Terrestrial Reference Frame Realization from Combined GPS/LEO Orbit Determination

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Outline

• Introduction
• Precise Orbit Determination Strategies for TRF Realization
• Results
  • Ground network + GPS
  • Ground network + GPS + GRACE-A
• Summary and Future Work
Introduction

• Goal is to develop strategies for realizing the terrestrial reference frame (TRF) using GPS alone

• Approach
  • Perform precise orbit determination (POD) of GPS constellation
  • Loose constraints on a priori station positions
  • Process multi-day arcs to take advantage of spacecraft dynamics
  • Use homogeneous geodetic ground network
  • Topex/GRACE-based transmitter antenna calibrations
  • Next step: add LEO data and solve for ground network + GPS + LEO simultaneously

• Very different from JPL’s operational POD / contributions to IGS
• Desire homogeneous station set
  • Limit distribution to sites with choke-ring antennas
  • TurboRogue-inspired design is most common antenna type in global geodetic network
  • Use calibration from JPL test range for all sites (Young and Dunn, 1992)

• Select stations based on data quality metrics and geometry to balance hemispheres:
  • Choose 30-40 stations, half in each hemisphere
  • Yields improved Z origin
Topex/GRACE-Based GPS Transmitter Antenna Calibrations

- Directly estimate from Topex/GRACE precise orbit determination
  - Topex is reference
  - LEOs above troposphere, low multipath
- Constrain calibration to be zero mean for Topex for a given elevation
- No constraint to TRF since POD uses fiducial-free approach
- Scale constraint from satellite force models
## POD Strategy Summary

<table>
<thead>
<tr>
<th></th>
<th>JPL Ops/IGS</th>
<th>Long-Arcs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Orbit Arc</strong></td>
<td>30 hours (centered at noon)</td>
<td>3 or 9 days</td>
</tr>
<tr>
<td><strong>Number of GPS Stations</strong></td>
<td>80</td>
<td>30-40</td>
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<tr>
<td><strong>Elevation Angle Cutoff</strong></td>
<td>7 deg</td>
<td>7 deg</td>
</tr>
<tr>
<td><strong>Albedo Model</strong></td>
<td>Applied</td>
<td>Applied</td>
</tr>
<tr>
<td><strong>Transmitter Antenna Calibration Model</strong></td>
<td>IGS standard APV maps</td>
<td>Topex/GRACE-based APV maps</td>
</tr>
<tr>
<td><strong>Receiver Antenna Calibration Model</strong></td>
<td>IGS standard APV map</td>
<td>JPL Antenna Test Range (Young and Dunn, 1992)</td>
</tr>
<tr>
<td><strong>Pole Position</strong></td>
<td>X, Y offset and rate per arc</td>
<td>X, Y offset as random walk (daily update)</td>
</tr>
<tr>
<td><strong>UT1-UTC</strong></td>
<td>Rate per arc</td>
<td>Not estimated</td>
</tr>
<tr>
<td>1 and 2 CPR Empirical Accelerations</td>
<td>Not estimated</td>
<td>UVW coordinates as random walk</td>
</tr>
</tbody>
</table>
LEOs Improve Geometry

40 Station Ground Network

Sample GRACE-A Ground Track
Results for Ground + GPS + GRACE-A

• 5 year time span

• 3 day arcs

• GRACE receiver anechoic chamber calibration
  • Average of 7 measured antennas

• Estimated GRACE-A parameters
  • Epoch state
  • Stochastic empirical accelerations
    • 1 CPR in cross, along track
    • Constant in radial, cross, along track
TRF from GPS: Scale

Epoch = 2008.0

Bias: -2.95 ppb
Trend: 0.07 ppb/yr
Annual: 0.11 ppb
Postfit: 0.26 ppb RMS

Bias: -2.95 ppb
Trend: 0.07 ppb/yr
Annual: 0.12 ppb
Postfit: 0.26 ppb RMS
TRF from GPS: X Origin

Epoch = 2008.0

GPS Only

Bias: -5.6 mm
Trend: -0.2 mm/yr
Annual: 0.9 mm
Postfit: 4.7 mm RMS

GPS + GRACE

Bias: -5.5 mm
Trend: -0.3 mm/yr
Annual: 0.9 mm
Postfit: 4.4 mm RMS
TRF from GPS: Y Origin

Epoch = 2008.0

GPS Only

Bias: -0.7 mm
Trend: 0.3 mm/yr
Annual: 4.5 mm
Postfit: 6.3 mm RMS

GPS + GRACE

Bias: -0.7 mm
Trend: 0.4 mm/yr
Annual: 4.2 mm
Postfit: 5.8 mm RMS
TRF from GPS: Z Origin

Epoch = 2008.0

Bias: -8.7 mm
Trend: 1.1 mm/yr
Annual: 2.7 mm
Postfit: 15.4 mm RMS

Bias: -6.9 mm
Trend: 0.5 mm/yr
Annual: 1.4 mm
Postfit: 11.2 mm RMS
Summary and Future Work

• Demonstrated improved TRF realization with simultaneous estimation of ground network + GPS + GRACE-A
  • Origin bias agreement with ITRF/IGS08
    • < 9 mm (GPS)
    • < 7 mm (GPS+GRACE-A)
  • Z origin scatter reduced from 15 mm to 11 mm (RMS)
  • Scale unaffected by LEO
  • Scale bias is related to chosen combination of antenna calibrations, further investigation needed

• Future work
  • Increase GRACE data weight
  • Perform ambiguity resolution for GRACE
  • Include LEO in 9-day arc solutions
GPS 9-Day Arc TRF vs. ITRF/IGS08

Epoch: 2005.0

Bias -3.0 ppb, Trend 0.03 ppb/yr, Annual 0.05 ppb

Bias -4.2 mm, Trend -0.3 mm/yr, Annual 0.2 mm

Bias -3.7 mm, Trend 0.9 mm/yr, Annual 4.5 mm

Bias -9.5 mm, Trend 0.3 mm/yr, Annual 2.5 mm