 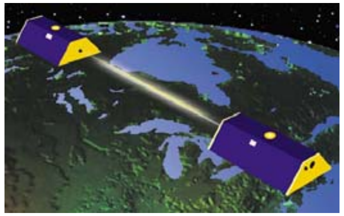 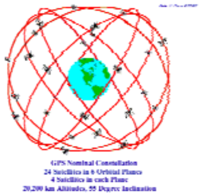  

The Seasonal Cycle in Global Mass Transport: Combining Geodetic Observations to Get the Picture

Xiaoping "Frank" Wu

Danan Dong, Richard Gross, Michael Heflin, Angie Moore, Fabiano Oyafuso, and Susan Owen

Jet Propulsion Laboratory

California Institute of Technology

Surface Mass Variations and Data

$$\sigma(R_e, \vartheta, \varphi, t) = \sum_{n=1}^{\infty} \sum_{m=0}^{n} \sum_{q=c,s} M_{nmq}(t) Y_{nmq}(\vartheta, \varphi)$$

Geodetic and Other Signatures:

- Gravity change
- Surface displacements
- Ocean Bottom Pressure (OBP) change
- Geocenter motion, Earth rotation
- Relative Sea Level

GRACE: Near global coverage, Accurate intermediate degree range
Missing n=1 terms, Noisy very-low and high-degree terms

GPS: ~540 continuous sites,
Sparse in oceans, polar and southern continents

OBP: JPL ECCO Data-assimilated model, missing spatial mean

n=1 Mass Variation and Geocenter Motion

$Y_{10c} / \sqrt{3}$

- **Gravity Coefficients**

$$V_{nmq} = \frac{4\pi a^2}{M_E} \frac{(1+k'_n)}{2n+1} M_{nmq}, \qquad k'_1 = -1$$

- **Geophysical Geocenter Motion due to *n*=1 loading**

$$\vec{S}_{cm} - \vec{S}_{cf} = \frac{4\pi}{\sqrt{3}} \frac{R_e^3}{M_e} \left[1 - \frac{h'_1 + 2l'}{3} \right] (M_{11c}\hat{e}_x + M_{11s}\hat{e}_y + M_{10c}\hat{e}_z)$$

- **Geocenter Motion + Gravity $\Rightarrow$ Complete Surface Mass Spectrum**

Significance of Geocenter Motion

Effects of 1 mm Geocenter Motion on GRACE Mean Mass Change Determination

Region / Geocenter	Eustatic Sea Level mm	Mean Antarctic Ice mm	Mean Greenland Ice mm
X	-0.46	0.07	1.26
Y	-0.24	0.49	-1.1
Z	-0.51	-5.6	5.6

JPL

Geocenter Motion Determination Methods

- **Direct Satellite Determination**
  - In the CM frame $\vec{S}_{cm} - \vec{S}_{cn} = -\frac{1}{N}\sum_i \vec{S}_i = -\vec{T}$
  - SLR
  - GPS

- **Inverse Solution of** $\mathbf{M_{1mq}} \propto \vec{\mathbf{S}}_{\mathbf{cm}} - \vec{\mathbf{S}}_{\mathbf{cf}}$
  - GPS
  - Ocean Bottom Pressure (OBP)
  - GRACE

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

- **CF and CN are different**

$$\vec{S}_{cf} = \frac{1}{4\pi} \oiint S d\Omega \neq \vec{S}_{cn}$$

Global SVD/LSE/BLE Inverse Methodology

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

- **Parameters in spherical harmonic domain**
- **SVD decomposition**
- **LSE of Good data + reduced a priori model**
- **High degree and order**
- **Robust low+intermediate degree results**
- **Noisy individual high degree coefficients**
- **Accurate linear combinations for regional recovery**

Inverse Uncertainty Spectra

n=1 Mass and Geocenter Results

From GPS+OBP

From GPS+OBP+GRACE

$X^a = 1.9 \pm 0.3$ mm

$Y^a = 3.0 \pm 0.4$ mm

$Z^a = 3.6 \pm 0.3$ mm

Compare with SLR and Hydrological Model

Figure by Xavier Collilieux

— **SLR from ITRF2005 Altamimi**

— **AOW Mass Model from van Dam**

— **GPS/OBP Inversion**

C20 Surface Density from GPS/OBP, SLR, GRACE

J2 Time Series

Degree 2 and 3

Compare GPS/OBP and GRACE (2002-2003) Annual Variations - Old GPS Data

Compare GPS/OBP and GRACE (2002-2003)
Annual Variations - New GPS Data

Interannual Surface Mass Variation

Mean Mass over Oceans and Sea Level

Air and Water
AA=8.7±0.6mm
DOY=242

Non-Steric Sea Level
AA=6.8±0.5mm
DOY=291

Improved Point and Regional Filters

$$\overline{G}(\mathbf{\Omega}_0) = \iint A(\mathbf{\Omega},\mathbf{\Omega}_0)G(\mathbf{\Omega})d\mathbf{\Omega} = \sum a_{nmq}G_{nmq}$$

Antarctica and Greenland Mean Mass

AA=51±9mm, DOY=12

AA=13±3mm, DOY=236

- **Supp. GRACE**
- **Supp. GRACE-ATM**

AA=82±13mm, DOY=156

AA=51±10mm, DOY=83

Uncertainty Reduction

- GRACE + N=1 + OBP
- Full Data Covariance Matrix
- Unimodular Optimal Regional Averages
- More Realistic Quantitative A priori

JPL

Challenges in Surface Mass Trend

- Present-Day Trend and GIA Duality in Data
- Drift in CM in 2 Recent ITRF Realization, $\dot{T}_z = 2.1 \pm 2.0$ mm/yr
- $\dot{J}_2$
- Hydrology Trend

Conclusions

- GRACE, GPS/OBP ⇒ Complete coverage, better results
- High precision seasonal/interannual geocenter motion > 10 yrs
- +OBP+GRACE ⇒ >5 fold improvement in geocenter motion
- Combining OBP improves Antarctica average accuracy by ~1.8
- Accounting for correlation can improve resolution by a factor of 2
- Improved filter with more realistic a priori

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

GPS/OBP Sine

Uncertainty Reduction