GOCE Precise Science Orbits for the entire mission

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Content

- Precise Science Orbit (PSO) Determination
- Investigation of Systematic Effects
- Orbit Determination for the Final Phase
- Summary
GOCE orbital evolution

- Commissioning
- Routine mission at 255 km mean altitude
- Low orbit operations campaign

Mean altitude [km]

- 254.9 km (979:61)
- 246 km (997:62)
- 240 km (1079:57)
- 235 km (1177:73)
- 224 km (2311:148)

- 30/03/2009
- 01/11/2009
- 01/08/2012

Courtesy: ESA
GOCE SSTI

- Satellite-to-Satellite Tracking Instrument (SSTI)
- Dual-frequency L1, L2
- 12 channel GPS receiver
- 1 Hz data rate
- => Primary instrument for orbit determination
- Antenna phase center variations amount up to ±3cm on ionosphere-free linear combination
- => Mission requirement for precise science orbits: 2 cm (1D RMS)
GOCE High-level Processing Facility (HPF)

- Responsibilities for orbit generation:
  - DEOS: => RSO (Rapid Science Orbit)
  - AIUB: => PSO (Precise Science Orbit)
  - IAPG: => Validation

Institute of Theoretical Geodesy, University Bonn, Germany (ITG)
Astronomical Institute, University Berne, Switzerland (AIUB)
Centre Nationale d’Etudes Spatiales, Toulouse, France (CNES)
"National Space Research Center of the Netherlands (SRON)
Institute of Geophysics, University Copenhagen, Denmark (UCPH)
GeoForschungsZentrum Potsdam, Dept. 1 Geodesy and Remote Sensing, Germany (GFZ)
PI & Project Management: Institute of Astronomical and Physical Geodesy, Techn. Univ. Munich, Germany (IAPG)
Institute for Navigation and Satellite Geodesy, Graz University of Techn., Austria (TUG)
Politecnico di Milano, Italy (POLIMI)
GOCE PSO procedure

- Tailored version of Bernese GPS Software used
- Undifferenced processing
- Automated procedure
- 30 h batches => overlaps
- CODE final products
- Reduced-dynamic and kinematic orbit solutions are computed

The results are based on 5h overlaps (21:30–02:30) and reflect the **internal consistency** of subsequent reduced-dynamic solutions.

The same orbit determination settings were used for the operational PSO computation over the entire mission period.
Orbit validation with SLR

SLR statistics:

Mean $\pm$ RMS (cm)

Reduced–dynamic

Kinematic

The results show the **consistency** between both orbit-types and mainly reflect the quality of the kinematic orbits.

A high correlation with **ionosphere activity** and **L2 data** losses is observed.
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Differences reduced-dynamic vs. kinematic

Ascending arcs (RMS)  

Descending arcs (RMS)  

Systematic effects in the orbits

- Systematic effects around the geomagnetic equator are present in the ionosphere–free GPS phase residuals $\Rightarrow$ affects kinematic positions
- Degradation of kinematic positions around the geomagnetic equator propagates into gravity field solutions (see also poster 77551).

Phase observation residuals ($-2\text{ mm} \ldots +2\text{ mm}$) mapped to the ionosphere piercing point

Geoid height differences ($-5\text{ cm} \ldots 5\text{ cm}$): TIM–R4 model
Attempts to model the systematic effects (1)

- Conventional modeling of HOI correction terms does not show any improvements. Also the application of further HOI correction terms than recommended by the IERS Conventions 2010 does not bring any further improvements.

- Ionosphere delays (= slant TEC) need to be directly derived from the geometry–free linear combination to compute more realistic HOI correction terms.
Attempts to model the systematic effects (2)

- STEC estimations are fed into the kinematic orbit determination instead of the global ionosphere map
- HOI correction terms are computed based on the STEC estimations
- Only partial reduction achieved so far in gravity field solutions

Phase observation residuals

(-2 mm ... +2 mm) mapped to the ionosphere piercing point

Geoid height differences

(-5 cm ... 5 cm); Nov-Dec 2011
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Background and Motivation

Last available GPS measurements: 10 November, 17:15:20 UTC
Reduced–dynamic orbit determination

- 30 h processing batches (not for the last 10 days), 10 s sampling, undifferenced processing, ionosphere–free linear combination, CODE Final GNSS orbits and clocks (5 s) and Earth Rotation Parameters

- Orbit models and parameterization:
  - EIGEN5S 120x120, FES2004 50x50 (fixed by GOCE Standards)
  - Six initial orbital elements
  - Three constant accelerations in radial, along–track, out–of–plane
  - 6–min piece–wise constant accelerations in radial, along–track, out–of–plane \( (2 \times 10^{-8} \text{ m/s}^2) \)

- Test solutions with weaker constraints:
  - 2.5 \( \times \) \( 2 \times 10^{-8} \text{ m/s}^2 \)
  - 5 \( \times \)
  - 10 \( \times \)
  - 25 \( \times \)
  - 50 \( \times \)
Differences red. – dyn. ⇔ kinematic orbits

Original solution and 10x weaker constraints; 31 October 2013
Solutions with weaker constraints

- Test solutions with weaker constraints show better consistency with kinematic orbits.
- Differences between 5× and 50× weaker constraints are marginal.
- Except the very last days, these solutions are acceptable.
- SLR validation is not very helpful because of the very small number of passes

<table>
<thead>
<tr>
<th>3D RMS of differences between red.-dyn. and kinematic orbits</th>
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<tbody>
<tr>
<td>Day in 2013</td>
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<td>2.64 ± 5.52 cm</td>
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SLR validation RD orbits

Comparison with accelerometer data

- Good agreement of estimated and measured accelerations in along-track and cross-track direction
- No agreement at all in the radial direction => constraints should be tightened in this direction
Summary

- Precise Science Orbits are of excellent quality
  - 1.84 cm SLR RMS for reduced-dynamic orbits
  - 2.42 cm SLR RMS for kinematic orbits

- Orbit quality is correlated with ionosphere activity
  - L2 losses over geomagnetic poles
  - Systematic effects around geomagnetic equator

- Final phase orbit determination is challenging
  - Acceptable solutions with 10x weaker constraints
    (orbits available up to the very last GPS data)
Differences red.–dyn. ⇔ kinematic orbits

Original solution and 10x weaker constraints; 10 November 2013, the very last day!!

Surprisingly good agreement at the very last day for altitudes between 130 and 150 km !!