Center for Orbit Determination in Europe (CODE) Analysis Center Technical Report 2023

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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., 2015).

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., 2015) .
  List of result files are provided in Table 2 .
- **Final series** is submitted once per week (GPS+GLONASS+Galileo).
  Until GPS week 2037 (November 27$^{\text{th}}$, 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 28$^{\text{th}}$, 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 compiles 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

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

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

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

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

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

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

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

`CODOOPSULT_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)

`CODOOPSULT_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

`CODOOPSPRD_05D.SP3` (old: `COD.EPH_5D`)
: CODE 5-day GNSS orbit predictions

`CODOOPSPRD_yyyyddd0000_05D_05M_ORB.SP3` (old: `CODwwwwd.EPH_5D`)
: CODE 5-day GNSS orbit predictions

`CODOOPSPRD_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/

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

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

`yyyy/COD0OPSFIN_yyyyddd0000_01D_30S_CLK.CLK.gz` (old: `yyyy/CODwwwwd_v3.CLK.Z`)
`yyyy/COD0OPSFIN_yyyyddd0000_01D_30S_CLK.CLK_V2.gz` (old: `yyyy/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

`yyyy/COD0OPSFIN_yyyyddd0000_01D_05S_CLK.CLK.gz` (old: `yyyy/CODwwwwd_v3.CLK_05.Z`)
`yyyy/COD0OPSFIN_yyyyddd0000_01D_05S_CLK.CLK_V2.gz` (old: `yyyy/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

`yyyy/COD0OPSFIN_yyyyddd0000_01D_01D_OSB.BIA.gz` (old: `yyyy/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.

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

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

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

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

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

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

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

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

`yyyy/COD0OPSFIN_yyyyddd0000_07D_01D_SUM.SUM.gz` (old: `yyyy/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/

`yyyy/P1C1yymm.DCB.Z`	CODE monthly P1−C1 DCB solution, Bernese format, containing only the GPS satellites
`yyyy/P1P2yymm.DCB.Z`	CODE monthly P1−P2 DCB solution, Bernese format, containing the GPS and GLONASS satellites
`yyyy/P1P2yymm_ALL.DCB.Z`	CODE monthly P1−P2 DCB solution, Bernese format, containing the GPS and GLONASS satellites and all stations used
`yyyy/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
`yyyy/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/

`yyyy/COD0MGXFIN_yyyyddd0000_01D_05M_ORB.SP3.gz` (old: `yyyy/COMwwwwd.EPH.Z`)
CODE MGEX final GNSS orbits for GPS, GLONASS, Galileo, BeiDou, and QZSS satellites, SP3 format

`yyyy/COD0MGXFIN_yyyyddd0000_01D_12H_ERP.ERP.gz` (old: `yyyy/COMwwwwd.ERP.Z`)
CODE MGEX final ERPs belonging to the MGEX final orbits

`yyyy/COD0MGXFIN_yyyyddd0000_01D_30S_CLK.CLK.gz` (old: `yyyy/COMwwwwd_v3.CLK.Z`)
(old: `yyyy/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

`yyyy/COD0MGXFIN_yyyyddd0000_01D_01D_OSB.BIA.gz` (old: `yyyy/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.

`yyyy/COD0MGXFIN_yyyyddd0000_01D_30S_ATT.OBX.gz` (old: `yyyy/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:

`COD0OPSFIN_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

`COD0OPSFIN_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

`COD0OPSFIN_yyyyddd0000_01D_01D_SOL.SNX.gz` (old: `codwwwwd.snx.Z`)
GNSS daily coordinates/ERP/GCC from the long–arc solution in SINEX format

`COD0OPSFIN_yyyyddd0000_01D_30S_CLK.CLK.gz` (old: `codwwwwd_v3.clk.Z`)
`COD0OPSFIN_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)

`COD0OPSFIN_yyyyddd0000_01D_05S_CLK.CLK.gz` (old: `codwwwwd_v3.clk_05s.Z`)
`COD0OPSFIN_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)

`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

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

`COD0OPSFIN_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

`COD0OPSFIN_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

`COD0OPSFIN_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:
`CODOMGXFIN_yyyyddd0000_01D_05M_ORB.SP3.gz` CODE MGEX final GNSS orbits for GPS, GLONASS, Galileo, BeiDou, and QZSS satellites, SP3 format
`CODOMGXFIN_yyyyddd0000_01D_12H_ERP.ERP.gz` CODE MGEX final ERPs belonging to the MGEX final orbits
`CODOMGXFIN_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
`CODOMGXFIN_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
`CODOMGXFIN_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, Rolf; Schaer, Stefan; Arnold, Daniel; Brockmann, Elmar; Kalarus, Maciej Sebastian; Prange, Lars; Stebler, Pascal; Jäggi, Adrian (2023). *CODE final product series for the IGS*. Published by Astronomical Institute, University of Bern. URL: https://www.aiub.unibe.ch/download/CODE; DOI: 10.48350/185744.
- Dach, Rolf; Schaer, Stefan; Arnold, Daniel; Brockmann, Elmar; Kalarus, Maciej Sebastian; Prange, Lars; Stebler, Pascal; Jäggi, Adrian (2023). *CODE rapid product series for the IGS*. Published by Astronomical Institute, University of Bern. URL: `https://www.aiub.unibe.ch/download/CODE`; DOI: 10.48350/185740.
- Dach, Rolf; Schaer, Stefan; Arnold, Daniel; Brockmann, Elmar; Kalarus, Maciej Sebastian; Prange, Lars; Stebler, Pascal; Jäggi, Adrian (2023). *CODE ultra-rapid product series for the IGS*. Published by Astronomical Institute, University of Bern. URL: `https://www.aiub.unibe.ch/download/CODE`; DOI: 10.48350/185741.
- Prange, Lars; Arnold, Daniel; Dach, Rolf; Brockmann, Elmar; Kalarus, Maciej Sebastian; Schaer, Stefan; Stebler, Pascal; Jäggi, Adrian (2023.). *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: 10.48350/185742.

3 Statistics on the CODE solution

3.1 Selected general statistics

The development of the included satellite systems in the CODE solution is illustrated in Figure 1. 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. Since that change, the MGEX solution includes about 118 satellites of five satellite systems.

The network used by CODE for the final processing is shown in Figure 2.

3.2 Ambiguity resolution rate

It is interesting to inspect the percentage of resolved ambiguities displayed in Figure 3. During the year 2023 it is for the fist time, where more ambiguities for Galileo than for GPS are resolved. This holds for the CODE rapid and MGEX series. In the CODE final

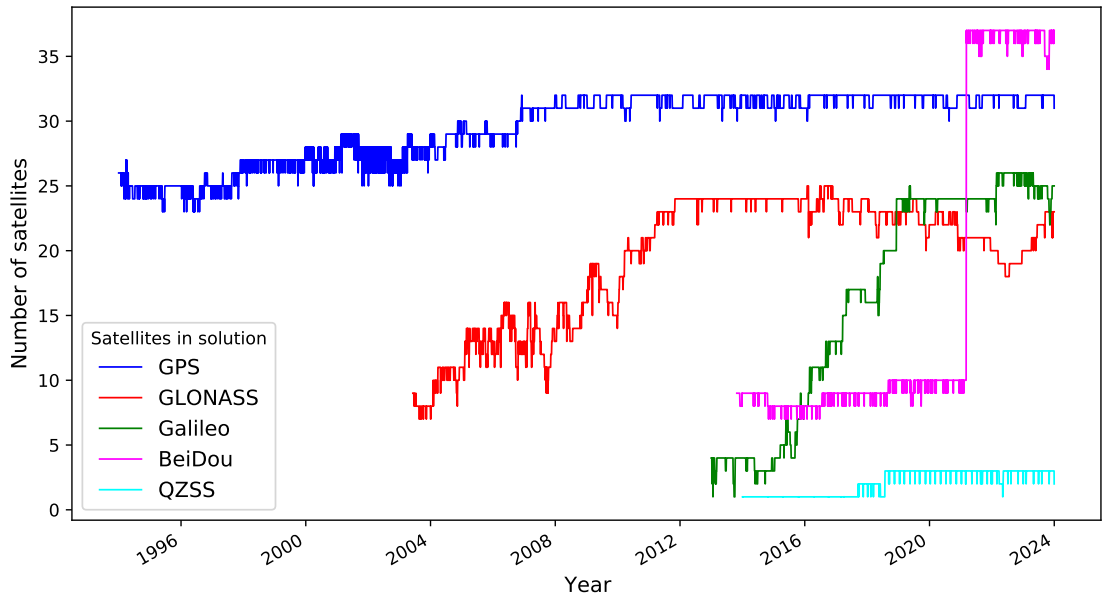


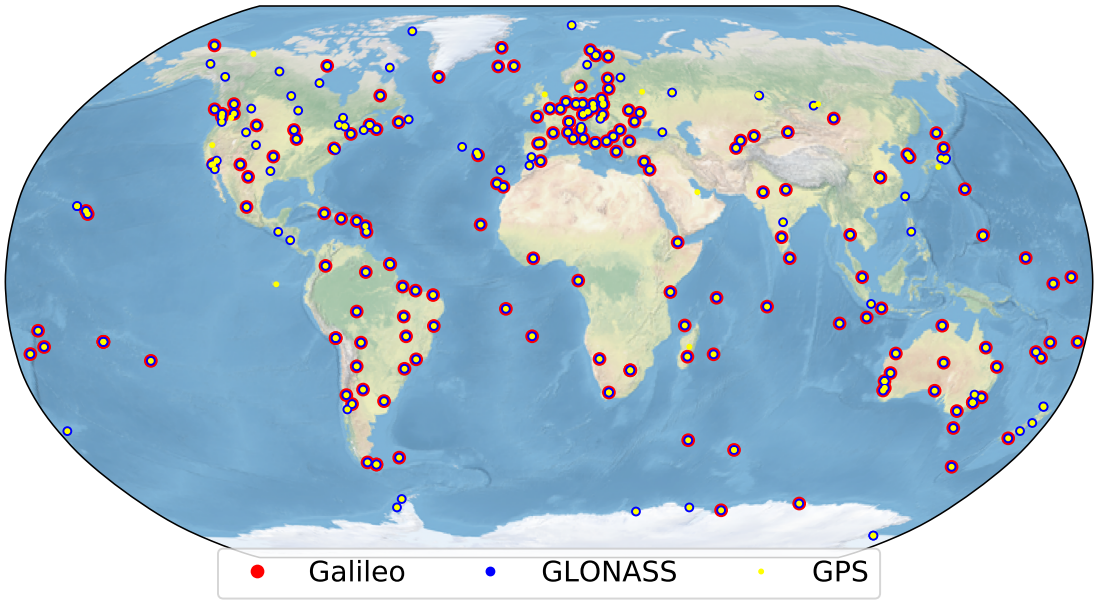
Figure 1: Development of the number of satellites in the CODE orbit products.

series both numbers are still in the same range with a small advantage for GPS (as in Figure 3 for the first part of year 2022). We assume that with a denser network of Galileo tracking stations (and calibrated receiver antennas) the picture for Galileo will change as well in future.

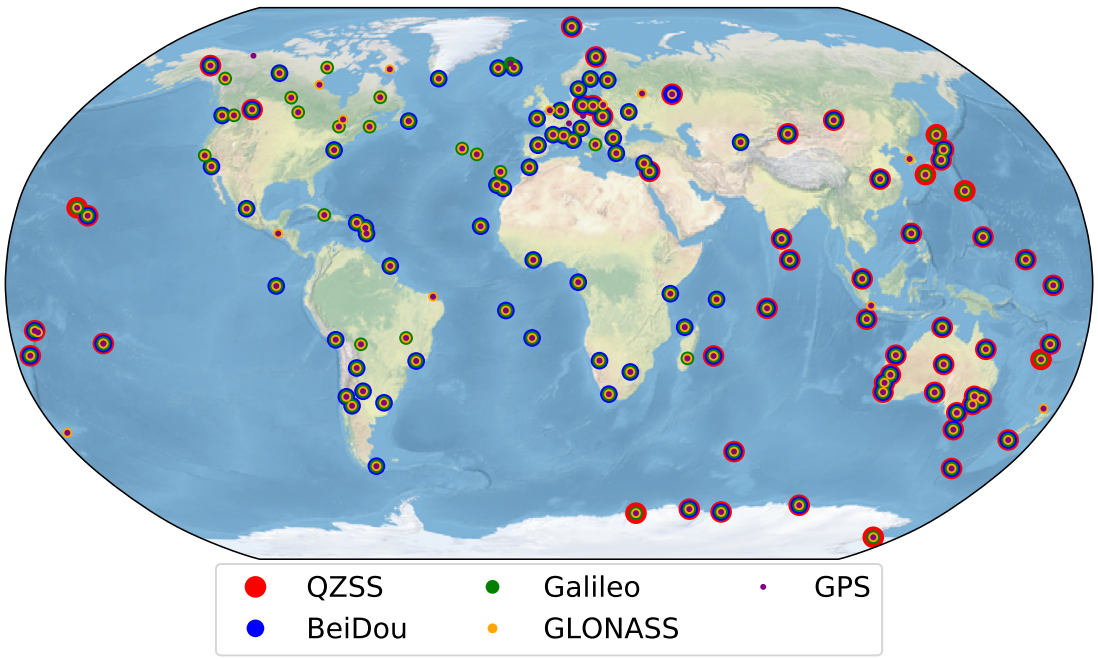
3.3 Performance of the satellite clock solution

An overview on the performance of the clock products (final series with a sampling of 30 seconds) is provided in Figure 4. The RMS of a linear fit of all estimated clock corrections of a day is shown. The plots show the different performance of the satellites for the GPS and Galileo constellations. The great performance of most of the Galileo satellite clocks is nicely visible by the dark blue color. At the same time, a few Galileo satellite show a degraded clock performance (in particular E11, E19, and E12).

Whereas the Galileo satellites are ordered according to the orbital planes (number 99 was used for the two satellites in the elliptic plane) the GPS satellites are ordered according to the SVN ID, meaning regarding their age. Disregarding the two satellites SVN G072 (PRN G08) and G073 (PRN G10) there is an improvement in the performance for the newer satellite types with respect to the older ones. Satellites from the Block IIF type range between SVN G062 to G073. The latest type Block IIIA starts the numbering with SVN G077. In particular for the satellites of the various Block II-types a dependency of the clock performance in the CODE solution from the elevation of the Sun above the orbital plane is visible.



(a) final solution (more than 250 stations)



(b) MGEX solution (140 stations)

Figure 2: Network used for the processing at CODE by the end of 2023.

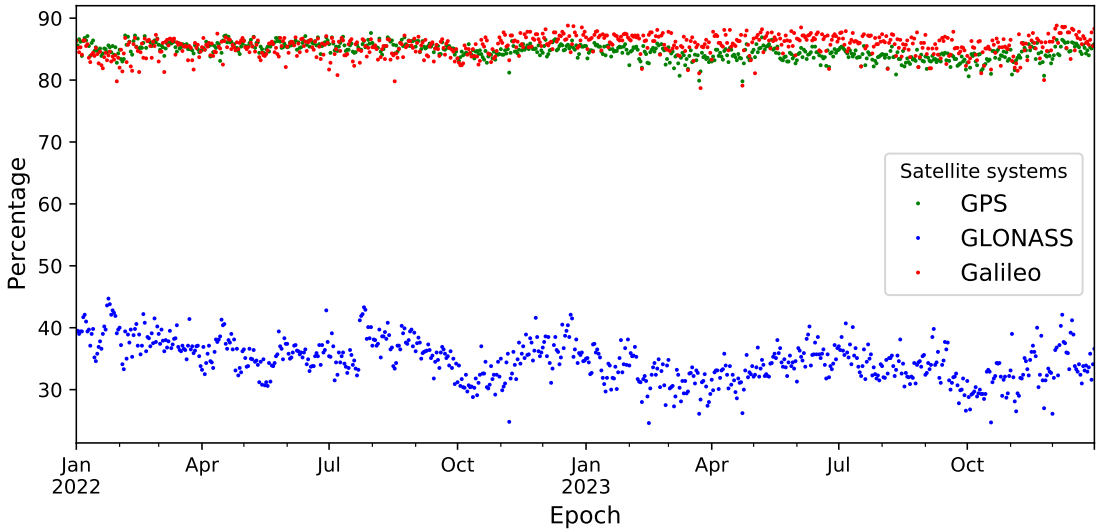
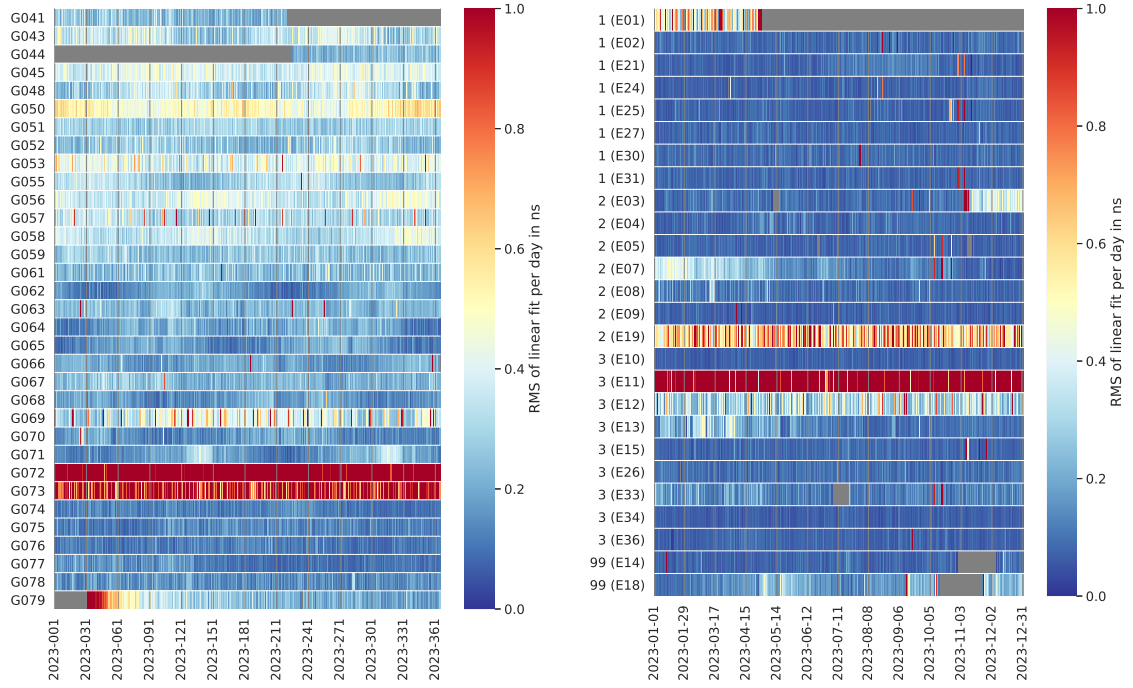


Figure 3: Percentage of resolved ambiguities in the CODE rapid product series.



GPS constellation
plotted with respect to the SVN

Galileo constellation
plotted by PRN sorted by the orbital planes

Figure 4: Performance of the GPS and Galileo satellite clock corrections as provided in the CODE final solution (30-second sampling).

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 2022 were published in the last technical report in Dach et al. (2023).

In Section 4.1 we give an overview of important development steps in the year 2023. The change of the gravity field in the CODE operational processing for the IGS is described in Section 4.2 .

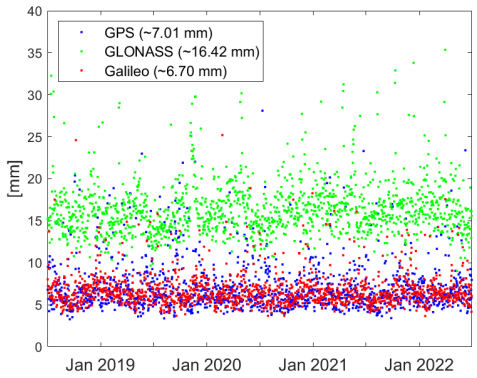
4.1 Overview of changes in the processing scheme in 2023

Table 7 gives an overview of the major changes implemented during the year 2023. 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`).

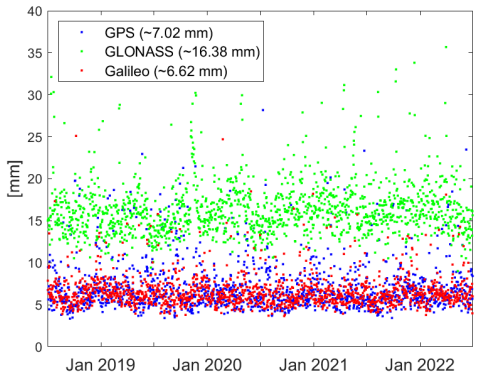
Several other improvements not listed in Table 7 were implemented, too. Those mainly concern data download and management, sophistication of CODE's analysis strategy, software changes (improvements), and many more. As these changes are virtually not relevant for users of CODE products, they will not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

Table 7: Selected events and modifications of the CODE processing during 2023.

Date	DoY/Year	Description
18-Jan-2023	015/2023	Ignore observations from systems where no system-specific receiver antenna corrections are available. For the CODE final processing line (**about 30% of the Galileo-tracking stations get lost**))
01-Mar-2023	056/2023	Use estimated ionosphere model from the CODE rapid solution chain for ambiguity resolution and higher order ionosphere corrections in the CODE MGEX solution.
11-Apr-2023	099/2023	GLONASS R25/R807 included in all CODE analysis lines.
09-May-2023	127/2023	Replace the static gravity field model (EGM2008) by a time variable Fitted Signal Model as provided by the COST-G service (COSTG_FSM_2212, where 2212 indicates that the coefficients have been fitted with data up to December 2022)
09-Aug-2023	221/2023	Consideration of RINEX4 observation data enabled
20-Sep-2023	260/2023	Updated time variable gravity field model from COSTG_FSM_2212 to COSTG_FSM_2303.
04-Oct-2023	277/2023	Fix a bug in the ambiguity resolution scheme, mainly affecting short baselines
14-Nov-2023	308/2023	R26 switch from R801-R803 (GLONASS-K2) Reprocessing of the interval for GPS weeks from 2253 to 2287 with the corrected satellite type for R26; resubmitted the related results



Using EGM2008 gravity model



Using COSTG_FSM model

Figure 5: Orbit overlaps (RMS of the 3-dimensional vector) using different gravity fields.

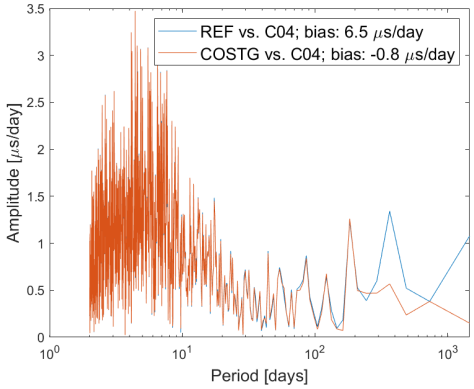


Figure 6: Amplitude spectrum of the Length of Day component estimated from GNSS based on different gravity fields (REF: EGM2008 and COSTG_FSM) with respect to the C04(20) values.

4.2 Changing the gravity field

To aid operational precise satellite orbit determination the Combination Service for Time-variabel Gravity fields (COST-G) of the International Association of Geodesy (IAG) provides a Fitted Signal Model (FSM), which allows to reliably predict temporal gravity variations over time-spans of several months Peter et al. (2022). The FSM is adjusted to the monthly GRACE-FO gravity field combinations (Meyer et al., 2024), which are generated with a latency of about 3 months, and is updated quarterly.

The impact of the temporal gravity variations on the orbits of the high-flying GNSS satellites is only marginal in general. Consequently the orbit misclosures at midnight do not change due to the exchange of the used gravity field (EGM2008 and COSTG_FSM

in Figure 5). On the other hand, the variations in the Earth's flattening, represented by the C_{20} coefficient, strongly correlate with the Length Of Day estimates determined in the frame of the GNSS-POD. When comparing the obtained Length of Day values to the C04(20) series in Figure 6, a non-negligible positive impact on LOD has been observed.

Since GPS week 2261 (May 2023) the CODE analysis center is using the the COST-G FSM gravity model for its operational GNSS POD (see 7). Meanwhile, the first update in September 2023 has been carried out without any degradation of the (multi-day) solution. There was even an alarming system implemented before such a time variable gravity field expires.

5 Development of a combined Earth Orientation Parameters product at BKG

The Earth Orientation Parameters (EOP) 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 EOP time series provided by the IERS, e.g. Bulletin A or C04, result from the combination of EOP derived from individual space geodetic solutions, i.e. a combination at 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.

One of the current activities of the Federal Agency for Cartography and Geodesy (BKG) focuses on the development of a more rigorous combination strategy at the level of normal equations (NEQs). The main objective is to improve the consistency between space geodetic techniques through common parameters, in particular Earth Rotation Parameters (ERPs). The developed ERP product is characterized by a continuous, daily and regular temporal resolution and a short latency. This is particularly important for the highly variable parameter dUT1.

The processing is based on datum-free NEQs. 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. The combination procedure is repeated on a daily basis. This gives a time series with daily resolution for the ERPs. Each daily ERP solution is represented by a continuous 7-day polygon with piece-wise linear offsets estimated every 24 hours.

Different combination approaches were investigated using VLBI and GNSS data provided via SINEX (Solution INdependent EXchange) files from the BKG IVS Analysis Center and the CODE IGS Analysis Center.

Overall, a significant improvement in accuracy was achieved compared to the individual

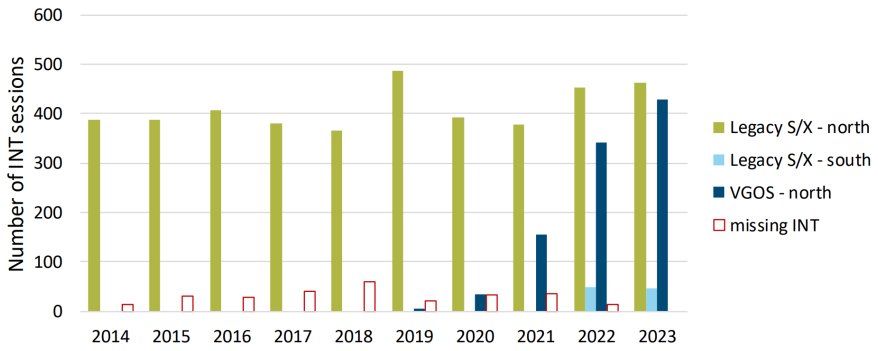


Figure 7: Number of different types of Intensives sessions per year: the legacy S/X sessions with networks in the Northern (green) and Southern (light blue) Hemispheres, and the new VGOS sessions. Additionally, the number of days with missing Intensives SINEX file in the IVS data center is shown in red.

technique-specific solutions, especially for the highly variable component dUT1. A detailed description of the different combination methods, including the chosen parameterization, the parameter a priori values, the datum conditions, as well as a detailed discussion of the resulting ERP series can be found in Lengert et al. (2021, 2022) and Klemm et al. (2024a,c).

Daily and rapid availability of input data is essential to achieve the above characteristics of the ERP product. In particular, the daily VLBI INT sessions play an important role for accurate and rapid dUT1 estimation. However, there are gaps in the series of daily SINEX files of the legacy VLBI INT campaigns in the past. Most of the gaps are caused by missing observations due to technical outages of an antenna or problems in the correlation process. For example, in 2018 there are no SINEX files available for a total of 60 days (see Figure 7).

Data gaps in the INT series are problematic for the continuity and reliability of the combined ERP. With the development of the VLBI Global Observing System (VGOS), the next generation of VLBI, numerous new VLBI INT sessions have been added to the VLBI observing schedule since 2020, and the missing data situation has improved significantly in recent years. The integration of VGOS data in the combination process leads to a constant slight decrease in the WRMS of the dUT1 residuals compared to external ERP series. For example, for the most recent day of the combination (i.e., the seventh day of the 7-day polygon), the WRMS of the dUT1 estimates with respect to the IERS Bulletin A series decreases by 0.5 µs from 16.7 μs to 16.2 μs when comparing a solution based on all INT sessions to a solution based on legacy INT sessions only. The increasing number of available INT sessions with independent networks, up to four per day, also increases the continuity and reliability of the combined ERP solution. More detailed information can be found in Klemm et al. (2024a).

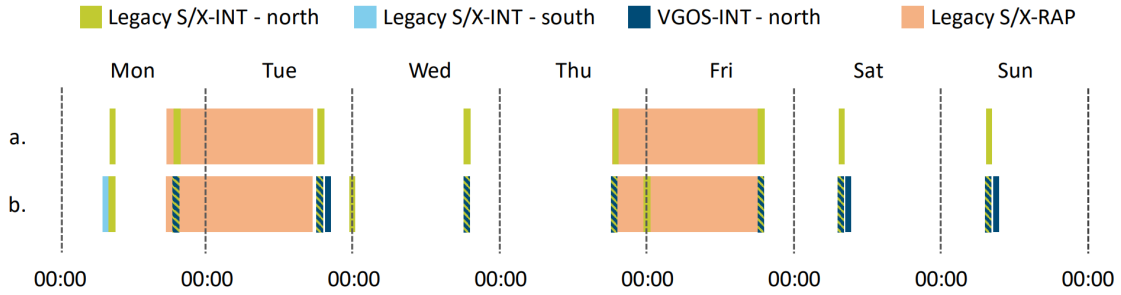


Figure 8: Weekly session distribution of the different VLBI sessions in 2014 (a.) and 2022 (b.): legacy S/X INT of the Northern (green) and Southern (light blue) Hemispheres, Rapid (R1/4) (light orange), and the new VGOS INT (dark blue).

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