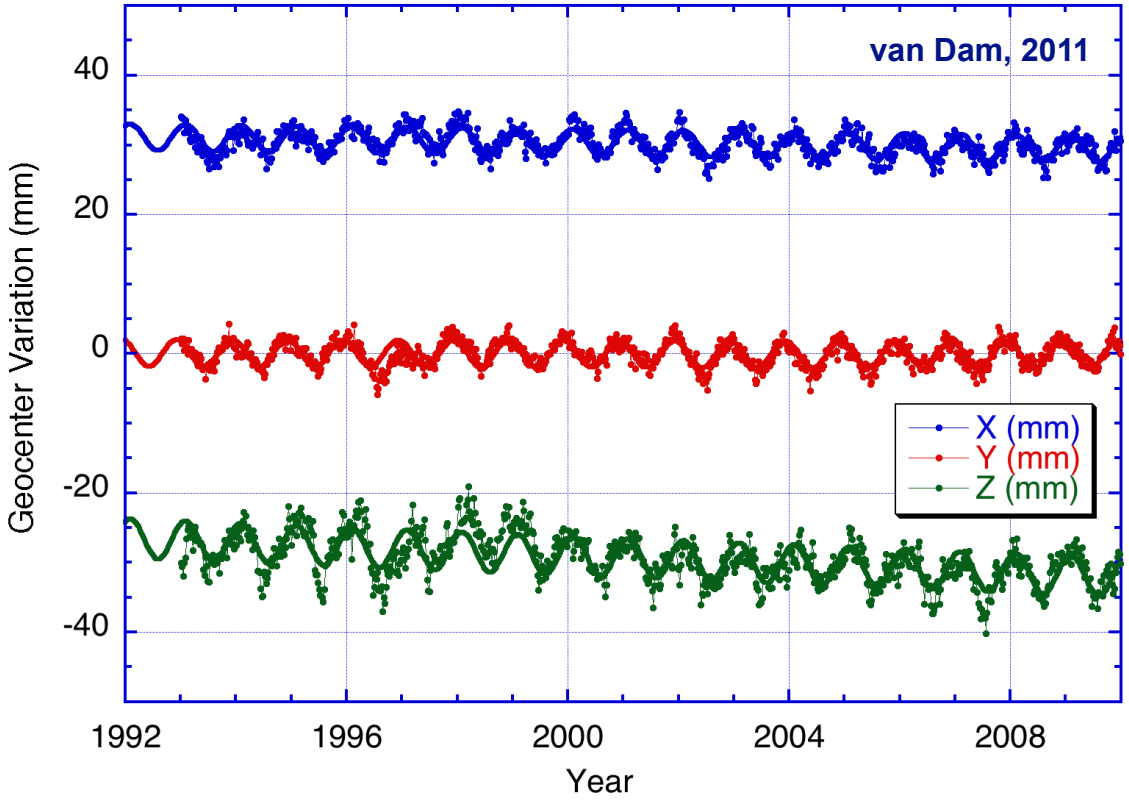


Wu et al., 2010

X (amp)	X (phase)	Y (amp)	Y (phase)	Z (amp)	Z (phase)	Reference (comments) (phase is in degrees)
1.9	42	3.2	328	3.6	25	Wu, 2006
2.0	21	2.6	334	3.6	24	Jansen et al., 2009
1.8	49	2.7	325	4.2	31	Wu et al., 2010
2.0	62	3.5	322	3.1	19	Rietbroeck et al., 2011 (updated June 2011)

Geophysical Models

Geophysical models of atmosphere, ocean, and hydrology (including arctic regions) can provide degree-1 mass redistribution and predict the corresponding geocenter motion after accounting for the load deformation



X (amp)	X (phase)	Y (amp)	Y (phase)	Z (amp)	Z (phase)	Reference (comments) (phase is in degrees)
1.8	36	2.1	332	2.3	24	Chen, 2008
2.1	28	2.1	338	2.7	48	Coullilieux et al., 2009 (Forward model, NCEP, LaDWORLD-Frasier, ECCO OBP)
1.9	34	1.9	337	2.8	35	van Dam, 2011 (NCEP, ECCO, GLDAS, no arctic)

Ensemble of 'Reasonable' Estimates

Geodetic observations	X (amp)	X (phase)	Y (amp)	Y (phase)	Z (amp)	Z (phase)	Reference (comments) (phase is in degrees)
SLR (L1/L2)	2.2	59	3.2	299	2.8	45	Eanes et al., 1997
SLR/DORIS/GPS	2.9	58	3.7	304	4.5	3	Montag, 1999
SLR	2.1	48	2.0	327	3.5	43	Bouille et al., 2000
Topex/Poseidon (SLR/DORIS)	1.8	41	2.9	320	2.4	37	Eanes & Ries, 2000
SLR (L1/L2)	2.6	32	2.5	309	3.3	36	Creteaux et al., 2002
SLR (ILRS)	3.0	36	3.3	327	2.5	6	Altamimi et al., 2007 (ILRS contribution to ITRF2005)
SLR (L1/L2)	1.3	45	2.2	321	2.6	31	Eanes, 2005 (12-year series of weekly solutions; scale also adjusted)
GPS	2.1	42	3.2	343	3.9	77	Lavallée et al., 2006 (errors estimated to by 0.5-0.8 mm and ~20° phase
GPS loading + GRACE + OBP	1.9	42	3.2	328	3.6	25	Wu, 2006
GRACE+Ocean Model	2.0	53	2.2	325	1.9	67	Swenson, Chambers & Wahr, 2008 (GRACE + OMCT)
SLR (ILRS)	2.7	45	3.8	327	3.6	4	Collilieux et al., 2009 (translation model; no scale)
SLR (ILRS)+GPS+OBP	2.4	32	2.6	322	5.3	23	Collilieux et al., 2009 (translation model estimated with inverse loading model)
SLR (ILRS)+loading model	3.7	34	1.8	324	3.7	34	Collilieux et al., 2009 (translation model estimated with forward loading model)
SLR(ILRS)+GPS	2.5	19	3.2	327	3.4	17	Collilieux et al., 2009 (use GPS to correct for loadingl)
GPS + OBP	1.3	6	3.0	338	4.6	23	Collilieux et al., 2009 (Inverse model, GPS+OBP)
GPS loading + GRACE	2.0	21	2.6	334	3.6	24	Jansen et al., 2009
SLR (L1/L2)	2.7	42	2.5	324	5.5	36	Ries, 2010 (60-day solutions; 1993-2010)
SLR (L1/L2)	1.9	33	2.5	323	4.4	14	Ries, 2010 (30-day solutions; 1993-2010, est. biases w 5 mm sigma)
GPS loading + GRACE + OBP	1.8	49	2.7	325	4.2	31	Wu et al., 2010
SLR (ILRS)	2.6	42	3.1	315	5.5	22	Altamimi et al., 2010 (ILRS contribution to ITRF2008)
SLR (5 satellites)	2.7	35	2.8	309	5.2	25	Cheng et al., 2011 (weekly solutions, estimating 5x5 gravity, 1993-2010)
SLR (5 satellites)	3.0	43	2.6	321	4.4	42	Cheng et al., 2011 (monthly solutions, estimating 5x5 gravity, 2002-2010)
GPS loading + GRACE + OBP	2.0	62	3.5	322	3.1	19	Rietbroeck et al., 2011 (updated June 2011)
Mean (mm)	2.3	40	2.8	322	3.8	30	
Stdev (mm)	0.6	13	0.5	10	1.0	18	

Selected Geodetic Estimates and Models

Selected geodetic estimates							
Geodetic observations	X (amp)	X (phase)	Y (amp)	Y (phase)	Z (amp)	Z (phase)	Reference (comments) (phase is in degrees)
SLR (ILRS)+GPS+OBP	2.4	32	2.6	322	5.3	23	Collilieux et al., 2009 (translation model estimated with inverse loading model)
SLR (ILRS)	2.6	42	3.1	315	5.5	22	Altamimi et al., 2010 (ILRS contribution to ITRF2008)
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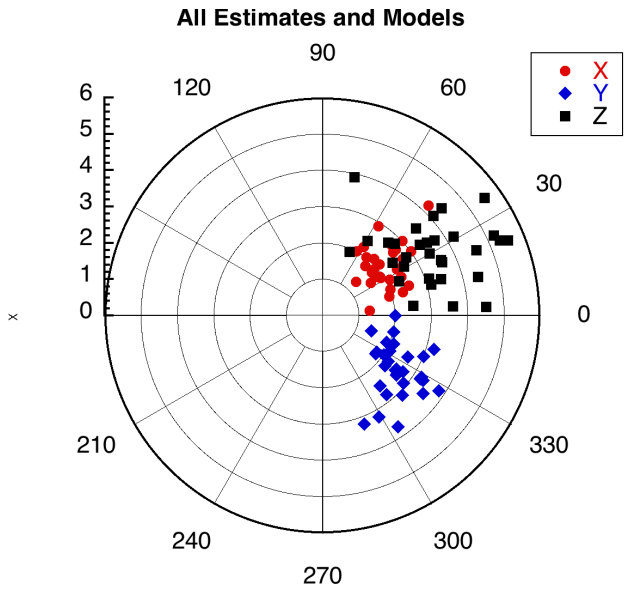
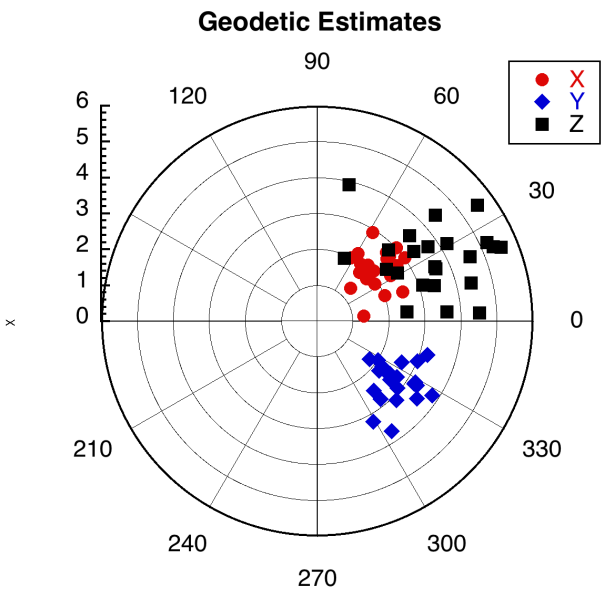
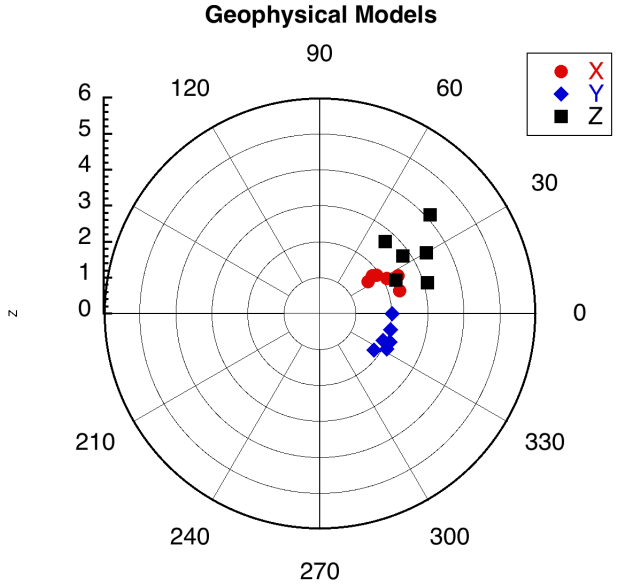
GPS loading + GRACE + OBP	2.0	62	3.5	322	3.1	19	Rietbroeck et al., 2011
Mean (mm)	2.3	40	2.8	322	4.6	26	
Stdev (mm)	0.4	13	0.4	8	1.0	6	

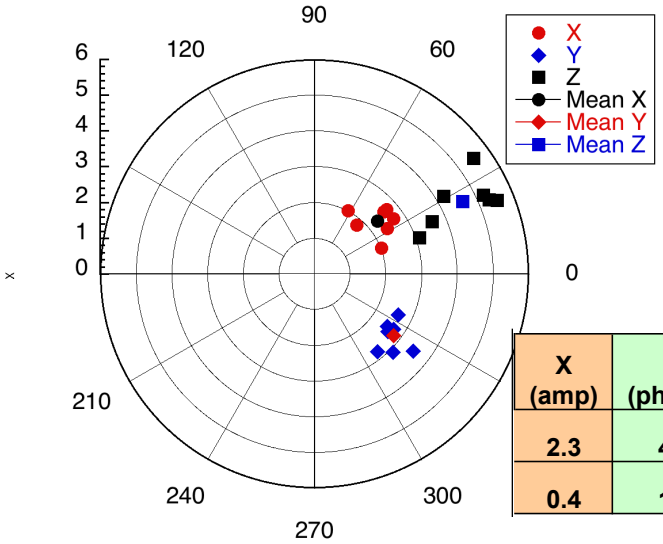
Geophysical model predictions	X (amp)	X (phase)	Y (amp)	Y (phase)	Z (amp)	Z (phase)	Reference (comments) (phase is in degrees)
Geophysical models	2.4	26	2.0	360	4.1	42	Chen et al., 1999
Geophysical models	1.6	34	1.8	326	3.1	16	Bouille et al., 2000
Geophysical models	4.2	46	3.2	291	3.5	35	Dong et al., 2003
Geophysical models	2.3	16	2.0	347	3.4	30	Moore & Wang, 2003 (CDAS-1 for land water)
Geophysical models	1.8	36	2.1	332	2.3	24	Chen, 2008
Geophysical models	2.1	28	2.1	338	2.7	48	Coullilieux et al., 2009 (Forward model, NCEP, LaDWORLD-Frasier, ECCO OBP)
Geophysical models	1.9	34	1.9	337	2.8	35	van Dam, 2011 (NCEP, ECCO, GLDAS, no arctic)
Mean (mm)	2.3	31	2.2	333	3.1	33	
Stdev (mm)	0.9	9	0.5	22	0.6	11	

Geocenter Estimates









X (amp)	X (phase)	Y (amp)	Y (phase)	Z (amp)	Z (phase)
2.3	40	2.8	322	4.6	26
0.4	13	0.4	8	1.0	6

Effect of Model Improvements

Incremental variance reduction in mm^2 using various models

7-day arcs, estimating only orbit parameters, 2008-2009
(reference fixed to SLRF2005/LPOD2005 and IERSC04)
RMS ~10 mm (6-8 mm for best stations)

	FES2004 OL (not incl. GCM)	Include tidal GCM	New MP and C21/S21*	Annual Geocenter
LAGEOS-1	19	11	6	3
LAGEOS-2	22	11	5	3

* C21/S21 derived from cubic IERS2010 mean pole model

Summary

- Most reasonable geodetic and model estimates agree well in phase and for the amplitude of X and Y, but for Z, the models tend to have a smaller signal.
  - Probably due to model limitations at high latitudes
- Using the average of selected recent geodetic estimates from both SLR and GPS global inversions to determine an annual geocenter model (translation only), a small but significant variance reduction is obtained in SLR fits.
- Annual geocenter motion could be included as a conventional model (for operational altimeter orbit determination, for example), but not necessarily a Class-1 model for analysis.
  - Translation model does not address degree-1 deformation.
  - If degree-1 deformation is included in geocenter model, then it would be necessary to remove annual degree-1 from loading models.
  - Can translation and deformation be cleanly separated?