INTEROPERABILITY OF THE GNSS'S FOR POSITIONING AND TIMING

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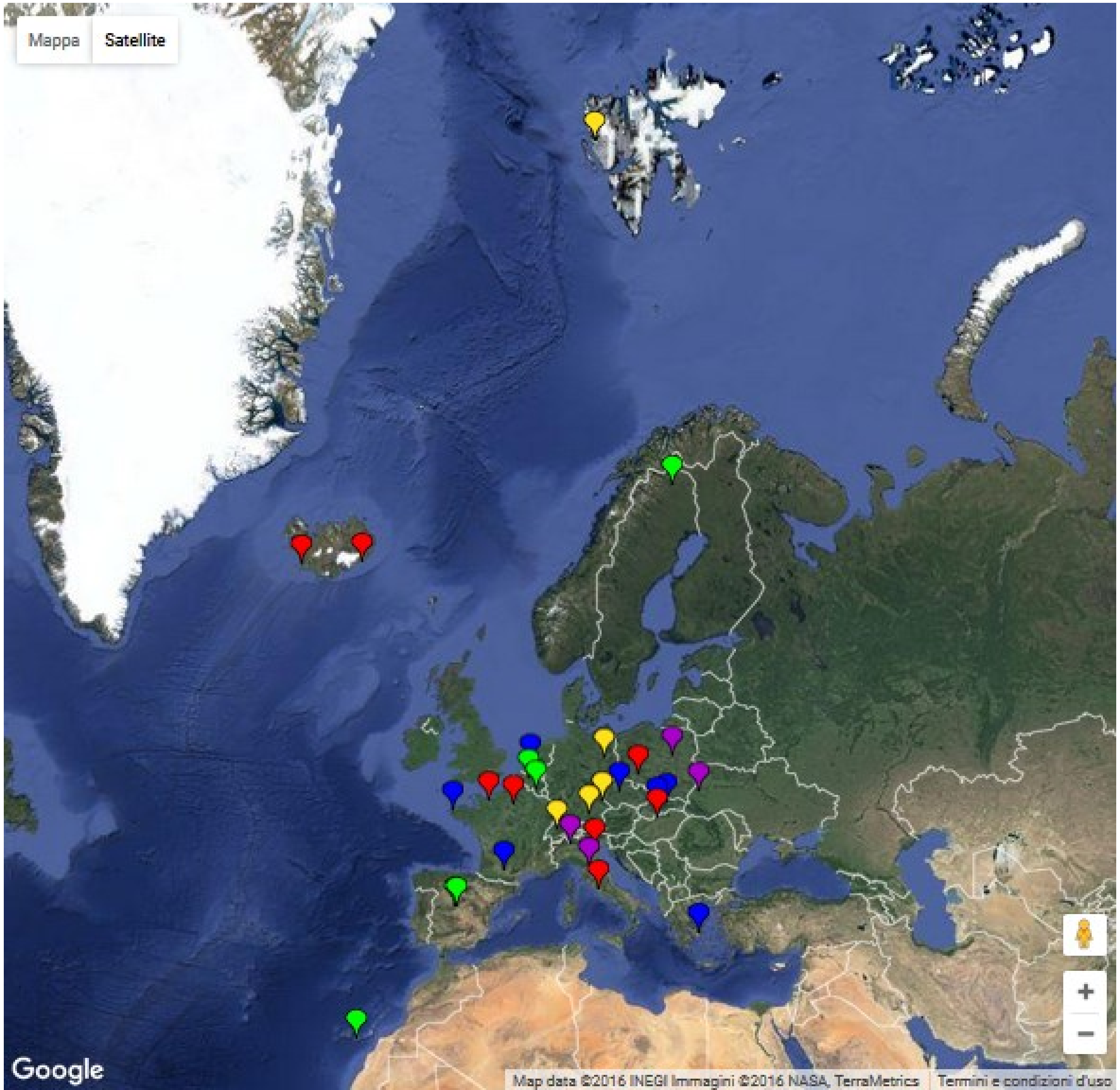
Outlook

- Monitor 31 European GNSS sites with 5 different receivers (Javad, Leica, Septentrio, Topcon, Trimble)
- Questions to be addressed:
  - Offset among the time scales of different GNSS constellations? (Note: 3 m ⇔ 10 ns: we observe biases of tens to hundreds of ns)
  - Do different receivers measure different offsets?
- Use own MATLAB software
- Focus on Glonass, Galileo, Beidou, QZSS, SBAS taking GPS as reference
- Use Broadcast ephemeris, and SP3 from GFZ and CODE
- Use RINEX 3.x data, except Topcon Stations, for which the provided RINEX 2.x are converted to RINEX 3.x with gfzrnx of GFZ (http://semisys.gfz-potsdam.de/semisys/scripts/download/)

Stations Map

- Javad
- Leica
- Septentrio
- Trimble
- Topcon



Input Data

- Static receivers -> sample at 15 min, synchronous with SP3 epochs; at each epoch solve for coords, clock, TZD
- Pseudoranges/carrier phases combined in iono free mode

	Carrier/Frequency [MHz]		Coding in RINEX 3.03		
GPS	L1 (1575.42)	L2 (1227.60)	C1C	C2W	
GLONASS	G1 (1602+k*9/16)	G2 (1246+k*7/16)	C1C	C2P	
Galileo	E1 (1575.42)	E5b (1207.14)	C1	C7I/C7Q/C7X	I/NAV
	E1 (1575.42)	E5a (1176.45)	C1	C5I/C5Q/C5X	F/NAV
BeiDou	B1 (1561.098)	B2 (1207.14)	C1I	C7I	
QZSS	L1 (1575.42)	L2 (1227.60)	C1C	C2S/C2L/C2X	
NAVIC	L5 (1176.45)	S (2492.028)	C5A	C9A/C9B/C9C	
SBAS (GAGAN)	L1 (1575.42)	L5 (1176.45)	C1C	C5I	

According to Rinex version 3.03, tables 4-10.

Pseudo-range model for a combined multiGNSS positioning

$$p(t) = range - c \cdot dt(t') + c \cdot (TSC_X + dT_{Rec}) + \frac{TZD}{\sin(El)} + DCB^i$$

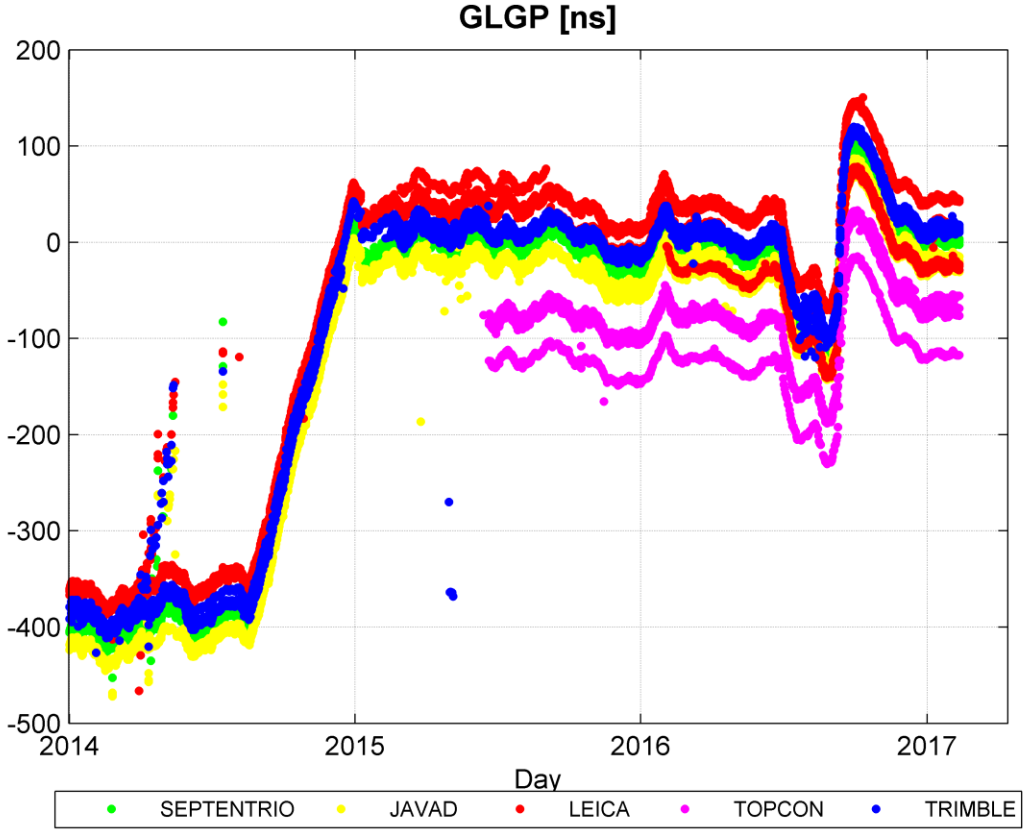
TSC_X: Time System Correction of the X GNSS relative to a common Time Scale:

- G: GPS
- R: GLONASS
- E: Galileo
- C: BeiDou
- J: QZSS
- I: Navic (formerly IRNSS)
- N: GAGAN

Time Offset	Definition
GLGP	$(TSC_R + dT_{Rec}) - (TSC_G + dT_{Rec})$
GPGA	$(TSC_G + dT_{Rec}) - (TSC_E + dT_{Rec})$
BDGP	$(TSC_C + dT_{Rec}) - (TSC_G + dT_{Rec})$
QZGP	$(TSC_J + dT_{Rec}) - (TSC_G + dT_{Rec})$
NAGP	$(TSC_I + dT_{Rec}) - (TSC_G + dT_{Rec})$
GNGP	$(TSC_N + dT_{Rec}) - (TSC_G + dT_{Rec})$

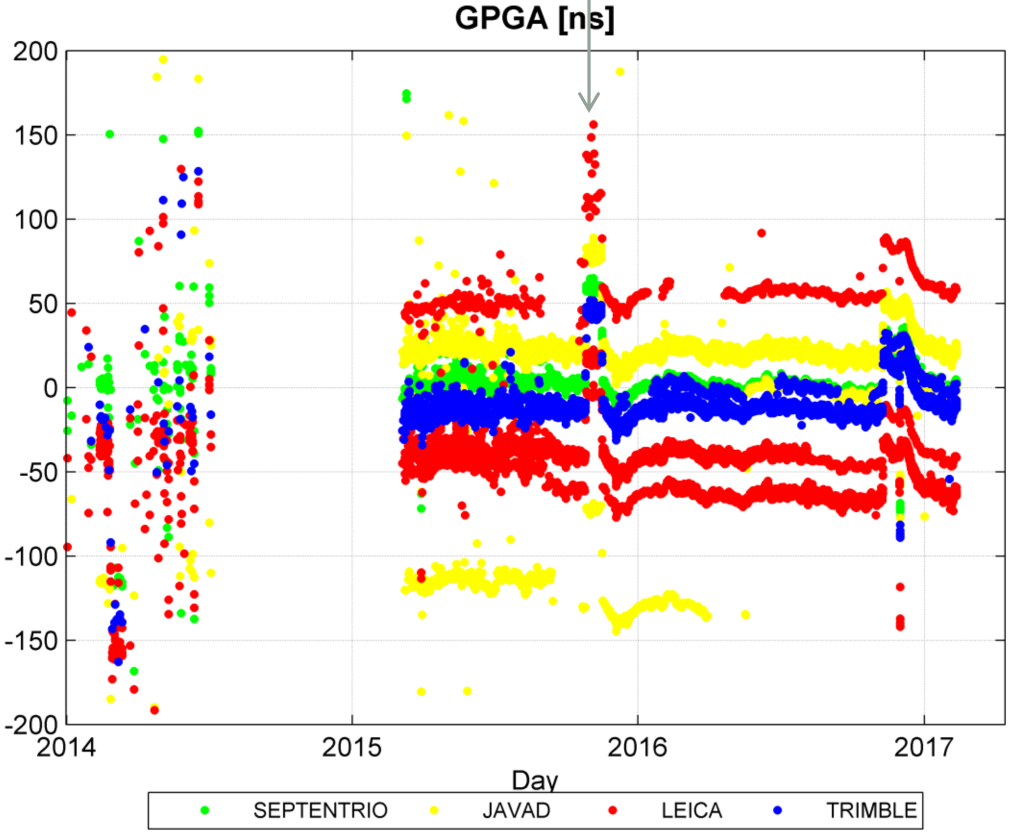
GLGP: Glonass to GPS Time Offset

- Large offset until summer 2014
- Offset steered to nearly zero
- However different receivers show different offsets
- Different sites with same type of receiver can have slightly biased offsets



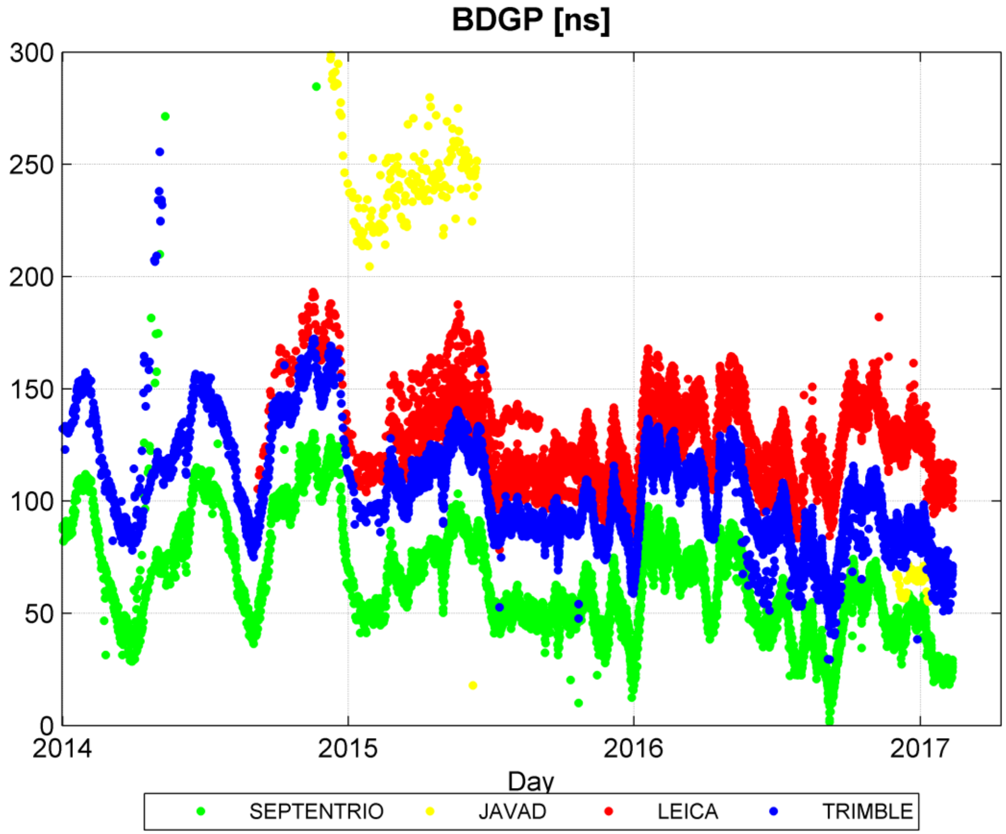
GPGA: Galileo to GPS Time Offset

- Very good performance in 2015
- **Offset ~50 ns between 26/10 and 16/11 2015**
- Receiver dependent biases are clearly visible



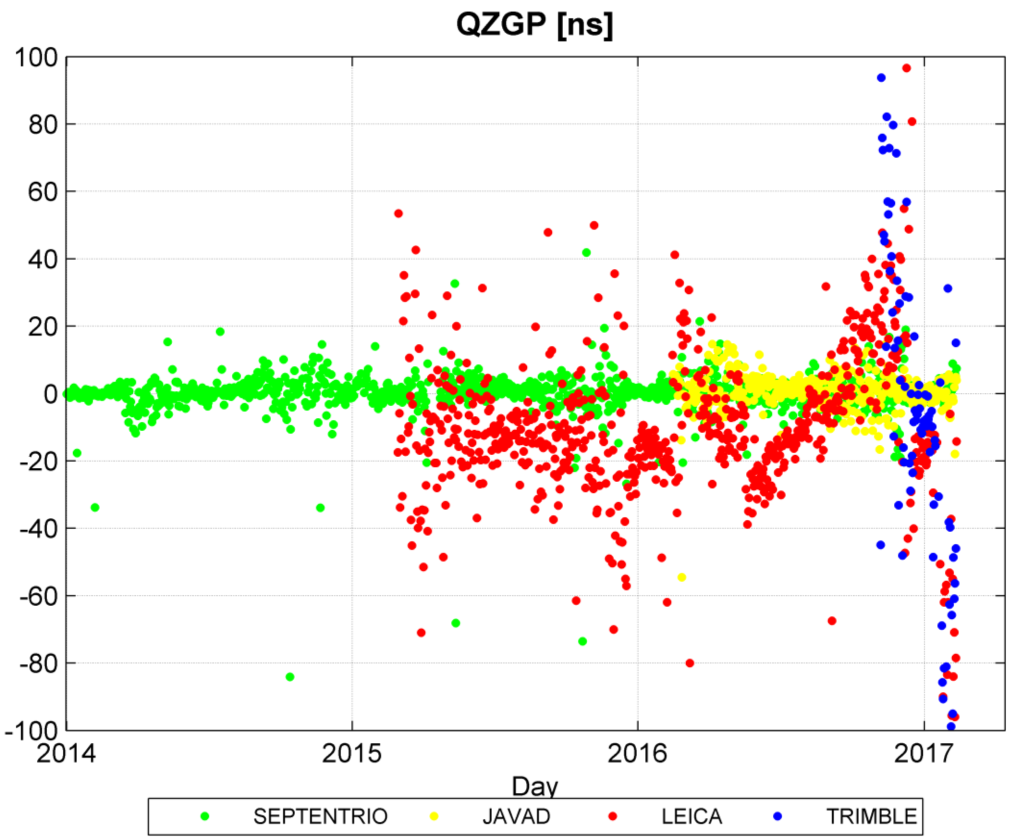
BDGP; BeiDou to GPS Time Offset

- Contrary to GPGA and GLGP, BDGP seems to vary in time periodically with a large mean value (80-100 ns)
- Receiver dependent biases are visible



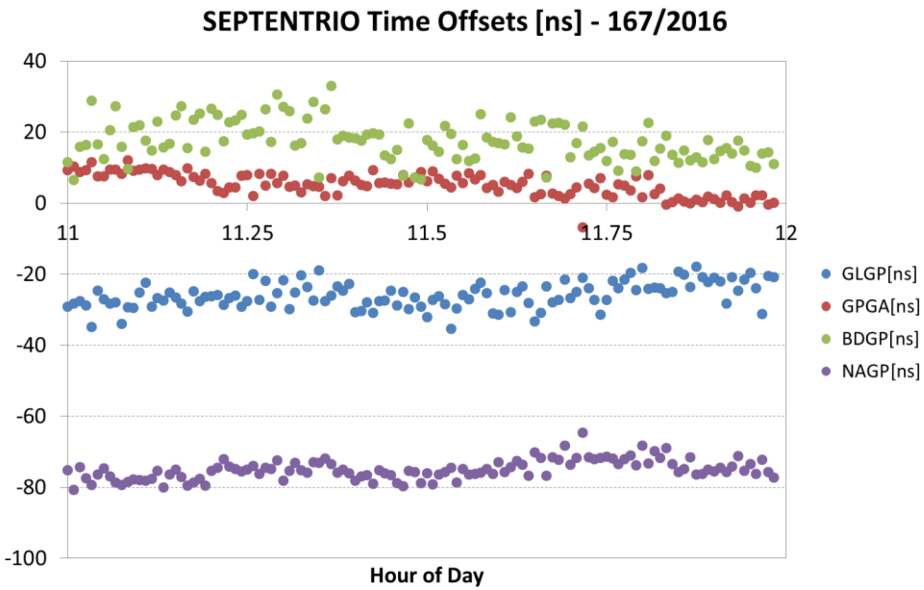
QZGP; QZSS to GPS Time Offset

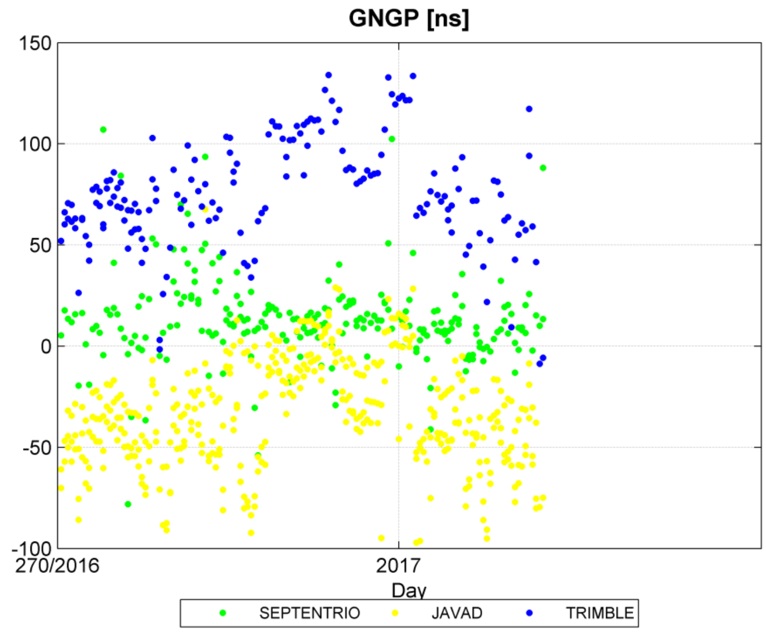
- KIRU (Septentrio) and NYA2 (Javad) stations show a zero mean time offset
- WROC (Leica) and GANP (Trimble) show a bias and more scattered results



Latest developement

- Introduction of NAVIC system (previously IRNSS)
- Introduction of SBAS: among all SBAS satellites tracked we have found valid ephemeris only for S27 and S28, which belong to GAGAN
- There are not European stations which track NAVIC.
- One hour NAVIC data has been provided by SEPTENTRIO
- GAGAN satellites are synchronized between them?





SINEX_BIAS Solution

We provide daily results of time offsets in SINEX_BIAS format V1.00

FILE/REFERENCE format block

```
+FILE/REFERENCE
 REFERENCE FRAME     IGb08
 DESCRIPTION         Department of Geosciences, University of Padova
 INPUT               RNX 3.02 data, Broadcast eph. ftp://cddis.gsfc.nasa.gov/
 OUTPUT              UPA solutions in Bias-SINEX format 1.00
 CONTACT             alessandro.caporali@unipd.it
 HARDWARE            PC Windows
 SOFTWARE            multiGNSS Software (GPS Solutions 2015 19(2) 297-307)
-FILE/REFERENCE
```

BIAS/DESCRIPTION format block

```
+BIAS/DESCRIPTION
 OBSERVATION SAMPLING           900
 DETERMINATION METHOD           CLOCK ANALYSIS
 BIAS MODE                      DIFFERENTIAL
 TIME SYSTEM                    G
 REFERENCE SYSTEM               G
 REFERENCE OBSERVABLES          G  C1C  C2W
 REFERENCE OBSERVABLES          R  C1P  C2P
 REFERENCE OBSERVABLES          E  C1?  C7?
 REFERENCE OBSERVABLES          C  C1I  C7I
 REFERENCE OBSERVABLES          J  C1C  C2?
-BIAS/DESCRIPTION
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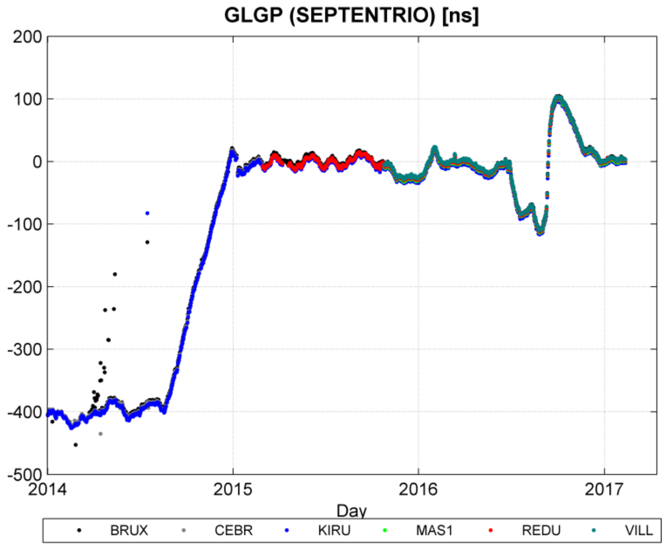
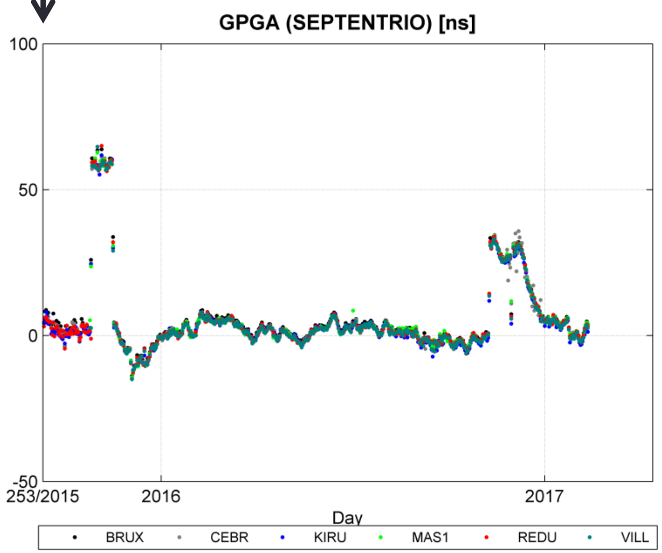
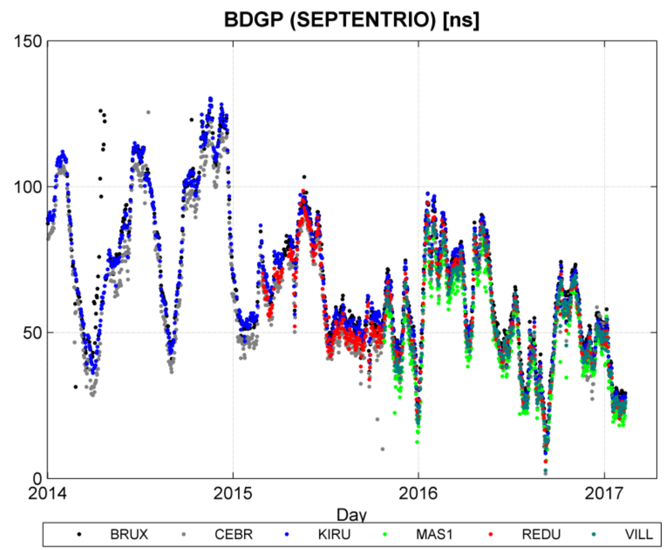
Septentrio timeoffsets

Septentrio stations compare well to each other: for each day the RMS is generally lower than 3 ns



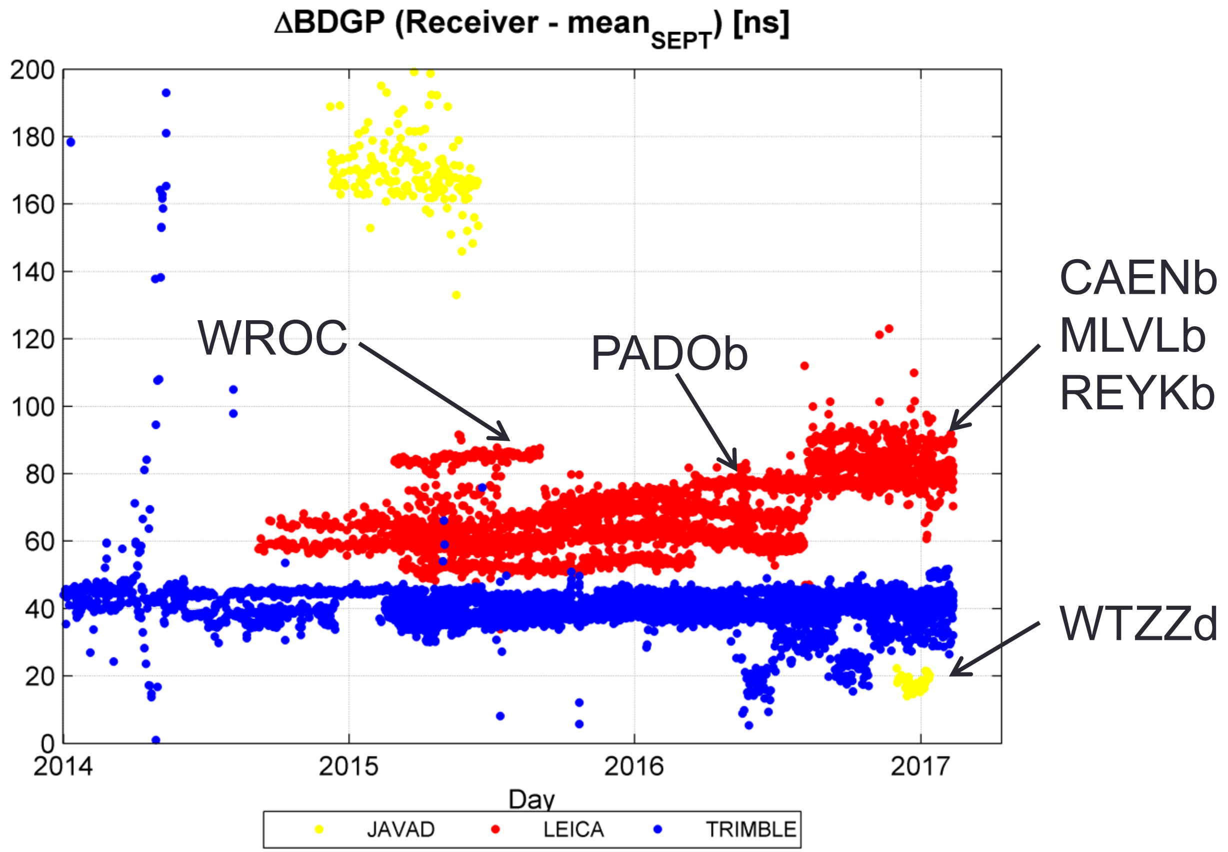
GPGA results are considered starting from 2015/10/09





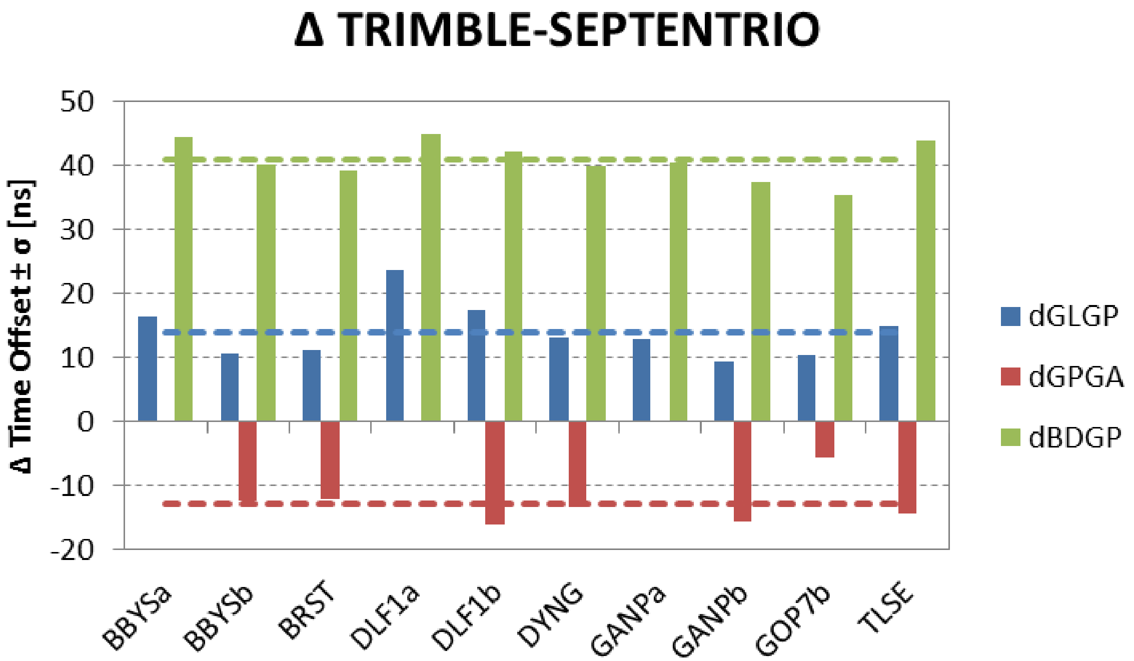
dBDGP (Receiver - Septentrio)

- Leica: CAENb, MLVLb, PADOb, REYKb, WROC
- Javad: WTZZd



Trimble - Septentrio

- DLF1: GLGP
- GOP7b: GPGA



POSSIBLE EXPLAINATION	STATION	FROM	TO	DATE
Receiver Firmware	BBYS	(a) 4.81/4.71	(b) 4.85/4.71	2014/05/30
Receiver Firmware	DLF1	(a) 4.81	(b) 5.01	2016/06/17
Receiver Firmware	GANP	(a) 4.81/4.29	(b) 4.85/4.29	2014/05/30
Receiver	GOP7	(a) JAVAD TRE_G3TH DELTA	(b) TRIMBLE NETR9	2015/08/21

Calibration wrt the mean of Septentrio 1/3

Updated to 2017-02-11

STATION			RECEIVER			ANTENNA		CALIBRATION [ns]				
ID	FROM	TO	RECEIVER	TYPE	FIRMWARE	TYPE	RADOME	dGLGP	dGPGA	dBDGP	dQZGP	dGNGP
BBYSa	01/01/2014	30/05/2014	TRIMBLE	NETR9	4.81/4.71	TRM59800.00	NONE	16.5 ± 2.7		44.4 ± 2.8		
BBYSb	30/05/2014	NOW	TRIMBLE	NETR9	4.85/4.71	TRM59800.00	NONE	10.6 ± 1.0	-12.4 ± 0.7	40.1 ± 1.8		
BOGO	21/06/2015	NOW	TOPCON	EUROCARD	2.6.1 Jan,10,2008	ASH700936C_M	SNOW	-117.9 ± 1.0				
BRST	01/01/2014	26/03/2014	TRIMBLE	NETR9	4.81	TRM57971.00	NONE	11.2 ± 1.0	-12.0 ± 0.9	39.2 ± 1.9		
BRST	26/03/2014	NOW	TRIMBLE	NETR9	4.85	TRM57971.00	NONE	11.2 ± 1.0	-12.0 ± 0.9	39.2 ± 1.9		
BRUX	01/01/2014	17/03/2014	SEPTENTRIO	POLARX4TR	2.3.4	JAVRINGANT_DM	NONE	2.8 ± 2.8	0.6 ± 0.6			
BRUX	17/03/2014	07/09/2015	SEPTENTRIO	POLARX4TR	2.5.2	JAVRINGANT_DM	NONE	2.8 ± 2.8	0.6 ± 0.6	3.4 ± 3.5		
BRUX	07/09/2015	24/10/2016	SEPTENTRIO	POLARX4TR	2.9.0	JAVRINGANT_DM	NONE	2.8 ± 2.8	0.6 ± 0.6	3.4 ± 3.5		
BRUX	24/10/2016	03/01/2017	SEPTENTRIO	POLARX4TR	2.9.5	JAVRINGANT_DM	NONE	2.8 ± 2.8	0.6 ± 0.6	3.4 ± 3.5		
BRUX	03/01/2017	NOW	SEPTENTRIO	POLARX4TR	2.9.6	JAVRINGANT_DM	NONE	2.8 ± 2.8	0.6 ± 0.6	3.4 ± 3.5		
CAENa	01/01/2014	20/02/2014	LEICA	GR25	3.01	TRM57971.00	NONE	41.5 ± 3.2	-42.1 ± 1.1	68.0 ± 3.3		
CAENa	20/02/2014	19/09/2014	LEICA	GR25	3.03	TRM57971.00	NONE	41.5 ± 3.2	-42.1 ± 1.1	68.0 ± 3.3		
CAENa	19/09/2014	06/11/2014	LEICA	GR25	3.10	TRM57971.00	NONE	41.5 ± 3.2	-42.1 ± 1.1	68.0 ± 3.3		
CAENa	06/11/2014	05/08/2016	LEICA	GR25	3.11	TRM57971.00	NONE	41.5 ± 3.2	-42.1 ± 1.1	68.0 ± 3.3		
CAENb	12/08/2016	09/11/2016	LEICA	GR25	3.11	TRM57971.00	NONE	-23.9 ± 0.5	-65.3 ± 1.0	90.1 ± 2.7		
CAENb	09/11/2016	NOW	LEICA	GR25	4.02	TRM57971.00	NONE	-23.9 ± 0.5	-65.3 ± 1.0	90.1 ± 2.7		
CEBR	01/01/2014	10/12/2014	SEPTENTRIO	POLARX4	2.5.1p1	SEPCHOKE_MC	NONE	-0.3 ± 2.9	0.0 ± 0.9	-3.3 ± 3.2		
CEBR	10/12/2014	27/08/2015	SEPTENTRIO	POLARX4	2.5.2-esa3	SEPCHOKE_MC	NONE	-0.3 ± 2.9	0.0 ± 0.9	-3.3 ± 3.2		
CEBR	27/08/2015	21/10/2016	SEPTENTRIO	POLARX4	2.9.0	SEPCHOKE_MC	NONE	-0.3 ± 2.9	0.0 ± 0.9	-3.3 ± 3.2		
CEBR	21/10/2016	NOW	SEPTENTRIO	POLARX4	2.9.5-extref1	SEPCHOKE_MC	NONE	-0.3 ± 2.9	0.0 ± 0.9	-3.3 ± 3.2		
COMOa	21/06/2015	19/10/2016	TOPCON	E_GGD	3.4 Dec,12,2009 p2	TPSCR3_GGD	CONE	-76.2 ± 2.0				
COMOb	19/10/2016	07/02/2017	TOPCON	NET-G5	5.0 Nov,20,2015 p2	TPSCR3_GGD	CONE	-60.1 ± 0.9				
COMOb	07/02/2017	NOW	TOPCON	NET-G5	5.1 Sep,07,2016	TPSCR.G3	TPSH	-60.1 ± 0.9				
DLF1a	01/01/2014	17/06/2015	TRIMBLE	NETR9	4.81	LEIAR25.R3	LEIT	23.6 ± 1.8		44.8 ± 1.4		
DLF1b	17/06/2015	13/07/2015	TRIMBLE	NETR9	5.01	LEIAR25.R3	LEIT	17.5 ± 0.7	-16.2 ± 0.9	42.2 ± 1.4	-151.5 ± 186.3	59.4 ± 20.1
DLF1b	13/07/2015	20/07/2016	TRIMBLE	NETR9	5.03	LEIAR25.R3	LEIT	17.5 ± 0.7	-16.2 ± 0.9	42.2 ± 1.4	-151.5 ± 186.3	59.4 ± 20.1
DLF1b	20/07/2016	21/12/2016	TRIMBLE	NETR9	5.14	LEIAR25.R3	LEIT	17.5 ± 0.7	-16.2 ± 0.9	42.2 ± 1.4	-151.5 ± 186.3	59.4 ± 20.1
DLF1b	21/12/2016	NOW	TRIMBLE	NETR9	5.15	LEIAR25.R3	LEIT	17.5 ± 0.7	-16.2 ± 0.9	42.2 ± 1.4	-151.5 ± 186.3	59.4 ± 20.1
DYNG	02/03/2015	19/06/2015	TRIMBLE	NETR9	4.85	TRM59800.00	NONE	13.1 ± 1.9	-13.3 ± 1.1	40.0 ± 3.5		62.7 ± 10.3
DYNG	19/06/2015	05/07/2016	TRIMBLE	NETR9	5.01	TRM59800.00	NONE	13.1 ± 1.9	-13.3 ± 1.1	40.0 ± 3.5		62.7 ± 10.3
DYNG	05/07/2016	14/12/2016	TRIMBLE	NETR9	5.14	TRM59800.00	NONE	13.1 ± 1.9	-13.3 ± 1.1	40.0 ± 3.5		62.7 ± 10.3
DYNG	14/12/2016	NOW	TRIMBLE	NETR9	5.15	TRM59800.00	NONE	13.1 ± 1.9	-13.3 ± 1.1	40.0 ± 3.5		62.7 ± 10.3
GANPa	01/01/2014	30/05/2014	TRIMBLE	NETR9	4.81/4.29	TRM55971.00	NONE	13.0 ± 2.6		40.5 ± 1.5		
GANPb	30/05/2014	10/02/2015	TRIMBLE	NETR9	4.85/4.29	TRM55971.00	NONE	9.3 ± 2.5	-15.6 ± 1.1	37.5 ± 2.5	-16.4 ± 68.3	
GANPb	10/02/2015	18/11/2015	TRIMBLE	NETR9	4.93/4.93	TRM55971.00	NONE	9.3 ± 2.5	-15.6 ± 1.1	37.5 ± 2.5	-16.4 ± 68.3	
GANPb	18/11/2015	14/10/2016	TRIMBLE	NETR9	5.10/5.02	TRM55971.00	NONE	9.3 ± 2.5	-15.6 ± 1.1	37.5 ± 2.5	-16.4 ± 68.3	
GANPb	14/10/2016	02/01/2017	TRIMBLE	NETR9	5.14/5.14	TRM55971.00	NONE	9.3 ± 2.5	-15.6 ± 1.1	37.5 ± 2.5	-16.4 ± 68.3	
GANPb	02/01/2017	11/01/2017	TRIMBLE	NETR9	5.15/5.15	TRM55971.00	NONE	9.3 ± 2.5	-15.6 ± 1.1	37.5 ± 2.5	-16.4 ± 68.3	
GANPb	11/01/2017	06/02/2017	TRIMBLE	NETR9	5.20/5.20	TRM55971.00	NONE	9.3 ± 2.5	-15.6 ± 1.1	37.5 ± 2.5	-16.4 ± 68.3	
GANPb	06/02/2017	NOW	TRIMBLE	NETR9	5.20	TRM59800.00	SCIS	9.3 ± 2.5	-15.6 ± 1.1	37.5 ± 2.5	-16.4 ± 68.3	

Conclusions

- Positioning and timing cannot be decoupled in multiGNSS positioning/navigation: 3 m ⇔ 10 ns is a reasonable level of sync one can require
- We have shown that the broadcast time sync polynomial contains considerable biases in the time scales, particularly for BeiDou, forcing to include a specific time bias in the navigation solution using broadcast ephemeris
- We present a first analysis of calibration constants which are specific of receivers at the various sites.
- We keep monitoring GNSS specific time biases and receiver specific time biases, in an attempt to precisely identify all those calibration constants which are necessary to know for a full interoperability of the various GNSSs with a variety of receivers.
- We also monitor the releases of SP3 data (by CODE, GFZ…), in the attempt to identify that release which best defines a continuous common time scale.