Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald
SLR Operations

- Laser down from November 2015 to 12. April 2016!
  - Laser head had to be repaired by Thales (no replacement hardware available)
  - April/May: energy ~4mJ (instead of 10mJ)
  - May–Nov: energy ~0.4mJ
  → Tracking of LEO up to LAGEOS o.k.
  → High-altitude satellites difficult
  → New laser head ordered in July

- Laser down since 21.10.2016
  - High voltage power supply failure
  → Repair at manufacturer’s premises
  → New head expected in December 2016
SLR Operations

- **New SLR projects**
  - New high-altitude satellite campaigns
  - European Laser Time Transfer project (ELT) (ACES experiment on ISS)
    - definition of hardware requirements
    - analysis of software requirements
  - Space Debris laser campaigns (new ILRS Space Debris Study Group)

- **Definition/evaluation of new laser**
  - 100Hz/kHz...
  - discussions with and offers from several suppliers
  - possible “in–house” solution with Institute for Applied Physics (IAP)

- **Main technical developments**
  - EFOS–8 Maser is operational frequency standard for SLR since 9.8.2016
  - usability of sCMOS tracking camera improved
  - migration of telescope/electronics control software from DOS to Linux (in progress)
ILRS Station Performance 2014/2015

ILRS October 1, 2014 through September 30, 2015: Observed Normal Points

- High Satellites
- Lageos 1+2
- Low Satellites

Station names include:
- Yarrgaloo
- Greenbelt
- Changhua
- Monument Peak
- Timmerwalde_S22
- Graz
- Hertmeuncou
- Mateur_MLR0
- Petzdonk_1
- Hardebeek
- Wetzel
- Badray
- Arcequi
- San_Fernando
- Stanghia_2
- Huelva
- Greece_MEO
- Katwijk
- Siemiatycze
- Beijing
- Popova
- Svetloe
- Altay
- Zeelandia
- M. Donnay
- Korneuburg
- Akchour
- Kiv
- Mekedef
- Snnqoun
- Khour
- Brasilia
- Bakoum
- Daxue
ZMD Station Performance 1997 – 2016

Zimmerwald: Number of Observed Passes per Month

- High Satellites
- Lageos 1+2
- Low Satellites
Optical Sensors in Zimmerwald

1-m ZIMLAT
Switzerland
First Light 2017 ...

- 0.8m telescope
- Space debris research (AIUB)
- Offload ZIMLAT
- Optical communication demonstration with LEO s/c
Space Debris Attitude Determination

**ENVISAT**

**SLR range residuals**

**light curve**
New Domes (2016)
New Domes (2016)
New Domes 2.9.2016
New Domes 10.2016
New Domes 10.2016
New Domes 10.11.2016
Aktivitäten der Forschungsgruppe
Satellitengeodäsie am AIUB

R. Dach
F. Andritsch, D. Arnold, K. Bentel, S. Bertone,
P. Frídez, Y. Jean, A. Maier, U. Meyer,
E. Orliac, L. Prange, S. Scaramuzza,
S. Schaer, D. Sidorov, P. Stebler,
A. Sušnik, A. Villiger, P. Walser
Satellite Geodesy Research Group

- Bernese GNSS Software
- CODE activities (IGS and EUREF)
- SLR data analysis
- LEO orbit determination and gravity field recovery
Satellite Geodesy Research Group

- Bernese GNSS Software
- CODE activities (IGS and EUREF)
- LEO orbit determination and gravity field recovery
- SLR data analysis

Astronomical Institute University of Bern
Updates from the CODE analysis center
Please acknowledge the usage of products from the CODE analysis center by the following references (see http://www.bernese.unibe.ch/publist/publist_code.php):

- Dach, Rolf; Schaer, Stefan; Arnold, Daniel; Orliac, Etienne; Prange, Lars; Sušnik, Andreja; Villiger, Arturo; Jäggi, Adrian (2016). CODE final product series for the IGS. Published by Astronomical Institute, University of Bern. URL: http://www.aiub.unibe.ch/download/CODE; DOI: 10.7892/boris.75876.

- Dach, Rolf; Schaer, Stefan; Arnold, Daniel; Orliac, Etienne; Prange, Lars; Sušnik, Andreja; Villiger, Arturo; Jäggi, Adrian (2016). CODE rapid product series for the IGS. Published by Astronomical Institute, University of Bern. URL: http://www.aiub.unibe.ch/download/CODE; DOI: 10.7892/boris.75854.

- Dach, Rolf; Schaer, Stefan; Arnold, Daniel; Orliac, Etienne; Prange, Lars; Sušnik, Andreja; Villiger, Arturo; Jäggi, Adrian (2016). CODE ultra–rapid product series for the IGS. Published by Astronomical Institute, University of Bern. URL: http://www.aiub.unibe.ch/download/CODE; DOI: 10.7892/boris.75676.

- Prange, Lars; Orliac, Etienne; Dach, Rolf; Schaer, Stefan; Arnold, Daniel; Jäggi, Adrian (2016). CODE product series for the IGS MGEX project. Published by Astronomical Institute, University of Bern. URL: http://www.aiub.unibe.ch/download/CODE_MGEX; DOI: 10.7892/boris.75882.

- Steigenberger, Peter; Lutz, Simon; Dach, Rolf; Schaer, Stefan; Jäggi, Adrian (2014). CODE repro2 product series for the IGS. Published by Astronomical Institute, University of Bern. URL: http://www.aiub.unibe.ch/download/REPRO_2013; DOI: 10.7892/boris.75680.
Key parameters from IGSRAPID as graphics

Result from an internship by Nicholas Wick in June 2016
Key parameters from IGSRAPID as graphics

Result from an internship by Nicholas Wick in June 2016
Key parameters from IGSRAPID as graphics
Key parameters from IGSRAPID as graphics

IGSRAPID solution

Activating the attitude model
Attitude models activated at CODE

- GLONASS SLR residuals without/with attitude modelling
  - Eclipse condition: $|\beta| < 14.1^\circ$ (greyed area on the plots)

- SLR residuals as a function of the Sun elevation above the orbital plane ($\beta$) and argument of latitude of the satellite
Advancing the bias handling in the Bernese GNSS Software
Pseudo–Absolute Code Biases: CLK

![Diagram showing satellite GPS signals with various codes]

- Satellite
  - G10: C1C, C1W, C2W
  - G02: C1C, C1W, C2W, C2C, C5Q

Receiver

C1C, C1W, C2W, C2C
Pseudo–Absolute Code Biases: CLK

![Diagram showing GPS satellite and receiver with different biases]

- GPS
- Satellite: C1C, C1W, C2W
- Receiver: C1C, C1W, C2W, C2C, C5Q
Pseudo–Absolute Code Biases: CLK

GPS

Satellite

C1C  C1W  C2W

G10

C1C  C1W  C2W

C5Q

Receiver

C2C

G02

C1C  C1W  C2W  C2C

$k_1 \cdot C1W + k_2 \cdot C2W$
Pseudo–Absolute Code Biases: CLK
Pseudo–Absolute Code Biases: CLK

GPS

\[ \kappa_1 \cdot C_{1W} + \kappa_2 \cdot C_{2W} \]

GLONASS

\[ \begin{array}{c}
R01 \\
C1P, C2P, C2C
\end{array} \quad \begin{array}{c}
R02 \\
C1P, C2P, C2C
\end{array} \]
Pseudo–Absolute Code Biases: CLK

GPS

Satellite

C1C
C1W
C2W

$k_1 \cdot C1W + k_2 \cdot C2W$

Receiver

C1C
C1W
C2W
C2C

GLONASS

R01
R02

C1P
C2P
C2C

C1P
C2P
C2C

$k_1 \cdot C1W + k_2 \cdot C2W$
Pseudo–Absolute Code Biases: CLK

GPS

Satellite

G10

C1C
C1W
C2W

G02

C1C
C1W
C2W
C2C
C5Q

Receiver

$\kappa_1 \cdot C1W + \kappa_2 \cdot C2W$

$\kappa_1 \cdot C1W + \kappa_2 \cdot C2W$

GLONASS

R01

C1P
C2P
C2C

R02

C1P
C2P
C2C
Pseudo–Absolute Code Biases: CLK
Pseudo–Absolute Code Biases: CLK

GPS

Satellite

G10

C1C

C1W

C2W

G02

C1C

C1W

C2W

C2C

C5Q

Receiver

k1 \cdot C1W + k2 \cdot C2W

k1 \cdot C1W + k2 \cdot C2W

k1 \cdot C1W + k2 \cdot C2W

GLONASS

R01

C1P

C2P

C2C

R02

C1P

C2P

C2C

k1 \cdot C1P + k2 \cdot C2P

k1 \cdot C1P + k2 \cdot C2P

k1 \cdot C1P + k2 \cdot C2P
Pseudo–Absolute Code Biases: CLK

GPS

Satellite

C1C
C1W
C2W

Receiver

C1C
C1W
C2W
C2C

GLONASS

R01

C1P
C2P
C2C

R02

C1P
C2P
C2C

$k_1 \cdot C1W + k_2 \cdot C2W$

$k_1 \cdot C1W + k_2 \cdot C2W$

$k_1 \cdot C1P + k_2 \cdot C2P$

$k_1 \cdot C1P + k_2 \cdot C2P$
Pseudo–Absolute Code Biases: CLK+ION

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Astronomical Institute University of Bern
Pseudo–Absolute Code Biases: CLK+ION

- **GPS**
  - G10
  - G02
- **GLONASS**
  - R01
  - R02

Satellite

- G10: C1C, C1W, C2W
- G02: C1C, C1W, C2W, C2C, C5Q

Receiver

- C1C, C1W, C2W, C2C
- C1P, C2P, C2C
CODE’s new Bias Estimation Workflow

1. **GNSS Observation Files**
   - **Clock Analysis:** Setup of observation equations (ionosphere-free linear combination)
   - **Ionosphere Analysis:** Setup of observation equations (geometry-free linear combination)

2. **Normal Equations (NEQ)**
   - **Clock Analysis:** Normal Equations (NEQ) (Clock Analysis)
   - **Ionosphere Analysis:** Normal Equations (NEQ) (Ionosphere Analysis)

3. **Parameter Adjustments and Inversion of Normal Equations**
   - **Clock Analysis:** Parameter adjustments and inversion of normal equations
   - **Ionosphere Analysis:** Parameter adjustments and inversion of normal equations

4. **Code Biases and Other Unknown Parameters**
   - **Clock Analysis:** Code biases and other unknown parameters (Clock Analysis)
   - **Ionosphere Analysis:** Code biases and other unknown parameters (Ionosphere Analysis)

5. **Code Biases and Other Unknown Parameters (Combined Solution)**

Additional Notes:
- Code bias parameters specific to each observable
- Without code bias datum definition.
- Selection of reference observables for the current IGS clock convention.
- Bias datum definition imposed on (combined) NEQ-system.
Multi-GNSS Bias Estimation

Input:
- Orbits from CODE’s MGEX solution
- RINEX 3 and RINEX 2 observation files

Output:
- Code Biases from ionosphere analysis, clock analysis and their combination (*Full set* of observable–specific code biases (OSB))
- Multiplier estimation (Receiver tracking mode)
- Ionosphere based on Multi–GNSS observations

![Graph showing GPS observable–specific code biases (OSB) (2016 176–186)]
Comparison with MGEX Bias Solutions (DLR)

CODE: Observable–specific code biases transformed to DCB’s (2016 176–186)

Galileo Satellites: C1C–C7Q

Beidou Satellites: C1I–C7I
Verification of receiver tracking mode using OSB multiplier estimation based on ionosphere analysis:

Estimation of a multiplier for each (known) satellite OSB per station and a regular receiver bias.

Remarks:
- C2C and C2S are very close together and have the same pattern for the satellite biases. They cannot be separated by the multiplier approach.
Reprocessing with the new Empirical CODE Orbit model
(in the frame of EGSJIM)
Orbit validation using SLR

repro02

current repro

range residual [mm]

abs(solar beta angle) [°]

Elongation angle [°]
The SLR residuals to the GLONASS satellites increase after a few years of lifetime. The reason is still unknown!
Improving the completeness of the clocks

Completeness of 30 s GPS clock corrections for year 2003.
Improving the completeness of the clocks

Completeness of 5 s GPS clock corrections for year 2003.
Improving the completeness of the clocks

Completeness of 5 s GPS clock corrections for year 2009.
Targeting the following products

- **GNSS–orbits:**
  - GPS: 1994–now
  - GLONASS: 2002–now

- **GNSS–satellite clocks:**
  - GPS, 30 sec 1994–now
  - GPS, 05 sec 2003–now
  - GLONASS, 30 sec 2008–now
  - GLONASS, 05 sec 2010–now

Limitations due to the global coverage with legacy and high-rate (IGS real-time) stations.
Introducing ITRF2014
ITRF2014 solutions

- **TUM–DGFI**
  - **DTRF2014**: based on a classical coordinate + linear velocity solution
  - **DTRF2014L**: ATM + Hydro.–loading applied

- **IGN**
  - **ITRF2014**: based on coordinate + linear velocities + empirical post–seismic deformation corrections (+annual/semi–annual periodic functions)
  - **ITRF2014P**: periodic functions recovered

- **JPL**
  - **JTRF2014**: based on a filter approach
Comparison of the ITRF2014 solutions

Comparison with REPRO_2015
Comparison of the ITRF2014 solutions

Comparison with REPRO_2015

$T_x$ from Helmert in mm
Comparison of the ITRF2014 solutions

Comparison with REPRO_2015

$R_y$ from Helmert in uas

94 95 96 97 98 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15
Comparison of the ITRF2014 solutions

Comparison with REPRO_2015

Scale from Helmert in pbm

94 95 96 97 98 00 01 02 03 04 05 07 08 09 10 11 12 13 14 15
CODE contribution to IGS MGEX
CODE MGEX (COM) activities

- Allocation of COM products also via AIUB ftp server
- Adaptation to long RINEX file naming convention (consideration of additional download paths at data centers; file priorities)
- Downweighting of observations from satellites in orbit normal mode (QZS-1, all BDS)
- Change to standard multi-GNSS ANTEX provided by the IGS
- Improved data screening
- Experiments with orbit normal attitude mode and related SRP models
- Experiments with Galileo attitude
- Experiments with ground network geometry
- Long-term quality assessment and documentation (=> JoG paper)
MGEX products availability

Status: 01-July-2016

Satellite system IDs according to the content of the precise orbit files at ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/
MGEX station distribution

Station distribution for orbit solution (DOY 232/2016)

- GPS
- GLONASS
- Galileo
- X BeiDou
- QZSS
CODE MGEX data monitoring

Satellite systems being monitored (RINEX3 files):
Galileo orbit validation

⇒ Significant reduction of dependency on beta-angle, when changing to the ECOM2
Clock validation 2014: median RMS of daily linear fit

(Median and IQR; satellites in eclipse or normal mode are not considered)

Galileo PHM, QZS-1, most GPS IIR and IIF: excellent performance

Improvement with ECOM2 visible for Galileo PHM and QZS-1 clocks (=> these clocks are suitable for orbit validation)
CODE MGEX solution (3d arc)

The ECOM2 decomposition is designed for the yaw-steering mode but not for the orbit normal mode.

SLR residuals
CODE MGEX solution (3d arc)

Alternative coordinate systems are needed for the empirical orbit parameters.

SLR residuals
CODE MGEX solution (3d arc)

SLR residuals
Figure 4: For each AC, mean value and standard deviation [mm] of SLR residuals with respect to GLONASS, Galileo, BeiDou, and QZS-1 satellites is shown. Note that all residuals larger than 300 mm (GLONASS), 500 mm (Galileo), 300 mm (BeiDou), and 1500 mm (QZS-1) were regarded as outliers. In addition, SLR observations during eclipses for GLONASS and during intervals with solar beta angle smaller than 20° for QZS-1 were not taken into account. For the description of acronyms see caption of Table 1.
European vs. global network: orbit differences
(Position differences of Galileo orbits with arclengths of 1 day)

Differences of 1-day Galileo orbits based on global and European station networks, respectively

⇒ In unobserved regions the orbit differences might exceed 10 m
Compensating Deficiencies in the Receiver Antenna Calibration in an multi-GNSS environment
Receiver antenna biases

- A GNSS antenna should be individually calibrated for each GNSS.
- GEO++ (main source of IGS calibration) only provides receiver antenna calibrations for GPS and GLONASS (dual frequency).
- The coordinate/troposphere GLONASS–GPS translation bias has been implemented in order to compensate for a potential deficiency in the GNSS–specific calibration of the antenna phase center offset.
GPS–GLONASS antenna bias: Coordinates

- Station coordinate from GPS-only
- Station coordinate from GLONASS-only
- Vector between GPS– and GLONASS–coordinates
- Two independent networks with independent datum definition
- Zero–mean condition over all GPS–GLONASS–bias in $xyz$
GPS–GLONASS antenna bias: Troposphere

The troposphere GLONASS-GPS translation bias shall compensate for a potential deficiency in the GNSS-specific calibration of the antenna phase center variation.

- Troposphere estimates from GPS-only
- Troposphere estimates from GLONASS-only
- Difference between GPS– and GLONASS–troposphere series
GPS–GLONASS antenna bias: Troposphere

GLONASS-GPS troposphere ZPD biases
(for up to 143 IGS GNSS stations)

Model switch from IGS05 to IGS08
The currently used IGS08.atx and IGS14.atx sets of corrections provide sufficient calibration for legacy GPS and GLONASS measurements.

The missing receiver antenna calibration values are a significant problem in the current status of multi-GNSS processing.

If this method is applied to multi-GNSS the influence of the deficiency on the results may be limited given that a sufficient amount of data are available.

- Extending the parameters to all GNSS
- Include also troposphere gradients
GNSS–specific characteristics in Earth rotation and geocenter parameter series

SNF project on GNSS orbit modelling
## Method

### GPS-only & GLONASS-only

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<tr>
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<th>GPS recCLK</th>
<th>GLO recCLK</th>
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### GNSS specific GCC/ERP

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### GNSS specific GCC/ERP of sub-systems

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**SNF project on GNSS orbit modelling**
Results: Polar Motion

SNF project on GNSS orbit modelling
ESA project related to GNSS activities
Other projects:

- **TGVF/OVF**: «Ground truth» for Galileo GMS GSA–project with ESOC, BKG, GFZ, IGN

- **ORBIT /SRP Modelling for Long Term Prediction**
  ESA–project with Airbus (defense and space)

- **Improved GNSS–Based Precise Orbit Determination by using highly accurate clocks**
  ESA–project with ETH Zurich and TU Munich

- **Combination of inhomogeneous multi–GNSS products**
  ESA–NPI project with ESOC Darmstadt
Satellite Geodesy Research Group

- Bernese GNSS Software
- LEO orbit determination and gravity field recovery
- SLR data analysis
- CODE activities (IGS and EUREF)
Simulating SLR Data

<table>
<thead>
<tr>
<th>Satellite Name</th>
<th>Satellite ID</th>
<th>SIC Code</th>
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<th>Altitude (Km)</th>
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Target: optimizing the observation scenarios at SLR tracking stations.
Simulating SLR Data

Realistic SLR observation simulation:

- Considers differences between stations
- Operating times, day/night capabilities, strengths in high/low target tracking,…
- Noise resembles real bin RMS properties
- Possibility to factor in weather forecast/cloud coverage models
- Probabilistic availability of a given station at a given time

Resulting are synthetic observations upon which comparison and optimization can be done.

- Impact of number and distribution of observations on LAGEOS/ETALON
- SLR+GNSS combination
Simulating SLR Data

Starting from real observations, alternative scenarios are developed.
Simulating SLR Data

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Simulating SLR Data

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SLR residual [mm]
Simulating SLR Data
Satellite Geodesy Research Group

- Bernese GNSS Software
- LEO orbit determination and gravity field recovery
- CODE activities (IGS and EUREF)
- SLR data analysis
Copernicus POD Service
Copernicus satellite fleet

At AIUB precise orbits of all Sentinel satellites are computed

Sentinel-1A

Sentinel-1B

Sentinel-2A

Sentinel-3A

Courtesy: ESA
RMS of GPS carrier phase residuals

Sentinel-1A Phase Residual (RMS; mm)

Epoch (2016)
# 3D–RMS of mutual orbit comparisons

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**S3A**
SLR validation of Sentinel-3

ILRS Stations allowed to track Sentinel-3
SLR validation of Sentinel-3

Sentinel-3A SLR Residuals (averages)

<table>
<thead>
<tr>
<th></th>
<th>AIUB</th>
<th>CNES</th>
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<th>DLR</th>
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<td>1.86</td>
<td>1.76</td>
<td>1.70</td>
<td>2.94</td>
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LEO non-gravitational force modeling
Force models considered
Comparison with other approaches

Aerodynamic acceleration acting on Swarm-C (satellite-fixed frame). **Red:** Bernese GNSS Software. **Green:** Acceleration computed by E. Doornbos from TU Delft. **Black:** Rescaled acceleration from TUD.
Reduction of empirical accelerations

Daily mean values (left) and standard deviations (right) of the piecewise-constant accelerations estimated for Swarm-C.

- **R mean (m/s²)**
  - X-axis: Time (day of the year 2014)
  - Y-axis: Values range from $10^{-8}$ to $5 \times 10^{-8}$

- **S mean (m/s²)**
  - X-axis: Time (day of the year 2014)
  - Y-axis: Values range from $10^{-8}$ to $0$

- **W mean (m/s²)**
  - X-axis: Time (day of the year 2014)
  - Y-axis: Values range from $10^{-8}$ to $0$

- **R STD (m/s²)**
  - X-axis: Time (day of the year 2014)
  - Y-axis: Values range from $10^{-8}$ to $7 \times 10^{-8}$

- **S STD (m/s²)**
  - X-axis: Time (day of the year 2014)
  - Y-axis: Values range from $10^{-8}$ to $10$

- **W STD (m/s²)**
  - X-axis: Time (day of the year 2014)
  - Y-axis: Values range from $10^{-8}$ to $5 \times 10^{-8}$
Comparison with accelerometer data

Computed and measured acceleration for GRACE-A
Precise orbit determination for the final stages of GOCE
Details of air–drag modeling

- Implementation of air drag modelling
  - Air drag models have been implemented into Bernese GNSS software.
  - Two types of macro models:
    - 6-plate box model of S. Bruinsma (2013) GOCE+ Theme 3: Air density and wind retrieval using GOCE data, Validation report. Surfaces: 0.70m² (x), 10.77m² (y), 5.90m² (z).
    - 44-plate model of GO-TN-AI-0179 (GOCE Stand-alone Aerodynamic Model of ThalesAlenia) resp. the 36-plate variant without radiator (self-shadowing?)
  - Computation of drag and lift coefficients for each plate according to Sentman’s theory.

\[
\begin{align*}
    a_D &= - \frac{\rho A_{ref}}{2m} C_D v^2 e_D, \\
    a_L &= - \frac{\rho A_{ref}}{2m} C_L v^2 e_L, \\
    e_D &= - \frac{v}{v}, \\
    e_L &= - \frac{(v \times n) \times v}{|v \times n|^2} 
\end{align*}
\]
GOCE macro model
Reduction of empirical accelerations

1: No air drag modelling
2: DTM2013, no HWM, 6-plate macro model
3: DTM2013, no HWM, 44-plate macro model
4: DTM2013, no HWM, 36-plate macro model
5: DTM2013, HWM14, 36-plate macro model
6: DTM2013, HWM14, 36-plate macro model, SESAM for energy accommodation coefficient
Constraining of empirical accelerations

- Differences to kinematic orbits and orbit overlaps show that a tightening of the constraints to \(~ 5 \times 10^{-8} \text{ m/s}^2\) is possible without degrading the orbits (actually improving).

- Reached level: Roughly as without air drag modeling and very loose constraints \((1 \times 10^{-6} \text{ m/s}^2)\), except for single days \((296, 307, 309)\) and the very last days (better).
Application to Sentinel–3
Orbit differences to DLR orbits

Sentinel-3A orbits have been computed with more dynamical stiffness (important for altimetry) and compared to DLR orbits. No radial offsets between the orbits from the two agencies.
SLR validation

SLR residuals

SLR offsets
Swarm GPS receiver issues
Bi–Monthly Gravity Field Solutions up to d/o 90

Original GPS Data

Mar/Apr 2014

Jun/Jul 2014

Nov/Dec 2014

Screened GPS Data

Differences wrt GOCO05S

400 km Gauss smoothing adopted
Global ionosphere behavior

**RMS of ΔL_{gf} (full signal)**

Swarm-A, days 14/305-14/365

**RMS of ΔL_{gf} (high-pass)**

Swarm-A, days 14/305-14/365

Equatorial regions are mainly governed by deterministic features

Polar regions are mainly governed by scintillation-like features
History of FOV and tracking loop changes

- Up to 20 Oct 2014: GPS antenna field-of-view (FOV) 80°, antenna correction applied in GPSx Level1b products
- 20 Oct 2014: Antenna FOV enlarged to 83°, antenna corrections switched off
- 01 Dec 2014: FOV enlarged to 86° for Swarm C
- 13 Jan 2015: FOV enlarged to 88° for Swarm C
- 06 May 2015: L1-carrier loop increased by 50% and L2-carrier and P(Y)-code loops increased by 100% for Swarm C. FOV enlarged to 88° for Swarm A and B.
- 08 Oct 2015: Swarm A: same tracking loop changes
- 10 Oct 2015: Swarm B: same tracking loop changes
RMS of kinematic POD

- Changed tracking loop settings lead to smaller carrier phase RMS (mainly due to reduction of large residuals over the polar regions)
- Differences between RMS of Swarm A and Swarm C only during period with different settings
Gravity field solutions: June 2015

Screened GPS data ($\Delta L_{gf} > 2\text{cm/s excl.}$)

- **Swarm-A**
- **Swarm-C**

Original GPS data

- **Swarm-A**
- **Swarm-C**

**Gravity field solutions**

- **750km Gauss**
- **500km Gauss**
- **400km Gauss**
Missing observations in RINEX files (June 2015)

- No obvious gaps for Swarm–C along geomagnetic equator.
- Reduction of artefacts in gravity field solutions is therefore not due to skipped data.
Summary

- RINEX screening is useful for gravity field recovery, but rejects a lot (too much) of GPS data
- Improved tracking loop settings are most promising to use the full amount of GPS data while significantly reducing the observed artefacts in the gravity field recovery.
Situation for Sentinel

→ No trace of geomagnetic equator!

Swarm-A, June and September 2015
Contribution of Sentinel

Monthly gravity fields, w/o near-zonals

Leaving out near-zonal coefficients according to van Gelderen and Koop due to the polar gap of the Sentinel satellites.
Activities in the frame of EGSIEM
EGSIEM project

European Gravity Service for Improved Emergency Management

Services will be tailored to the needs of governments, scientists, decision makers, stakeholders and engineers. Special visualisation tools will be used to inform, update, and attract also the large public.
EGSIEM: Scientific Combination Service of monthly GRACE gravity fields
Scientific Combination Service

- Only one product for the user
- Reduced noise
Individual contributions: AIUB

- AIUB: Celestial mechanics approach (dynamic approach relying on frequent pseudo-stochastic accelerations)
  - ~ 500‘000 KRR observations and
  - ~ 500‘000 kinematic positions (30s) / month
Individual contributions: ITSG

- ITSG: originally short arc approach, empirical noise model
  - ~ 500'000 KRR observations and
  - ~ 50'000 kinematic positions (300s) / month
Individual contributions: GFZ

- GFZ: dynamic approach, dense accelerometer parametrization
  - ~ 500,000 KRR observations and
  - > 2,500,000 GPS observations / month
Individual contributions: GRGS

- **GRGS: dynamic approach**
  - approx. 500000 KRR observations and
  - 50000 kinematic positions (300s) / month
Monthly Combination

Anomalies up to order 29

- $l_{max} = 80$
- AIUB
- GFZ
- ITSG
- GRGS
- COMB solution
- COMB w * NEQ

<table>
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<tr>
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Monthly Combination

Anomalies up to order 29

I_{max} = 80

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Monthly Combination

Anomalies up to order 29

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EGSIEM: Extension to GPS only gravity fields from GRACE and SWARM
Solutions based on AIUB orbits show a very good performance. This is probably mainly related to the quality of the underlying kinematic orbits.

Combination of solutions from different groups (using different orbits and approaches for gravity field recovery) show further reduced noise.
Validation against GRACE K-band
EGSIEM: Many other activities …
e.g. daily solutions from TU Graz

- Daily updated solution shall be generated in near real-time (max. 5 days delay) in the future
e.g. outreach activities from University of Hannover

News and updates will be regularly published on various media, e.g., by the quarterly EGSIEM Newsletter.

Issues can be accessed at [www.egsiem.eu](http://www.egsiem.eu)

EGSIEM is also present on social media:

- [https://twitter.com/EGSIEM](https://twitter.com/EGSIEM)
- [www.facebook.com/egsiem](http://www.facebook.com/egsiem)
- [https://egsiem.wordpress.com](https://egsiem.wordpress.com)
Planetary Geodesy
The GRAIL mission

Courtesy: NASA
Observation residuals

Doppler observations can be used for orbit and gravity field determination

Daily Doppler RMS values for GRAIL-A when using SGM150J and 2-way Doppler observations, as well as GRGM900C up to d/o 300 and 1-way and 2-way Doppler observations.
Observation residuals

Doppler observations can be used for orbit and gravity field determination

Daily KBRR RMS values when using SGM150J and 2-way Doppler observations, as well as GRGM900C up to d/o 300 and 1-way and 2-way Doppler observations
Difference degree amplitudes (w.r.t. GRGM900C) of degree-200 AIUB solutions based on 2-way, 1-way, and combined 1- and 2-way Doppler and KBR observations, as well as a preliminary degree-300 solution based on 2-way Doppler and KBR observations. GRGM900C up to d/o 660 has been used as a priori field.

GRAIL orbits should be modeled more dynamically …