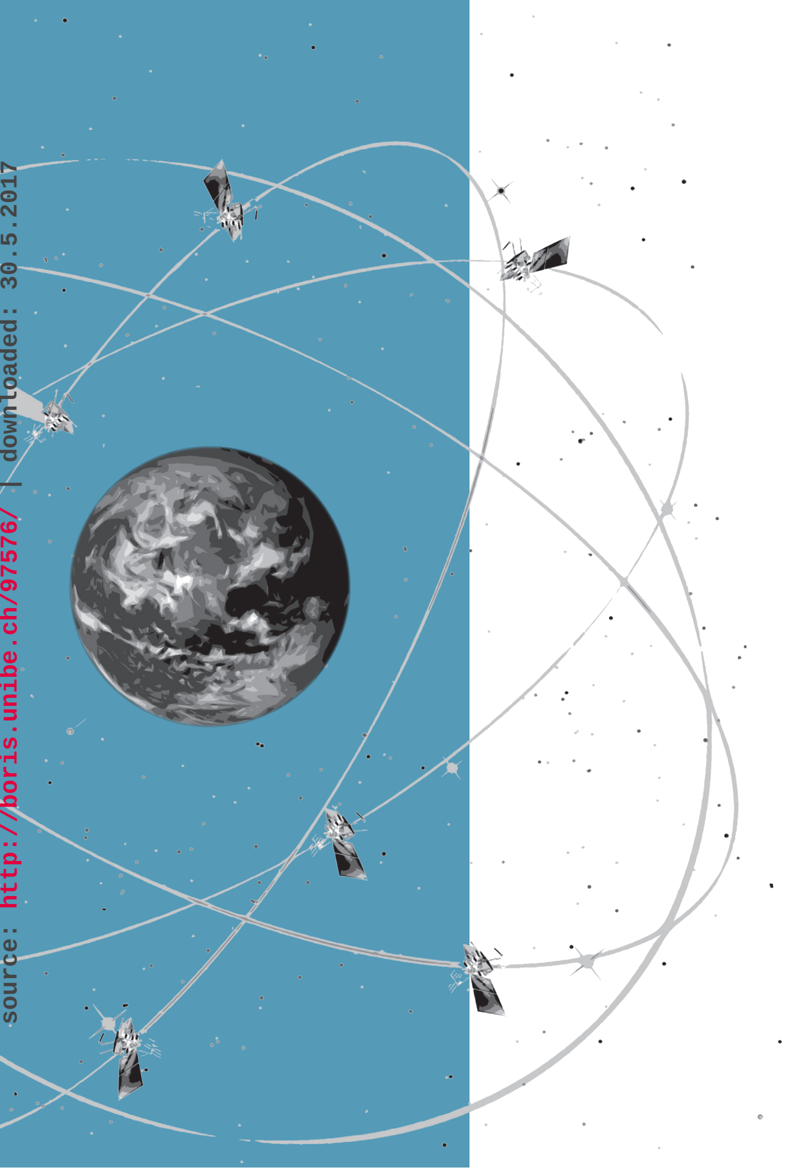
IGS INTERNATIONAL GNSS SERVICE

TECHNICAL REPORT 2015



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CODE Analysis Center Technical Report 2015

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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 for Cartography and Geodesy (BKG), Frankfurt a. M., Germany
- Institut für Astronomische und Physikalische Geodäsie, Technische Universität München (IAPG, TUM), Munich, Germany

The operational computations are performed at AIUB, whereas IGS–related reprocessing activities are typically 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).

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2 CODE products available to the public

A wide range of GNSS solutions based on a rigorously combined GPS/GLONASS data processing scheme is computed at CODE. The products are made available through anonymous ftp at:
`ftp://ftp.unibe.ch/aiub/CODE/` or `http://www.aiub.unibe.ch/download/CODE/`
An overview of the files is given in Tab. 1.

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

With GPS week 1706, CODE started to generate a pure one–day solution (label "COF") in addition to the traditional three–day long–arc solution (label "COD"). The result files from both series are submitted to the IGS data centers hosting the products. The related files are listed in Tab. 2.

The network used by CODE for the final processing is shown in Fig. 1. Almost 80% of the stations support GLONASS (red stars).

Referencing of the products

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

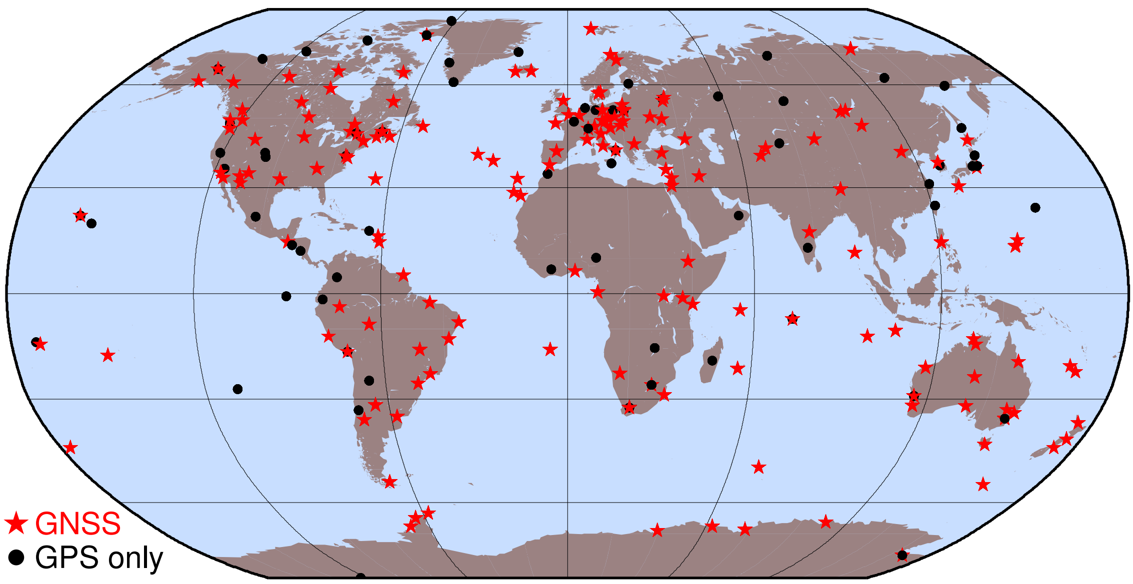


Figure 1: Network used for the GNSS final processing at CODE by the end of 2015.

- 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*

Table 1: CODE products available through anonymous ftp

CODE *final* products available at ftp://ftp.unibe.ch/aiub/CODE/yyyy/	
`yyyy/CODwwwwd.EPH.Z`	CODE final GNSS orbits
`yyyy/CODwwwwd.ERP.Z`	CODE final ERPs belonging to the final orbits
`yyyy/CODwwwwd.CLK.Z`	CODE final clock product, clock RINEX format, with a sampling of 30 sec for the satellite and reference (station) clock corrections and 5 minutes for all other station clock corrections
`yyyy/CODwwwwd.CLK_05S.Z`	CODE final clock product, clock RINEX format, with a sampling of 5 sec for the satellite and reference (station) clock corrections and 5 minutes for all other station clock corrections
`yyyy/CODwwwwd.SNX.Z`	CODE daily final solution, SINEX format
`yyyy/CODwwwwd.TRO.Z`	CODE final troposphere product, troposphere SINEX format
`yyyy/CODGddd0.yyI.Z`	CODE final ionosphere product, IONEX format
`yyyy/CODwwwwd.ION.Z`	CODE final ionosphere product, Bernese format
`yyyy/CODwwww7.SNX.Z`	CODE weekly final solution, SINEX format
`yyyy/CODwwww7.SUM.Z`	CODE weekly summary file
`yyyy/CODwwww7.ERP.Z`	Collection of the 7 daily CODE-ERP solutions of the week
`yyyy/COXwwwwd.EPH.Z`	CODE final GLONASS orbits (for GPS weeks 0990 to 1066; 27-Dec-1998 to 17-Jun-2000)
`yyyy/COXwwww7.SUM.Z`	CODE weekly summary files of GLONASS analysis
`yyyy/CGIMddd0.yyN.Z`	Improved Klobuchar–style ionosphere coefficients, navigation RINEX format
`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 all GPS and GLONASS satellites
`yyyy/P1P2yymm_ALL.DCB.Z`	CODE monthly P1−P2 DCB solution, Bernese format, containing all GPS and GLONASS satellites and all stations used
`yyyy/P1C1yymm_RINEX.DCB`	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`	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 1: CODE products available through anonymous ftp (continued)

CODE *rapid* products available at ftp://ftp.unibe.ch/aiub/CODE	
CODwwwwd.EPH_M	CODE final rapid GNSS orbits
CODwwwwd.EPH_R	CODE early rapid GNSS orbits
CODwwwwd.EPH_P	CODE 24–hour GNSS orbit predictions
CODwwwwd.EPH_P2	CODE 48–hour GNSS orbit predictions
CODwwwwd.EPH_5D	CODE 5–day GNSS orbit predictions
CODwwwwd.ERP_M	CODE final rapid ERPs belonging to the final rapid orbits
CODwwwwd.ERP_R	CODE early rapid ERPs belonging to the early rapid orbits
CODwwwwd.ERP_P	CODE predicted ERPs belonging to the predicted 24–hour orbits
CODwwwwd.ERP_P2	CODE predicted ERPs belonging to the predicted 48–hour orbits
CODwwwwd.ERP_5D	CODE predicted ERPs belonging to the predicted 5–day orbits
CODwwwwd.CLK_M	CODE GNSS clock product related to the final rapid orbit, clock RINEX format
CODwwwwd.CLK_R	CODE GNSS clock product related to the early rapid orbit, clock RINEX format
CODwwwwd.TRO_R	CODE rapid troposphere product, troposphere SINEX format
CODwwwwd.SNX_R.Z	CODE rapid solution, SINEX format
CORGddd0.yyI	CODE rapid ionosphere product, IONEX format
COPGddd0.yyI	CODE 1–day or 2–day ionosphere predictions, IONEX format
CODwwwwd.ION_R	CODE rapid ionosphere product, Bernese format
CODwwwwd.ION_P	CODE 1–day ionosphere predictions, Bernese format
CODwwwwd.ION_P2	CODE 2–day ionosphere predictions, Bernese format
CODwwwwd.ION_P5	CODE 5–day ionosphere predictions, Bernese format
CGIMddd0.yyN_R	Improved Klobuchar–style coefficients based on CODE rapid ionosphere product, RINEX format
CGIMddd0.yyN_P	1–day predictions of improved Klobuchar–style coefficients
CGIMddd0.yyN_P2	2–day predictions of improved Klobuchar–style coefficients
CGIMddd0.yyN_P5	5–day predictions of improved Klobuchar–style coefficients
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 all GPS and GLONASS satellites
P1P2_ALL.DCB	CODE sliding 30–day P1−P2 DCB solution, Bernese format, containing all 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

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 1: CODE products available through anonymous ftp (continued)

CODE *ultra–rapid* products available at ftp://ftp.unibe.ch/aiub/CODE	
COD.EPH_U	CODE ultra–rapid GNSS orbits
COD.ERP_U	CODE ultra–rapid ERPs belonging to the ultra–rapid orbit product
COD.TRO_U	CODE ultra–rapid troposphere product, troposphere SINEX format
COD.SNX_U.Z	SINEX file from the CODE ultra-rapid solution
COD.SUM_U	Summary of stations used for the latest ultra–rapid orbit
COD.ION_U	Last update of CODE rapid ionosphere product (1 day) complemented with ionosphere predictions (2 days)
COD.EPH_5D	Last update of CODE 5–day orbit predictions, from rapid analysis, including all active GPS and GLONASS satellites
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 solutions of the day)
CODwwwwd.ERP_U	CODE ultra-rapid ERPs belonging to the ultra-rapid orbits

Table 2: CODE final products available in the product areas of the IGS data centers

Files generated from three–day long–arc solutions:	
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
CODwwwwd.SNX.Z	GNSS daily coordinates/ERP/GCC from the long–arc solution in SINEX format
CODwwwwd.CLK.Z	GPS satellite and receiver clock corrections at 30–sec intervals referring to the COD–orbits from the long–arc analysis in clock RINEX format
CODwwwwd.CLK_05S.Z	GPS satellite and receiver clock corrections at 5–sec intervals referring to the COD–orbits from the long–arc analysis in clock RINEX format
CODwwwwd.TRO.Z	GNSS 2–hour troposphere delay estimates obtained from the long–arc solution in troposphere SINEX format
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
CODwwww7.SUM	Analysis summary for 1 week
Files generated from pure one–day solutions:	
COFwwwwd.EPH.Z	GNSS ephemeris/clock data in daily files at 15–min intervals in SP3 format, including accuracy codes computed from a pure one–day solution
COFwwwwd.SNX.Z	GNSS daily coordinates/ERP/GCC from the pure one–day solution in SINEX format
COFwwwwd.CLK.Z	GPS satellite and receiver clock corrections at 30–sec intervals referring to the COF–orbits from the pure one–day analysis in clock RINEX format
COFwwwwd.CLK_05S.Z	GPS satellite and receiver clock corrections at 5–sec intervals referring to the COF–orbits from the pure one–day analysis in clock RINEX format
COFwwwwd.TRO.Z	GNSS 2–hour troposphere delay estimates obtained from the pure one–day solution in troposphere SINEX format
COFwwww7.ERP.Z	GNSS ERP (pole, UT1−UTC) solution, collection of the 7 daily COF–ERP solutions of the week in IGS IERS ERP format
COFwwww7.SUM	Analysis summary for 1 week

Note that the COD–series is identical with the files posted at the CODE's aftp server, see Tab. 1.

Table 2: CODE final products available in the product areas of the IGS data centers (continued)

Other product files (not available at all data centers):	
CODGddd0.yyI.Z	GNSS 2-hour global ionosphere maps in IONEX format, including satellite and receiver P1−P2 code bias values
CKMGddd0.yyI.Z	GNSS daily Klobuchar-style ionospheric (alpha and beta) coefficients in IONEX format
GPSGddd0.yyI.Z	Klobuchar-style ionospheric (alpha and beta) coefficients from GPS navigation messages represented in IONEX format

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 .

3 Changes in the daily processing for the IGS

The CODE processing scheme for daily IGS analyses is constantly subject to updates and improvements. The last technical report was published in Dach et al. 2015b.

In Sect. 3.1 we give an overview of important development steps in the year 2015. Section 3.2 describes the introduction of the extended Empirical CODE orbit model (ECOM) and Section 3.3 provides details on the extension of the clock rapid product at CODE .

3.1 Overview of changes in the processing scheme in 2015

Table 3 gives an overview of the major changes implemented during the year 2015. Details on the analysis strategy can be found in the IGS analysis questionnaire at the IGS Central Bureau (ftp://igscb.jpl.nasa.gov/igscb/center/analysis/code.acn).

Several other improvements not listed in Tab. 3 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 3: Selected modifications of the CODE processing over 2015

Date	DoY/Year	Description
04-Jan-2015	004/2015	Extended ECOM as described in Arnold et al. 2015 has been activated in the final, rapid and ultra-rapid processing scheme by adding the twice- and four times-per revolution terms in *D*-component
09-Feb-2015	040/2015	Include a completeness check for RINEX observation files that are used for the rapid or ultra-rapid processing
15-Feb-2015	046/2015	Switch from IGRF11 to IGRF12 Tébault et al. 2015 for computing the higher-order ionosphere (HOI) corrections
15-Feb-2015	046/2015	Correct a software bug that may extract VMF1 coefficients and atmosphere pressure loading corrections from an extrapolation to outside a cell in the grid file instead of interpolating within grid cells. Whether the problem occurred or not depends on the baseline and network configuration. An effect is more likely if dense regional networks instead of global networks are processed; but a limited number of examples have also been found in the operational and repro2 series for the IGS.
19-Feb-2015	050/2015	Update the Bernese GNSS Software to allow for filenames longer than 32 characters
27-Febr-2015	058/2015	Relax some screening criteria in the data preprocessing
24-Apr-2015	115/2015	Earth rotation parameters are set up per orbital plane and geocenter parameters per satellite for internal purposes when generating the normal equations in the final processing chain. These parameters are stacked to one global set of parameters over all satellites when computing the solutions submitted to the IGS
28-Jun-2015	179/2015	Disable the four times per revolution terms in the new ECOM because they degrade some of the GLONASS orbits
01-Jul-2015	182/2015	Add the leap second
20-Jul-2015	201/2015	Request at least 8 hours between a stochastic pulse for GNSS satellite orbit modelling and a repositioning event, otherwise the pulse is removed
21-Jul-2015	202/2015	A new version of download script was activated in order to support RINEX3 files with long filenames. This includes a priority selection for several RINEX files from the same station: 1. RINEX3 file created by the receiver 2. RINEX3 file created from streamed data 3. RINEX3 file with unknown source or short filenames 4. RINEX2 files
03-Aug-2015	214/2015	A new multi-GNSS procedure to generate the clock corrections in the rapid chain was activated considering GPS and GLONASS at the moment.
27-Aug-2015	112–239/2015	The RMS for the linear fit of the estimated clock corrections for station BRAZ was significantly higher for the 5 s clock solution (based on streamed data) than in the 30 s solution (based on legacy RINEX data). The effect on the ultra-high-rate satellite clock corrections is unclear.
14-Sep-2015	214–255/2015	In the new clock generation procedure for the rapid, observations that have not passed the residual screening procedure may have been used for the final parameter estimation. The Problem was fixed.

3.2 Introducing the extended ECOM

The Empirical CODE Orbit Model (ECOM, Beutler et al. 1994) was developed in the early 1990s, motivated by the lack of reliable satellite information. It is widely used in the IGS and allows for a successful modeling of non-gravitational accelerations — especially induced by solar radiation pressure — acting on GPS satellites.

The ECOM decomposes the perturbing accelerations into three orthogonal directions of a Sun-oriented coordinate system in the center of mass of the satellite, namely a D component oriented from the satellite to the Sun, a Y component pointing along the satellite's solar panel axes, and a B component to complete the orthogonal system. In the original ECOM the functions $D(u)$, $Y(u)$ and $B(u)$ are represented as Fourier series truncated after the once-per-revolution (1pr) terms, whereas Springer et al. 1999 proposed the so-called reduced ECOM,

$$\begin{aligned} D(u) &= D_0 \\ Y(u) &= Y_0 \\ B(u) &= B_0 + B_\mathrm{c}\cos u + B_\mathrm{s}\sin u\,, \end{aligned} \tag{1}$$

where u is the argument of latitude for the satellite. It was used for the IGS contributions of CODE for a long time. Arnold et al. 2015 proposed an extension of the ECOM according to:

$$\begin{aligned} D(u) &= D_0 + \sum_{i=1}^{n_D} \{D_{2i,\mathrm{c}}\cos 2i\Delta u + D_{2i,\mathrm{s}}\sin 2i\Delta u\} \\ Y(u) &= Y_0 \\ B(u) &= B_0 + \sum_{i=1}^{n_B} \{B_{2i-1,\mathrm{c}}\cos(2i-1)\Delta u + B_{2i-1,\mathrm{s}}\sin(2i-1)\Delta u\}\ , \end{aligned} \tag{2}$$

where $\Delta u \doteq u - u_\mathrm{s}$ and u_s is the argument of latitude of the Sun. The extended ECOM thus contains even-order periodic terms in $\vec{e}_\mathrm{D}$-direction and odd-order periodic terms in $\vec{e}_\mathrm{B}$-direction.

Starting with GPS week 1826 (January 04, 2015), CODE started to use the extended model with $n_B = 1$ and $n_D = 2$ (resulting in 2pr and 4pr terms according to Equation 2). Although Arnold et al. 2015 have demonstrated the advantages of the new with respect to the old ECOM, the introduction of the new model has led to a reduction of consistency with the other IGS ACs (see Fig. 2).

Unfortunately, some of the (older) GLONASS satellites did show a degradation due to the additional terms. The relations between the cosine and sine terms and between the twice and four-times per revolution terms did not agree with the expected magnitudes in Arnold et al. 2015. Obviously, the higher-order terms do amplify other not modelled effects on the satellites. For that reason the 4pr D-terms of the extended ECOM were

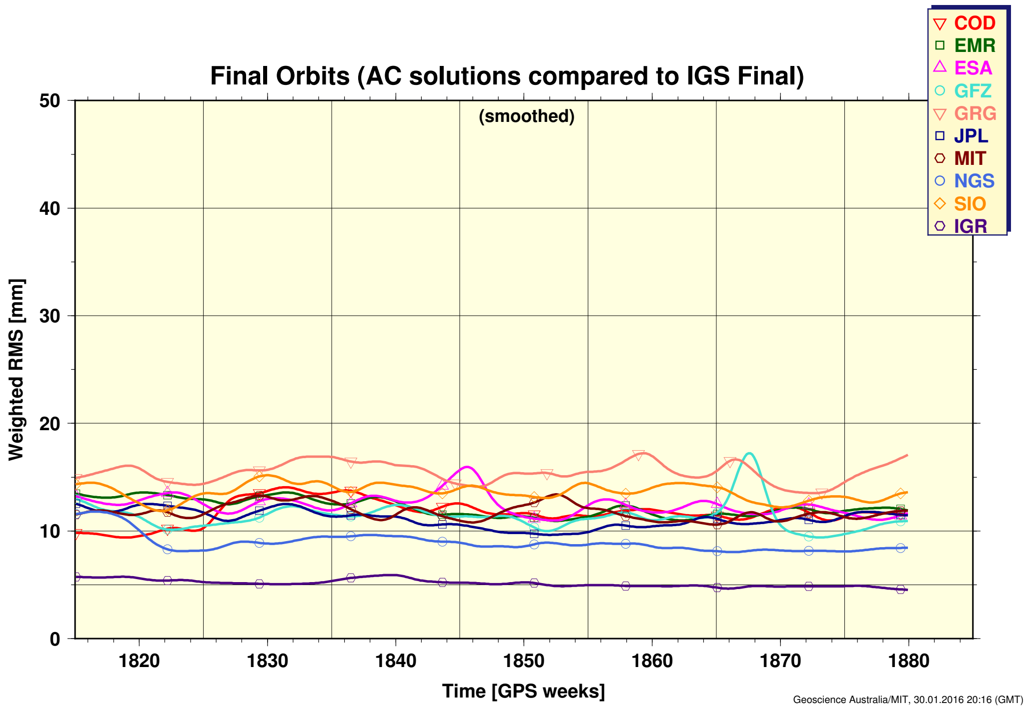


Figure 2: Consistency of the GPS final orbits among the IGS analysis centers during the recent weeks (from http://acc.igs.org/media/Gmt_sum_final_all_orb_smooth.ps.

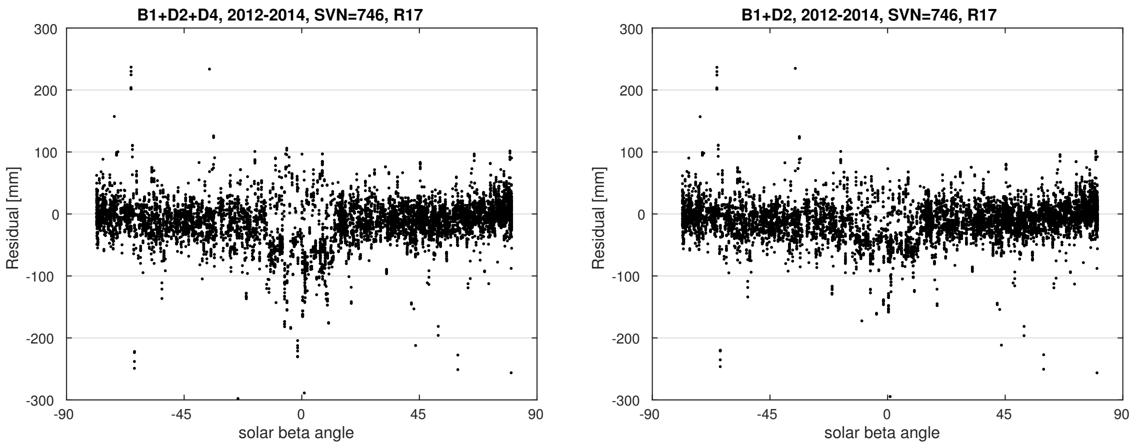


Figure 3: SLR residuals to GLONASS satellite R17 (SVN 746).

deactivated starting from GPS week 1851 (June 28th, 2015). The benefit can be seen in the SLR residuals displayed in Fig. 3 for one of the affected GLONASS satellites.

3.3 Extending the CODE rapid clock product

For the CODE clock product, GNSS satellite orbits, Earth rotation parameters (ERPs) and station coordinates are introduced as known from the double-difference solution. Figure 4 illustrates the processing flow to generate the GPS/GLONASS rapid clock corrections. The procedure is executed two times per day: once for the early and a second time for the final rapid solution (see Dach et al. 2015b).

After some general preparatory steps described in the violet boxes in Fig. 4 (steps 1.1 and 1.2), the independent preprocessing of the code and phase measurements is initiated. In the green chain (steps 2.1 to 2.4), the pseudorange data are preprocessed. This includes apart from a residual screening also the computation of station-specific weights because of the different noise level of the individual stations due to the different environmental conditions and receiver/firmware behavior. Furthermore, the inter-system and inter-frequency biases are computed for all stations.

In parallel the preprocessing of the phase measurements takes place following the steps described in the brown boxes (steps 3.1 and 3.2) including the cycle slip and outlier detection as well as the update of the list of ambiguities. For this step satellite clock corrections are needed that are computed from a limited subset of the stations that offer a global coverage.

After cleaning the pseudorange and phase measurements in the two separate chains, they need to be processed first together in a further preprocessing step to make sure that the full consistency is given (an overview on potential receiver events is given, e.g., in Dach et al. 2006).

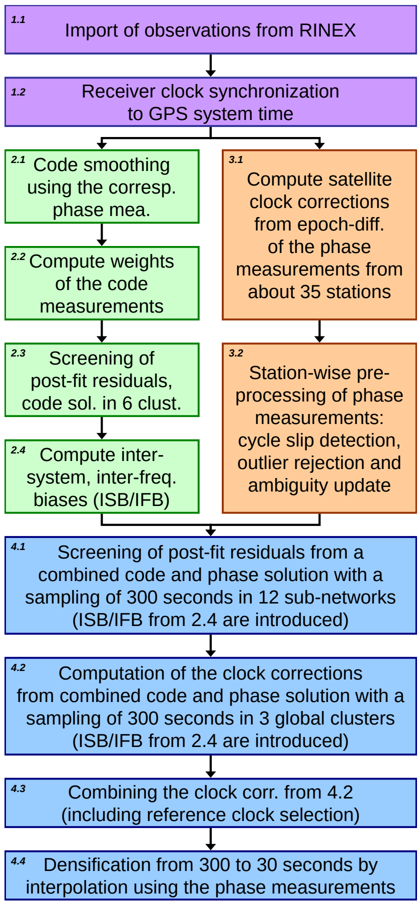


Figure 4: Flow chart of the GPS/GLONASS rapid clock product generation.

Now the observations are prepared to compute the clock corrections. The stations are divided into three clusters that are analysed in parallel with a sampling of 5 minutes where also the biases from processing step 2.4 are introduced as known. In a subsequent step the clock corrections of the three clusters are combined and the reference clock for the solution submitted to the IGS is selected. The densification from 300 to 30 seconds is done according to the phase-based interpolation procedure as described in Bock et al. 2009.

4 CODE contribution to the IGS–MGEX campaign

Since 2012 CODE contributes to the IGS Multi-GNSS EXperiment (MGEX) aiming on the integration of new GNSS into existing processing chains (Prange et al. 2016a). The product is generated using the latest development version of the Bernese GNSS Software package and is derived from a rigorously combined five system solution considering GPS, GLONASS, Galileo, BeiDou (MEO and IGSO), and QZSS satellites. Even if the focus is on the satellite orbits and satellite clock corrections, also other parameters need to be estimated like diverse biases for the receivers, ERPs, station coordinates, and troposphere parameters. A more detailed description is given in Prange et al. 2016b.

During the year 2015 the following updates have been introduced in the processing scheme:

- Since January 2015 the MGEX solution is regularly computed and posted to the product file area at CDDIS:

  `ftp://cddis.gsfc.nasa.gov/gnss/products/mgex`

  as well as since beginning of 2016 also to the anonymous ftp server of AIUB:

  `ftp://ftp.unibe.ch/aiub/CODE_MGEX/CODE`

  The list of products is given in Table 4.

Table 4: CODE MGEX products available through anonymous ftp

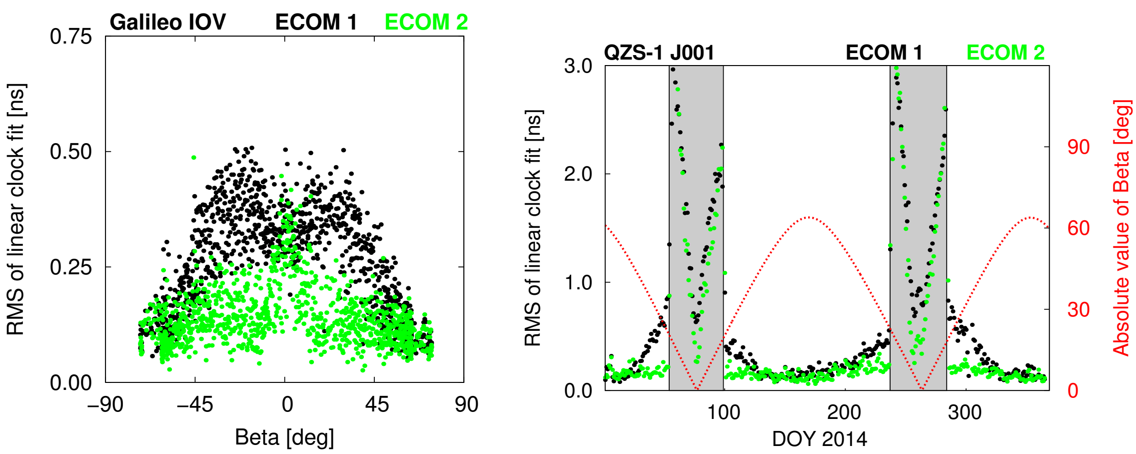
CODE *final* products available at ftp://ftp.unibe.ch/aiub/CODE_MGEX/CODE/yyyy/	
`yyyy/COMwwwwd.EPH.Z`	CODE GNSS orbits for GPS, GLONASS, Galileo, BeiDou, and QZSS satellites, SP3 format
`yyyy/COMwwwwd.ERP.Z`	Earth rotation parameters related to the MGEX orbits, IERS format
`yyyy/COMwwwwd.CLK.Z`	Satellite and Receiver clock corrections consistent to the MGEX orbits with a sampling of 5 minutes, clock RINEX format
`yyyy/COMwwwwd.BIA.Z`	GNSS code biases related to the MGEX clock correction product, bias SINEX format v0.01
`yyyy/COMwwwwd.DCB.Z`	GNSS code biases related to the MGEX clock correction product, Bernese format

- Since January 2015 the extended ECOM (Arnold et al. 2015) is used for Solar radiation pressure modelling in the MGEX product generation including the 2pr and 4pr terms in the D direction ($n_D = 2$ in Equation 2).
  As in the operational processing, the 4pr terms in the D direction are skipped since day 251 of year 2015 (08-Sep-2015).

  Figure 5 confirms the positive impact of the new orbit model (green dots, label ECOM 2) over the traditional one (black dots with label ECOM 1). For the Galileo and the QZSS satellites the RMS of a linear fit of the epoch-wise independently estimated satellite clock corrections are shown. As long as the satellites are flying in the yaw-steering mode there is a clear reduction of the dependency of the orbit quality parameter from the elevation of the Sun above the orbital plane (beta angle). In the gray shaded areas, the QZSS satellite is switched to the so-called orbit normal mode where the ECOM decomposition as introduced by Beutler et al. 1994 is not designed for. An adaptation is currently under development.

- Since August 2015 the observations from QZSS and BeiDou satellites, that come close to the beta angle where the attitude mode of the satellite is changed, are introduced with a very low weight. In this way, the mis-modelling of the Solar radiation pressure cannot degrade the solution and the orbits of other satellites.

Based on the MGEX solution, CODE has also contributed to a comparison and validation of estimated satellite antenna phase center offsets for Galileo satellites (Steigenberger et al. 2015).



(a) Galileo IOV satellites, except of E20 (SVN 104)

(b) QZSS satellite J001 (QZS–1)

Figure 5: RMS of daily linear fit through estimated epoch-wise satellite clocks as a function of the beta angle.

5 Influence of the length of the orbit arc on GNSS results

Based on the reprocessing series computed in the year 2013 (see Dach et al. 2014) – the contribution of CODE to the IGS repro2 effort – detailed investigations on the influence of the orbit arc length on several products have been carried out. In this context the clean one day and three day long arc solutions (that are also regularly computed by the CODE AC in the operational final processing chain) were evaluated. Because the IGS is requesting daily coordinate solutions (for correcting the loading effect on solution level) and daily independent polar motion parameters, an additional *special long arc solution* has been generated where only continuity conditions were applied to the orbit parameters.

The detailed analysis can be found in Lutz et al. 2016. The improvement of the estimated polar motion rates when increasing the arc length from one day (red) to three days (blue) is a highlight of the article (see Fig. 6). On the one hand, the reduced number of independent sets of polar motion parameters in the three day long arc solution due to the continuity conditions results in the best agreement to the C04 series. On the other hand, the clean one day solutions show a significant deviation with periods of one and half a year. With the increasing influence of GLONASS (from top to bottom) also a third of a year period becomes relevant for the clean one day solutions.

The special long arc solution with only applying continuity conditions on the orbit parameters reduces the amplitudes of the annual and biannual periods in the differences to the C04 series by a factor of two with respect to the clean one day solutions. It is remarkable that particularly the periods at a third of a year that are introduced by the increasing number of GLONASS satellites in the clean one day solution are nearly completely removed. Lutz et al. 2016 also studied the properties of non-overlapping 3-day solutions. The polar motion rates of such solutions are close in quality to those of the classic overlapping 3-day solutions. This corresponds to the observation that longer arcs improve the robustness of the orbit estimates more for GLONASS than for GPS satellites (e.g., in terms of discontinuities at the day boundaries in the celestial frame by a factor of 2 for GPS but 3.5 for GLONASS).

6 CODE contribution to the EGSIEM reprocessing

In the framework of the European Gravity Service for Improved Emergency Management (EGSIEM) project, monthly gravity field solutions derived from the Gravity Recovery and Climate Experiment (GRACE) mission will be combined. Since a consistent reference frame is a prerequisite for precise orbit and related gravity field determination, a reprocessing campaign was initiated at AIUB (subsequently labelled as repro15). To get a consistent series of GNSS satellite clock corrections, GNSS orbits, Earth rotation parameters, and station coordinates, more than 250 globally distributed tracking stations of the IGS network are homogeneously reprocessed for the interval between 2003 to the end of 2014 following the processing standards from the CODE analysis center by March 2015.

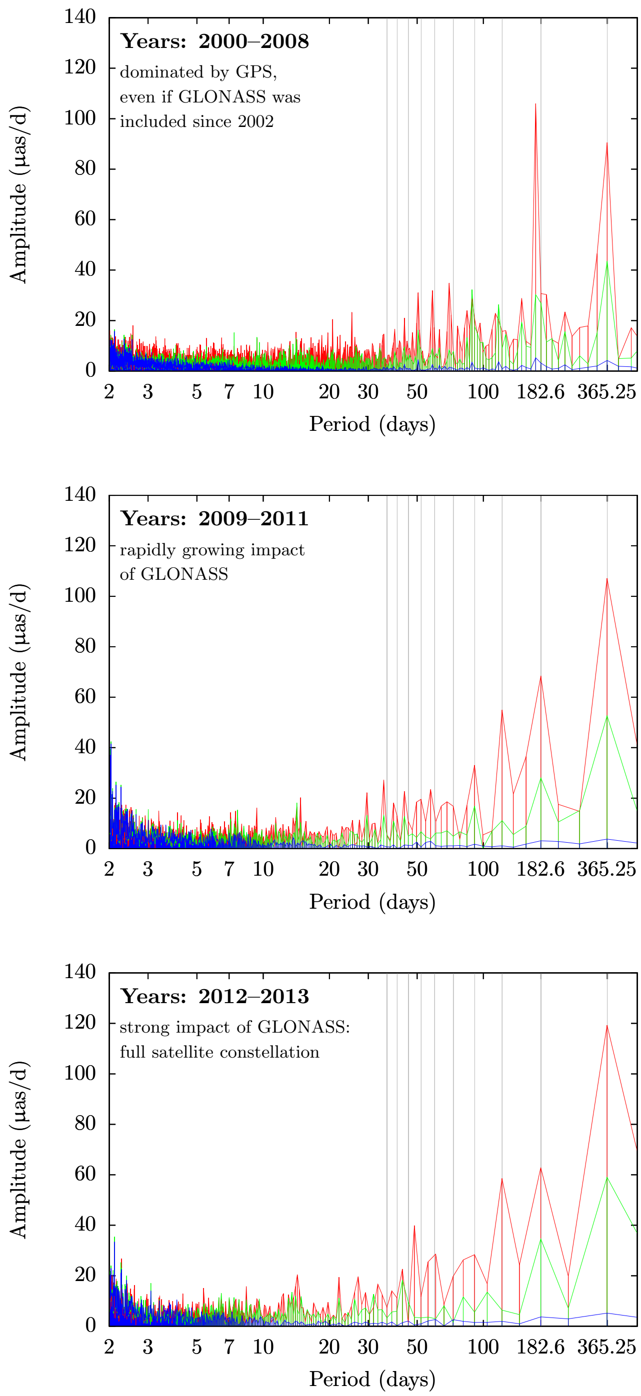


Figure 6: Amplitude spectra of polar motion rate $\dot{x}$ differences between the C04 series and the combined GPS/GLONASS solutions: clean one day solution (red), three day long arc solution (blue), and special long arc solution (green).

Even if the POD for GRACE will only base on GPS satellites, the reprocessing activity considered GPS and GLONASS measurements.

In order to provide within the EGSIEM project reference frame products using latest GNSS orbit modelling effort, reprocessing of the GNSS data was performed using the extended Empirical CODE orbit model (Arnold et al. 2015), which significantly improves the accuracy of the GNSS orbits (in particular for the GLONASS satellites) and reduces the deficiencies in the geodynamical parameters. Since the reference frame for the most recent reprocessing is still IGb08 the same station selection as in IGS-repro2 from CODE was reused for the repro15 effort. The processing starts from the original GNSS observations in the RINEX files. As a priori orbit information the results from the repro2 campaign for the IGS was used and completed by alternative sources (e.g., broadcast orbits) in order to include as many satellites into the processing as possible. This effort resulted in a bigger number of satellites for the repro15 series when comparing with the number of satellites in the result files of the 1-day solutions of repro2 (see Fig. 7).

Since all GLONASS and two GPS satellites are equipped with retro-reflector arrays, SLR provides an independent tool to validate microwave-based GNSS orbits. Because the maximum angle of incidence of a laser pulse to a GNSS satellite does not exceed 14°, SLR residuals indicate mainly the radial accuracy of microwave-based GNSS orbits (Sośnica et al. 2014; Fritsche et al. 2014; Maier et al. 2015). Figure 8 shows SLR residuals w.r.t. the 1-day GLONASS-M orbits – once using the old ECOM (repro2, left side) and once using the extended ECOM (repro15, right side). When the old ECOM model is used (left plot of Fig. 8), there is a clear dependency of the SLR residuals on the elongation angle: whereas the residuals to the satellite positions near solar beta angle 90° are scattered around zero, those to satellite positions of smaller absolute solar beta angle show a significant offset to zero. The dependency of the SLR residuals on the elongation angle is significantly reduced

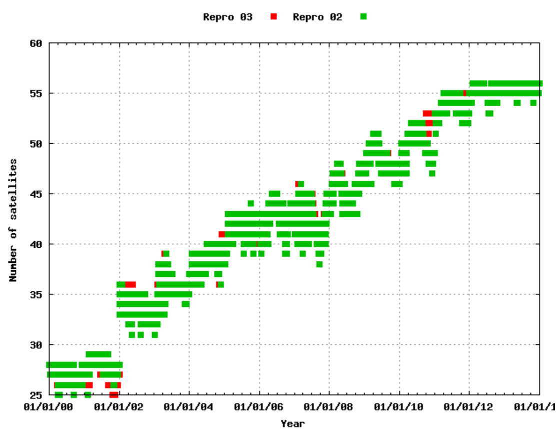


Figure 7: Number of GNSS satellites available in 1-day orbits for the period between 2000 and 2013. Red color represents repro15 and green repro2.

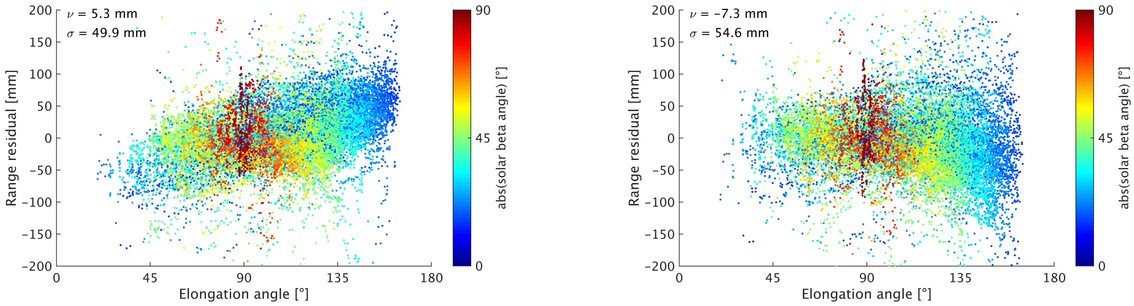


Figure 8: SLR residuals w.r.t. GLONASS-M orbits using the original ECOM (left) and the extended ECOM (right). Mean value (ν) and standard deviation (σ) are based on all residuals whose absolute value is smaller than 150 mm. Observations to four GLONASS satellites (SVN 723, 725, 736, 737) have been excluded due to anomalous patterns. Furthermore, all residuals having an absolute beta angle smaller than 15° have been not taken into account due to unmodeled attitude during eclipses.

in the case of the new ECOM (right plot of Fig. 8).

For the POD of the GRACE satellites the Precise Point Positioning (PPP, Jäggi 2007) is well established. It requires the knowledge of precise and consistent GNSS orbits and satellite clock corrections. Assuming 1 Hz sampling of GNSS data of LEOs, the GNSS satellite clock corrections are required with a sampling of at least 5 seconds (Bock et al. 2009). For the generation of 5 second clock products, GNSS observation files with a higher sampling than the common 30 seconds are needed. They are available from the IGS real-time service with a sampling of 1 Hz (Caissy et al. 2012). At least in the early years, the IGS real-time network was to a large extent independent from the legacy network. In this context, in particular for generation of GLONASS satellite clock products, we have been confronted with the limitation of available GLONASS tracking data in early years of the IGS real-time network. The number of available stations providing 5 s data is shown on the left side of Fig. 9, where grey color represents GPS only, green GPS/GLONASS and white no data available. As can be seen from Fig. 9 before the end of 2010 no 5 s RINEX2 files with GLONASS data are available. On the right side of the Fig. 9 the percentage of completeness of the GLONASS satellite clock products is shown for the 30 s sampling rate.

Figure 10 shows the percentage of completeness of the satellite clock products with 30 s (left side) and 5 s sampling (right side) over the period 2006–2007. It can be noticed that for the period shown, the overall completeness is 100% for both sampling rates, however there are some GPS satellites (namely G12, G15, G29, G31 and G32) for which both, 30 s and 5 s clock corrections are not complete. These data gaps are mainly due to reduced tracking of (unhealthy) satellites.

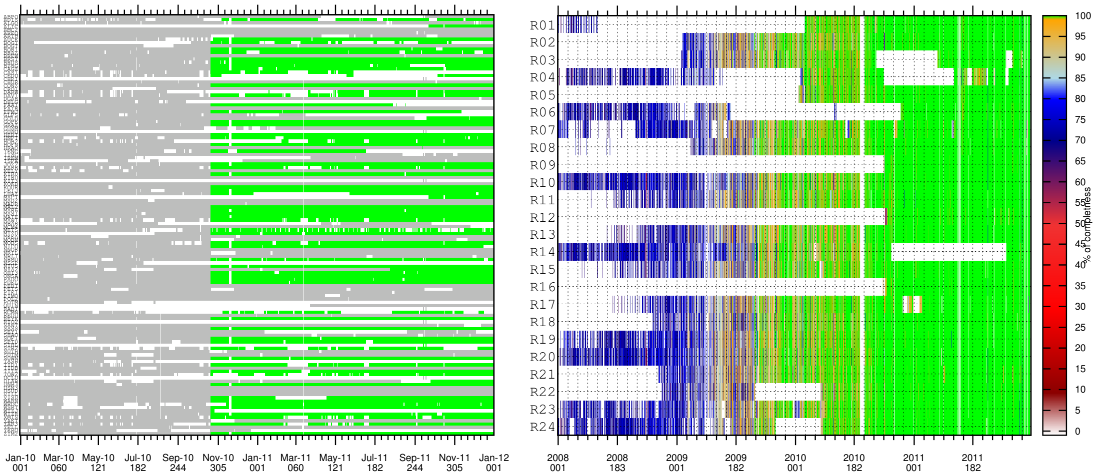


Figure 9: (Left): number of stations delivering 5 s RINEX2 files, where grey color presents GPS only, green GPS/GLONASS and white no data available. (Right): completeness of 30 s GLONASS clock corrections for the 2008-2011 period.

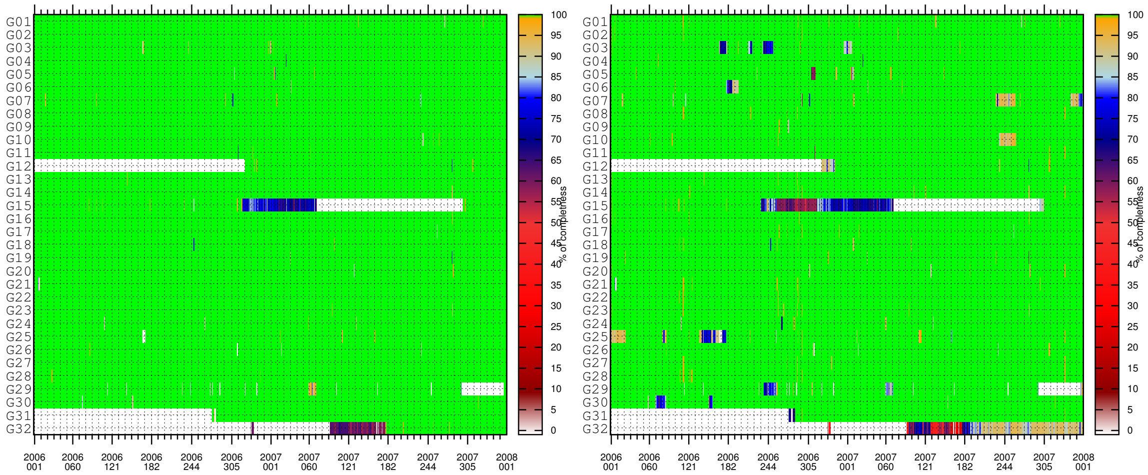


Figure 10: Completeness of 30 s (left) and 5 s (right) GPS clock corrections for the time period between 2006 and 2007.

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