EGSIEM reprocessing products

A. Susnik

Astronomical Institute, University of Bern

Motivation

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- For Precise Orbit Determination (POD) of Low Earth Orbiting (LEO) satellites, Precise Point Positioning (PPP) is a well established technique.
- However PPP requires the knowledge of precise and, even more importantly, consistent set of GPS orbits and satellite clock corrections.

- To provide consistent set of GPS satellite clock corrections, orbits, Earth rotation parameters and station coordinates, Astronomical Institute of University of Bern (AIUB) initiated a dedicated reprocessing campaign.

- The activity has been extended to a full reprocessing campaign, starting in year 1994. With year 2002 GLONASS was included into the processing. The reprocessing is based on Center for Orbit Determination (CODE) analysis strategy (as of Summer 2015), including the extended ECOM (Empirical CODE Orbit Model, Arnold et al., 2015).

Motivation

	GPS	GLONASS
Orbits	since 1994	since 2002
Satellite clock corrections (30 s)	since 2000	since 2008
Satellite clock corrections (5 s)	since 2003	since 2010

In this context GLONASS 5 s satellite clock corrections were computed for the first time.

Processing strategy

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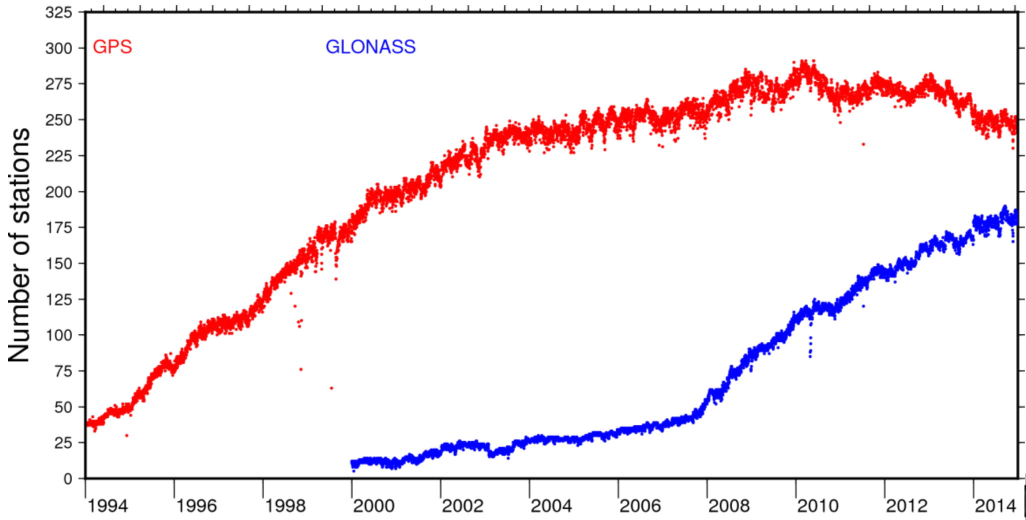
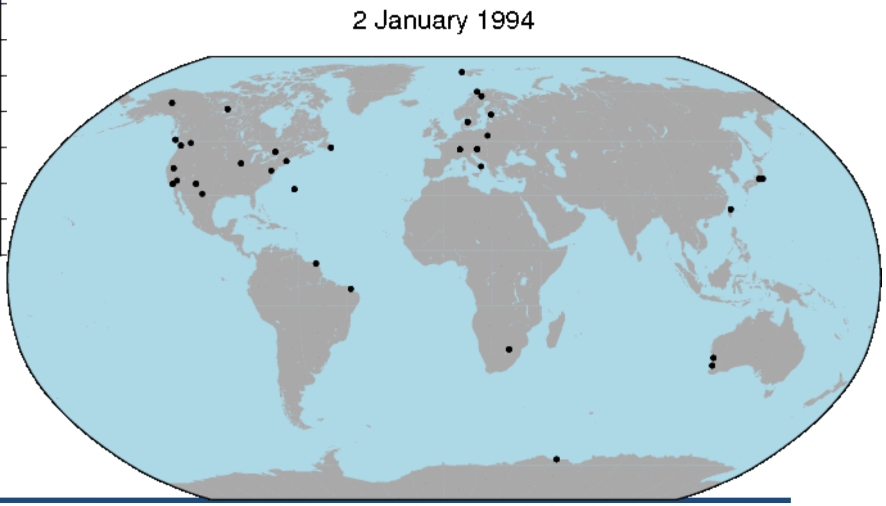
- Data from more than 250 globally distributed stations were homogenously processed for the time period 1994 – 2014.
- The reprocessing starts on 2 January 1994 (with GPS only) and ends in 31 December 2014. Starting with 1 January 2002, GLONASS is included.





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Processing strategy

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- Since the reference frame for the most recent International GNSS Service (IGS) reprocessing camping (repro2) is still IGb08, the same station selection was used for EGSIEM-REPRO.
- The latest development version of Bernese GNSS Software was used, together with the extension of the Empirical CODE orbit model (ECOM2):

	Parameters estimated in		
	D	*Y*	*B*
Original ECOM	constant	constant	constant, 1-cpr
Extended ECOM	**constant, 2-cpr, 4-cpr**	**constant**	**constant, 1-cpr**

Empirical parameters estimated in *D* (satellite-Sun direction), *Y* (direction along the satellite's solar panels axes), and *B* (completes the orthogonal right-handed system) for the original ECOM and the extended ECOM (cycle-per-revolution is denoted as cpr).

Processing strategy

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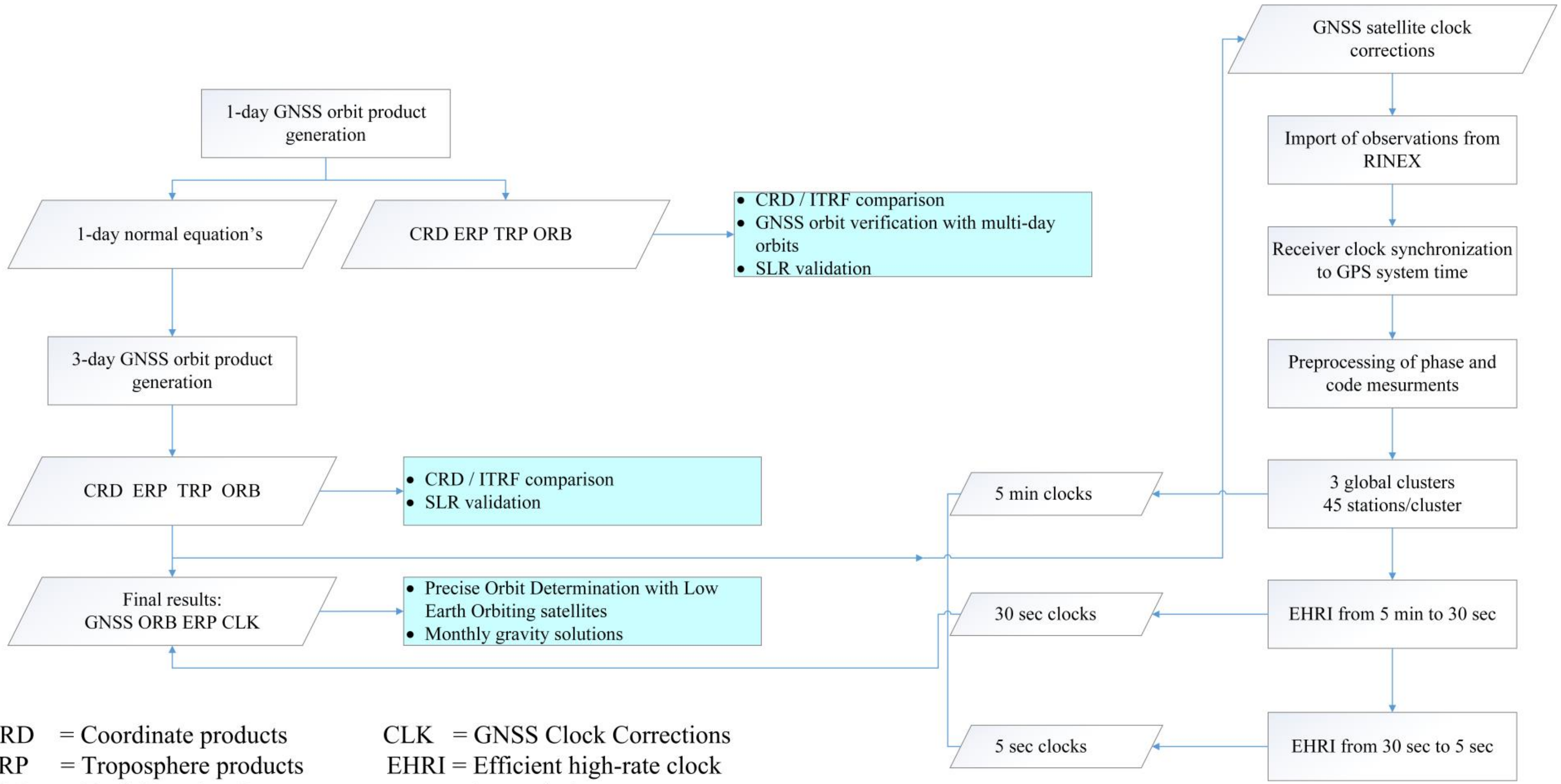

CRD = Coordinate products
TRP = Troposphere products
ERP = Earth Rotation Parameters
ORB = Orbit products

CLK = GNSS Clock Corrections
EHRI = Efficient high-rate clock interpolation

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Generation of GNSS Orbits

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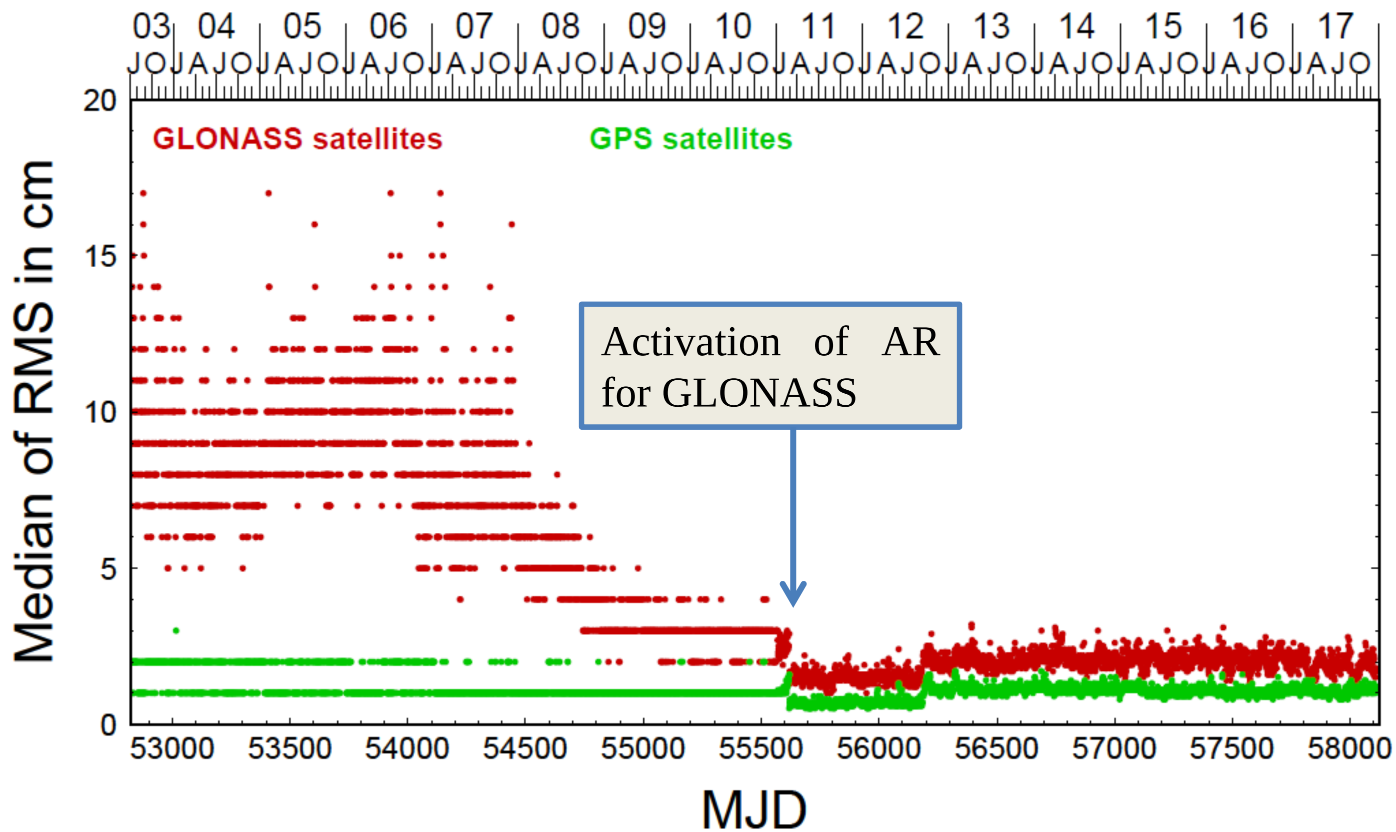
- An important aspect in obtaining high-quality GNSS results is the resolution of the carrier phase double difference ambiguities to their integer values.



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Generation of GNSS Orbits

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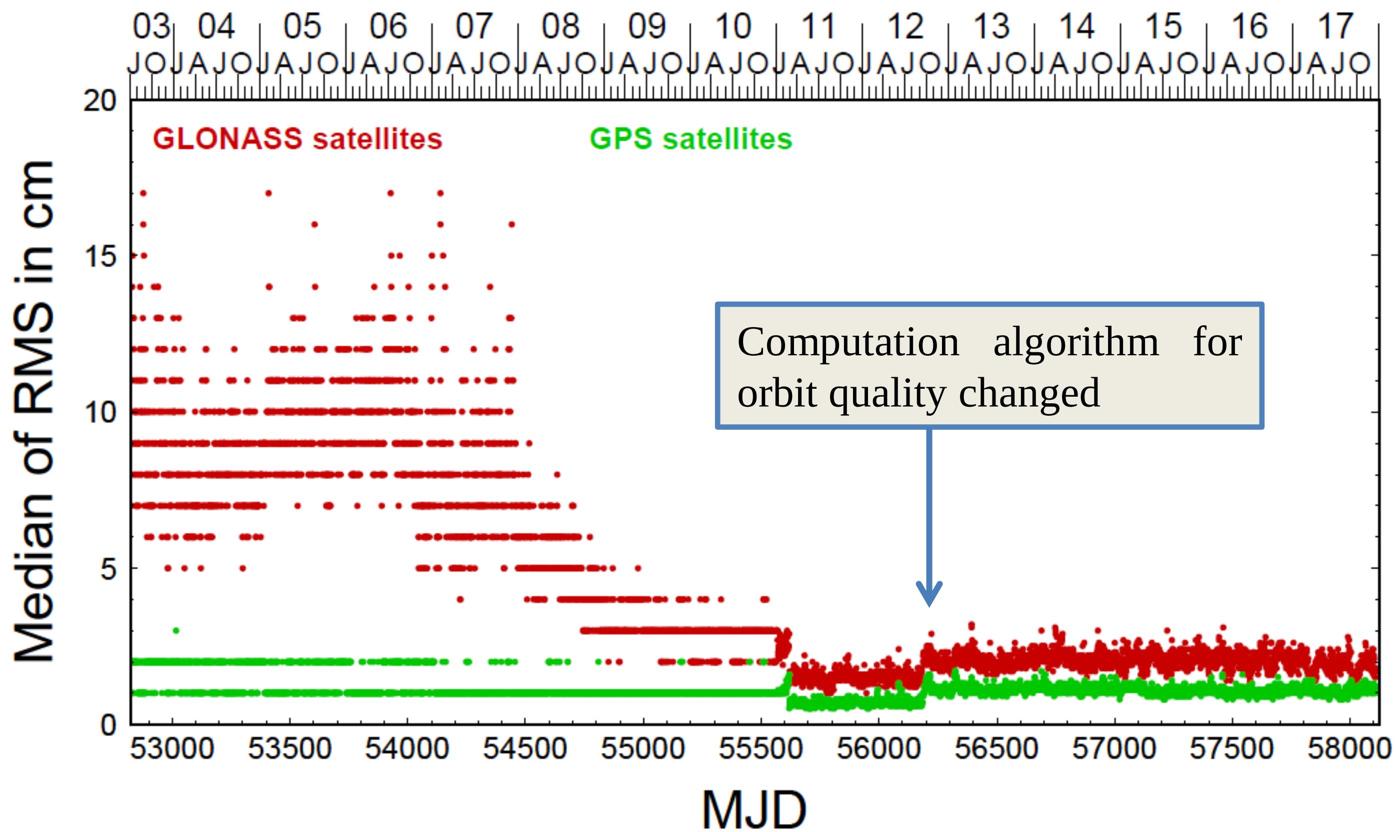

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Generation of GNSS Orbits

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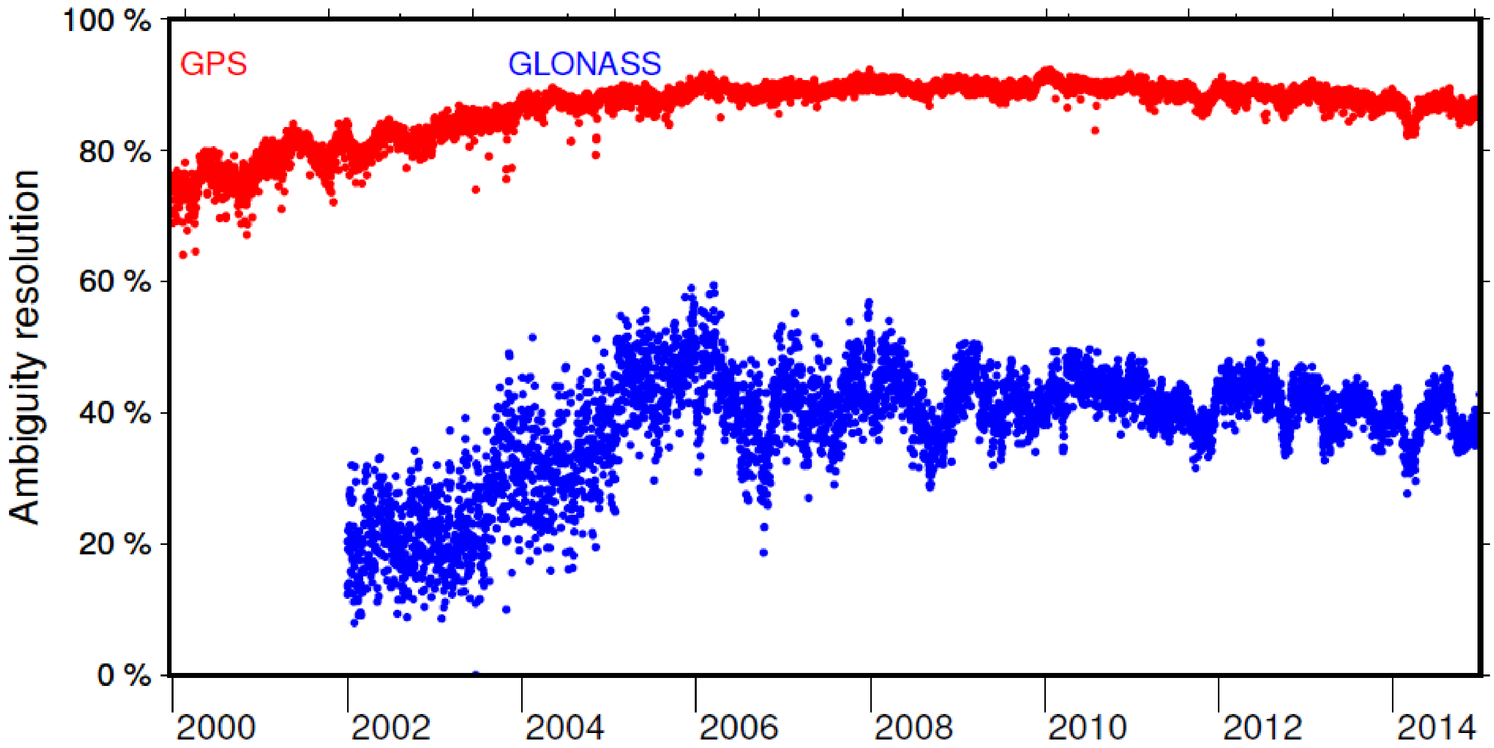

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Generation of GNSS Orbits

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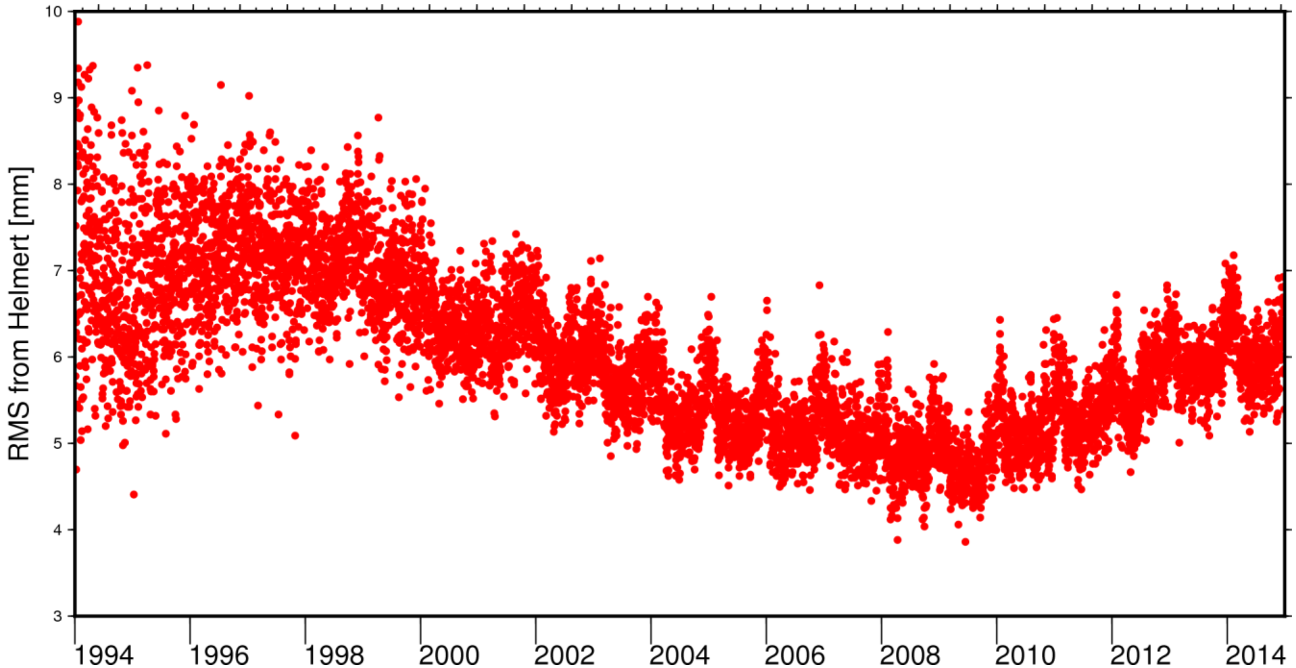
Also verification of station-related parameters was performed, in order to detect stations with discontinuities between subsequent days (e.g. due to equipment changes or Earthquakes). Only if no event was detected, the coordinates have been stacked to three-day solutions.



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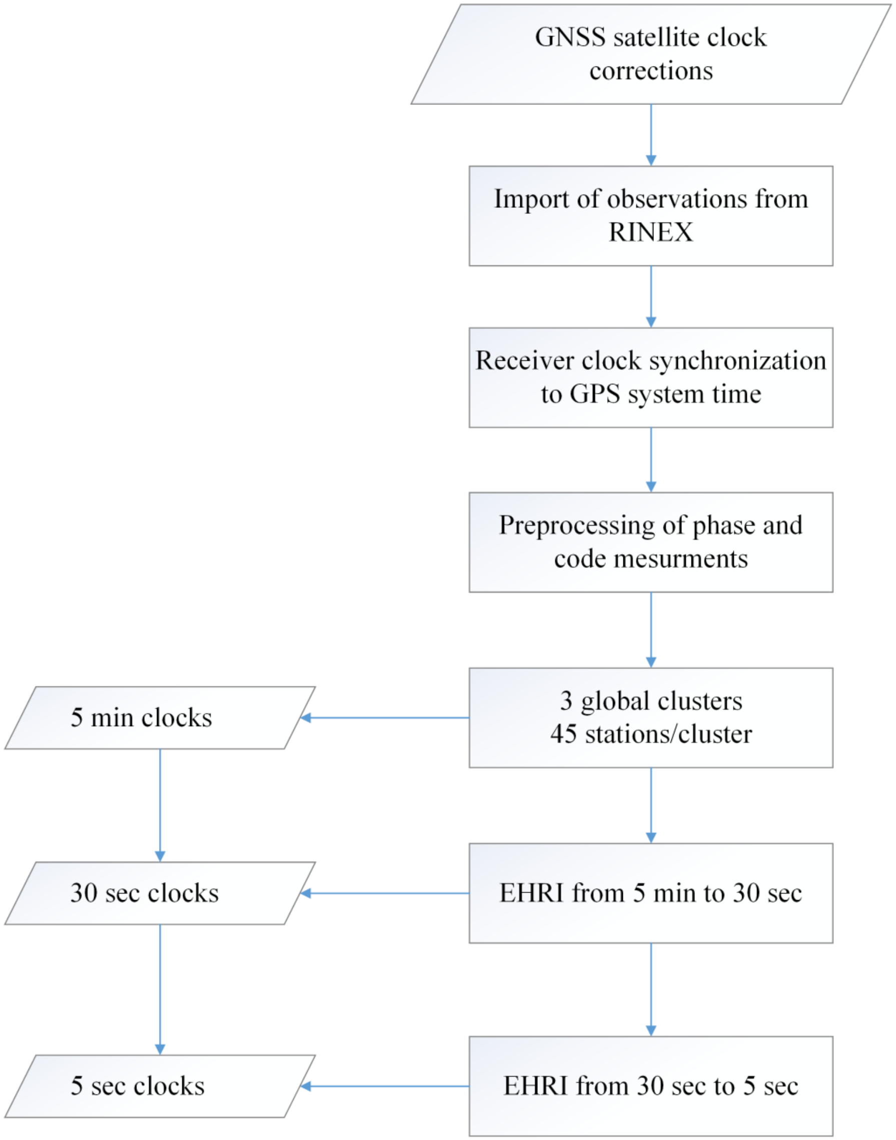

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GNSS clock products

- Results from the double difference processing were introduced as know in generation of GNSS clock products. In first step a zero-difference network solution is performed for estimation of satellite and receiver clock parameters with 300 s sampling.
- However, the procedure is limited to a sampling of 30 s, since the standard IGS stations provide data only with this sampling. GNSS observations with a sampling of 1 Hz are provided from IGS real-time project (Caissy et al., 2012).

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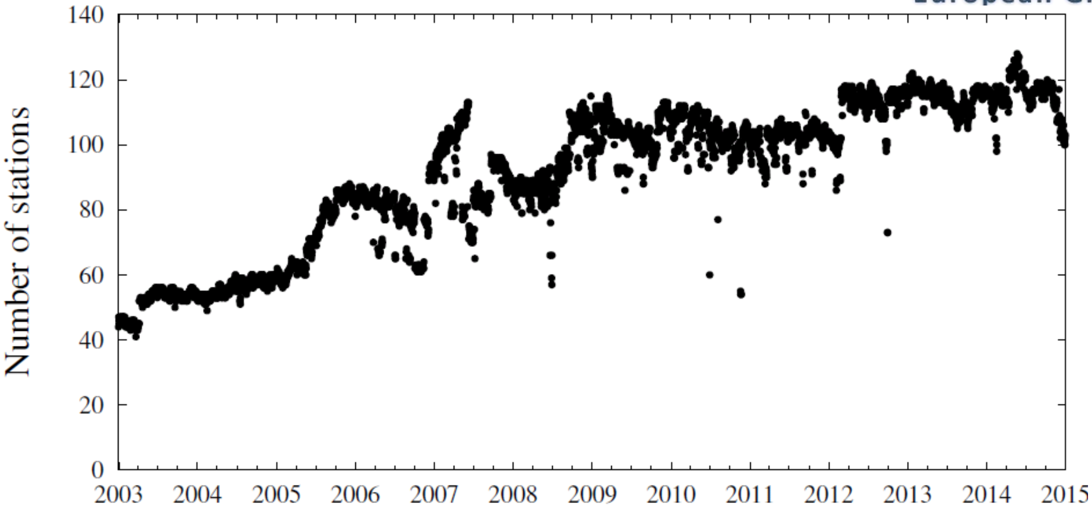
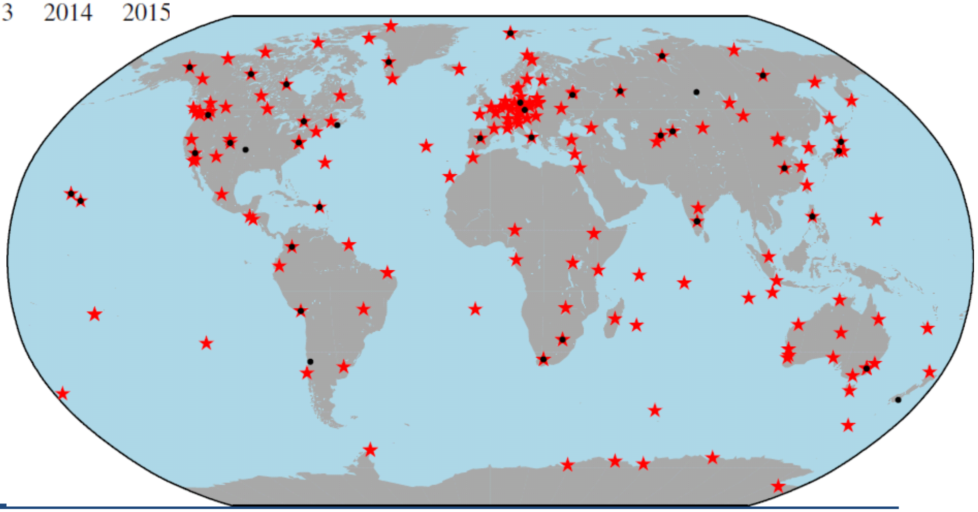
GNSS clock products



Number of stations delivering high-rate RINEX2 data for the period between 2003 and the end of 2014.



Geographical distribution of stations providing high-rate RINEX2 data on January 1, 2003 (black dots) and on January 1, 2014 (red stars).

GNSS clock products

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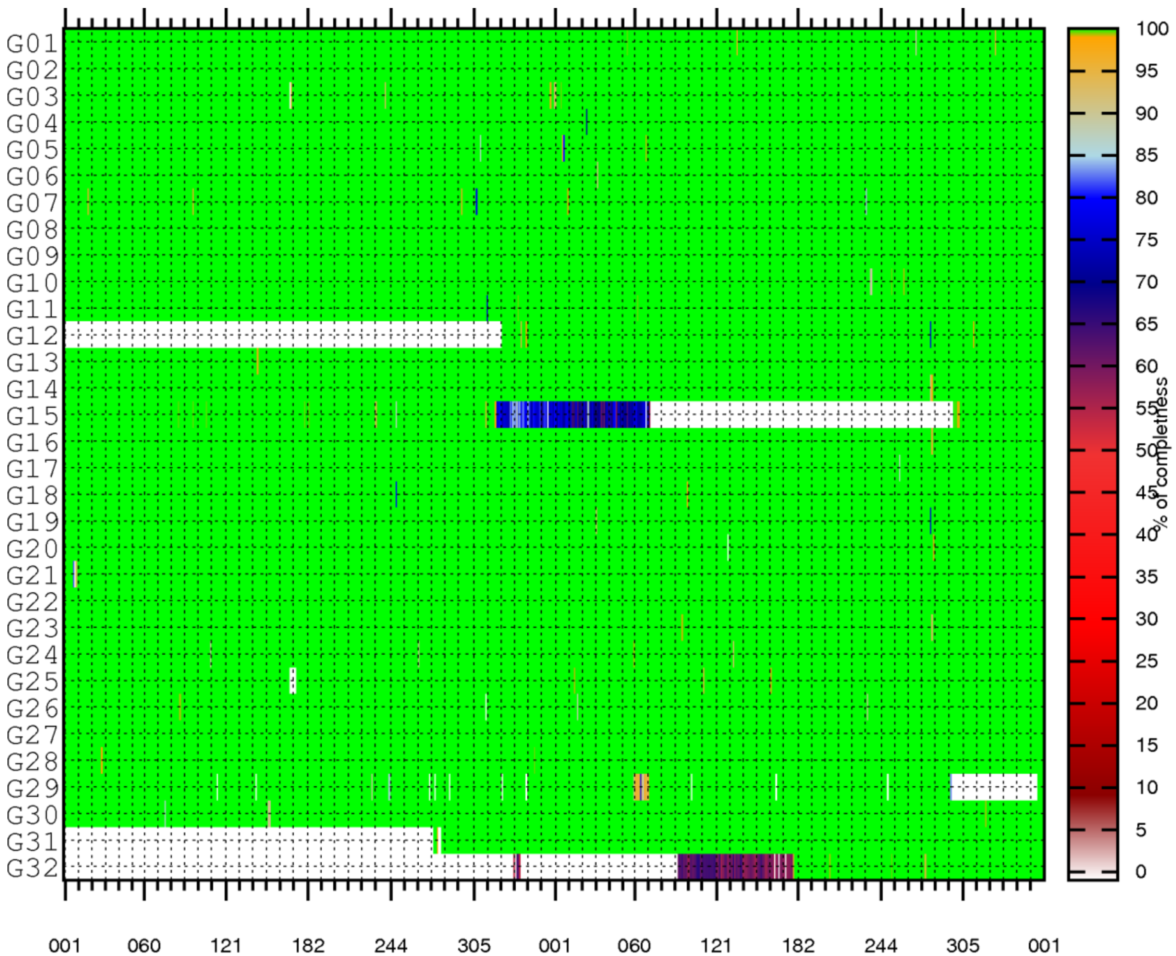

Completeness of GPS satellite clock corrections with a sampling of 30 s for the time period 2006 – 2007.

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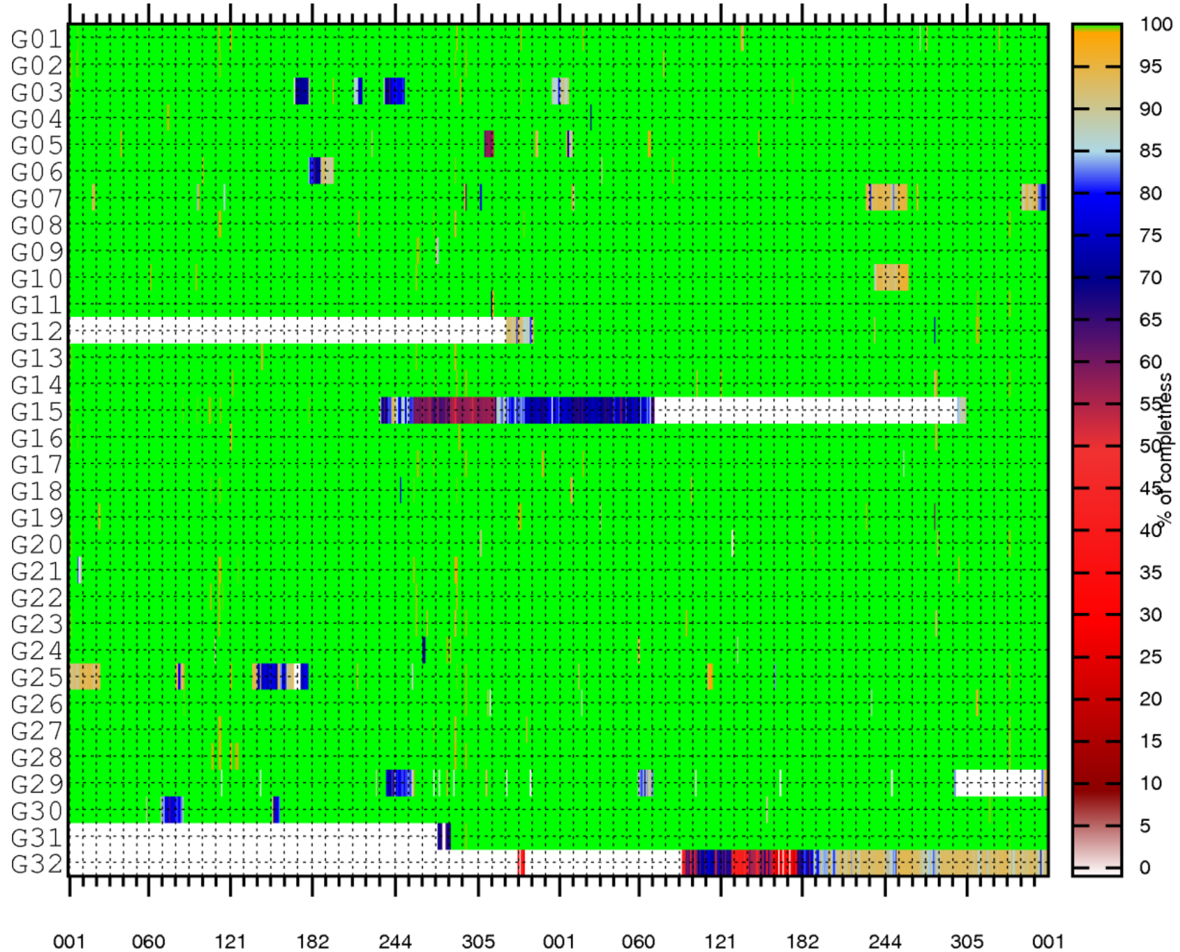
GNSS clock products



Completeness of GPS satellite clock corrections with a sampling of 5 s for the time period 2006 – 2007.

Validation of the products

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GRACE Precise Orbit Determination

Validation of GNSS orbits by means of Satellite Laser Ranging

GRACE Precise Orbit Determination

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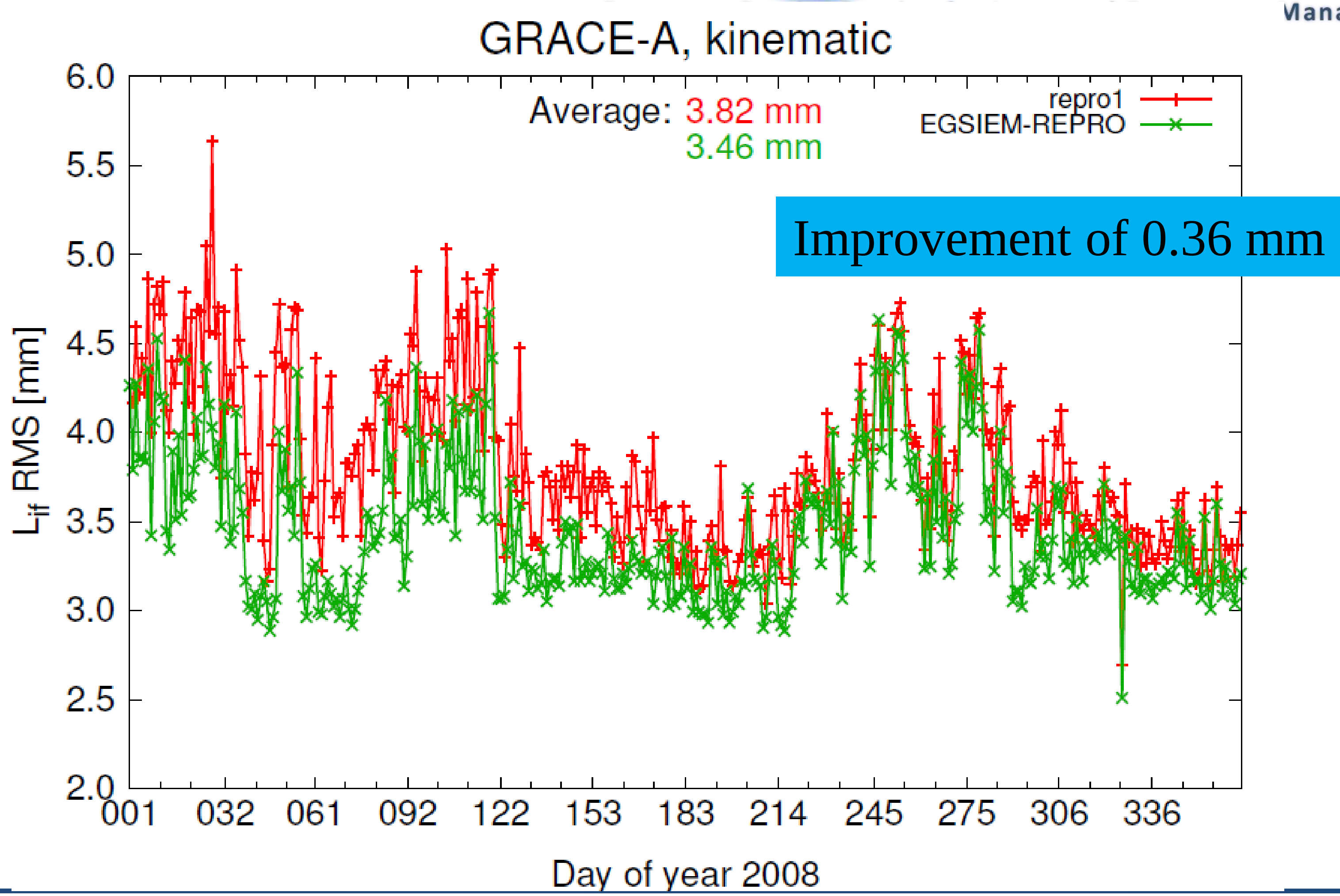
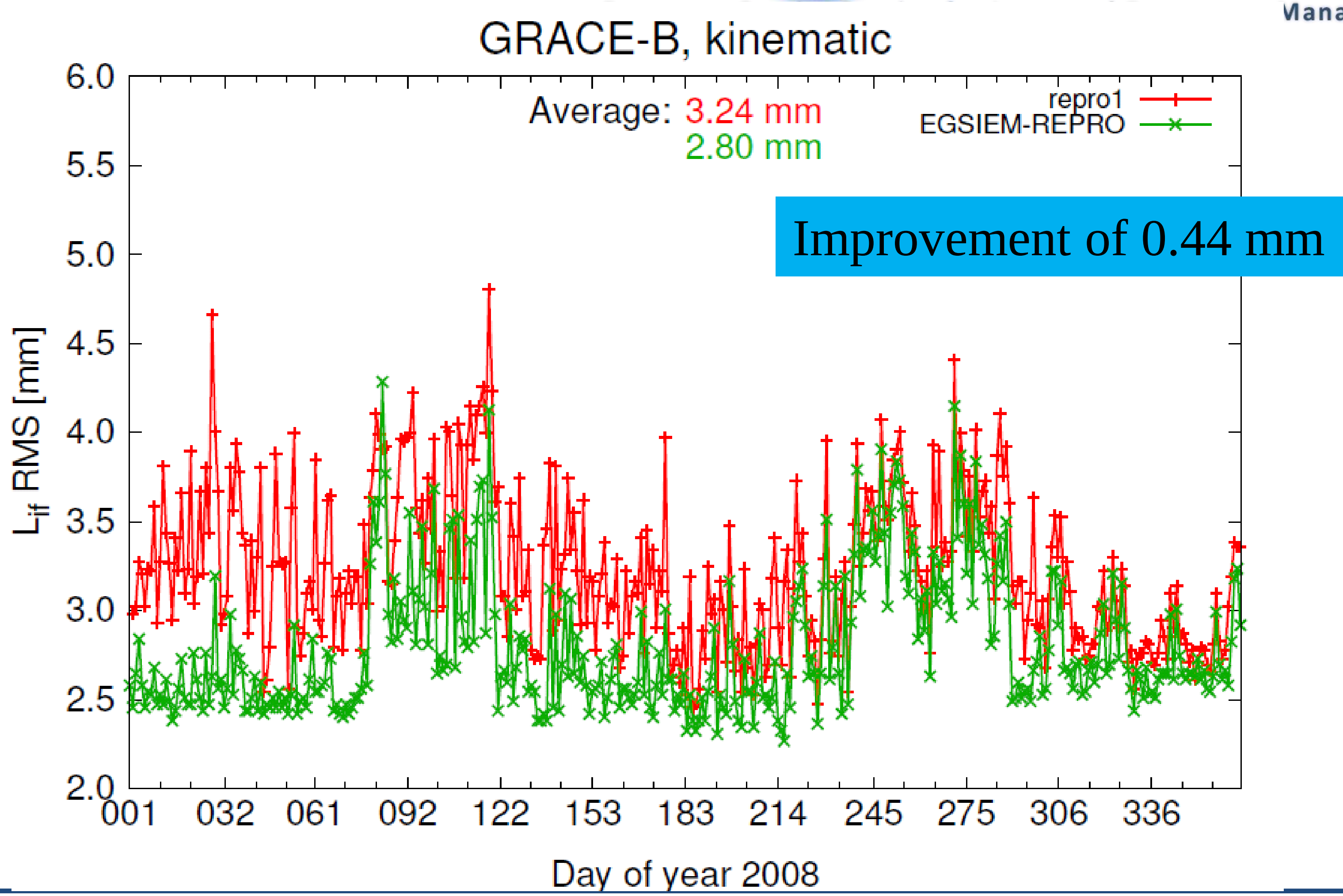
- For efficient validation of global GPS orbits and clock solutions over all regions of the Earth by processing data from one single receiver.
- Based on undifferenced GPS data.
- Results were compared to solutions obtained with products from IGS repro1 (since from repro2 there are no consistent clock corrections available at CODE).
- As an independent orbit validation of obtained GRACE orbits, Satellite Laser Ranging was used, using normal points from 16 SLR stations.

GRACE Precise Orbit Determination



GRACE Precise Orbit Determination



GRACE Precise Orbit Determination

Mean and standard deviation in mm of SLR residuals for reduced-dynamic orbits over entire year 2008. Numbers in brackets indicate number of observations.

	GRACE A	GRACE B
repro1	1.99 ± 18.14 (32587)	0.09 ± 18.51 (31008)
EGSIEM-REPRO	2.21 ± 12.93 (32639)	0.70 ± 14.14 (31030)

Mean and standard deviation in mm of SLR residuals for kinematic orbits over entire year 2008. Number in brackets indicate number of observations.

	GRACE A	GRACE B
repro1	1.24 ± 19.98 (32358)	0.44 ± 23.00 (30343)
EGSIEM-REPRO	2.11 ± 17.00 (32409)	1.24 ± 19.75 (30456)

Satellite Laser Ranging to GNSS

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Satellite Laser Ranging to GNSS

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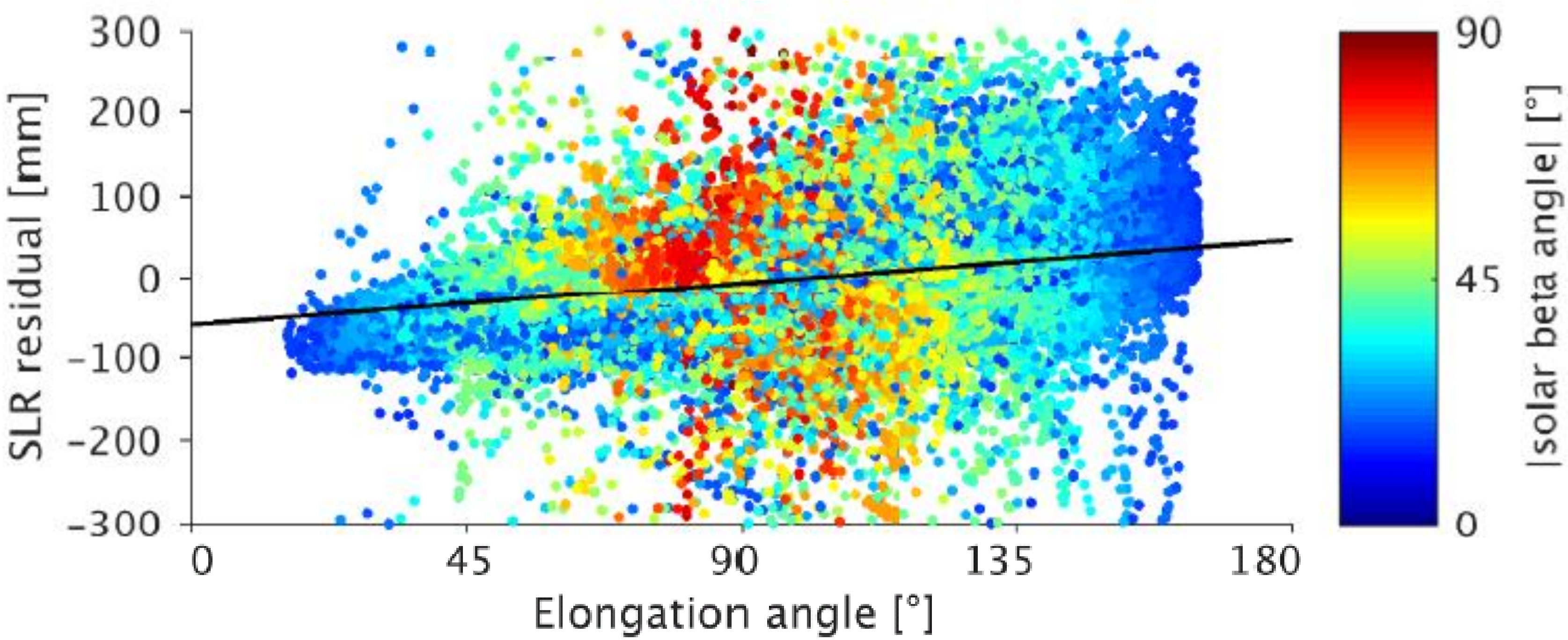

SLR residuals with respect to GLONASS-M orbits from repro2 using the original ECOM. Residuals between January 2003 and December 2013 are shown. Observations to four GLONASS satellites (SVN 723, 725, 736, 737) were excluded due to anomalous patterns. Furthermore, all residuals having an absolute beta angle smaller than 15 are not shown due to unmodeled attitude during eclipses. The black line indicates the linear regression behavior between the SLR residuals and the elongation angle.

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Satellite Laser Ranging to GNSS

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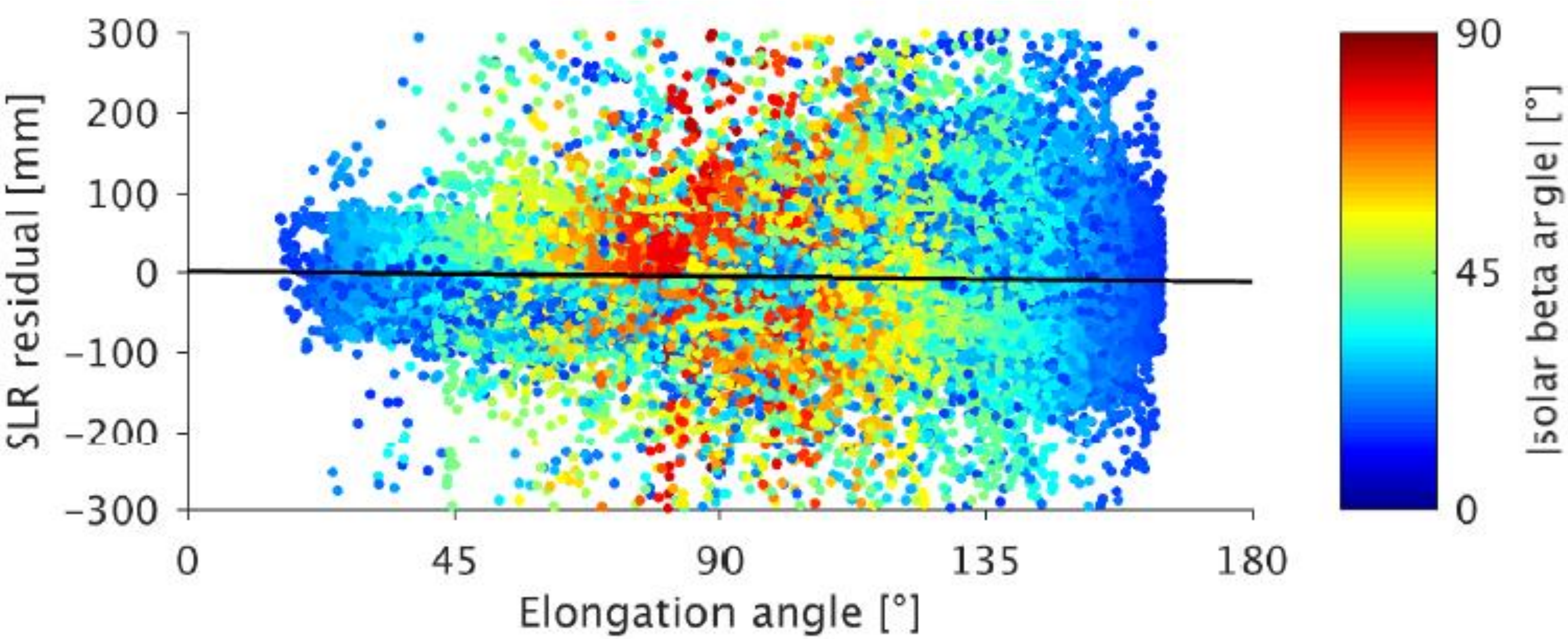

SLR residuals with respect to GLONASS-M orbits from EGSIEM-REPRO using the extended ECOM. Residuals between January 2003 and December 2013 are shown. Observations to four GLONASS satellites (SVN 723, 725, 736, 737) were excluded due to anomalous patterns. Furthermore, all residuals having an absolute beta angle smaller than 15 are not shown due to unmodeled attitude during eclipses. The black line indicates the linear regression behavior between the SLR residuals and the elongation angle.

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Reference Frame Products

- Reference Frame Products covering GPS (1994-2001) and combined GPS+GLONASS (2002-2014) are available in the directory:

http://www.aiub.unibe.ch/download/REPRO_2015

- A detailed analysis strategy summary is available in:

CODE_REPRO_2015.ACN

- Referencing Reference Frame Products:

Susnik, Andreja; Dach, Rolf; Villiger, Arturo; Maier, Andrea; Arnold, Daniel; Schaer, Stefan; Jaeggi, Adrian (2016). CODE reprocessing product series. Published by Astronomical Institute, University of Bern. URL: http://www.aiub.unibe.ch/download/REPRO_2015; DOI: 10.7892/boris.80011.

Reference Frame Products

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CODE
 yyyy/
   CODwwwwd.EPH.Z   Final GNSS orbits
   CODwwwwd.TRO.Z   Daily troposphere SINEX file from final solution
   CODwwwwd.ERP.Z   Daily final Earth rotation parameter files, IERS format
   CODwwwwd.SNX.Z   Daily SINEX product
   CODwwww7.ERP.Z   Weekly final Earth rotation parameter files, IERS format
   CODwwww7.SNX.Z   Weekly SINEX product
   CODwwww7.SUM.Z   Weekly processing summary

   CODwwwwd.CLK.Z   Final clock product(GPS since GPS week 1060 DOY 124,
                    03-May-2000; GPS+GLONASS since GPS week 1460 DOY 001,
                    01-Jan-2008), 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

   CODwwwwd.CLK_05S.Z
                    Final clock product (GPS since GPS week 1199 DOY 001,
                    01-Jan-2003; GPS+GLONASS since GPS
                    week 295, 22-Oct-2010), 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
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Publications

- **A. Sušnik, A. Grahsl , D. Arnold , A. Villiger, R. Dach A. Jäggi, 2017: GNSS reprocessing results in the framework of the EGSIEM project, Short Note, submitted to Journal of Geodesy.**
- Maier, A., A. Sušnik, D. Arnold, K. Sośnica, R. Dach, A. Jäggi; 2015: **Validation of GNSS orbits using Satellite Laser Ranging data.** IUGG 2015, Prague, Czech Republic, June 22 - July 2, 2015.
- Maier A., A. Sušnik, D. Arnold, K. Sośnica, U. Meyer, R. Dach, A. Jäggi, D. Thaller; 2015: **SLR in the framework of the EGSIEM project.** ILRS Technical Workshop, Matera, Italy, 26 - 30 October, 2015.
- Dach, R., A. Sušnik, A.Maier, A.Villiger, D. Arnold, A, Jäggi,;2016: **Evaluation of ITRF2014 Solutions.** 2016 AGU Fall Meeting, San Francisco, USA, 12-16 December, 2016.
- Grahsl, A., A. Sušnik, L. Prange, D. Arnold, R.Dach,A, Jäggi,;2016: **GNSS orbit validation activities at the Astronomical Institute in Bern.** ILRS Workshop 2016, Potsdam, Germany, 9 14 October, 2016.
- Maier A., A. Sušnik, R. Dach, A. Jäggi, L. Prange, K. Sośnica; 2016: **GNSS orbit validation using SLR observations at CODE.** IGS Workshop 2016, Sydney, Australia, 8-12 February, 2016
- Sušnik A., R. Dach, D. Arnold, A. Maier, A. Jäggi; 2016: **Reprocessing campaign in the framework of the EGSIEM project at AIUB.** IGS Workshop 2016, Sydney, Australia, 8-12 February, 2016.
- Beutler G., M. Meindl, S. Lutz, R. Dach, S. Scaramuzza, A. Sušnik, D. Arnold, A. Jäggi; 2016: **Estimation of polar motion, polar motion rates, and GNSS orbits in the IGS.** IGS Workshop 2016, Sydney, Australia, 8-12 February, 2016.
- Meyer, U., Y. Jean, A. Jäggi, A. Sušnik, D. Arnold, C. Dahle, T. Mayer-Gürr, J.-M. Lemoine; 2016: **EGSIEM combination of GRACE monthly gravity fields** GRACE Science Team meeting (GSTM), Potsdam, Germany, October 5-7, 2016.
- Scaramuzza, S., R. Dach, G. Beutler, D. Arnold, A. Sušnik A. Jäggi; 2017: **Dependency of geodynamic parameters on the GNSS constellation.** Journal of Geodesy, in press. DOI 10.1007/s00190-017-1047-5;
- Arnold, D., U. Meyer, A. Sušnik, R. Dach, A. Jäggi; 2017: **Impact of GNSS orbit modeling on LEO orbit and gravity field determination.** European Geosciences Union (EGU) General Assembly 2017, Vienna, Austria, April 24-28, 2017
- Sušnik, A., D. Arnold, A. Villiger, R. Dach, A. Jäggi; 2017: **Validating EGSIEM Reprocessing Products by LEO POD and PPP.** International GNSS Service (IGS) Workshop 2017, Paris, France, July 3-7, 2017
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