Progress in Marine Geoid Modeling

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Ocean Surface Topography from Space

• Mission Accomplishments:
  – 2007 William T. Pecora Award (US DoI/NASA/USGS)
  – Gravity Models
    • Mean fields (GGM03S, EIGEN-GL05S/C, ITG-GRACE03S and others)
    • Time variable fields (75 monthly solutions through September 2008)
  – Time variable effects in gravity field are stimulating mass flux studies in Hydrology, Oceanography, Glaciology and Solid Earth Sciences

• NASA 2007 Senior Review and DLR approved mission extension and funding through 2009
  – Extension to 2011 approved by NASA “in-principle”
  – Discussions underway at DLR

• Flight Segment
  – Nearly 100 % of scientific measurements for nearly seven years have been collected and analyzed
  – Instrument performance continues to meet mission requirements

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GRACE Mission Status

• Orbit
  Launched: March 17, 2002
  Nearly 7 years in orbit
  Initial Altitude: 500 km
    Current Altitude: ~460 km (-10 m/day)
  Inclination: 89 deg
  Eccentricity: ~0.001
  Separation Distance: ~220 km
  Nominal Mission: 5 years
  Non-Repeat Ground Track, Earth Pointed, 3-Axis Stable
  Predicted Lifetime until 2013
Gravity Model Evaluation
(limited to degree/order 360)

• Orbit determination tests
  – Laser ranging to geodetic satellites and using models consistent with RL04 processing (IERS2003 standards, ITRF2005, RL04 Atmosphere-Ocean Dealiasing)
  – GRACE K-band range-rate

• Marine geoid tests
  – Test consistency of inferred ocean circulation from (DOT - geoid) (up to d/o 120)
  – Tests consistency of short-wavelength geoid with mean sea surface from altimetry (up to d/o 360)
Geoid Models

• **EGM96** (360x360, Lemoine et al., 1998)
  — Pre-GRACE model

• **EIGEN-GL04C** (360x360, Förste et al., 2008)

• **EGM2008** (2190x2159, Pavlis et al., 2008)
  — Only 360x360 part tested here

• **EIGEN-GL05C** (360x360, Förste et al., 2008)

• **GGM03S** (180x180, Tapley et al., 2007)
  — Satellite-only model
Ocean Surface Topography from Space

Progress from EGM96

Improvement

More power
Geodetic Orbit Fits (1)

Satellite laser ranging fits to 6 geodetic satellites (units are cm)

<table>
<thead>
<tr>
<th>Satellite</th>
<th>EGM96</th>
<th>EGM08</th>
<th>GGM03S</th>
<th>GFZ05C</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAGEOS-1</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.4</td>
</tr>
<tr>
<td>LAGEOS-2</td>
<td>1.3</td>
<td>1.4</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Ajisai</td>
<td>5.9</td>
<td>5.3</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Starlette</td>
<td>5.1</td>
<td>4.8</td>
<td>3.4</td>
<td>3.3</td>
</tr>
<tr>
<td>Stella</td>
<td>9.0</td>
<td>3.0</td>
<td>2.8</td>
<td>2.6</td>
</tr>
<tr>
<td>BEC</td>
<td>11.1</td>
<td>9.4</td>
<td>9.1</td>
<td>9.0</td>
</tr>
</tbody>
</table>

Average laser ranging residual RMS from one year (2003) of 3-day orbit fits without adjusting once-per-revolution (1-cpr) empirical accelerations

Fits may be dominated by longer wavelength gravity model errors, particularly secular perturbations and long-period resonances, as well as non-gravitational effects

RL04 background models used (including AOD1B)
### Geodetic Orbit Fits (2)

Satellite laser ranging fits to 6 geodetic satellites  
(units are cm)

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<thead>
<tr>
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<th>EGM08</th>
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<th>GFZ05C</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAGEOS-1</td>
<td>1.05</td>
<td>0.97</td>
<td>0.97</td>
<td>0.96</td>
</tr>
<tr>
<td>LAGEOS-2</td>
<td>0.96</td>
<td>0.85</td>
<td>0.85</td>
<td>0.84</td>
</tr>
<tr>
<td>Ajisai</td>
<td>5.6</td>
<td>4.4</td>
<td>4.4</td>
<td>4.8</td>
</tr>
<tr>
<td>Starlette</td>
<td>3.7</td>
<td>1.8</td>
<td>1.8</td>
<td>1.7</td>
</tr>
<tr>
<td>Stella</td>
<td>6.5</td>
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Average laser ranging residual RMS from one year (2003) of 3-day orbit fits  
with adjusting once-per-revolution (1-cpr) empirical accelerations

Empirical accelerations remove longer wavelength orbit errors, including secular  
perturbations, long-period resonances and some part of the non-gravitational effects

RL04 background models used (including AOD1B)
GRACE K-band Range-Rate Residual RMS per 1-day Arcs

RL04 RMS = 0.302 μ/sec
EGM08 RMS = 0.299 μ/sec
GFZ05C RMS = 0.288 μ/sec
Correlated Orbit Error

Mean geographically correlated orbit error for Jason/Topex orbit (EGM08 vs EIGEN-GL05C)

Geographically correlated orbit error now dominated by time variable component (tides, atmosphere, ocean, hydrology, ice loss, GIA)
Residuals of the geostrophic currents implied by the mean surface (CSRMSS98) minus various marine geoid models compared to the World Ocean Atlas 2001 (WOA01) data (Stephens et al., 2002) (relative to 4000 m, courtesy of V. Zlotnicki)

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<tr>
<th>Model</th>
<th>Standard Deviation (cm/s)</th>
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<td></td>
<td>Zonal</td>
<td>Meridional</td>
</tr>
<tr>
<td>EGM96</td>
<td>8.18</td>
<td>7.00</td>
</tr>
<tr>
<td>GGM02C</td>
<td>3.04</td>
<td>3.23</td>
</tr>
<tr>
<td>EIGEN-GL04C</td>
<td>3.01</td>
<td>3.01</td>
</tr>
<tr>
<td>EIGEN-GL05C</td>
<td>3.24</td>
<td>3.10</td>
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<tr>
<td>GGM03S</td>
<td>2.91</td>
<td>2.97</td>
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Comparison is to degree/order 120, and 400 km smoothing has been applied.
(see Tapley et al., 2003, for additional information)
Short Wavelength Geoid Residuals
EIGEN-GL04C

The residuals are the difference between a ‘high-frequency DOT’ defined as (GSFCMSS00 – geoid) and the same DOT smoothed to ~900 km

Scale is +/- 25 cm.
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Short Wavelength Geoid Residuals EGM08

The residuals are the difference between a ‘high-frequency DOT’ defined as (GSFCMSS00 – geoid) and the same DOT smoothed to ~900 km

Scale is +/- 25 cm.
Short Wavelength Geoid Comparison

Calculate global RMS of the residual geoid after removing a model for the mean dynamic ocean topography (i.e. MSS - WOA01 DOT - geoid) at different wavelength filtering (shorter and longer than 300 km [$\lambda/2$]).

<table>
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<tr>
<th>Model</th>
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<tr>
<td>EGM96</td>
<td>9.3</td>
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Units are cm

Computed along new T/P groundtrack to provide independent assessment. Mean removed along each altimeter pass before computing the RMS.

(GGM02C extended above 200x200 by EGM96)
Ocean Surface Topography from Space

EGM2008 Complete

(from Pavlis et al., 2008)
Summary

• Newer global geoid models have more power at shorter wavelengths than EGM96

• Orbit fits show recent models performing similarly
  – Orbit errors/differences now dominated by time variable gravity

• EGM08 clearly performs well in the short-wavelength geoid tests
  – Best performance in the short-wavelength marine geoid
  – Provides smooth short-wavelength marine geoid residuals
  – Expansion to 2190x2159 provides considerably greater detail

• Looking forward to the contribution of GOCE to geoid accuracy at ~100 km resolution
Backups
Estimated Error Comparisons

Ocean Surface Topography from Space
Ocean Surface Topography from Space

EIGEN-GL04c 360x360

(from Pavlis et al., 2008)
Short Wavelength Geoid Residuals
GIF38A

The residuals are the difference between a ‘high-frequency DOT’ defined as (GSFCMSS00 – geoid) and the same DOT smoothed to ~900 km.

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<td>EGM08</td>
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<tr>
<td>GIF38B</td>
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Geostrophic Current Comparisons

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* GRACE-based component of EGM08

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