Activities at the CODE Analysis Center

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The CODE consortium

Four institutions compose the CODE consortium: the Astronomical Institute of the University of Bern (AIUB), Switzerland; the Swiss Federal Office of Topography (swisstopo); the German Federal Agency for Cartography and Geodesy (BKG) and the Institut für Astronomische und Physikalische Geodäsie (IAPG), Munich, Germany.

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Highlights

Rigorously combined processing of GPS, GLONASS, and Galileo observations is performed in all operational product lines (GLONASS: since May 2003; Galileo: final since Nov. 2022, rapid since Sep. 2019), see Figures 1 and 2 .
Regular contribution to IGS-MGEX since 2012 with a five-system solution: GPS + GLONASS + Galileo + BeiDou + QZSS is generated available as well. Since March 2021, also the BeiDou-3 constellation is considered, see Figure 2 .
Three-day long-arc solutions are preferred for all product lines based on NEQ-stacking. The rapid solution is repeated in the afternoon by including the NEQ by the 12 UTC ultra-rapid.
Continuous parameterization, particularly for Earth orientation parameters (EOP, Figure 3), troposphere zenith path delays (ZPD) and horizontal gradients, as well as for ionosphere parameters (Figure 4), allows the connection of the parameters at day boundaries.
Completeness of GNSS orbit products with respect to all transmitting GNSS satellites with reliable accuracy code information.
Generation of uninterrupted orbit information for the satellites being repositioned (Figure 5). Corresponding events are identified with a maneuver flag in the SP3c/d orbit files. An orbit initialization procedure is implemented for easy inclusion of brand new GNSS satellites, even if they do not provide broadcast navigation messages.
Automatic verification of IGS20 fiducial sites for consistent datum definition in the final, rapid, and ultra-rapid analysis chains.
GNSS ambiguity resolution: double-difference ambiguities are resolved for CDMA-based GNSS and GLONASS observations with a self-calibrating procedure for handling of GLONASS-DPCB (differential phase-code biases).
Monitoring parameters are set up in the final solutions for internal use:

- Satellite(-specific) antenna offsets and patterns.
- GLONASS/Galileo-GPS bias parameters with respect to station coordinates and troposphere ZPD and gradients.
- Scaling factors for higher-order ionosphere (HOI) and (station-wise) for the deformation models as provided by Dill and Dobslaw (2013),
- Geocenter coordinates (GCC).
- Plane-specific ERP and satellite-specific GCC.

Note: These parameters are contained in the daily NEQs that are archived. For efficiency reasons the monitoring parameters are stacked or removed from the NEQs before generating the final solution.
Fully automated GNSS data processing with the latest development version of the Bernese GNSS Software (Dach et al., 2015). The processing is embedded in a system of Perl scripts including instant alerting in case of processing and technical failures, general data flow problems, changes in the GNSS constellations.

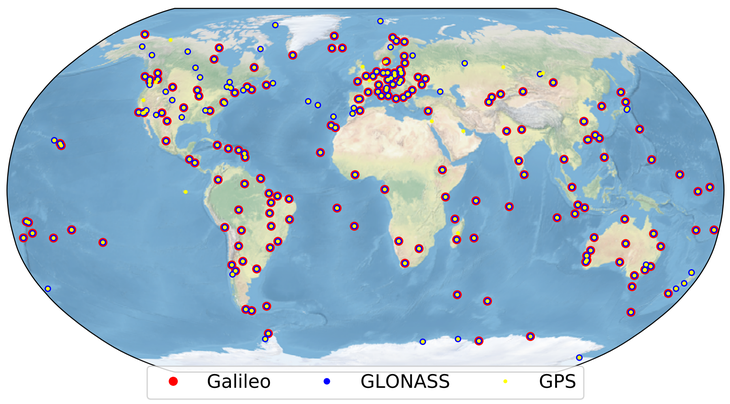

Figure 1: Tracking network as considered in CODE's GNSS final analysis in June 2024. About 70% of the tracking stations support all three systems (with the completely calibrated receiver antenna); about 7% of them only support GPS.

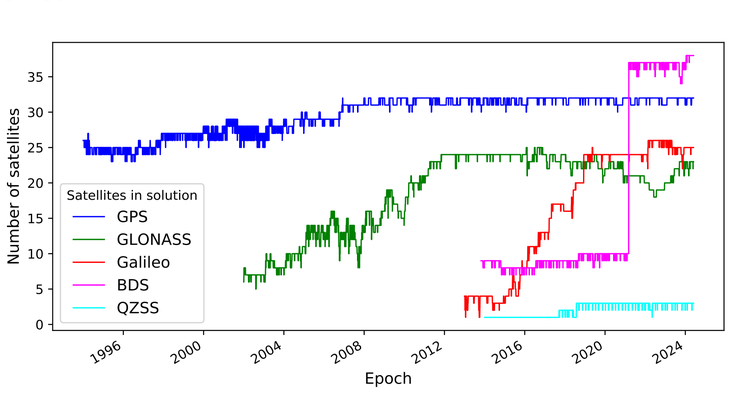

Figure 2: Number of GNSS satellites as considered in CODE's final and MGEX analyses.

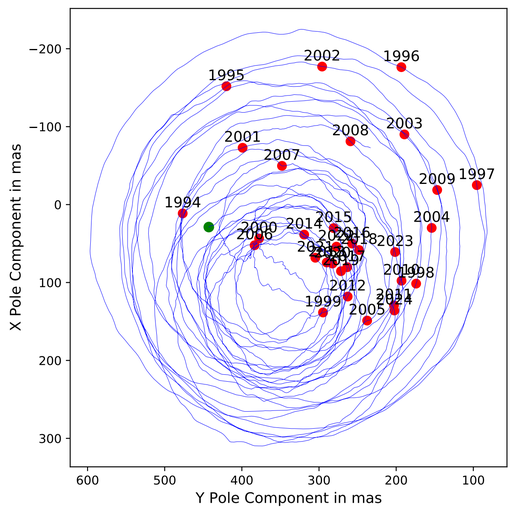

Figure 3: Polar motion from 19-Jul-1993 to 27-May-2024 as monitored by CODE.

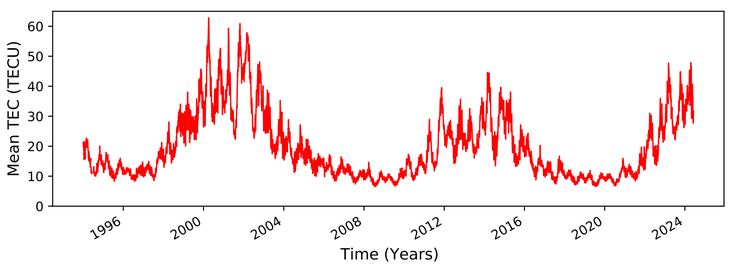

Figure 4: Global mean TEC extracted from the Global Ionosphere Maps (GIMs) produced by CODE. This particular daily time series, meanwhile covering nearly three solar cycles, was created on the basis of hourly GIMs obtained as a by-product from a bias-dedicated GNSS reprocessing effort.

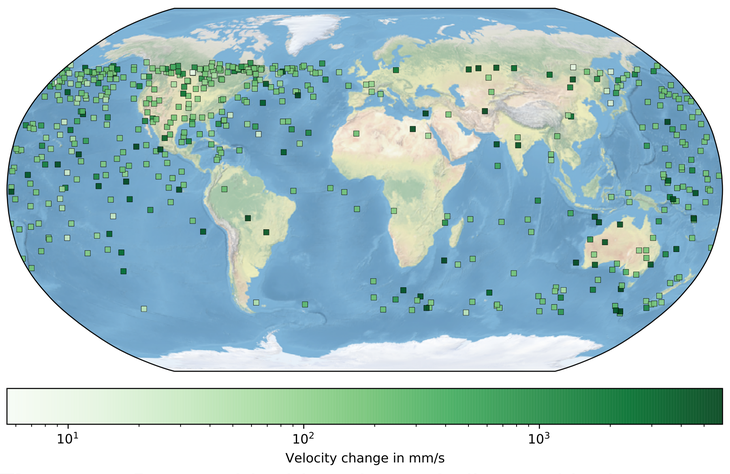

Figure 5: Geographical locations of all repositioning events of GPS satellites as determined by CODE since 2004.

CODE analysis product overview

	GNSS/Satellites	Stations
Ultra-rapid	**GPS+GLONASS+Galileo**; orbits: 5 min usually updated every 3 hours; including 24 h prediction	max. 100 sta; SINEX: CRD, ERP, GCC, SATA tropo SINEX: 2 h
Rapid	**GPS+GLONASS+Galileo**; orbits: 5 min; attitude: 30 sec satellite clocks: 30 sec; phase biases for PPP-AR (GE)	120 sta; SINEX: CRD, ERP, GCC, SATA station clocks: 5 min; tropo SINEX: 2 h
Final	**GPS+GLONASS+Galileo**; orbits: 5 min; attitude: 30 sec satellite clocks: 30&5 sec; phase biases for PPP-AR (GE)	ca. 280 sta; SINEX: CRD, ERP, GCC, SATA station clocks: 5 min; tropo SINEX: 2 h
MGEX	**GPS+GLO+GAL+BDS+QZSS**; orbits: 5 min; attitude: 30 sec satellite clocks: 30 sec; phase biases for PPP-AR (GEJ)	140 stations station clocks: 5 min

Selected recent developments, activities, and model changes

Since May 2023, CODE is using the fitted signal model (FSM) from COST-G service to consider the **time variable gravity field**. With this change, artefacts in the annual periods of the LOD estimates were reduced. More information in the presentation by Meyer et al,: "Products of the Combination Service for Time-variable Gravity fields for GNSS POD" in Session 5.
CODE is also contributing to IGS analysis efforts to estimate **satellite antenna parameters** from a global network solution, e.g., for the first GLONASS-K2 satellites. Currently it is computing the contributions to the BeiDdou-satellite calibration campaign agreed by a number of ACs in order to enable BeiDou in the legacy processing scheme.
In addition, CODE is making continuous progress in improving the reliable provision of **phase biases for PPP-AR**, as indicated in Table 1 (IAR was extended to QZSS in May 2024).

Table 1: Ambiguity resolution success-rate in the CODE MGEX processing (status as of May 2024).

	GPS	GLO	GAL	BDS	QZSS
Double-diff. (geometry)	85%	35%	87%	80%	60%
Zero-diff. (clocks)	86%		88%		63%

A steadily growing number of **regularly generated Python graphics** supports us in quality assurance. These graphs show known, expected or even unexpected patterns, which can then inspire further investigation, which in turn could lead to an improvement. A example of this is shown in Figure 6 with regard to Galileo features.

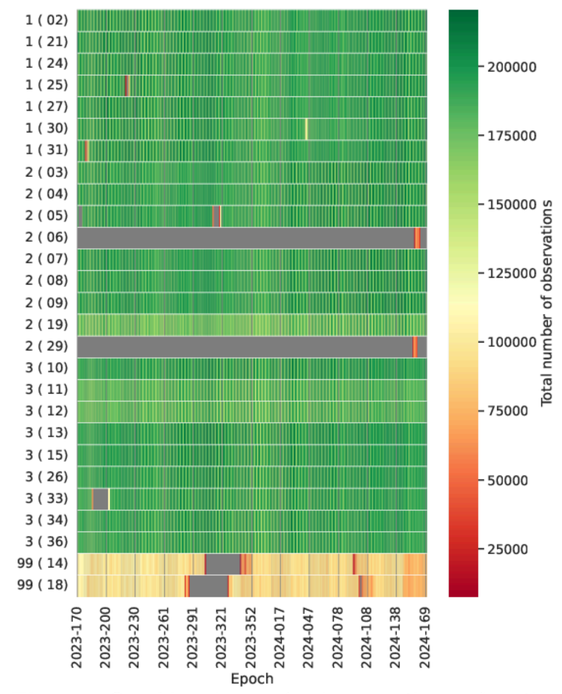

Figure 6: Number of observations for the Galileo constellation included in each daily CODE final solution.

Details on recent developments at the CODE AC are available in the latest IGS Technical Reports:
Dach, R., S. Schaer, et. al (2024). **Center for Orbit Determination in Europe (CODE) Analysis Center Technical Report 2023**. IGS Central Bureau and University of Bern, Bern Open Publishing, pp 49-66, May 2024. **DOI: 10.48350/191991**

Referencing CODE products

The products from CODE (ultra-rapid, rapid, final and MGEX series) are referable as:

Dach, R., S. Schaer, D. Arnold, E. Brockmann, M. Kalarus, M. Lasser, P. Stebler, and A. Jäggi (2024). CODE ultra-rapid product series for the IGS. Published by Astronomical Institute, University of Bern. **DOI: 10.48350/197027**
URL: `http://www.aiub.unibe.ch/download/CODE`

Dach, R., S. Schaer, D. Arnold, E. Brockmann, M. Kalarus, M. Lasser, P. Stebler, and A. Jäggi (2024). CODE rapid product series for the IGS. Published by Astronomical Institute, University of Bern. **DOI: 10.48350/197026**
URL: `http://www.aiub.unibe.ch/download/CODE`

Dach, R., S. Schaer, D. Arnold, E. Brockmann, M. Kalarus, M. Lasser, P. Stebler, and A. Jäggi (2024). CODE final product series for the IGS. Published by Astronomical Institute, University of Bern. **DOI: 10.48350/197025**
URL: `http://www.aiub.unibe.ch/download/CODE`

Dach, R., S. Schaer, D. Arnold, E. Brockmann, M. Kalarus, M. Lasser, P. Stebler, and A. Jäggi (2024). CODE product series for the IGS MGEX project. Published by Astronomical Institute, University of Bern. **DOI: 10.48350/197028**
URL: `http://www.aiub.unibe.ch/download/CODE_MGEX`

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