Center for Orbit Determination in Europe (CODE) Analysis Center Technical Report 2024

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1 The CODE consortium

CODE, the Center for Orbit Determination in Europe, is a joint venture of the following four institutions:

- Astronomical Institute, University of Bern (AIUB), Bern, Switzerland
- Federal Office of Topography swisstopo, Wabern, Switzerland
- Federal Agency of Cartography and Geodesy (BKG), Frankfurt a. M., Germany
- Institute for Astronomical and Physical Geodesy, Technical University of Munich (IAPG, TUM), Munich, Germany

The operational computations are performed at AIUB, whereas IGS–related reprocessing activities are usually carried out at IAPG, TUM. All solutions and products are generated with the latest development version of the Bernese GNSS Software (Dach et al., 2015a).

2 CODE products available to the public

A wide range of GNSS solutions based on a rigorously combined GPS/GLONASS/Galileo data processing scheme is computed at CODE supporting the following IGS legacy product chains:

- **Ultra-rapid series** with several updates per day (GPS+GLONASS+Galileo).
  The ultra-rapid products contain also a prediction for near-real time applications.
  List of result files are provided in Table 1 .
- **Rapid series** is computed once per day (GPS+GLONASS+Galileo).
  Note that there is an update of the rapid solution, see Dach et al. (2015b) .
  List of result files are provided in Table 2 .
- **Final series** is submitted once per week (GPS+GLONASS+Galileo).
  Until GPS week 2037 (November 27th, 2022) the final solution did only consider GPS+GLONASS measurements.
  List of result files are provided in Table 3 .

The products are made available through anonymous ftp at:

ftp://ftp.aiub.unibe.ch/CODE/ or
http://ftp.aiub.unibe.ch/CODE/ or
http://www.aiub.unibe.ch/download/CODE/

With GPS week 2238, the IGS started to use a new product filenaming scheme. The tables provide both, the new and old product filenames.

Furthermore, CODE contributes to the IGS MGEX project with a five-system solution considering GPS, GLONASS, Galileo, BeiDou, and QZSS where the related products are published at:

ftp://ftp.aiub.unibe.ch/CODE_MGEX/ or
http://www.aiub.unibe.ch/download/CODE_MGEX/

Up to the inclusion of Galileo into CODE's final solution in GPS week 2238 (November 28th, 2022), the triple-system solution (GPS, GLONASS, Galileo) from CODE's rapid processing is also kept accessible at:

ftp://ftp.aiub.unibe.ch/CODE/yyyy_M or
http://www.aiub.unibe.ch/download/CODE/yyyy_M/

An overview of the related product files is given in Table 4.

Tables 5 and 6 compile the product files submitted by CODE to the IGS data centers.

Within the table the following abbreviations are used:

yyyy	Year (four digits)	ddd	Day of Year (DOY) (three digits)
yy	Year (two digits)	wwww	GPS Week
yymm	Year, Month	wwwwd	GPS Week and Day of week

Table 1: CODE's ultra-rapid products available through anonymous ftp.

CODE *ultra-rapid* products available at `ftp://ftp.aiub.unibe.ch/CODE`

`COD0OPSULT.SP3` (old: `COD.EPH_U`)
: CODE ultra-rapid GNSS orbits (GPS+GLONASS+Galileo) with 5 minutes sampling

`COD0OPSULT.ERP` (old: `COD.ERP_U`)
: CODE ultra-rapid ERPs belonging to the ultra-rapid GNSS orbit product

`COD0OPSULT.TRO` (old: `COD.TRO_U`)
: CODE ultra-rapid troposphere product, troposphere SINEX format

`COD0OPSULT.SNX` (old: `COD.SNX_U.Z`)
: SINEX file from the CODE ultra-rapid solution containing station coordinates, ERPs, and satellite antenna Z-offsets

`COD0OPSULT_TRO.SNX` (old: `COD_TRO.SNX_U.Z`)
: CODE ultra-rapid solution, as above but with troposphere parameters for selected sites, SINEX format

`COD0OPSULT.SUM` (old: `COD.SUM_U`)
: Summary of stations used for the latest ultra-rapid orbit product

`COD0OPSULT.ION` (old: `COD.ION_U`)
: Last update of CODE rapid ionosphere product (1 day) complemented with ionosphere predictions (2 days), Bernese format

`COD0OPSULT_yyyyddd0000_01D_05M_ORB.SP3` (old:`CODwwwwd.EPH_U`)
: CODE ultra-rapid GNSS orbits from the 24UT solution available until the corresponding early rapid orbit is available (to ensure a complete coverage of orbits even if the early rapid solution is delayed after the first ultra-rapid solution of the day)

`COD0OPSULT_yyyyddd0000_01D_01D_ERP.ERP` (old: `CODwwwwd.ERP_U`)
: CODE ultra-rapid ERPs belonging to the above ultra-rapid GNSS orbits

The CODE ultra-rapid products are provided with static filenames containing the latest results.

Result files for CODE 5-day GNSS *orbit predictions*
available at `ftp://ftp.aiub.unibe.ch/CODE`

`COD0OPSPRD_05D.SP3` (old: `COD.EPH_5D`)
: CODE 5-day GNSS orbit predictions

`COD0OPSPRD_yyyyddd0000_05D_05M_ORB.SP3` (old: `CODwwwwd.EPH_5D`)
: CODE 5-day GNSS orbit predictions

`COD0OPSPRD_yyyyddd0000_21D_06H_ERP.ERP` (old: `CODwwwwd.ERP_5D`)
: CODE predicted ERPs belonging to the predicted orbits

Note, that as soon as a final product is available the corresponding rapid, ultra-rapid, or predicted products are removed from the anonymous FTP server.

Table 2: CODE's rapid products available through anonymous ftp.

CODE *early rapid* products: GPS+GLONASS+Galileo; third day of a 72-hour solution
available at `ftp://ftp.aiub.unibe.ch/CODE`

`COD0OPSRAP_yyyyddd0000_01D_05M_ORB.SP3` (old: `CODwwwwd.EPH_R`)
CODE early rapid GNSS orbits with 5 minutes sampling

`COD0OPSRAP_yyyyddd0000_01D_01D_ERP.ERP` (old: `CODwwwwd.ERP_R`)
CODE early rapid ERPs belonging to the early rapid orbits

`COD0OPSRAP_yyyyddd0000_01D_30S_CLK.CLK` (old: `CODwwwwd.CLK_R`)
`COD0OPSRAP_yyyyddd0000_01D_30S_CLK.CLK_V2`
CODE GNSS clock product related to the early rapid orbit, clock RINEX format (versions 3.04 and 2.00)

`COD0OPSRAP_yyyyddd0000_01D_01H_TRO.TRO` (old: `CODwwwwd.TRO_R`)
CODE rapid troposphere product, troposphere SINEX format

`COD0OPSRAP_yyyyddd0000_01D_01D_SOL.SNX` (old: `CODwwwwd.SNX_R.Z`)
SINEX file from the CODE rapid solution containing station coordinates, ERPs, and satellite antenna Z-offsets, SINEX format

`COD0OPSRAP_yyyyddd0000_01D_02H_TRO.SNX` (old: `CODwwwwd_TRO.SNX_R.Z`)
CODE rapid solution, as above but with troposphere parameters for selected sites, SINEX format

`COD0OPSRAP_yyyyddd0000_01D_01D_OSB.BIA`
Code/phase biases related to the early rapid orbit and clock corrections, Bias-SINEX format
Note: Integer-cycle clocks in conjunction with accompanying code/phase biases enable PPP-AR (ftp://ftp.aiub.unibe.ch/CODE/IAR_README.TXT)

`COD0OPSRAP_yyyyddd0000_01D_30S_ATT.OBX`
Satellite attitude, ORBEX format

CODE *final rapid* products: GPS+GLONASS+Galileo; middle day of a long-arc solution
where the rapid observations were completed by a subsequent ultra-rapid dataset
available at `ftp://ftp.aiub.unibe.ch/CODE`

`CODMOPSRAP_yyyyddd0000_01D_05M_ORB.SP3` (old: `CODwwwwd.EPH_M`)
CODE final rapid GNSS orbits with 5 minutes sampling

`CODMOPSRAP_yyyyddd0000_01D_01D_ERP.ERP` (old: `CODwwwwd.ERP_M`)
CODE final rapid ERPs belonging to the final rapid orbits

`CODMOPSRAP_yyyyddd0000_01D_30S_CLK.CLK` (old: `CODwwwwd.CLK_M`)
`CODMOPSRAP_yyyyddd0000_01D_30S_CLK.CLK_V2`
CODE GNSS clock product related to the final rapid orbit, clock RINEX format (versions 3.04 and 2.00)

`CODMOPSRAP_yyyyddd0000_01D_01D_OSB.BIA`
Code/phase biases related to the final rapid orbit and clock corrections, Bias-SINEX format
Note: Integer-cycle clocks in conjunction with accompanying code/phase biases enable PPP-AR (ftp://ftp.aiub.unibe.ch/CODE/IAR_README.TXT)

Note, that as soon as a final product is available the corresponding rapid, ultra-rapid, or predicted products are removed from the anonymous FTP server.

Table 2: CODE's rapid products available through anonymous ftp (continued).

Result files for CODE *rapid ionosphere* solution
available at ftp://ftp.aiub.unibe.ch/CODE

`COD0OPSRAP_yyyyddd0000_01D_01H_GIM.INX.gz` (old: `CORGddd0.yyI`)
CODE rapid ionosphere product, IONEX format
`COD0OPSRAP_yyyyddd0000_01D_01H_GIM.ION` (old: `CODwwwwd.ION_R`)
CODE rapid ionosphere product, Bernese format
`COD0OPSRAP_yyyyddd0000_01D_01D_GIM.RNX` (old: `CGIMddd0.yyN_R`)
Improved Klobuchar-style coefficients based on CODE rapid ionosphere product, RINEX format

`COD0OPSPRD_yyyyddd0000_01D_01H_GIM.INX.gz` (old: `COPGddd0.yyI`)
CODE ionosphere predictions, IONEX format
`COD0OPSPRD_yyyyddd0000_01D_01H_GIM.ION` (old: `CODwwwwd.ION_P`)
CODE ionosphere predictions, Bernese format
`COD0OPSPRD_yyyyddd0000_01D_01D_GIM.RNX` (old: `CGIMddd0.yyN_P`)
Predictions of improved Klobuchar-style coefficients, RINEX format

Result files for CODE *bias product* generation
available at ftp://ftp.aiub.unibe.ch/CODE

`P1C1.DCB`	CODE sliding 30-day P1−C1 DCB solution, Bernese format, containing only the GPS satellites
`P1P2.DCB`	CODE sliding 30-day P1−P2 DCB solution, Bernese format, containing the GPS and GLONASS satellites
`P1P2_ALL.DCB`	CODE sliding 30-day P1−P2 DCB solution, Bernese format, containing the GPS and GLONASS satellites and all stations used
`P1P2_GPS.DCB`	CODE sliding 30-day P1−P2 DCB solution, Bernese format, containing only the GPS satellites
`P1C1_RINEX.DCB`	CODE sliding 30-day P1−C1 DCB values directly extracted from RINEX observation files, Bernese format, containing the GPS and GLONASS satellites and all stations used
`P2C2_RINEX.DCB`	CODE sliding 30-day P2−C2 DCB values directly extracted from RINEX observation files, Bernese format, containing the GPS and GLONASS satellites and all stations used
`CODE.DCB`	Combination of `P1P2.DCB` and `P1C1.DCB`
`CODE_FULL.DCB`	Combination of `P1P2.DCB`, `P1C1.DCB` (GPS satellites), `P1C1_RINEX.DCB` (GLONASS satellites), and `P2C2_RINEX.DCB`
`CODE.BIA`	Same content but stored as OSBs in the Bias SINEX format
`CODE_MONTHLY.BIA`	Cumulative monthly OSB solution in Bias SINEX format

Note, that as soon as a final product is available the corresponding rapid, ultra-rapid, or predicted products are removed from the anonymous FTP server.

Table 3: CODE's final products available through anonymous ftp.

CODE *final* products available at ftp://ftp.aiub.unibe.ch/CODE/yyyy/

`COD0OPSFIN_yyyyddd0000_01D_05M_ORB.SP3.gz` (old: `CODwwwwd.EPH.Z`)
: CODE final GPS+GLONASS+Galileo orbits

`COD0OPSFIN_yyyyddd0000_01D_01D_ERP.ERP.gz` (old: `CODwwwwd.ERP.Z`)
: CODE final ERPs belonging to the final orbits

`COD0OPSFIN_yyyyddd0000_01D_30S_CLK.CLK.gz` (old: `CODwwwwd_v3.CLK.Z`)
`COD0OPSFIN_yyyyddd0000_01D_30S_CLK.CLK_V2.gz` (old: `CODwwwwd.CLK.Z`)
: CODE final clock product, clock RINEX format (versions 3.04 and 2.00), with a sampling of 30 sec for the GNSS satellite and reference (station) clock corrections and 5 minutes for all other station clock corrections

`COD0OPSFIN_yyyyddd0000_01D_05S_CLK.CLK.gz` (old: `CODwwwwd_v3.CLK_05.Z`)
`COD0OPSFIN_yyyyddd0000_01D_05S_CLK.CLK_V2.gz` (old: `CODwwwwd.CLK_05S.Z`)
: CODE final clock product, clock RINEX format (versions 3.04 and 2.00), with a sampling of 5 sec for the GNSS satellite and reference (station) clock corrections and 5 minutes for all other station clock corrections

`COD0OPSFIN_yyyyddd0000_01D_01D_OSB.BIA.gz` (old: `CODwwwwd.BIA.Z`)
: CODE daily code and phase bias solution corresponding to the above mentioned clock products, bias SINEX format v1.00
See `ftp://ftp.aiub.unibe.ch/CODE/IAR_README.TXT` for the usage of the phase biases.

`COD0OPSFIN_yyyyddd0000_01D_30S_ATT.OBX.gz` (old: `CODwwwwd.OBX.Z`)
: Satellite attitude information in ORBEX format

`COD0OPSFIN_yyyyddd0000_01D_01D_SOL.SNX.gz` (old: `CODwwwwd.SNX.Z`)
: CODE daily final solution, SINEX format

`COD0OPSFIN_yyyyddd0000_01D_01H_TRO.TRO.gz` (old: `CODwwwwd.TRO.Z`)
: CODE final troposphere product, troposphere SINEX format

`COD0OPSFIN_yyyyddd0000_01D_01H_GIM.INX.gz` (old: `CODGddd0.yyI.Z`)
: CODE final ionosphere product, IONEX format

`COD0OPSFIN_yyyyddd0000_01D_01H_GIM.ION.gz` (old: `CODwwwwd.ION.Z`)
: CODE final ionosphere product, Bernese format

`COD0OPSFIN_yyyyddd0000_01D_01D_GIM.RNX.gz` (also still available: `CGIMddd0.yyN.Z`)
: Improved Klobuchar-style ionosphere coefficients, navigation RINEX format

`COD0OPSFIN_yyyyddd0000_07D_07D_SOL.SNX.gz` (old: `CODwwww7.SNX.Z`)
: CODE weekly final solution, SINEX format (only for Sunday of the related week)

`COD0OPSFIN_yyyyddd0000_07D_01D_ERP.ERP.gz` (old: `CODwwww7.ERP.Z`)
: Collection of the 7 daily CODE-ERP solutions of the week (only for Sunday of the related week)

`COD0OPSFIN_yyyyddd0000_07D_01D_SUM.SUM.gz` (old: `CODwwww7.SUM.Z`)
: CODE weekly summary file (only for Sunday of the related week)

CODE *final bias* products available at ftp://ftp.aiub.unibe.ch/CODE/yyyy/

`P1C1yymm.DCB.Z`	CODE monthly P1−C1 DCB solution, Bernese format, containing only the GPS satellites
`P1P2yymm.DCB.Z`	CODE monthly P1−P2 DCB solution, Bernese format, containing the GPS and GLONASS satellites
`P1P2yymm_ALL.DCB.Z`	CODE monthly P1−P2 DCB solution, Bernese format, containing the GPS and GLONASS satellites and all stations used
`P1C1yymm_RINEX.DCB.Z`	CODE monthly P1−C1 DCB values directly extracted from RINEX observation files, Bernese format, containing the GPS and GLONASS satellites and all stations used
`P2C2yymm_RINEX.DCB.Z`	CODE monthly P2−C2 DCB values directly extracted from RINEX observation files, Bernese format, containing the GPS and GLONASS satellites and all stations used

Table 4: CODE's MGEX products available through anonymous ftp.

CODE *MGEX* products available at ftp://ftp.aiub.unibe.ch/CODE_MGEX/CODE/yyyy/

`CODOMGXFIN_yyyyddd0000_01D_05M_ORB.SP3.gz` (old: `COMwwwwd.EPH.Z`)
: CODE MGEX final GNSS orbits for GPS, GLONASS, Galileo, BeiDou, and QZSS satellites, SP3 format

`CODOMGXFIN_yyyyddd0000_01D_12H_ERP.ERP.gz` (old: `COMwwwwd.ERP.Z`)
: CODE MGEX final ERPs belonging to the MGEX final orbits

`CODOMGXFIN_yyyyddd0000_01D_30S_CLK.CLK.gz` (old: `COMwwwwd_v3.CLK.Z`)
(old: `COMwwwwd.CLK.Z` version 2.00)
: CODE MGEX final clock product consistent to the MGEX final orbits, clock RINEX format (version 3.04), with a sampling of 30 sec for the GNSS satellite and reference (station) clock corrections and 5 minutes for all other station clock corrections

`CODOMGXFIN_yyyyddd0000_01D_01D_OSB.BIA.gz` (old: `COMwwwwd.BIA.Z`)
: GNSS code and phase (GPS and Galileo only) biases related to the MGEX final clock correction product, bias SINEX format v1.00
See `ftp://ftp.aiub.unibe.ch/CODE/IAR_README.TXT` for the usage of the phase biases.

`CODOMGXFIN_yyyyddd0000_01D_30S_ATT.OBX.gz` (old: `COMwwwwd.OBX.Z`)
: Satellite attitude information in ORBEX format

Table 5: CODE final products available in the product areas of the IGS data centers.

Files generated from three–day long–arc solutions:

`CODOOPSFIN_yyyyddd0000_01D_05M_ORB.SP3.gz` (old: `codwwwwd.eph.Z`)
: GNSS ephemeris/clock data in daily files at 15–min intervals in SP3 format, including accuracy codes computed from a long–arc analysis

`CODOOPSFIN_yyyyddd0000_01D_01D_ERP.ERP.gz` (old: `codwwwwd.erp.Z`)
: GNSS ERP (pole, UT1−UTC) solution belonging to the COD–orbit files in IGS IERS ERP format

`CODOOPSFIN_yyyyddd0000_01D_01D_SOL.SNX.gz` (old: `codwwwwd.snx.Z`)
: GNSS daily coordinates/ERP/GCC from the long–arc solution in SINEX format

`CODOOPSFIN_yyyyddd0000_01D_30S_CLK.CLK.gz` (old: `codwwwwd_v3.clk.Z`)
`CODOOPSFIN_yyyyddd0000_01D_30S_CLK.CLK_V2.gz` (old: `codwwwwd.clk.Z`)
: GNSS satellite and receiver clock corrections at 30–sec intervals referring to the COD–orbits from the long–arc analysis in clock RINEX format (versions 3.04 and 2.00)

`CODOOPSFIN_yyyyddd0000_01D_05S_CLK.CLK.gz` (old: `codwwwwd_v3.clk_05s.Z`)
`CODOOPSFIN_yyyyddd0000_01D_05S_CLK.CLK_V2.gz` (old: `codwwwwd.clk_05s.Z`)
: GNSS satellite and receiver clock corrections at 5–sec intervals referring to the COD–orbits from the long–arc analysis in clock RINEX format (versions 3.04 and 2.00)

`CODOOPSFIN_yyyyddd0000_01D_01D_OSB.BIA.gz` (old: `codwwwwd.bia.Z`)
: CODE daily code and phase bias solution corresponding to the above mentioned clock products

`CODOOPSFIN_yyyyddd0000_01D_30S_ATT.OBX.gz` (old: `codwwwwd.obx.Z`)
: Satellite attitude information in ORBEX format

`CODOOPSFIN_yyyyddd0000_01D_01H_TRO.TRO.gz` (old: `codwwwwd.tro.Z`)
: GNSS 2–hour troposphere delay estimates obtained from the long–arc solution in troposphere SINEX format

`CODOOPSFIN_yyyyddd0000_07D_01D_ERP.ERP.gz` (old: `codwwww7.erp.Z`)
: GNSS ERP (pole, UT1−UTC) solution, collection of the 7 daily COD–ERP solutions of the week in IGS IERS ERP format

`CODOOPSFIN_yyyyddd0000_07D_01D_SUM.SUM.gz` (old: `codwwww7.sum`)
: Analysis summary for 1 week

Note that the `COD`–series is identical with the files posted at the CODE's aftp server, see Table 3.

Table 5: CODE final products available in the product areas of the IGS data centers (continued).

Other product files (not available at all data centers):

`CODOOPSFIN_yyyyddd0000_01D_01H_GIM.INX.gz` (old: `CODGddd0.yyI.Z`)
: GNSS hourly global ionosphere maps in IONEX format, including satellite and receiver P1−P2 code bias values

`CODNOPSFIN_yyyyddd0000_01D_01H_GIM.INX.gz` (old: `CKMGddd0.yyI.Z`)
: GNSS daily Klobuchar-style ionospheric (alpha and beta) coefficients in IONEX format

`CODKOPSFIN_yyyyddd0000_01D_01H_GIM.INX.gz` (old: `GPSGddd0.yyI.Z`)
: Klobuchar-style ionospheric (alpha and beta) coefficients from GPS navigation messages represented in IONEX format

Table 6: CODE MGEX products available in the product areas of the IGS data centers.

Files generated from three–day long–arc MGEX solutions:

`COD0MGXFIN_yyyyddd0000_01D_05M_ORB.SP3.gz`
: CODE MGEX final GNSS orbits for GPS, GLONASS, Galileo, BeiDou, and QZSS satellites, SP3 format

`COD0MGXFIN_yyyyddd0000_01D_12H_ERP.ERP.gz`
: CODE MGEX final ERPs belonging to the MGEX final orbits

`COD0MGXFIN_yyyyddd0000_01D_30S_CLK.CLK.gz`
: CODE MGEX final clock product consistent to the MGEX final orbits, clock RINEX 3.04 format, with a sampling of 30 sec for the GNSS satellite and reference (station) clock corrections and 5 minutes for all other station clock corrections

`COD0MGXFIN_yyyyddd0000_01D_01D_OSB.BIA.gz`
: GNSS code and phase (GPS and Galileo only) biases related to the MGEX final clock correction product, Bias SINEX format v1.00

`COD0MGXFIN_yyyyddd0000_01D_30S_ATT.OBX.gz`
: Satellite attitude information in ORBEX format

Note that the `COD`-MGEX-series is identical with the files posted at the CODE's aftp server, see Table 4.

Referencing of the products

The products from CODE have been registered and should be referenced as:

- Dach, R., S. Schaer, D. Arnold, E. Brockmann, M. Kalarus, M. Lasser, P. Stebler, A. Jaeggi (2024). *CODE final product series for the IGS*. Published by Astronomical Institute, University of Bern. URL: https://www.aiub.unibe.ch/download/CODE; DOI: 10.48350/197025.
- Dach, R., S. Schaer, D. Arnold, E. Brockmann, M. Kalarus, M. Lasser, P. Stebler, A. Jaeggi (2024). *CODE rapid product series for the IGS*. Published by Astronomical Institute, University of Bern. URL: `https://www.aiub.unibe.ch/download/CODE`; DOI: 10.48350/197026.
- Dach, R., S. Schaer, D. Arnold, E. Brockmann, M. Kalarus, M. Lasser, P. Stebler, A. Jaeggi (2024). *CODE ultra-rapid product series for the IGS*. Published by Astronomical Institute, University of Bern. URL: `https://www.aiub.unibe.ch/download/CODE`; DOI: 10.48350/197027.
- Dach, R., S. Schaer, D. Arnold, E. Brockmann, M. Kalarus, M. Lasser, P. Stebler, A. Jaeggi (2024). *CODE product series for the IGS MGEX project*. Published by Astronomical Institute, University of Bern. URL: `https://www.aiub.unibe.ch/download/CODE_MGEX`; DOI: 10.48350/197028.

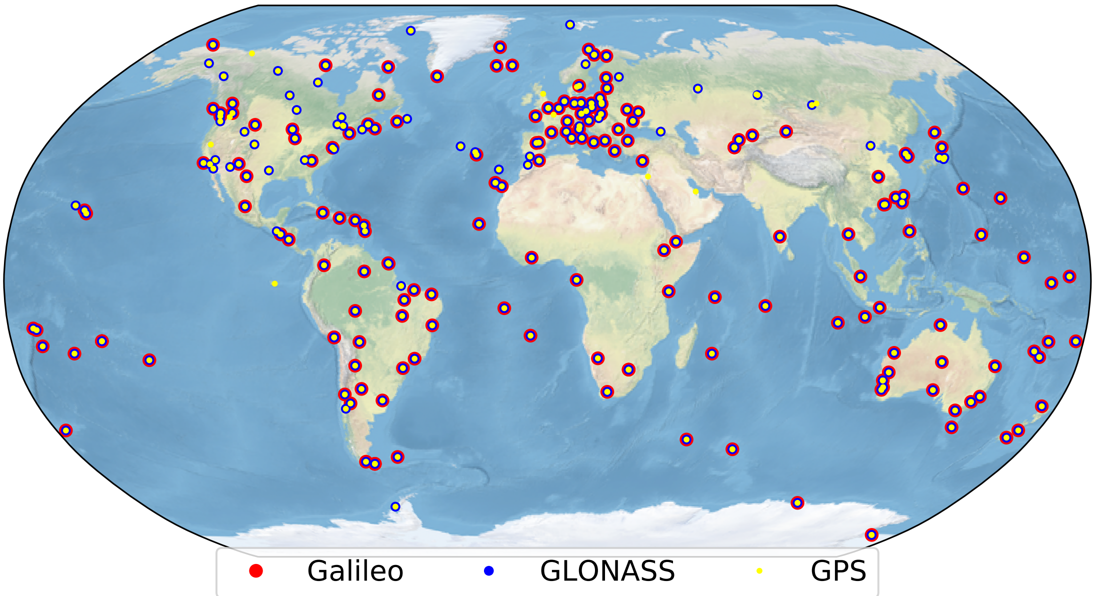
3 Statistics on the CODE solution

3.1 Selected general statistics

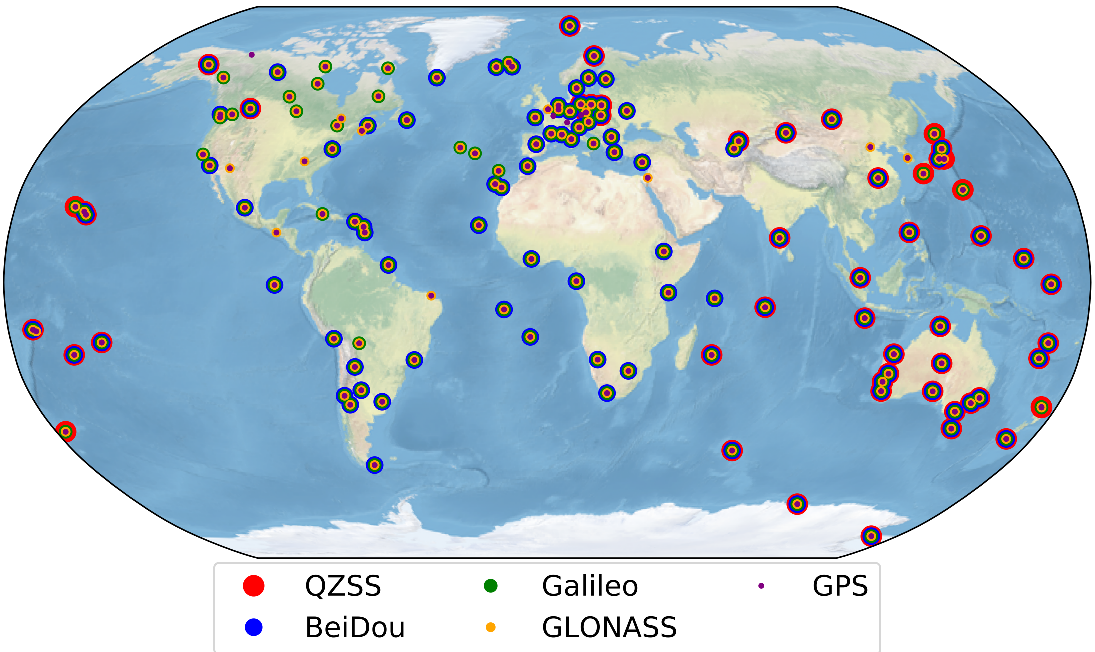
The network used by CODE for the final and MGEX processing is shown in Figure 1.

The development of the included satellite systems in the CODE solution is illustrated in Figure 2. Since May 2003 CODE is generating all its products for the IGS legacy series based on a combined GPS and GLONASS solution. Since 2012 the MGEX solution from CODE contains Galileo satellites and with beginning of 2014 also the satellites from the Asian systems BeiDou and QZSS. In March 2021, the BeiDou 3 constellation was added to the processing. For that reason a jump in the number of processed BeiDou satellites appears in the plot. End of 2024, the MGEX solution includes about 122 satellites of five satellite systems.

Figure 3 provides two key performance indicators for the CODE final products series: orbit misclosures at midnight (left panels) and the performance of the satellite clock (right panels) as the RMS of a linear fit through the values with a sampling of 30 s per day. Separate plots for the three constellations in the CODE solution (GPS, GLONASS, and Galileo) are provided.



(a) final solution (more than 250 stations)



(b) MGEX solution (more than 140 stations)

Figure 1: Network used for the processing at CODE by the end of 2024.

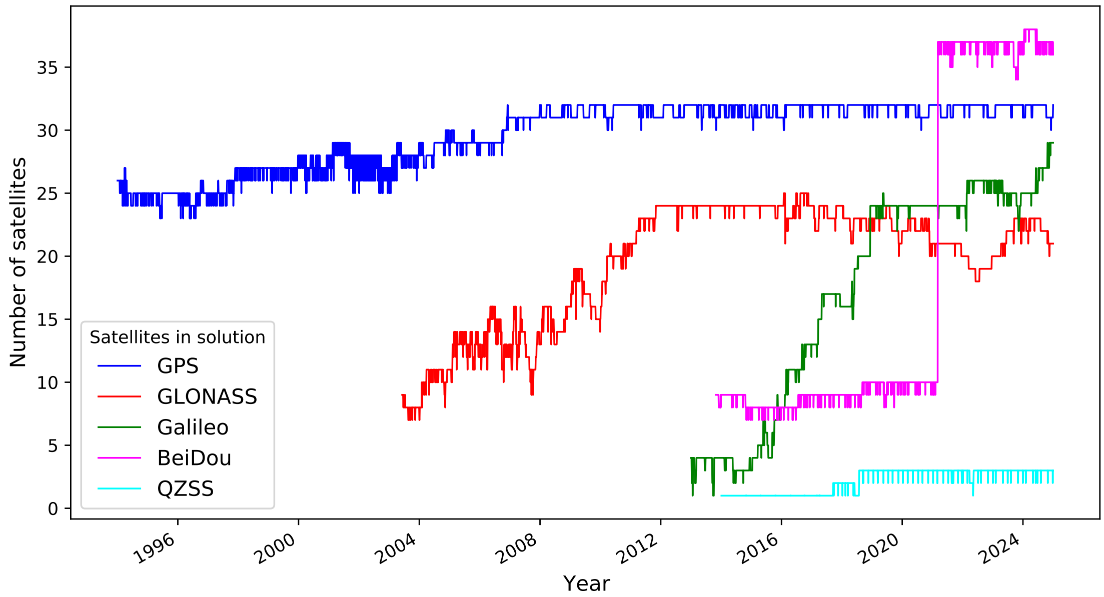
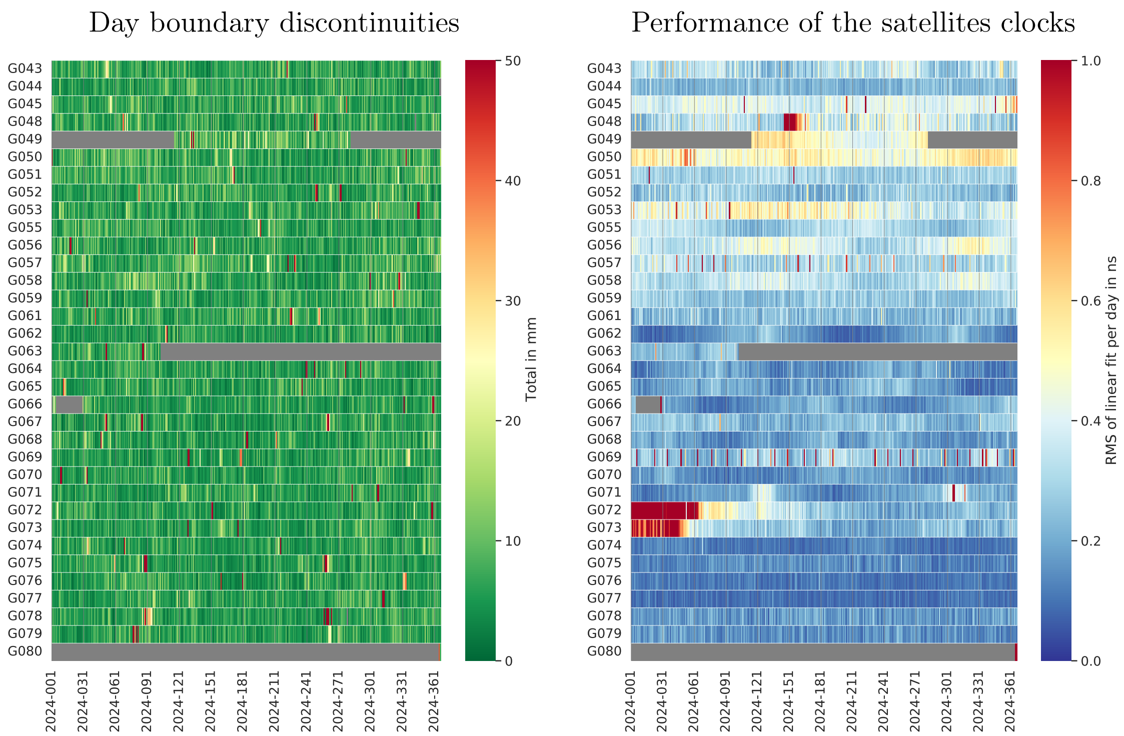
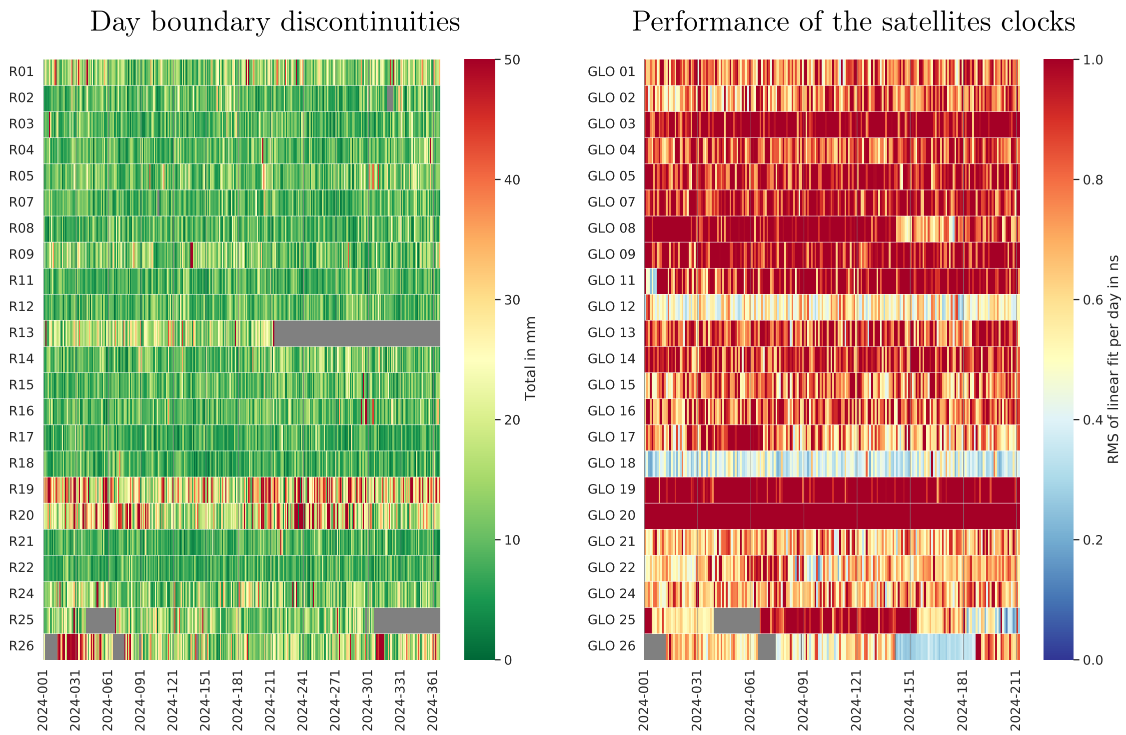


Figure 2: Development of the number of satellites in the CODE orbit products.

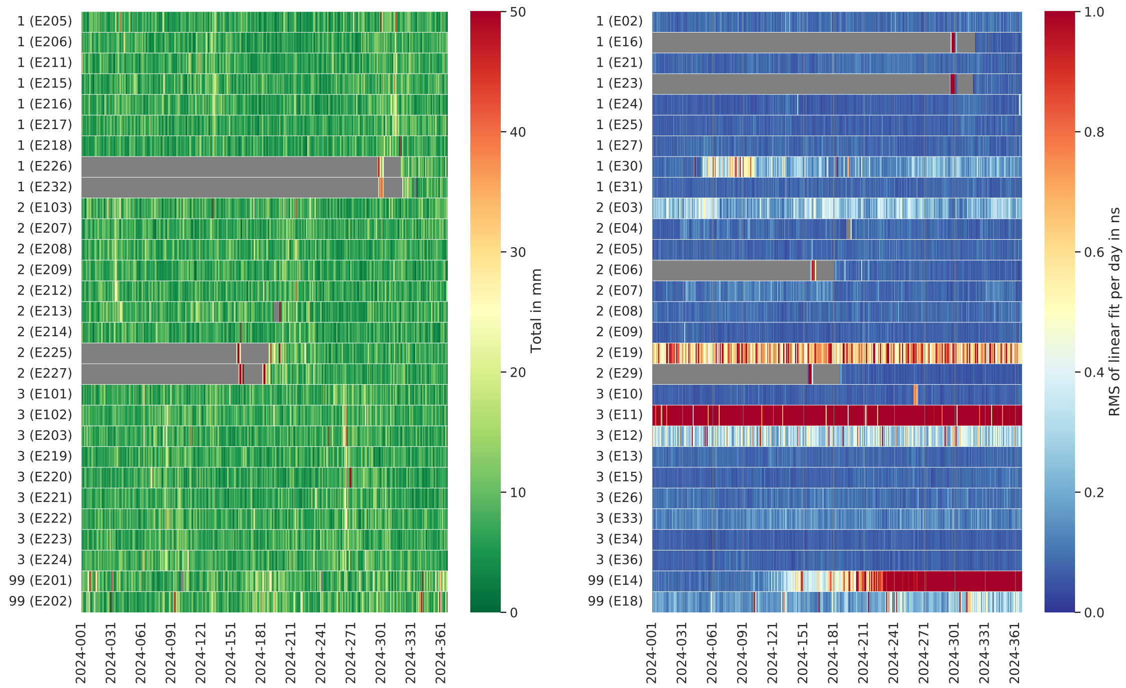


GPS constellation, sorted with respect to the SVN

Figure 3: Performance overview of the CODE three-day solution in 2024.



GLONASS constellation, sorted with respect to the slot numbers



Galileo constellation, sorted by PRN sorted by the orbital planes

Figure 3: Performance overview of the CODE three-day solution in 2024; continued.

The grey areas in the plots indicate periods where the related satellites are not active. The latest GPS satellite (SVN G80) became active within the last days of 2024 and was immediately included into the processing. Also the newly launched Galileo satellites emit first navigation signals for a few days before they are finally activated (e.g., E28 and E32 or E25 and E27). This is a characteristics of the CODE processing scheme that the satellites are included as soon as signals are tracked disregarding the health status.

The performance of the GPS satellite clocks is continuously increasing with the later satellite generations. On the other hand, the Galileo satellite clocks show in general an excellent performance. Nevertheless there are a number of satellites with a limited performance (e.g., the IOV satellites E11, E12, and E19). Also one of the two satellites in the elliptical orbit (E14) has a degraded performance since Summer 2024. The satellite orbit overlaps do not reflect the same development of performance which indicates that these are effects related to the performance of the satellite clock and not in the processing of the CODE analysis center. The discontinuities in the orbits between subsequent days is in general below 5 mm for GPS, at the level of 10 mm to 15 mm for GLONASS and below 10 mm for Galileo. In case of Galileo, the shadow periods show a slight degradation of the orbit quality parameter.

4 Changes in the daily processing for the IGS

The CODE processing scheme for daily IGS analyses is constantly subject to updates and improvements. The changes of the previous year 2023 were published in the last technical report in Dach et al. (2024).

In Section 4.1 we give an overview of important development steps in the year 2024.

4.1 Overview of changes in the processing scheme in 2024

Table 7 gives an overview of the major changes implemented during the year 2024. Details on the analysis strategy can be found in the IGS analysis questionnaire at the IGS Central Bureau (`https://files.igs.org/pub/center/analysis/code.acn`).

Several other improvements not listed in Table 7 were implemented, too. Those mainly concern data download and management, sophistication of CODE's analysis strategy, software changes (improvements), and many more. As these changes are virtually not relevant for users of CODE products, they will not be detailed on any further.

Table 7: Selected events and modifications of the CODE processing during 2024.

Date	DoY/Year	Description
26-Jan-2024	026/2024	Force a Galileo-only network prior the general network creation.
12-Apr-2024	103/2024	Disabled G01 after 13 yrs operation (SVN 63 and activated SVN 49 some days later).
01-May-2024	122/2024	CLK solution MGEX including widelane AR for BDS and QZSS.
14-May-2024	135/2024	Solutions strongly affected due to high geomagnatic activity.
10-Jun-2024	162/2024	Update of the Rocky Linux OS.
26-Aug-2024	239/2024	AU modified from 149597870691.D0 to 149597870700.D0 (impact < 0.1 mm on orbits).
21-Sep-2024	265/2024	Activation Gravity model derived from COST-G service COSTG_FSM_2309, where 2309 indicates that the coefficients have been fitted with data up to September 2023).
21-Oct-2024	295/2024	Activation Gravity model derived from COST-G service COSTG_FSM_2406, where 2406 indicates that the coefficients have been fitted with data up to June 2024).

4.2 BDS-3 / QZSS satellite antenna calibration campaign

In order to develop a fully multi-GNSS IGS product, several IGS ACs joined the activity to estimate improved BeiDou and QZSS antenna offsets and satellite antenna phase center corrections which are compatible with the IGS20 reference frame. In spring 2024, CODE participated in step 1 of this activity by deriving phase variation patterns for the BDS-3 satellites using the B1C/B2a frequency combination (and neglecting BDS-2 satellites). These values were derived from a one-year reprocessing using the MGEX processing chain. Daily solutions were accumulated to weekly solutions and an annual solution. The repeatability of the estimated antenna phase center variations with respect to the annual solution is shown for an arbitrary selected satellite in Figure 4, as well as the annual mean estimates for the CAST satellites.

Steigenberger et al. (2024) combined six AC contributions to an updated antenna model for each BeiDou satellite type (CAST, SECM-A, SECM-B, IGSO). This product was then used to derive in a second step the BeiDou and QZSS antenna offsets using frequencies B1C/B2a and L1C/L5, respectively. For the second step three years of data were reprocessed and results (daily SINEX file) were submitted mid of December 2024, again based on the MGEX processing chain.

The results of the combination of eight contributing ACs (Rebischung, 2024) are currently under discussion. CODE intends to integrate the BeiDou and QZSS system to the legacy products after analyzing the impact of such an enhancement in further detail.

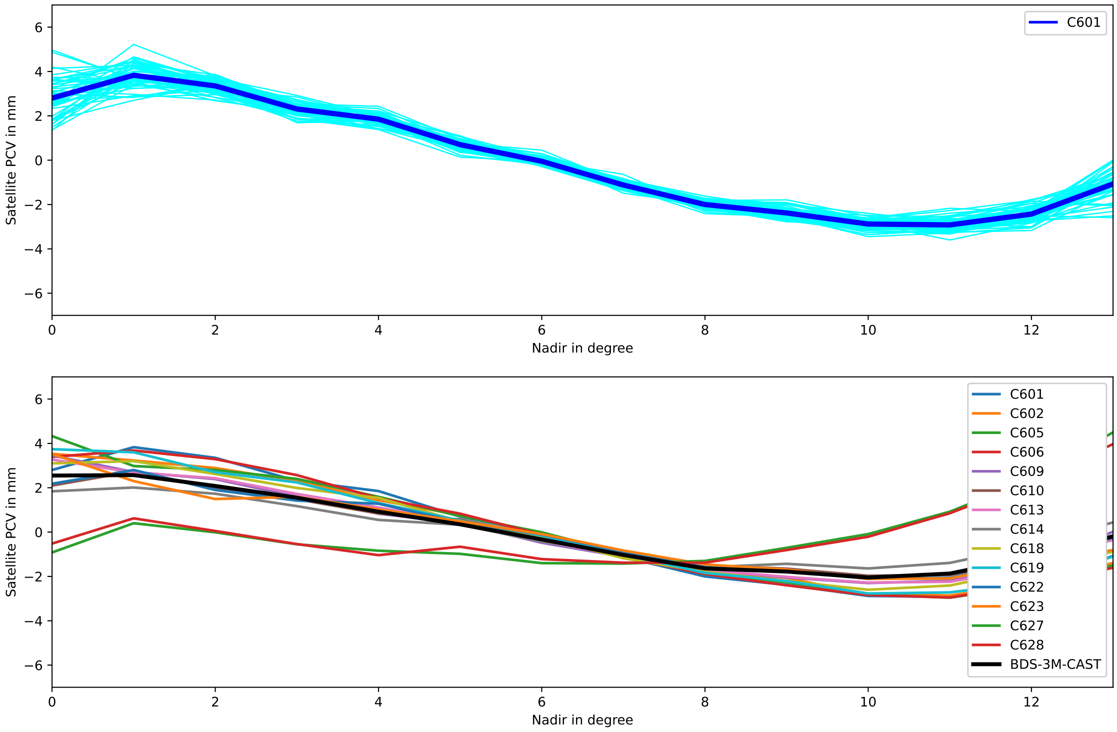


Figure 4: Antenna phase center variations derived from weekly solutions (in cyan) and the averaged value (in blue) for BeiDou satellite C19 (601, type CAST). Below, annual averages of the antenna phase center variations of the BeiDou CAST satellites.

4.3 Geocenter handling in global GNSS solutions

The recommendations for the "IGS Reference Frame Maintenance" from the IGS Workshop 2004 state:

- All IGS satellite clocks should be in ITRF center of network.
- Using IGS prodcuts for PPP shall provide coordinates in the ITRF realization.

The ITRF is a center-of-figure (CoF) based frame to obtain coordinates on the Earth surface that are not influenced by temporal changes of the origin of the reference frame. Nevertheless, the discussion on center-of-mass (CoM) based GNSS satellite clock solutions for IGS products came up, in particular for orbit determination purposes.

In order to implement the recommendations, the IGS solution at CODE Analysis Center is done by forcing the orbit and clock solution to the CoF – meaning to the current IGS/ITRF reference frame. This is of course not the perfect setup for orbit modelling because the satellites are flying around the instantaneous CoM. In order to assess the impact of this model deficiency, two solutions have been created based on CODE's rapid processing scheme for the days 180 to 189 in year 2023: once the solution was generated as usual, referring to the origin (CoF solution) and alternatively, the translation vector from the ITRF2020 geocenter motion model was considered when the coordinates are introduced for the datum definition (CoM solution). In both cases the datum definition was realized via an NNR and NNT condition on a verified list of stations with respect to the IGS20 frame.

A comparison of the two solutions shows:

- Station coordinates in IGS20 frame agree on an RMS level of < 0.5 mm without applying any transformation parameters
- Satellite positions agree in the IGS20 frame as well by < 1 mm RMS without the estimation of transformation parameters
- In the Earth centered inertial frame the satellite positions agree on the $5 \ldots 7$ mm level RMS with translations of about 2.2 mm in the Z-component and no translation in the X- and Y-components. They do not reflect the translation introduced into the datum definition.
- When comparing the satellite clock corrections between the CoF- and CoM-based solutions, systematic effects with the satellite revolution period appears (see Figure 5 showing the differences for selected Galileo satellites from the same orbital plane but with antipodal location in the constellation). The satellite clock differences can be translated into geocenter coordinates: $\mathrm{GCC}_X = 0.7$ mm, $\mathrm{GCC}_Y = 3.5$ mm, $\mathrm{GCC}_Z = 2.6$ mm. The introduced geocenter translation vector agrees well with $\mathrm{GCC}_X = 0.5$ mm, $\mathrm{GCC}_Y = 3.2$ mm, $\mathrm{GCC}_Z = 3.2$ mm (at least for the X and Y components).

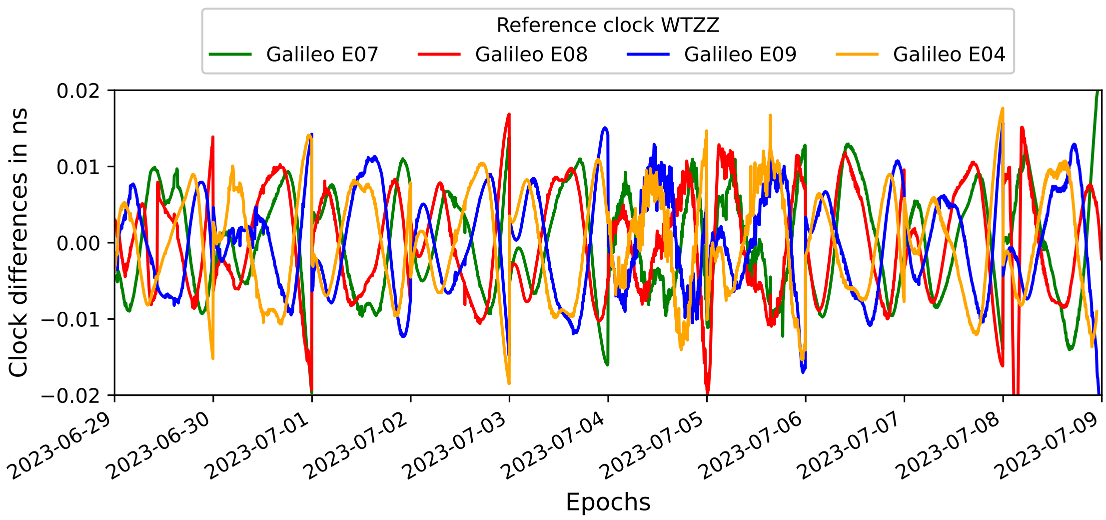


Figure 5: Differences between the satellite clock corrections between the CoF- and CoM-based solution for selected Galileo satellites.

This means that the satellite clock corrections do completely absorb the Geocenter corrections meaning that the satellite orbit modelling takes place in a CoM-based frame that is inherently realized by the GNSS solution – independent from the datum definition with respect to a CoF- or CoM-based frame.

Such a strong correlation between satellite clock corrections and the geocenter vector is only valid for an IGS-style estimation of GNSS satellite orbit and clock corrections. For instance, in the context of orbit determination for Low Earth Orbiting satellites (LEOs) the receiver clock cannot absorb the CoM variations because the observations are distributed down to the horizon (and not only to a nadir angle of 14° like for GNSS satellites).

The geocenter vector as it is established in the GNSS solution is typically degraded by orbit modelling effect – in particular the Z component. For that reason the inherent geocenter vector from the GNSS solution should be obtained and exchanged by a more realistic one for applications like LEO orbit determination. This can be done by estimating a geocenter translation vector in the orbit determination process. That also this vector is absorbed by the satellite clocks is demonstrated in Figure 6. The difference in the satellite clock correction between a solution with estimating the geocenter translation vector and without can be translated into a geocenter vector again, that agrees very well with the estimated one.

This allows for the following procedure to consider the CoM in a GNSS orbit solution assuming that the clock parameter are pre-eliminated if the geometry is computed.

1. The satellite positions are obtained in an inherent CoM-based frame. The corresponding geocenter translation vector can be estimated in the context of the orbit determination step.

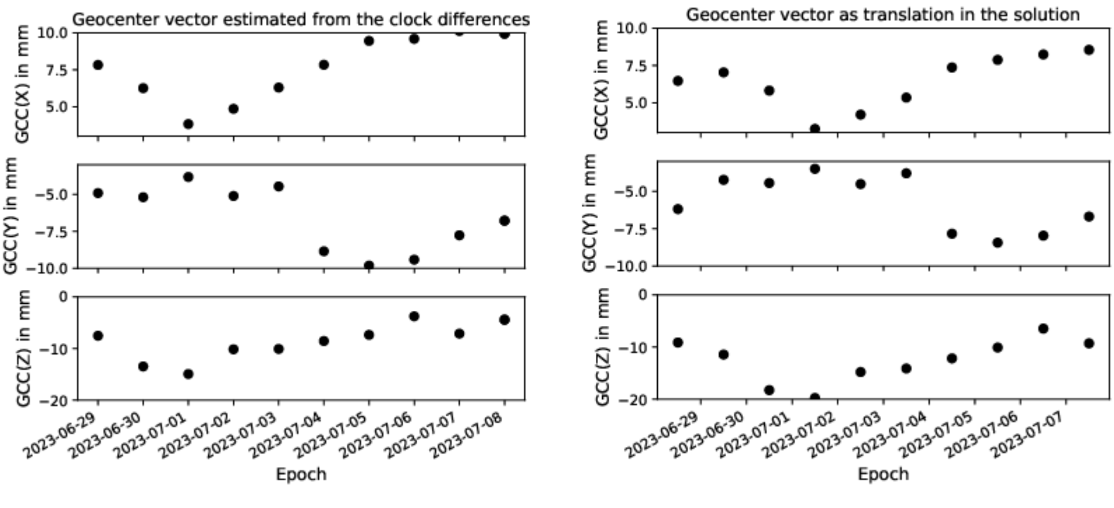


Figure 6: Comparison of the geocenter vector as obtained from the differences in the satellite clocks (left panel) and as estimated as translation parameter (right panel).

2. The satellite positions can be transformed into the CoF-based frame when correcting them by the estimated geocenter translation vector.
3. If a certain CoM modell shall be implemented to realize a CoM-based frame (e.g., for LEO orbit determination), the satellite positions can now be corrected by the related CoM vector.

After each of these operations the GNSS satellite positions can be used for the backsubstitution of the satellite and receiver clock corrections. The frame of the station coordinates defines whether a PPP application will end in a CoF- or CoM-based frame. Looking at the variations of the satellite clock parameters options 2. or 3. are minimizing the variations when applying CoF- or CoM-based station coordinates, which might for instance be interesting for modelling the satellite clocks instead of estimating them independently epoch by epoch.

5 Development of a combined Earth Orientation Parameters product at BKG

5.1 Extension of the combined Earth Rotation Parameters with SLR data

The Earth Rotation Parameters (ERPs) describe the rotation between the Terrestrial Reference Frame (TRF) and the Celestial Reference Frame (CRF) and represent an essential component of the Global Geodetic Reference Frame (GGRF).

The publicly available ERP series provided by the International Earth Rotation and Reference Systems Service (IERS), such as Bulletin A and the C04 series, are generated by combining individual technique-specific ERP solutions at the parameter level. This approach represents the least rigorous combination method, as each parameter type is combined independently and correlations between the different parameters are not taken into account.

To address these limitations, the BKG is developing a multi-technique combination strategy at the level of datum-free normal equations (NEQs). The core objective is to improve the estimation of ERPs through the use of consistent input data from multiple geodetic space techniques, currently GNSS, VLBI, and SLR. This combination ensures a homogeneous reference frame and a consistent set of estimated parameters. The NEQs of seven consecutive days are combined into one NEQ system before the datum constraints are applied, and the parameters, in particular ERPs and station coordinates, are estimated (see Figure 7). Repeating this procedure on a daily basis results in a continuous ERP series with a daily resolution and short latency of one day, which is particularly important for the highly variable parameter dUT1.

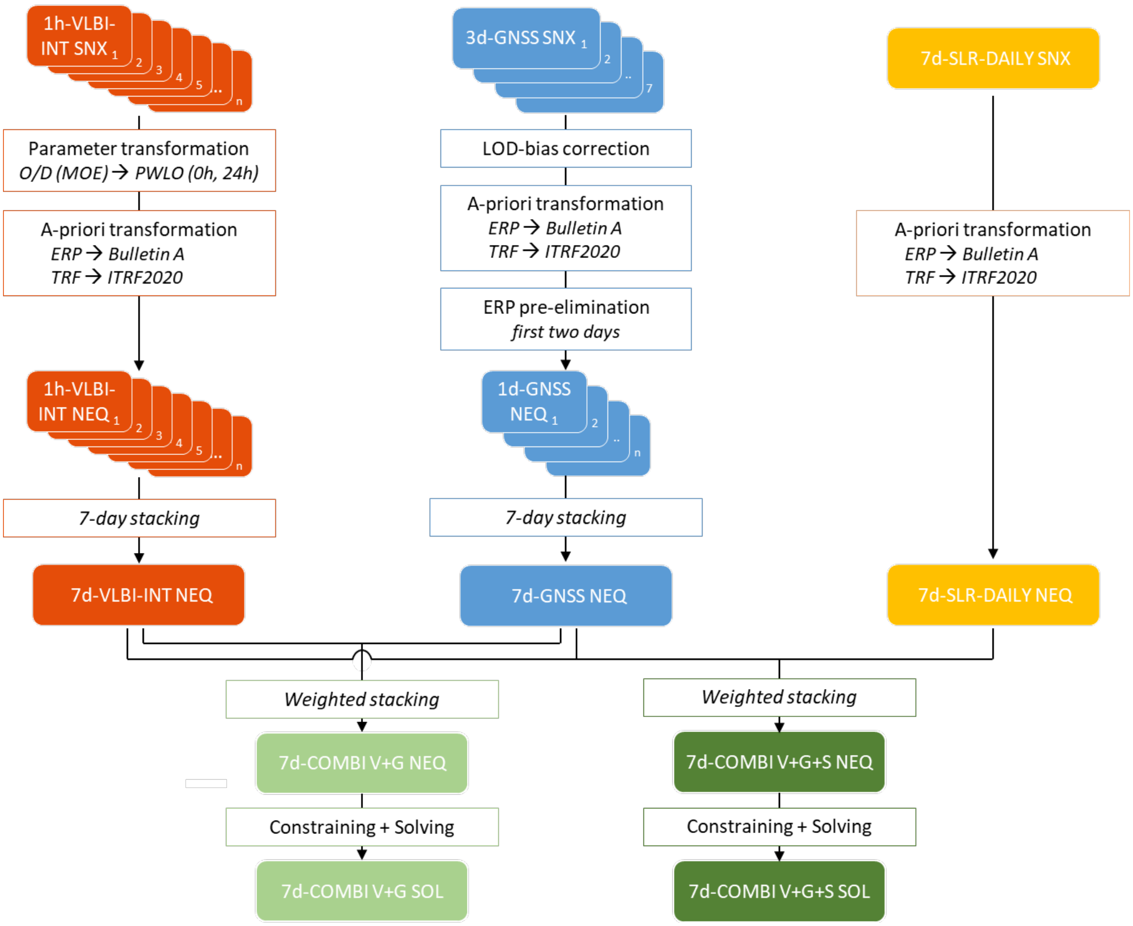


Figure 7: Flow chart of the multi-technique combinations for rapid ERP estimation including an overview of the different solutions.

Initial developments focused on the combination of GNSS and VLBI data using SINEX files from the CODE IGS Analysis Center and the BKG IVS Analysis Center. This combination led to a significant improvement in the accuracy of the resulting ERP series, particularly for dUT1, compared to individual technique-specific solutions. Detailed methodology and results are described in Lengert et al. (2021, 2022) and Klemm et al. (2024a,a).

To further enhance the combined solution, Satellite Laser Ranging (SLR) data has recently been integrated into the processing. SLR provides high-quality LOD estimates with short latency, complementing the strengths of GNSS and VLBI. With a latency of approximately one day, the SLR-DAILY product is, in principle, suitable for expanding the data basis of the short-latency ERP series, which currently relies on GNSS Rapid and VLBI Intensives data.

However, the official SLR-DAILY product of the ILRS is a 7-day solution that explicitly contains polar motion (only as constant offsets over 24 hours) and LOD, but no dUT1 parameters. Therefore, this solution is not optimal for our combination approach because the parameterization of the ERPs is not identical to that of the other techniques. To address this, BKG's in-house ILRS Analysis Center developed a tailored SLR solution that includes all required ERP components and their rates in a consistent format.

For a comprehensive validation of the combined ERP series, both internal and external comparison analyses were conducted. For the internal validation, the impact of including SLR data in the combination was evaluated by analyzing the differences between the GNSS+VLBI+SLR and GNSS+VLBI-only ERP solutions. The root mean square (RMS) values of the resulting difference time series (i.e., GNSS+VLBI minus GNSS+VLBI+SLR) serve as quantitative indicators of the contribution of SLR. For dUT1, RMS values range from 4 to 6 μs. The pole coordinates show RMS variations of 13 to 28 μs for the x-pole and 11 to 27 μs for the y-pole, depending on the day within the 7-day arc. These variations highlight the contribution of SLR data to the combined ERP solution and demonstrate its internal consistency. For external validation, the consistency of the GNSS+VLBI+SLR combined solution was evaluated by comparing it to independent reference series provided by the IERS, specifically C04 20 and Bulletin A. The comparisons were made at the midpoints of the 7-day arcs, and the weighted root mean square (WRMS) values were used as indicators of agreement. For dUT1, WRMS values of 23 μs (C04) and 11 μs (Bulletin A) were obtained. For the pole coordinates, WRMS values are 61 μs and 60 μs for the x-pole, and 42 μs and 41 μs for the y-pole, respectively. These WRMS values are similar in magnitude to those ERP series obtained from the GNSS+VLBI combination without the inclusion of SLR data.

Future work includes detailed investigations into the datum definition and weighting strategies within the combination, as well as a transition toward the fully automated operational production.

5.2 ERP prediction using GNSS products from the CODE analysis center

Accurate prediction of ERPs is vital for real-time applications in satellite orbit determination, GNSS positioning, deep space navigation, and Earth system monitoring (Śliwińska-Bronowicz et al. , 2024). While the IERS provides multi-technique combined ERP series (e.g., IERS C04, Bulletin A (finals.daily)), the operational latency and the combination strategy, based on parameter-level integration can limit both timeliness and internal consistency. To address these challenges, GNSS-derived ERP series, particularly those from the CODE Analysis Center, offer a reliable and low-latency alternative for operational ERP prediction (Modiri et al., 2024). CODE provides high-quality daily ERP solutions based solely on GNSS data, characterized by a dense temporal resolution, a consistent estimation strategy, and robust modeling using the Bernese GNSS Software. The rapid series is publicly available with a latency of only 1–2 days, making it particularly suitable for short-term ERP forecasting, especially for highly dynamic parameters such as LOD.

To evaluate the potential of CODE GNSS products specifically for LOD prediction, we applied a hybrid approach combining Singular Spectrum Analysis (SSA) to extract deterministic trends and Copula-based modeling to capture and forecast stochastic residuals (Modiri et al., 2018, 2020). Using CODE LOD data from January 2014 to December 2019 as training input, we performed sliding window forecasts across a three-year evaluation period (2020–2022), generating daily 30-day predictions.

As shown in Figure 8 (upper panel), the CODE LOD series exhibits clear seasonal and interannual variability. The lower panel presents the mean absolute errors (MAE) of the predicted LOD values. The yellow curve shows the MAE between predictions and the

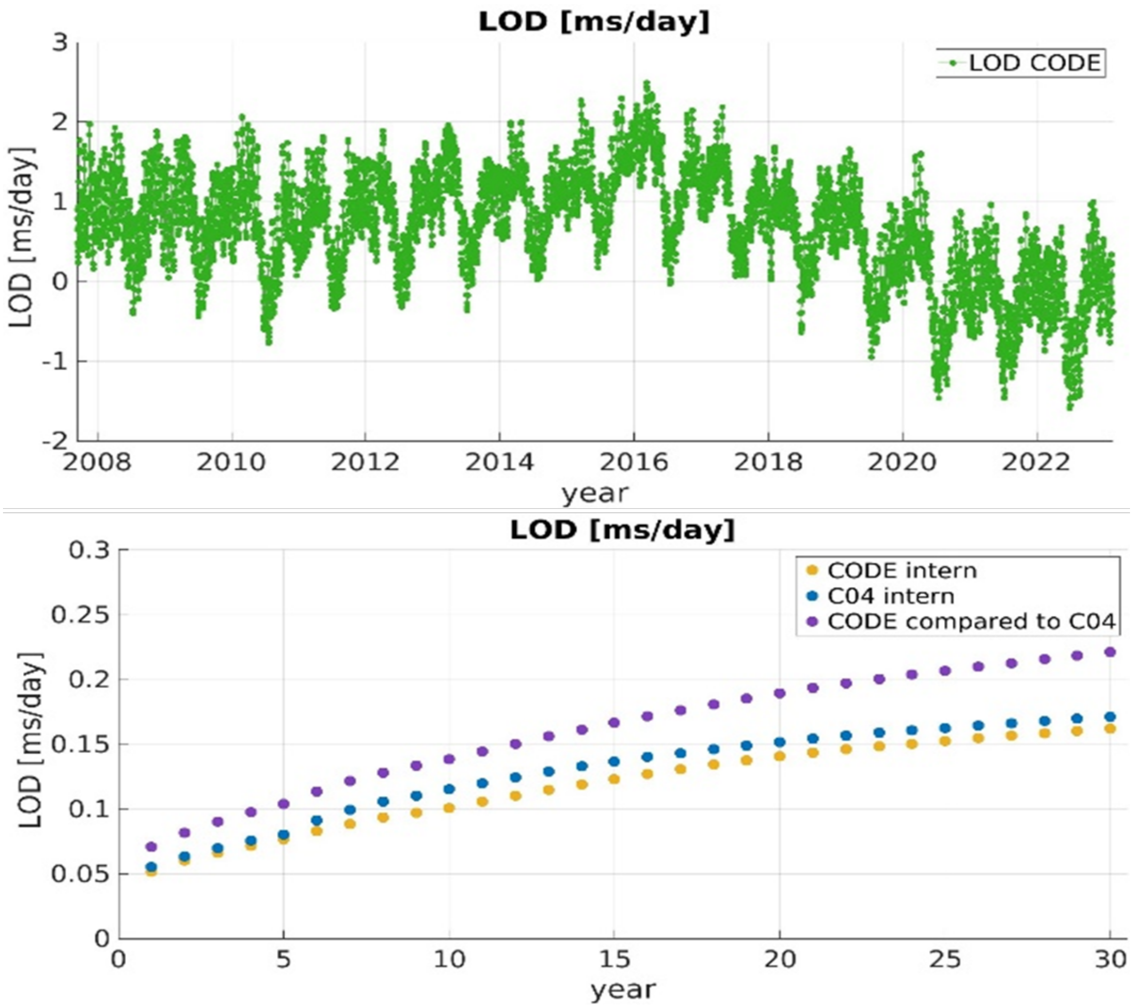


Figure 8: Top: CODE GNSS-derived LOD time series (2008–2022). Bottom: MAE of 30-day LOD predictions using CODE and IERS C04 as input and reference. CODE-based predictions show comparable or better accuracy.

original CODE time series, while the light blue curve represents the MAE for predictions based on IERS C04 data compared to its original time series. The purple curve indicates the MAE when CODE-based predictions are compared against the IERS C04 reference. These results demonstrate that CODE-based predictions offer similar or better internal consistency than IERS C04. Notably, the forecast error remains below 0.1 ms/day during the first 10 days and increases gradually, staying under 0.2 ms/day even for the longest 30-day prediction horizon.

The results confirm that CODE GNSS-derived products, when appropriately modeled, are capable of providing highly accurate short-term predictions of LOD, meeting or surpassing current international benchmarks. Their high temporal resolution, low latency, and internal consistency make them particularly suitable for operational Earth Orientation Parameter (EOP) prediction, addressing the limitations associated with delayed multi-technique solutions. As prediction frameworks continue to advance, particularly through the incorporation of data-driven and machine learning approaches, the CODE GNSS-based EOP series is expected to remain a fundamental resource within the global geodetic infrastructure.

6 IGS Symposium and Workshop

As we all know, IGS started its operational service of the IAG by January 1$^{\text{st}}$, 1994. Nevertheless, the first workshop of the IGS took place in March 1993 and was hosted by the University of Bern. So we are proud that the 30$^{\text{th}}$ anniversary of successful activities of the IGS was celebrated in Bern as well. Overall we welcomed 230 attendees from 37 countries all over the world.

The event was held for the week from 1 to 5 July in 2024. This in-person event took place in two parts: symposium (1-4 July) and workshop (4-5 July).

The symposium was covering 12 oral and 3 poster sessions related to the topics:

- GNSS Standards and Infrastructure (8 oral/21 poster)
- Building Global GNSS-Based Reference Frames (22 oral/23 poster)
- Giving Access To The Reference Frame Through GNSS (12 oral/14 poster)
- GNSS for Climate (12 oral/17 poster)
- GNSS-Enabled Applications (12 oral/14 poster)

In addition two keynote presentations have been included into the program:

- **Marco Falcone**: Galileo and the Future of European Navigation
- **Heike Peter**: Copernicus POD Service – What is the Connection to the IGS?

Disregarding the scientific program, a dedicated session for celebrating the anniversary was organized. Six out of seven IGS Governing Board chairs were presenting the highlights from their period which provided a nice overview on the developments and achievements of the IGS within the three decades.

In the second part (starting in the afternoon, July 4th and covering the complete July 5th) overall 13 sessions for discussions within the IGS committee, pilot project and working group components were held in a workshop format. In these sessions, actual developments and future plans have been discussed. Conclusions and a number of action items have been derived from these discussions. About 80% of the registered participants also attended this workshop part which reflects a strong interest in the activities of the IGS also outside from the core components.

Most of the presentations and posters can be inspected at https://igs.org/workshop/2024/. The Figures 9 to 11 may provide some impressions.

The members of the CODE consortium have also been involved in the scientific program. Arturo Villiger chaired the scientific organizing committee; four of the members of the CODE consortium helped organizing two of the sessions during the symposium as well as two of the workshop sessions. There have been significant number of contributions presented by CODE consortium members as well:

- Session 2: Building Global GNSS-Based Reference Frames
  - Pascal Stebler et al.: How Do Errors in Box-Wing Model Propagate in a Global GNSS Solution
  - Rolf Dach et al.: Earth's Center of Mass Handling for GNSS Orbit Determination and PPP
  - Daniel Arnold et al.: Genesis Orbit And Geodetic Parameter Estimation Based On GNSS: Impact Of Trasmit Antenna Phase Pattern Errors
  - Rolf Dach et al.: Activities at the CODE Analysis Center
  - Rolf Dach et al.: Evaluating Combined IGS Orbit Products
  - Bingbing Duan et al: Estimating GNSS Satellite Antenna Phase Center Offsets And Various Simultaneously With Flatness Constraints
- Session 3: Giving Access To The Reference Frame Through GNSS
  - Andrea Stürze et al.: IGS Real-Time ACC at BKG: First Experiences
- Session 5: GNSS-Enabled Applications
  - Ulrich Meyer et al.: Products of the Combination Service for Time-variable Gravity fields for GNSS POD
  - Daniel Arnold et al.: LEO Activities at AIUB

Figure 9: From left: Felix Perosanz (IGS Governing Board chair: 2020-2023), Rolf Dach (GB chair since 2023), Allison Craddock (director of the IGS central Bureau), Gerhard Beutler (GB chair: 1994-1998), Christoph Reigber (GB chair: 1998-2002), John M. Dow (GB chair: 2002-2010), Urs Hugentobler (GB chair: 2011-2014); Gary Johnston (GB chair: 2015-2020) was not present. Photo: Vanessa Mercea.

Figure 10: We would like to thank everyone for attending. Photo: Vanessa Mercea.

Figure 11: Rolf Dach, the head of the Local Organizing Committee thanks all the people from AIUB, the student assistants, the staff from the ExWi building, and everyone else that supported the event. Photo: Vanessa Mercea.

The Local Organizing Committee from AIUB wants to take the opportunity to thank the CODE partners (in particular BKG and swisstopo) for supporting this event together with the other sponsors: Leica Geosystems, GMV, and u-blox. There was a great support from the administrative and informatics groups from AIUB and the University, the logistics team (Hausdienst) from the Exact Science building, that has to be acknowledged as well. We are thankful to the students support team for helping with the technical environment during the Symposium. Last but not least we thank the Central Bureau for their help in preparing the event and the Scientific Organizing Committee for compiling the program. The time keeping tool was generously offered by Shingo Yonezawa from Kyoto University.

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All publications, posters, and presentations of the *Satellite Geodesy* research group at AIUB are available at http://www.bernese.unibe.ch/publist .