The Contribution of Laser Ranging to the Global Geodetic Observing System

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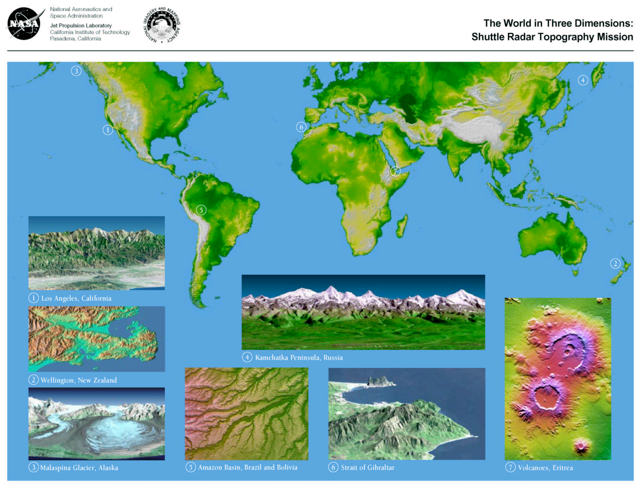
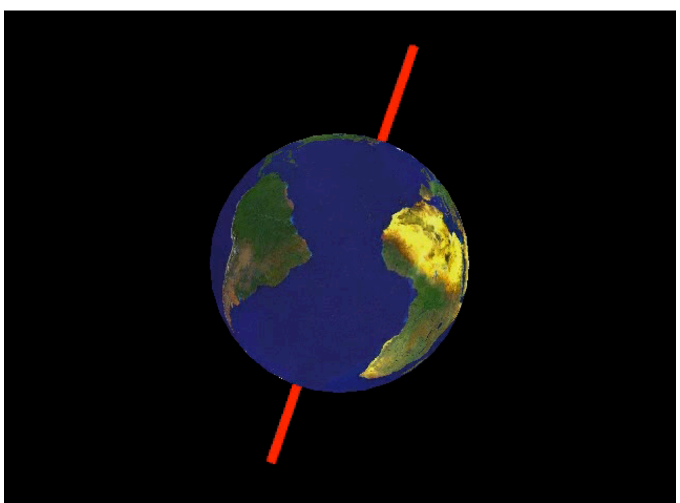
The Three Pillars of Geodesy

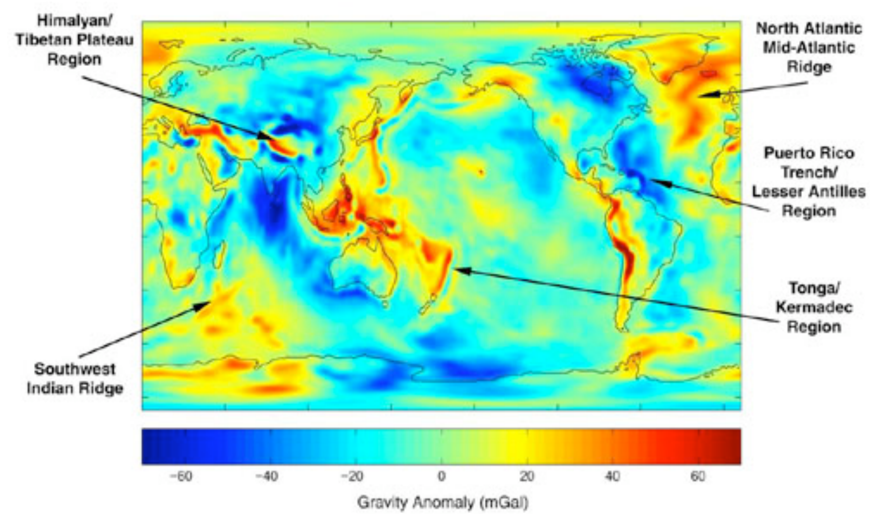


Shape & Deformation

Rotation



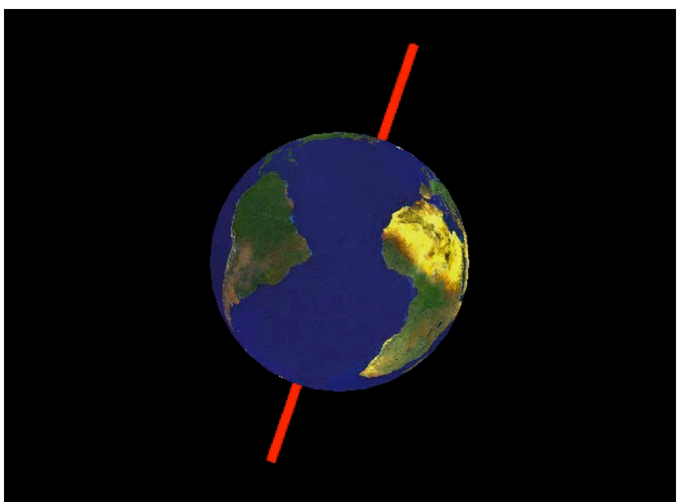
Gravity & Geoid



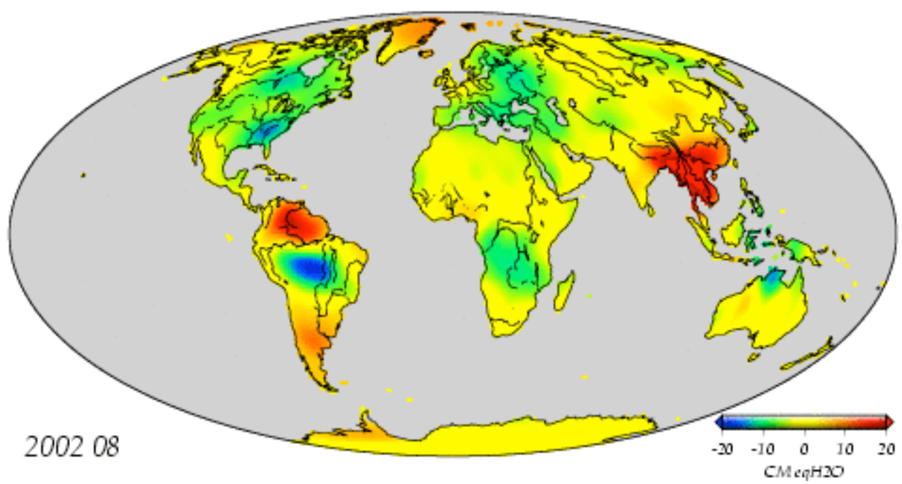
The Three Pillars of Geodesy

Shape & Deformation

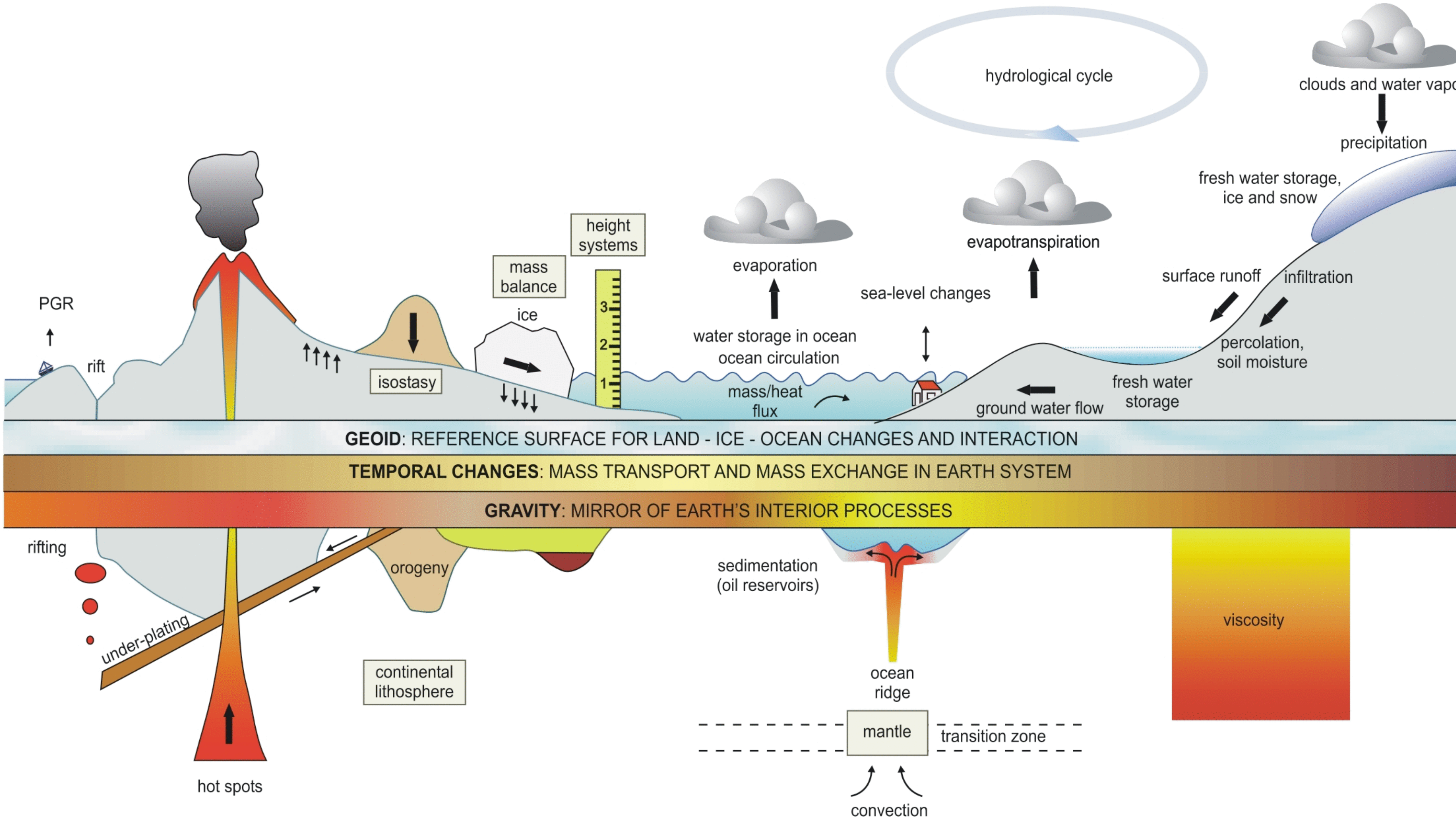
Rotation



Gravity & Geoid



Mass Transport in the Earth System



Ilk et al. (2005)

GGOS

The Global Geodetic Observing System works with the IAG components to provide the geodetic infrastructure necessary for monitoring the Earth system and global change research.

IAG bylaws


GGOS
http://www.ggos.org
IAG's Global Geodetic Observing System
Markus Rothacher (GGOS Chair), Achim Helm (GeoForschungsZentrum Potsdam)
Ruth E. Neilan (GGOS Vice-Chair) (Jet Propulsion Laboratory)
Hans-Peter Plag (GGOS Vice-Chair) (University of Nevada)
ICSU
International Council for Science
IUGG
Int. Union of Geodesy and Geophysics
IAG
Int. Association of Geodesy
Commissions
Services
GGOS
Global Geodetic Observing System
New Orleans 2005 Hurricane
Elbe 2002 Flood
Kobe 1995 Earthquake
Sumatra 2004 Tsunami
Water Storage Change
Sea Level Change
Disaster Monitoring
Gravity Field and its Variation
Earth Orientation and Rotation
Deformations
International Services
IGFS
IGS
IERS
ILRS
IVS
Global Geodetic Observation System (GGOS)
GPS, GLONASS, Galileo
Satellite Altimetry (JASON)
Geodetic Space Techniques
Satellite-to-satellite tracking (GRACE)
Atmospheric Sounding (CHAMP)
Satellite Laser Ranging
Tsunami Detection (GPS Buoy)
VLBI
IAG Services are based on more than 400 global observation stations
Atmospheric Sounding
Geometry and Kinematics
Surveying
St. Helens 1980 Eruption
Kainaman 2004 Mudflow

Contribution to the TRF

- Defines origin of terrestrial reference frame

"The ITRF2005 origin is defined in such a way that it has zero translations and translation rates with respect to the Earth center of mass, averaged by the Satellite Laser Ranging (SLR) time series spanning 13 years of observations."

(Altamimi et al. 2007)

- Contributes to determining scale of TRF

"Its scale is defined by nullifying the scale and its rate with respect to the Very Long Baseline Interferometry (VLBI) time series spanning 26 years of observations."

(Altamimi et al. 2007)

- Comparing ITRF2005 scale with SLR scale uncovered problem with VLBI solution

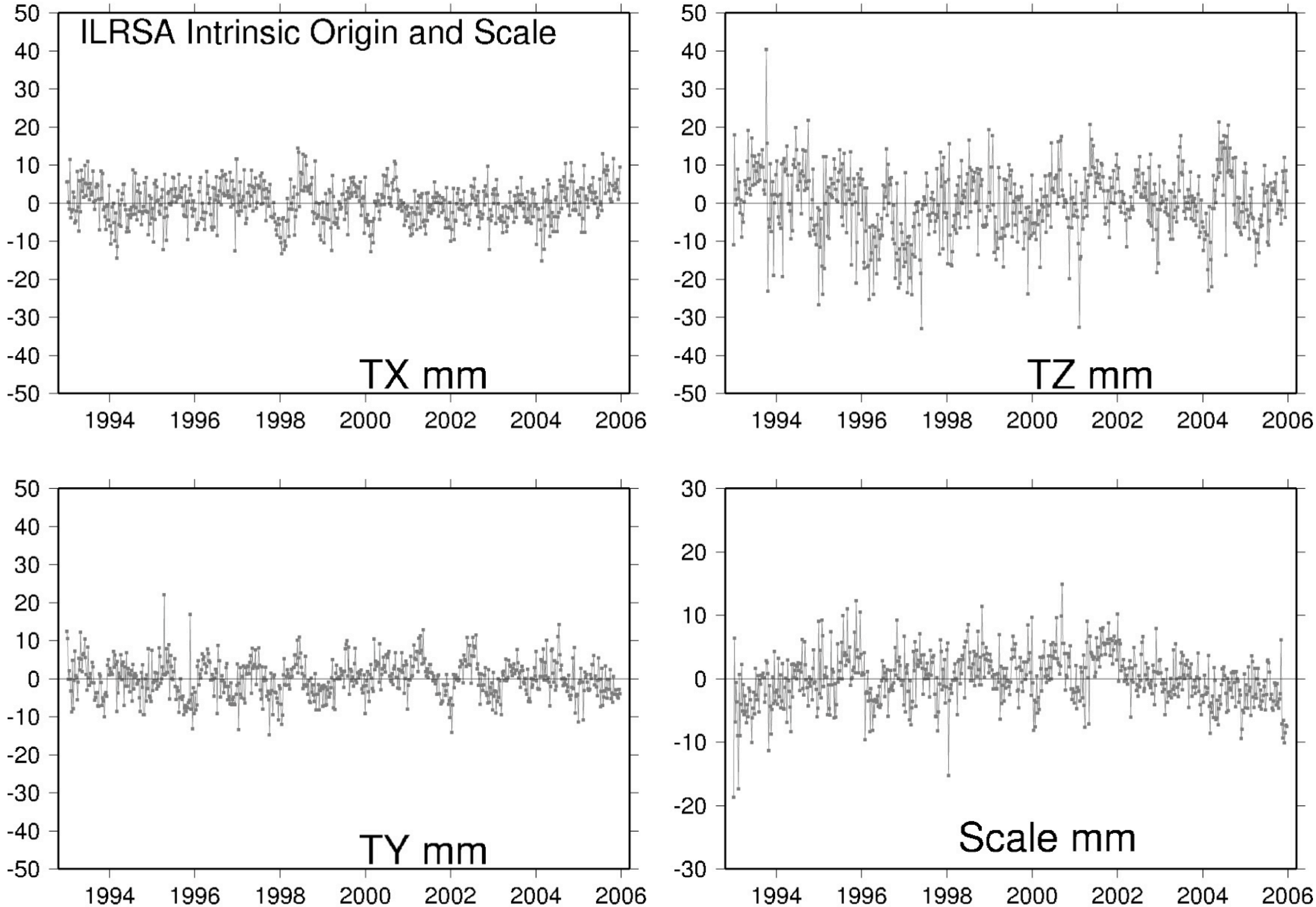
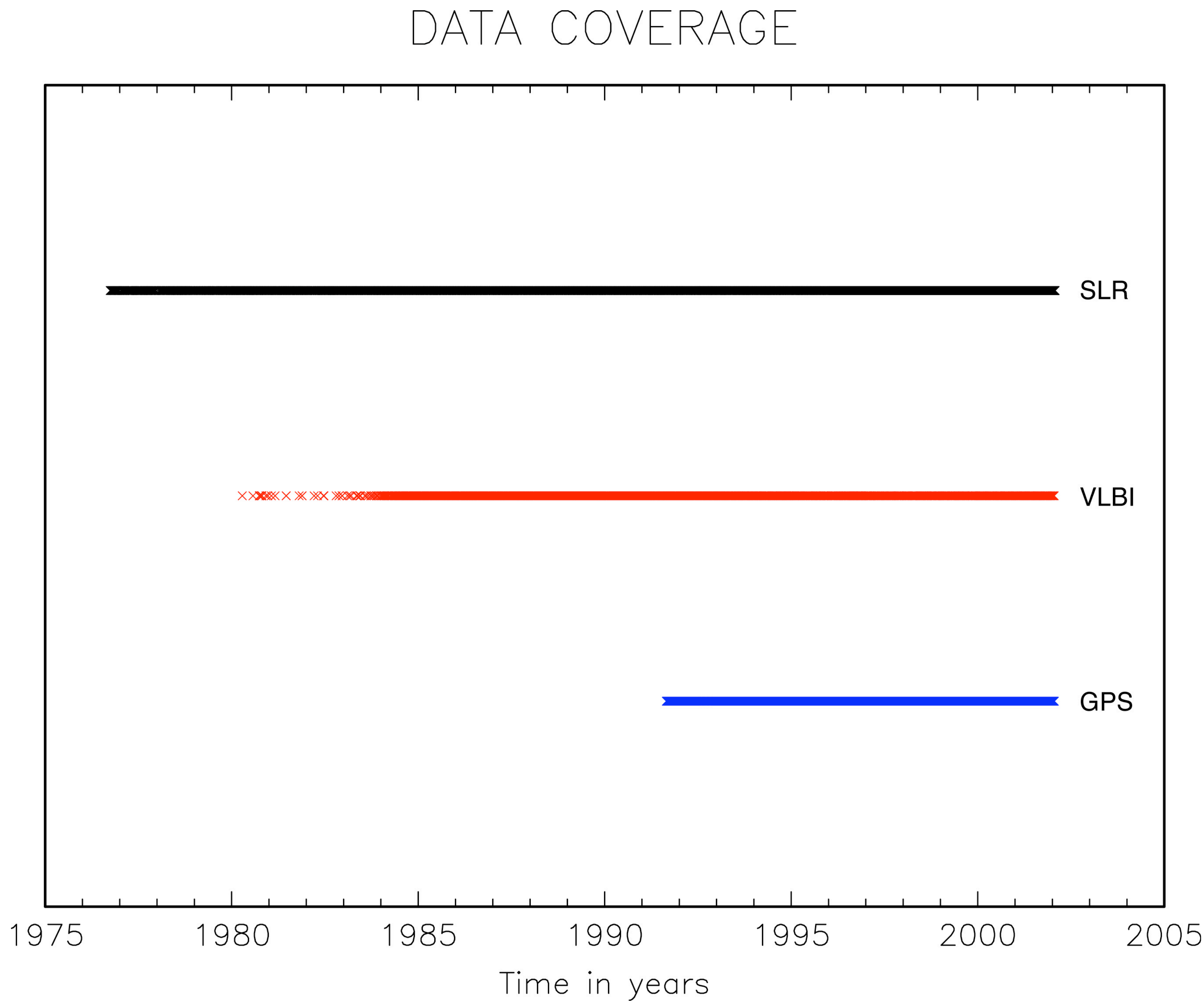


Figure 3. Intrinsic ILRS SLR translation and scale parameters.

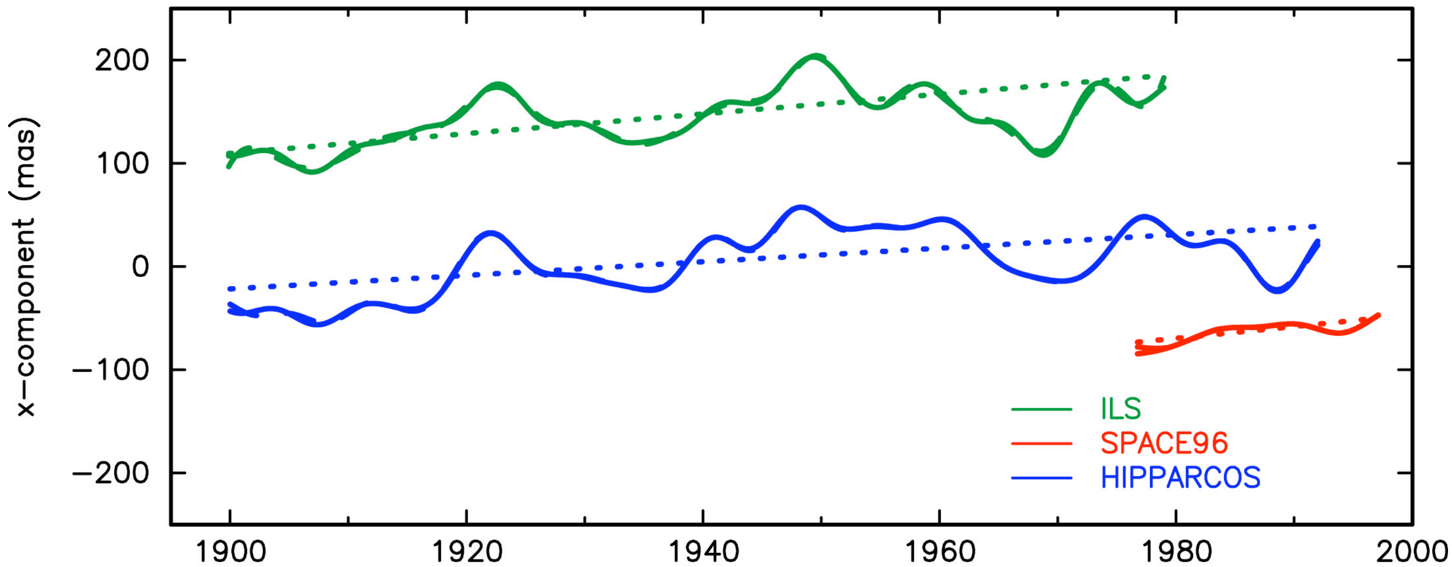
Altamimi et al. (2007)

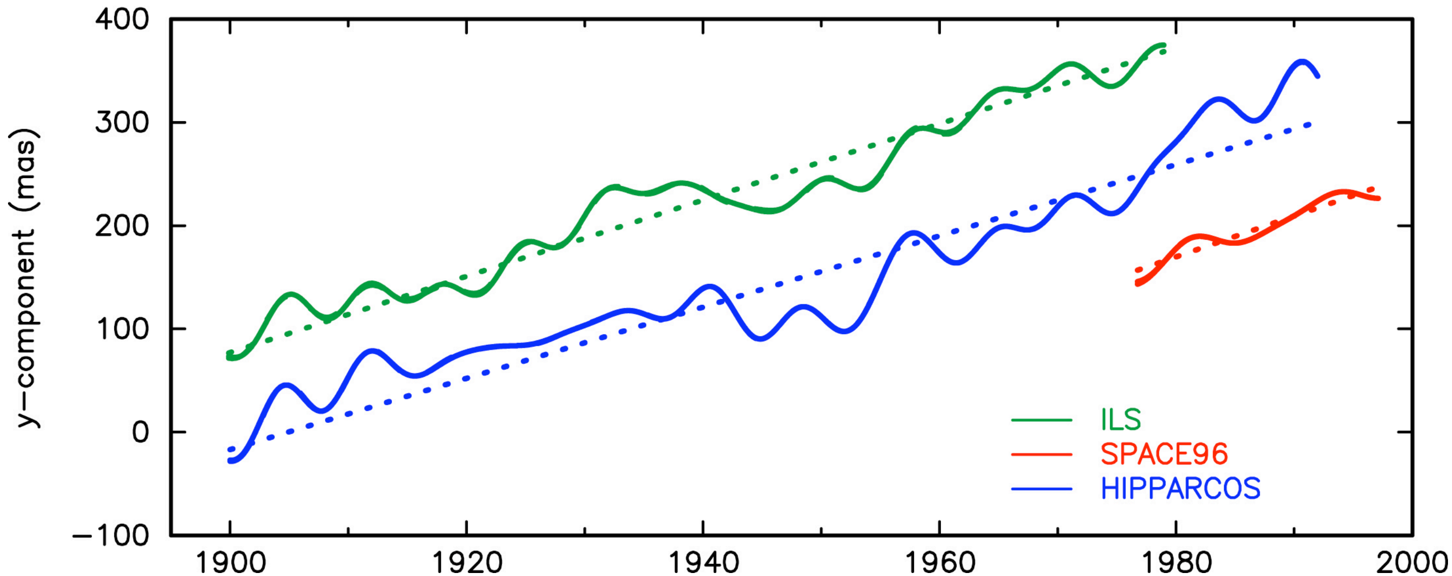
Contribution to Earth Rotation

- Longest available space-geodetic series of Earth orientation parameters
  - LLR measurements since 1970
  - SLR measurements since 1976
- Needed for studying long-period variations in Earth’s rotation
  - Markowitz wobble
    - Quasi-periodic variation on decadal time scales with amplitude of about 30 mas
    - Unknown origin
- Provides backbone for combining EOPs from different space-geodetic techniques


DATA COVERAGE
SLR
VLBI
GPS
1975
1980
1985
1990
1995
2000
2005
Time in years

Decadal Polar Motion Variations





Gross and Vondrák (1999)

Contribution to Global Gravity

- Longest available space-geodetic series of temporal variations in Earth's gravitational field
  - SLR measurements since 1976
- Needed for studying long-period variations
  - Interannual variations
    - El Niño / Southern Oscillation
  - Decadal variations
- Degree-2 zonal coefficients most accurate available
  - GRACE project provides SLR coefficients to replace the degree-2 zonals from GRACE

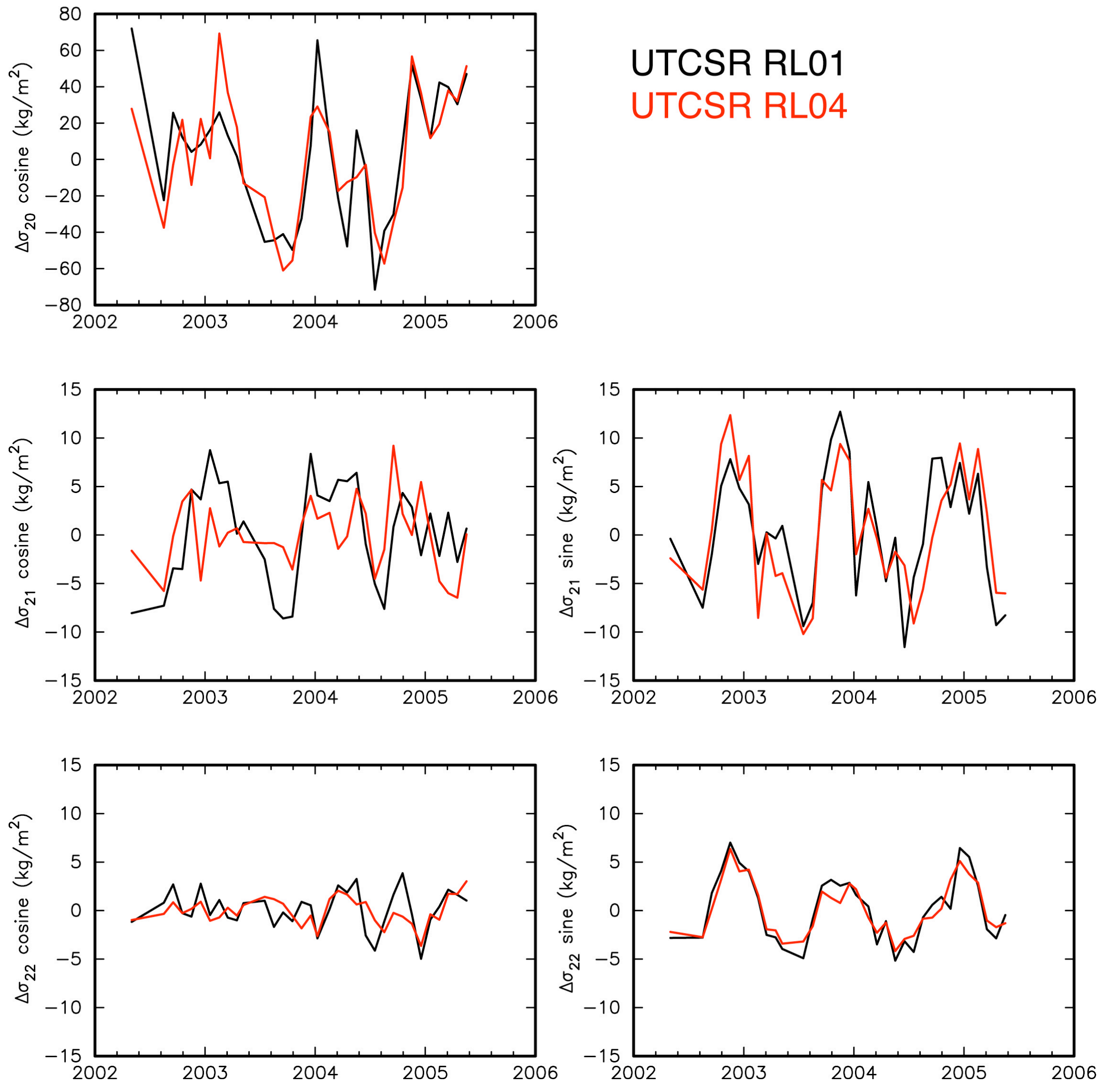
Overview

- Changes in the surface density field of the Earth
  - Change the Earth's shape
    - Measured by GPS
  - Change the Earth's rotation
    - Measured by various space-geodetic techniques
  - Change the Earth's gravitational field
    - Measured by SLR and GRACE
- Study the degree-2 harmonics of changing surface mass loads
  - Measurements
    - GRACE gravity (UTCSR RL01 & RL04)
    - SLR gravity
    - GPS shape
    - Earth rotation (SPACE2005)
  - Models
    - Atmospheric surface pressure (NCEP/NCAR Reanalysis)
    - Ocean bottom pressure (ECCO/JPL data assimilating model kf049f)
    - Land hydrology (LaDWorld-Euphrates)
    - Global surficial fluid mass conservation
- Assess consistency of measurements and models
  - Increases confidence in both measurements and models if they agree

GRACE Mass Load Measurements

- GRACE
  - Monthly values since April 2002
  - UTCSR RL01 and UTCSR RL04
    - 34 values spanning April 2002 to May 2005 (end of GPS data)
- Pre-processing
  - Add back monthly averaged AOD1B product
  - Remove effects of ocean pole tide from RL01 (but not RL04)
  - Convert degree-2 Stokes coefficients to coefficients of surface mass density
  - Remove mean and trend

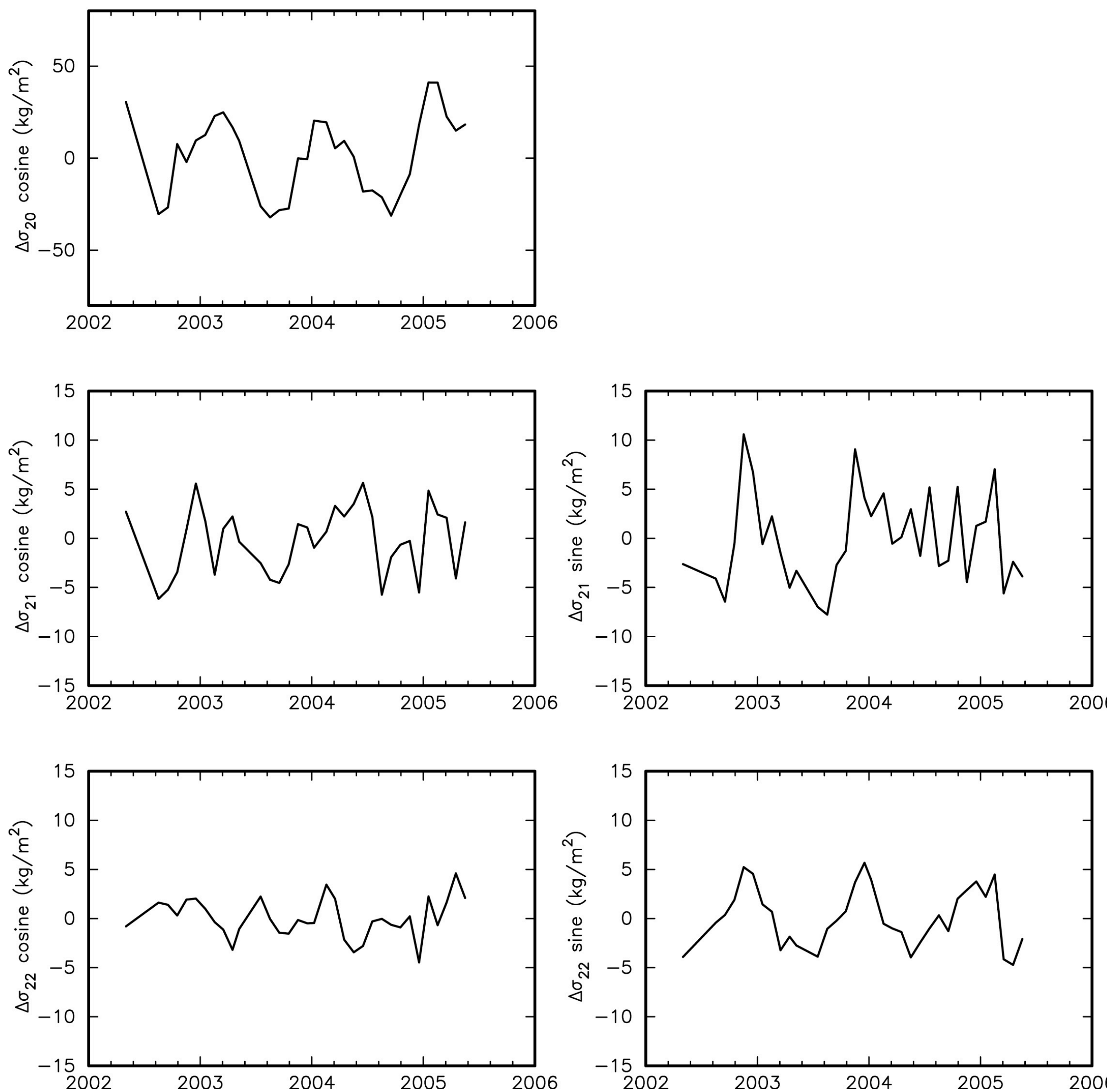
Degree-2 Mass Load Coefficients



SLR Mass Load Measurements

- UT Center for Space Research
  - GRACE replacement series
    - Provided to replace UTCSR RL01 C20 coefficient
    - C20 from GRACE Technical Note 05
    - C21, S21, C22, and S22 from Cheng (personal communication, 2007)
  - Monthly values since April 2002
    - 34 values spanning April 2002 to May 2005 (end of GPS data)
- Pre-processing
  - Add back monthly averaged AOD1B product
  - Remove effects of ocean pole tide
    - SLR series consistent with UTCSR RL01 which included ocean pole tide
  - Convert degree-2 Stokes coefficients to coefficients of surface mass density
  - Remove mean and trend

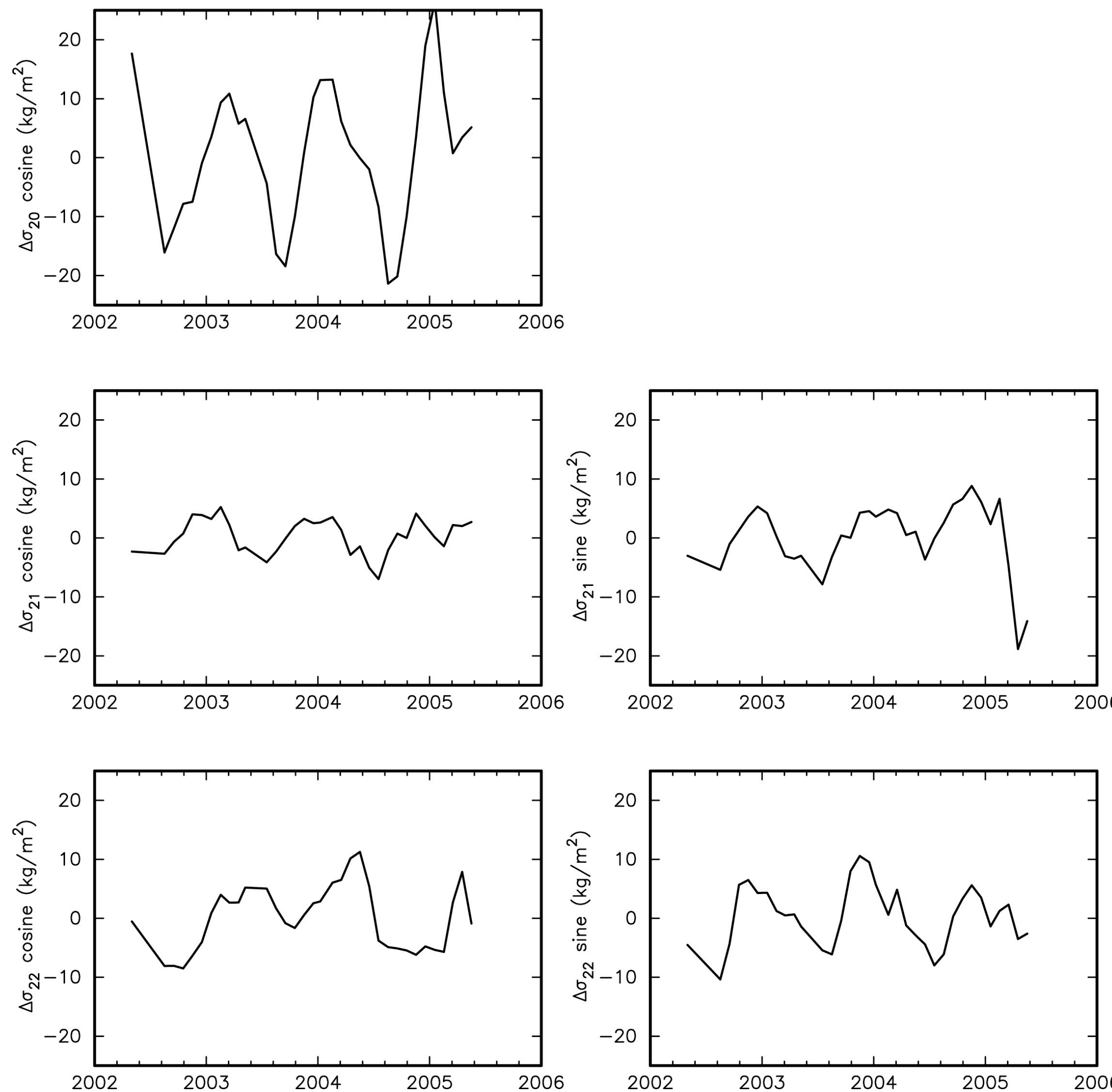
Degree-2 Mass Load Coefficients



GPS Mass Load Measurements

- GPS station distribution
  - Land-rich, ocean-poor
- Surface mass load
  - Strong over land, weak over oceans
- Designer basis functions (Clarke *et al.*, 2007)
  - Expand load over just the land
  - Ocean load included by conserving mass
    - Land-ocean mass transfer
    - Equilibrium response of oceans to load
  - Transform coefficients of new basis functions back to SH coefficients
- GPS mass load series
  - From SIO reanalysis GPS data
  - Spans 1996.0 – 2005.4 at fortnightly intervals
- Pre-processing
  - Form monthly averages
  - Linearly interpolate to epochs of GRACE data
  - Remove mean and trend

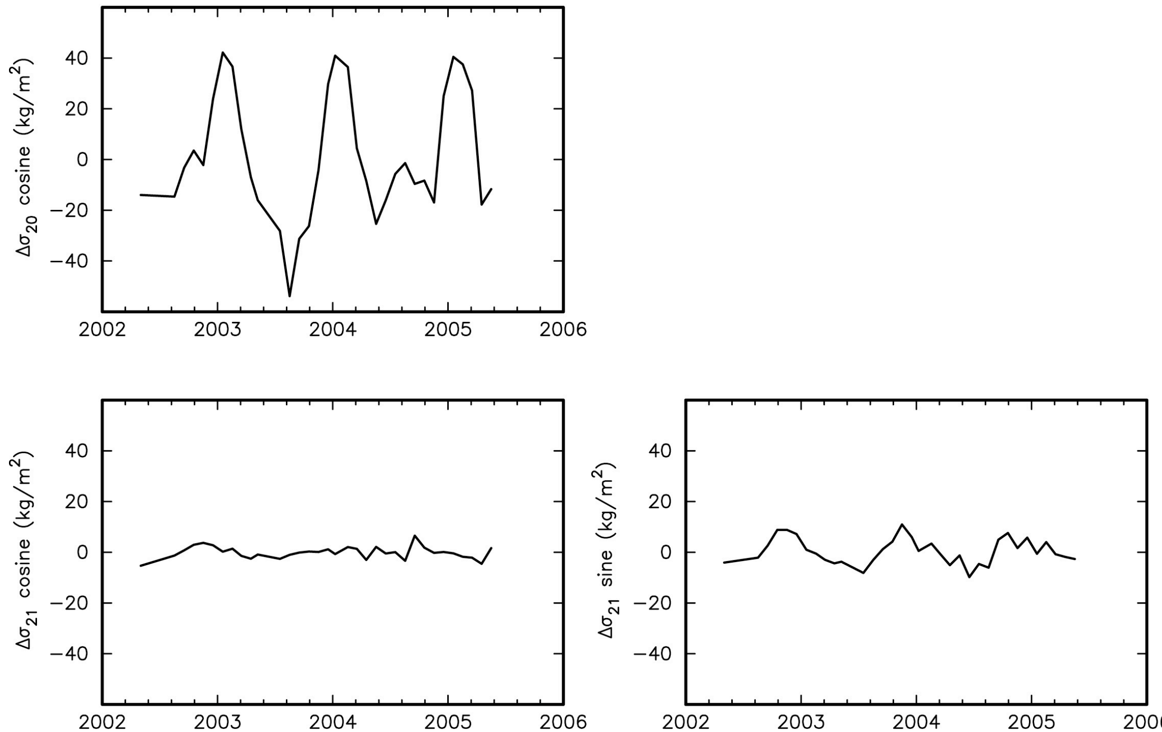
Degree-2 Mass Load Coefficients



Earth Rotation Mass Load Measurements

- Combined EOP Series
  - SPACE2005
    - Kalman filter-based combination of LLR, SLR, VLBI, and GPS Earth orientation measurements
    - Kalman filter self-consistently estimates polar motion rate & hence polar motion excitation functions
    - Spans 1976 – 2005 at daily intervals
- Pre-processing
  - Remove long-period tidal effects
  - High pass filter with 4-year cutoff period to remove signals longer than span of GRACE data
  - Remove NCEP Reanalysis winds and ECCO/JPL data assimilative (kf049f) currents
  - Convert residual to degree-2 harmonics of surface mass density
  - Form monthly averages to be consistent with GRACE and land hydrology data
  - Linearly interpolate to epochs of GRACE data
  - Remove mean and trend

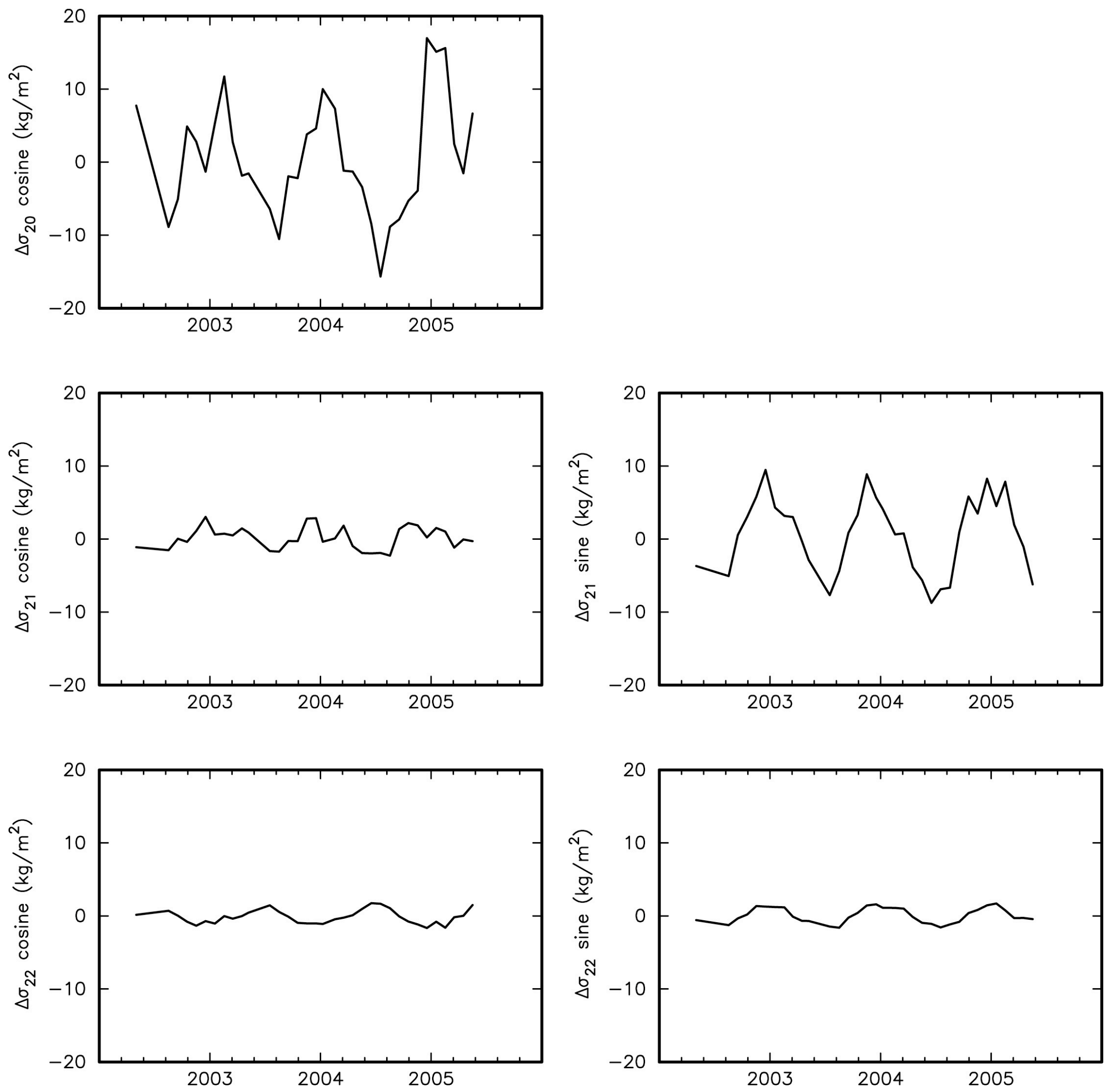
Degree-2 Mass Load Coefficients



Atmospheric Surface Pressure Model

- NCEP/NCAR Reanalysis
  - 6-hour values
  - Spans 1948 to present
  - Inverted barometer approximation
  - Obtained from IERS Special Bureau for the Atmosphere
- Pre-processing
  - Determine degree-2 harmonics of surface mass density
  - Form monthly averages to be consistent with GRACE and land hydrology data
  - Linearly interpolate to epochs of GRACE data
  - Remove mean and trend

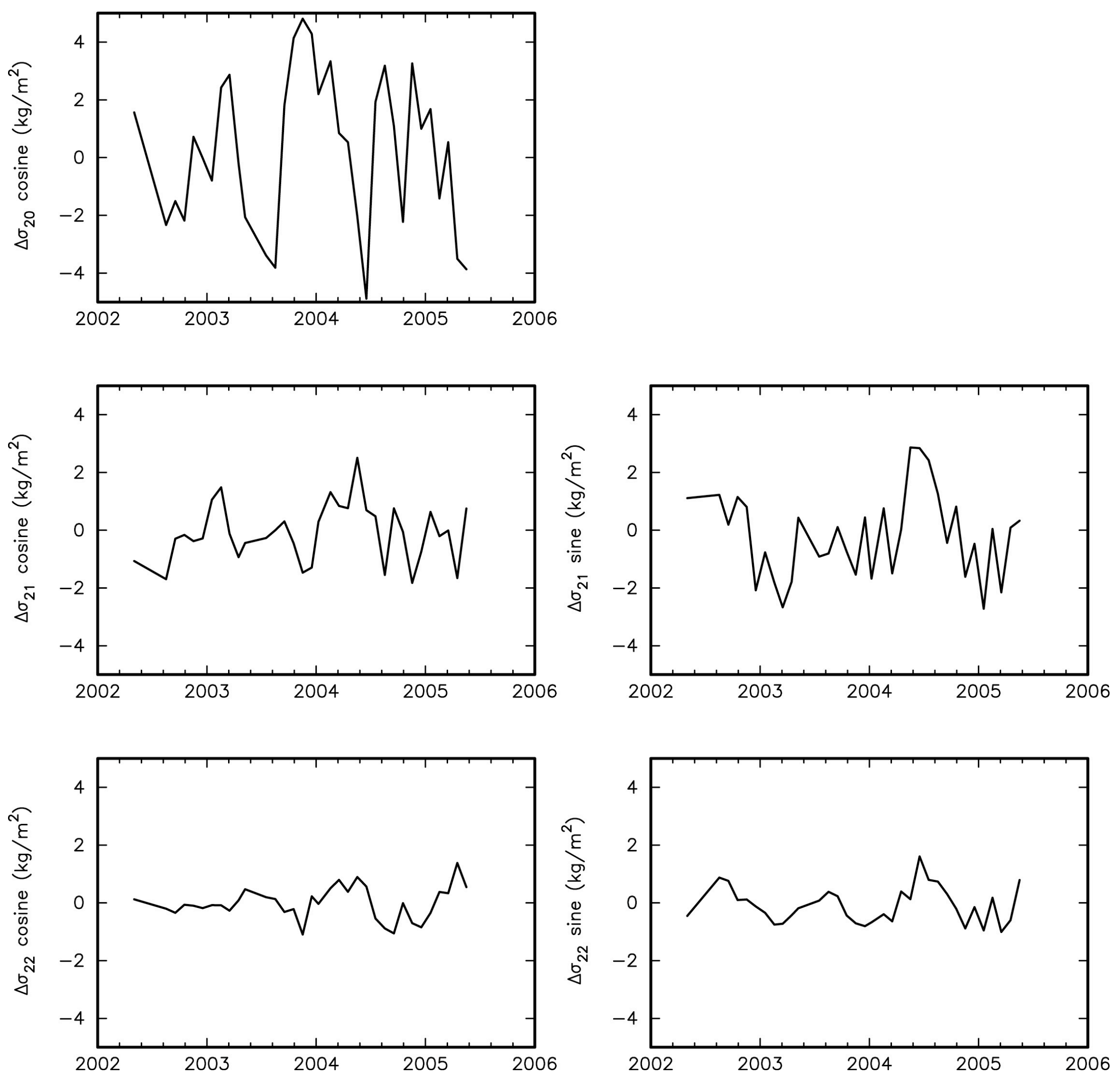
Degree-2 Mass Load Coefficients



Ocean Bottom Pressure Model

- ECCO/JPL data assimilative
  - Spans 1993 – 2006.2 at 12-hour intervals
  - Near global spatial domain
    - 72.5°S to 72.5°N latitude with a variable resolution of 1/3° at equator to 1° at poles and a longitudinal resolution of 1°
    - 46 vertical levels with thickness ranging from 10 m at surface to 400 m at depth
  - Forced with NCEP/NCAR reanalysis surface fluxes
    - Twice daily wind stress
    - Daily heat flux and evaporation-precipitation fields (freshening only)
    - Atmospheric surface pressure not used
  - Assimilated altimetry and XBT data
  - Series designator: kf049f
- Pre-processing
  - Correct for Boussinesq effects
  - Determine degree-2 harmonics of surface mass density
  - Form monthly averages
  - Linearly interpolate to epochs of GRACE data
  - Remove mean and trend

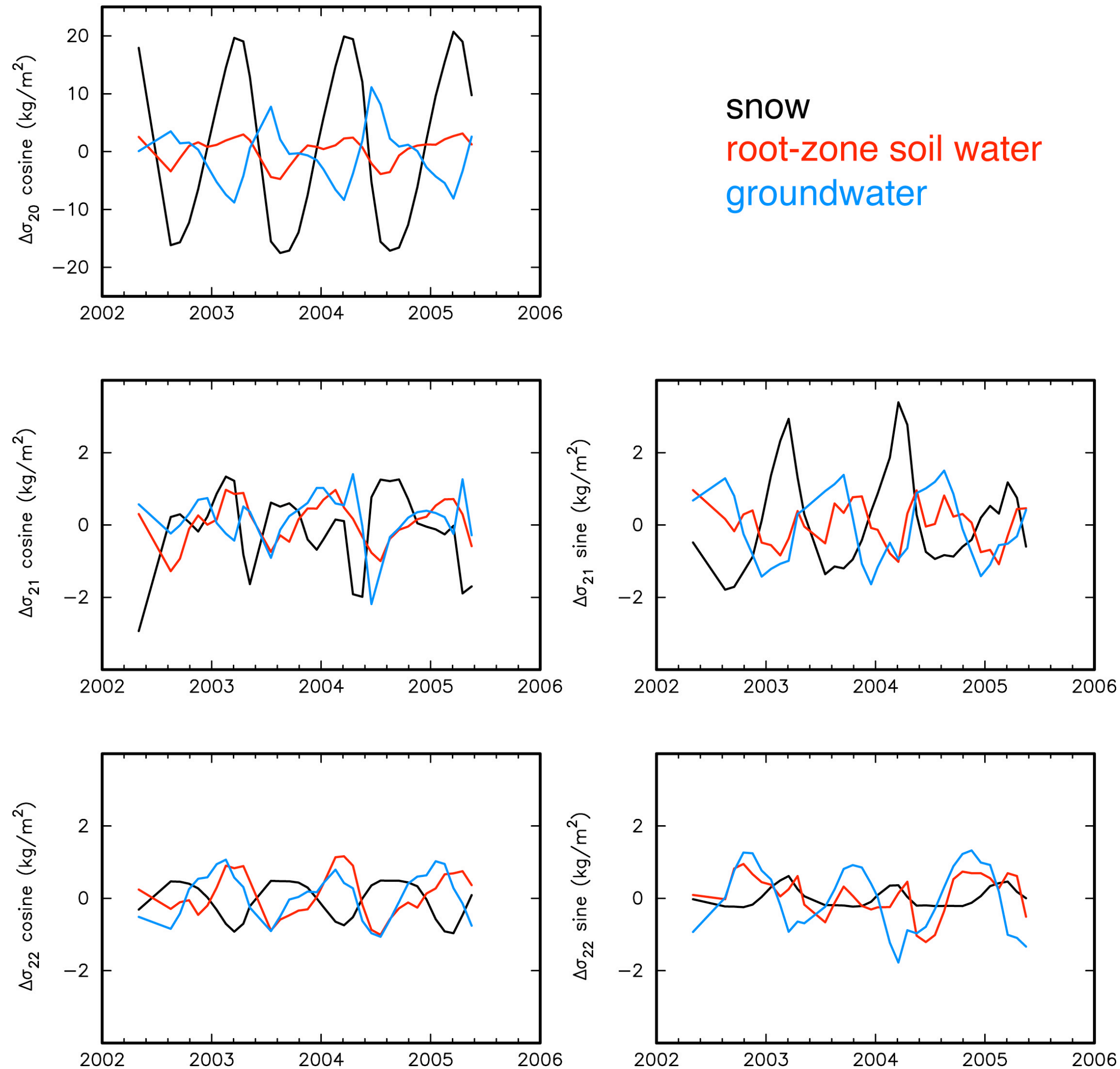
Degree-2 Mass Load Coefficients



Land Hydrology Model

- LaDWorld (Euphrates)
  - Land Dynamics (LaD) model of Milly and Shmakin (2002)
  - Global spatial domain
    - 89.5°S to 89.5°N latitude with a 1°x1° horizontal resolution
  - Forced by
    - Climate Prediction Center Merged Analysis of Precipitation (CMAP)
    - Near-surface air temperature, humidity, and wind speed
    - Radiation
  - Spans 1980–2005.4 at monthly intervals
- Pre-processing
  - Determine degree-2 harmonics of surface mass density
  - Sum contributions of snow, root-zone soil water, and groundwater
  - Linearly interpolate to epochs of GRACE data
  - Remove mean and trend

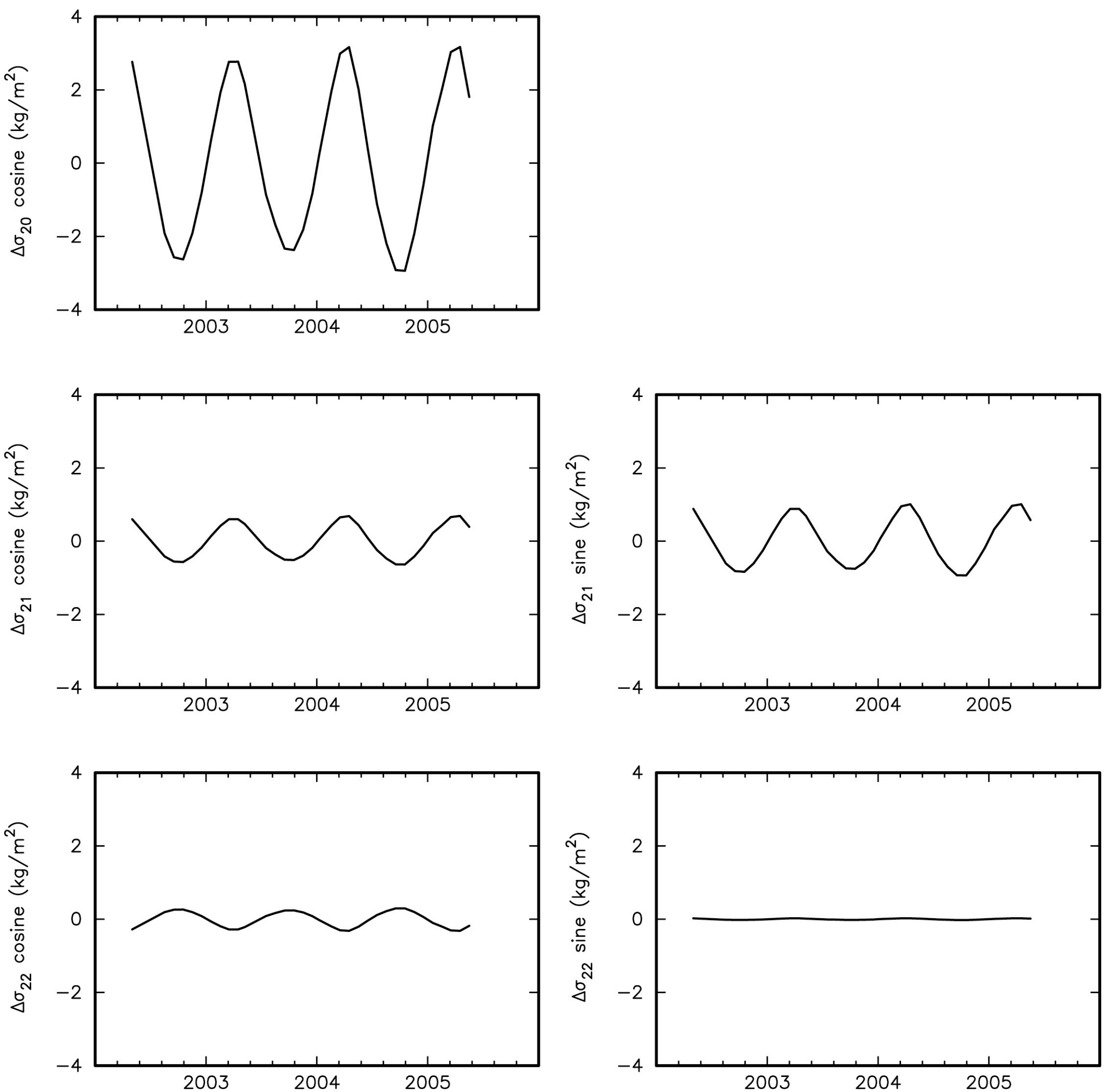
Degree-2 Mass Load Coefficients



Global Mass Conservation

- Impose global mass conservation
  - Total mass of atmosphere, oceans, and land water should be constant
    - Mass of an individual component, such as the atmosphere, will change as water in its various phases cycles through it
  - Models of atmosphere and land hydrology include mass changes
  - Ocean model does not
    - Applied forcing mechanisms do not change mass of ocean model
  - Add layer of water to surface of oceans of just the right time varying thickness to make total mass of atmosphere, oceans, and land water a constant
- Pre-processing
  - Determine degree-2 harmonics of surface mass density of this global mass conserving layer
  - Remove mean and trend

Degree-2 Mass Load Coefficients



Mass Load Measurements & Models

(95% significance level of correlation = 0.51)

greatest correlation between independent measurements

greatest correlation with models

(variance of measurement explained by models in percent)

(greatest variance explained)

(2,0) cosine

	Models	*RL01*	*RL04*	*SLR*	*GPS*	*EOP*
Models	1.0	0.62	0.70	0.94	0.88	0.57
RL01	(37.9)	1.0	0.83	0.65	0.61	0.47
RL04	(48.5)		1.0	0.73	0.71	0.53
SLR	(88.3)			1.0	0.87	0.68
GPS	(6.1)				1.0	0.60
EOP	(25.7)					1.0

(2,1) cosine

	Models	*RL01*	*RL04*	*SLR*	*GPS*	*EOP*
Models	1.0	0.70	0.26	0.33	0.65	0.46
RL01	(44.4)	1.0	0.40	0.52	0.49	0.37
RL04	(−14.4)		1.0	0.03	0.19	0.59
SLR	(−5.9)			1.0	−0.03	0.07
GPS	(38.1)				1.0	0.40
EOP	(−14.9)					1.0

(2,1) sine

	Models	*RL01*	*RL04*	*SLR*	*GPS*	*EOP*
Models	1.0	0.76	0.78	0.67	0.56	0.78
RL01	(55.9)	1.0	0.81	0.56	0.71	0.83
RL04	(58.9)		1.0	0.53	0.61	0.81
SLR	(42.4)			1.0	0.53	0.60
GPS	(30.2)				1.0	0.56
EOP	(61.0)					1.0

(2,2) cosine

	Models	*RL01*	*RL04*	*SLR*	*GPS*
Models	1.0	0.40	0.74	0.26	0.59
RL01	(16.2)	1.0	0.55	0.34	0.18
RL04	(51.4)		1.0	0.45	0.43
SLR	(5.0)			1.0	−0.09
GPS	(15.2)				1.0

(2,2) sine

	Models	*RL01*	*RL04*	*SLR*	*GPS*
Models	1.0	0.93	0.92	0.82	0.60
RL01	(69.2)	1.0	0.95	0.83	0.61
RL04	(75.9)		1.0	0.85	0.64
SLR	(61.9)			1.0	0.63
GPS	(29.1)				1.0

Summary

- Contribution to the Terrestrial Reference Frame
  - Defines origin of TRF
  - Contributes to determining scale of TRF
- Contribution to Earth rotation
  - Longest available space-geodetic series of EOPs
  - Most accurate series available for studying decadal variations
  - Provides backbone for EOP combinations
- Contribution to global gravity
  - Longest available space-geodetic series of temporal variations in Earth's gravitational field
  - Most accurate series of J_2 variations available

GGOS Mission

The mission of GGOS is to advance geodetic observing methods for Earth and planetary system science and applications by:

- *defining the geodetic infrastructure needed by science and society;*
- *advocating for the establishment and maintenance of this geodetic infrastructure;*
- *improving the quality and accessibility of geodetic observations and products;*
- *coordinating interaction between the IAG Services, Commissions, and stakeholders; and*
- *educating the scientific community about the benefits of geodetic research and the public about the fundamental role that geodesy plays in society.*

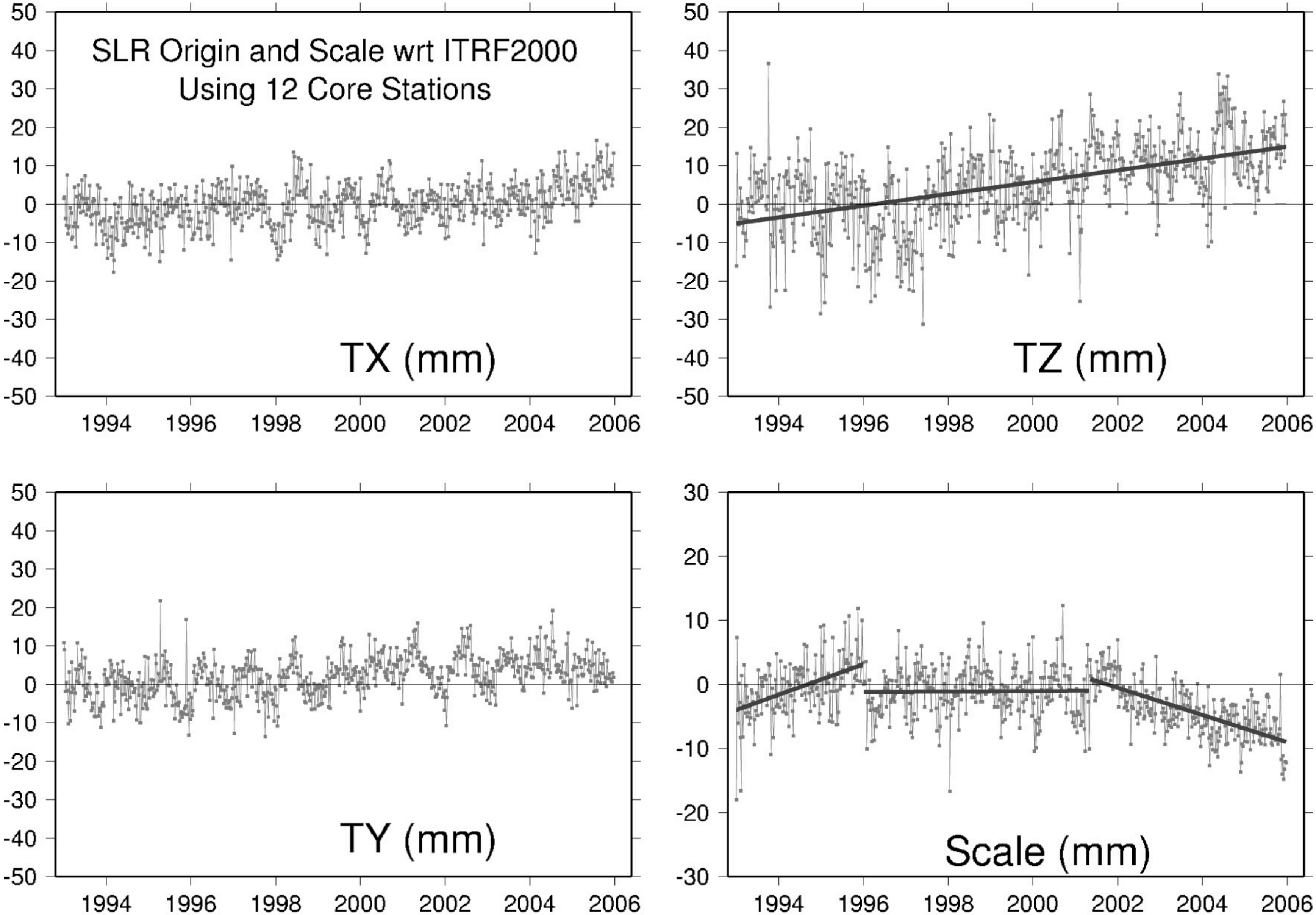


Figure 4. ILRS SLR translation and scale parameters with respect to ITRF2000.

Altamimi et al. (2007)

Transformation Parameters between ITRF2005 and ITRF2000

14 transformation parameters between ITRF2005 and ITRF2000 have been estimated and listed in Table 1, using 70 stations listed in Table 2 and located at sites shown on Figure 2.

	T1	T2	T3	D	R1	R2	R3
	mm	mm	mm	10-9	mas	mas	mas
	0.1	-0.8	-5.8	0.40	0.000	0.000	0.000
+/-	0.3	0.3	0.3	0.05	0.012	0.012	0.012
Rates	-0.2	0.1	-1.8	0.08	0.000	0.000	0.000
+/-	0.3	0.3	0.3	0.05	0.012	0.012	0.012

Table 1: Transformation parameters at epoch 2000.0 and their rates from ITRF2005 to ITRF2000 (ITRF2000 *minus* ITRF2005)