INTEROPERABILITY OF THE GNSS'S FOR POSITIONING AND TIMING

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Outlook

- Monitor 26 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 taking GPS as reference (QZSS could also be included but: 1 S/C only, few european stations track it, no SP3)

Input Data

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

	Carrier/Frequency [MHz]		Coding in RINEX 3.02		
GPS	L1 (1575.42)	L2 (1227.60)	C1C	C2W	
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	

According to Rinex version 3.02, tables 2, 4, 5.

(*) For Galileo we use E1-E5b (I/NAV)

	E11	E12	E14[2]	E18[2]	E19	E20[1]	E22[2]	E26[2]
obs	✓	✓		✓	✓	✓		✓
brdm	✓	✓			✓			
sp3	✓	✓		✓	✓			✓

(1) Unavailable

(2) In Commissioning

Pseudo-range model for a combined multiGNSS positioning

$$p(t) = \sqrt{[X(t') + \omega_e \cdot Y(t-t') - x]^2 + [Y(t') - \omega_e \cdot X(t-t') - y]^2 + [Z(t') - z]^2} +$$
$$+c \cdot dt(t') + c \cdot (TSC_X + dT_{Rec}) + \frac{TZD}{\sin(El)}$$

- *t* = time of reception; *t'* = time of trasmission; ω_e = earth rotation rate
- TSC_X = Time System Correction of the X GNSS System (G = GPS; R = Glonass; E = Galileo; C = BeiDou) relative to an average time scale
- dT_{Rec} = Receiver Clock Error
- *dt(t')* = Satellite Clock Error + leap seconds (LS: full leap seconds for Glonass; 14 seconds for BeiDou) .
  - Broadcast ephemeris: $dt(t') = a_0 + a_1 \cdot (t' - T_{oc}) + a_2 \cdot (t' - T_{oc})^2 - \frac{2\sqrt{\mu a}}{c^2} e \cdot \sin E(t') + LS$
  - Sp3 ephemeris: input data
- *TZD* = Tropospheric Zenith Delay

$$GLGP = c \cdot (TSC_R + dT_{Rec}) - c \cdot (TSC_G + dT_{Rec})$$

$$GPGA = c \cdot (TSC_E + dT_{Rec}) - c \cdot (TSC_G + dT_{Rec})$$

$$BDGP = c \cdot (TSC_C + dT_{Rec}) - c \cdot (TSC_G + dT_{Rec})$$

What we did:

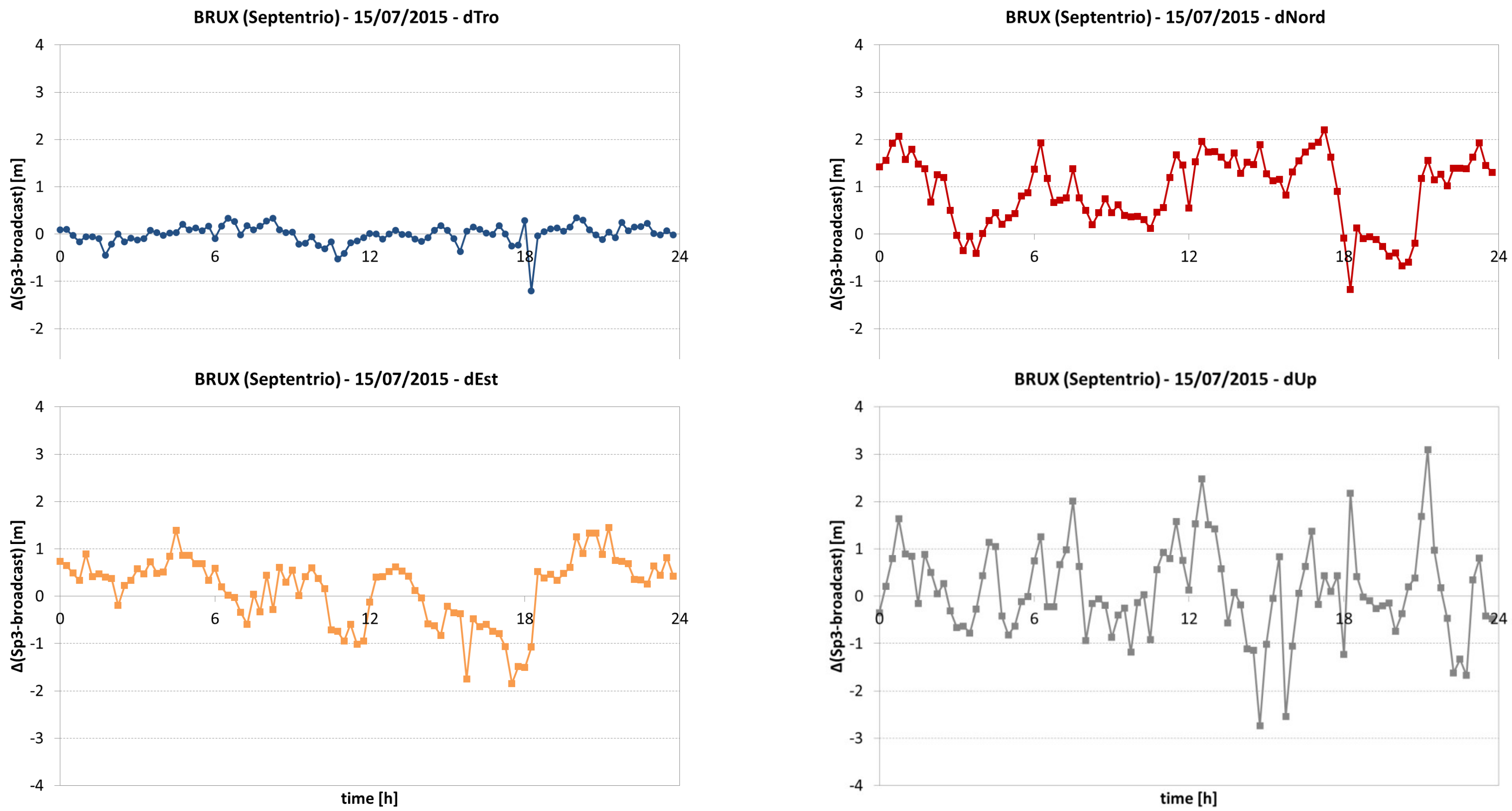
- Testing the SP3 of GFZ
  - ✓ Processing the ionofree pseudoranges with broadcast and SP3(GFZ) yields differences in ZTD within few cm and position differences within 1 m rms
  - ✓ Computing the GLGP, GPGA and BDGP time biases with SP3(GFZ) and BRDC ephemeris indicates that the GFZ satellite clock is free of GNSS related time biases and provides a common time scale to within +/- 10 ns
- Using the average of four Septentrio receivers as ”reference receiver” we estimate calibration constants for each receiver, that is receiver dependent (as opposed to GNSS dependent) time biases we need to apply to make the receiver equivalent (==unbiased) relative to the ”reference receiver”
- Test the .bias sinex file uploaded by GFZ on the MGEX web site (site dependent biases) : common sites appear to have similar receiver dependent biases, but an open question is the ephemeris used by GFZ (brdc or SP3?)

Broadcast vs sp3 differences in Position & TZD : < 1 m rms and < 0.1 m rms respectively

- Broadcast & Sp3: ftp://cddis.gsfc.nasa.gov/

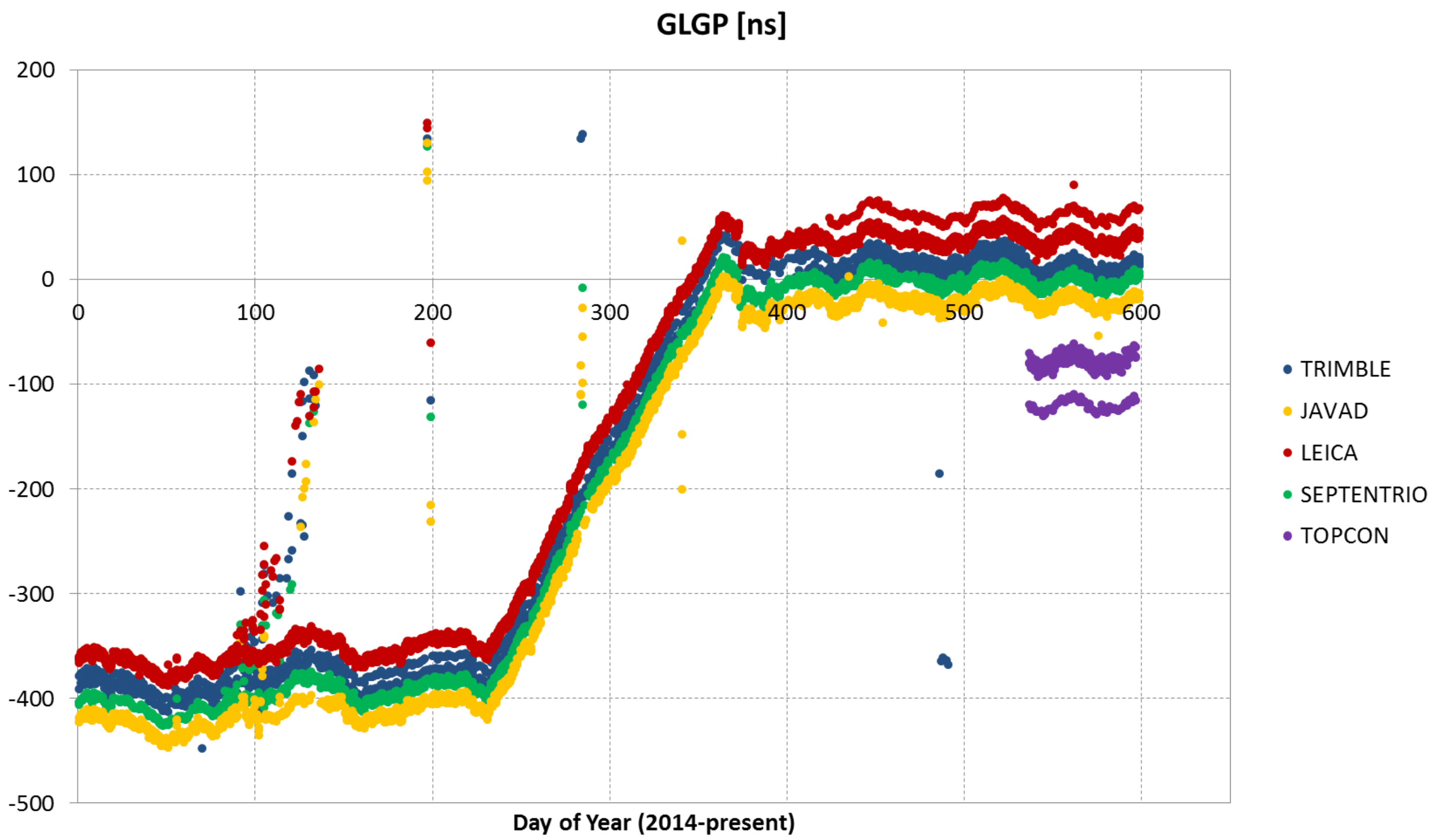
Broadcast: CONGO (./pub/gps/data/campaign/mgex/daily/rinex3/[yyyy]/[ddd]/[yy]p/**brdm[ddd]0.[yy]p.Z**)

Sp3: GFZ (./pub/gps/products/mgex/[wwww]/**gbm[wwww][d].sp3.Z**)



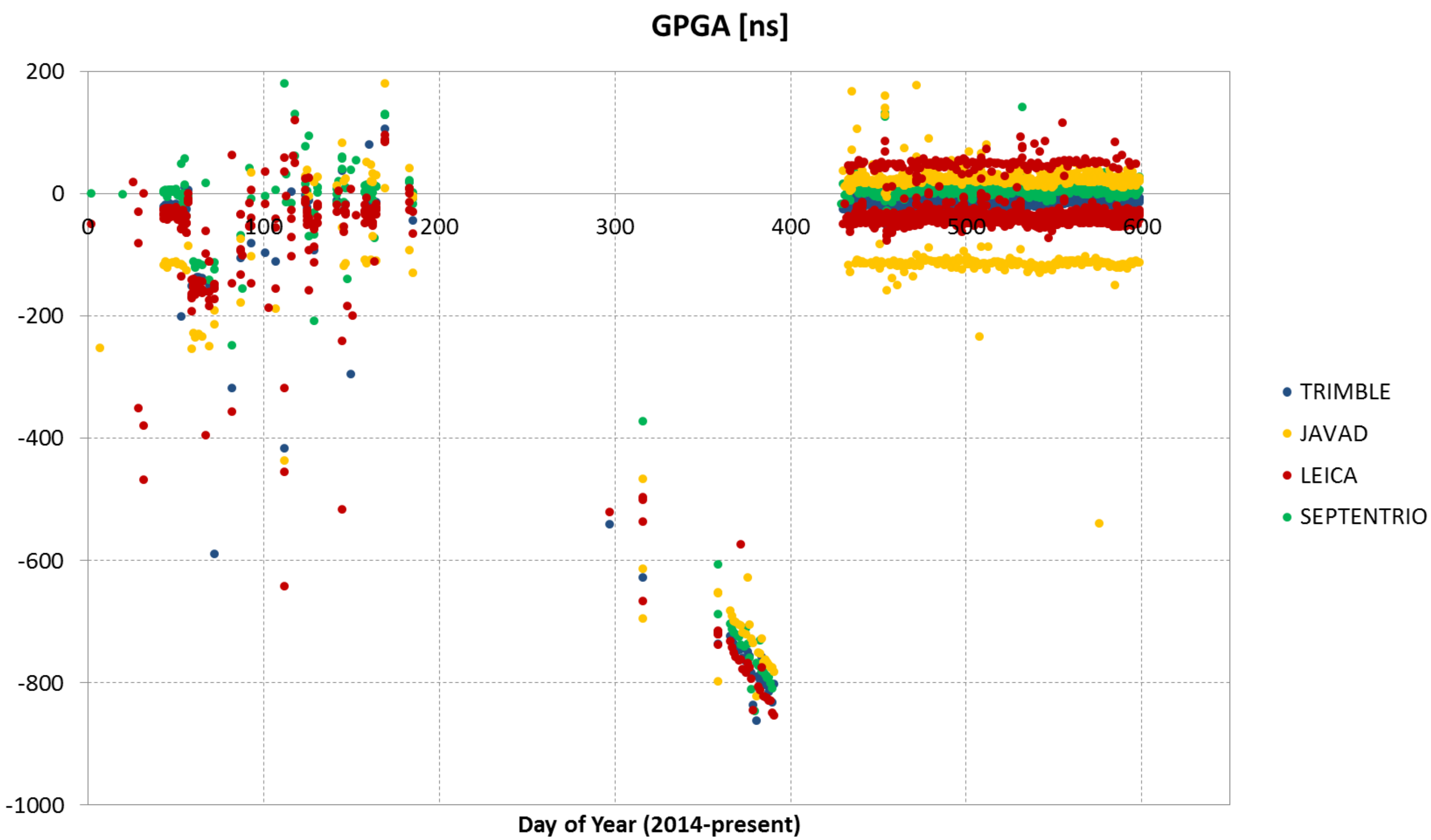
GLGP: Glonass to GPS Time Offset

- 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



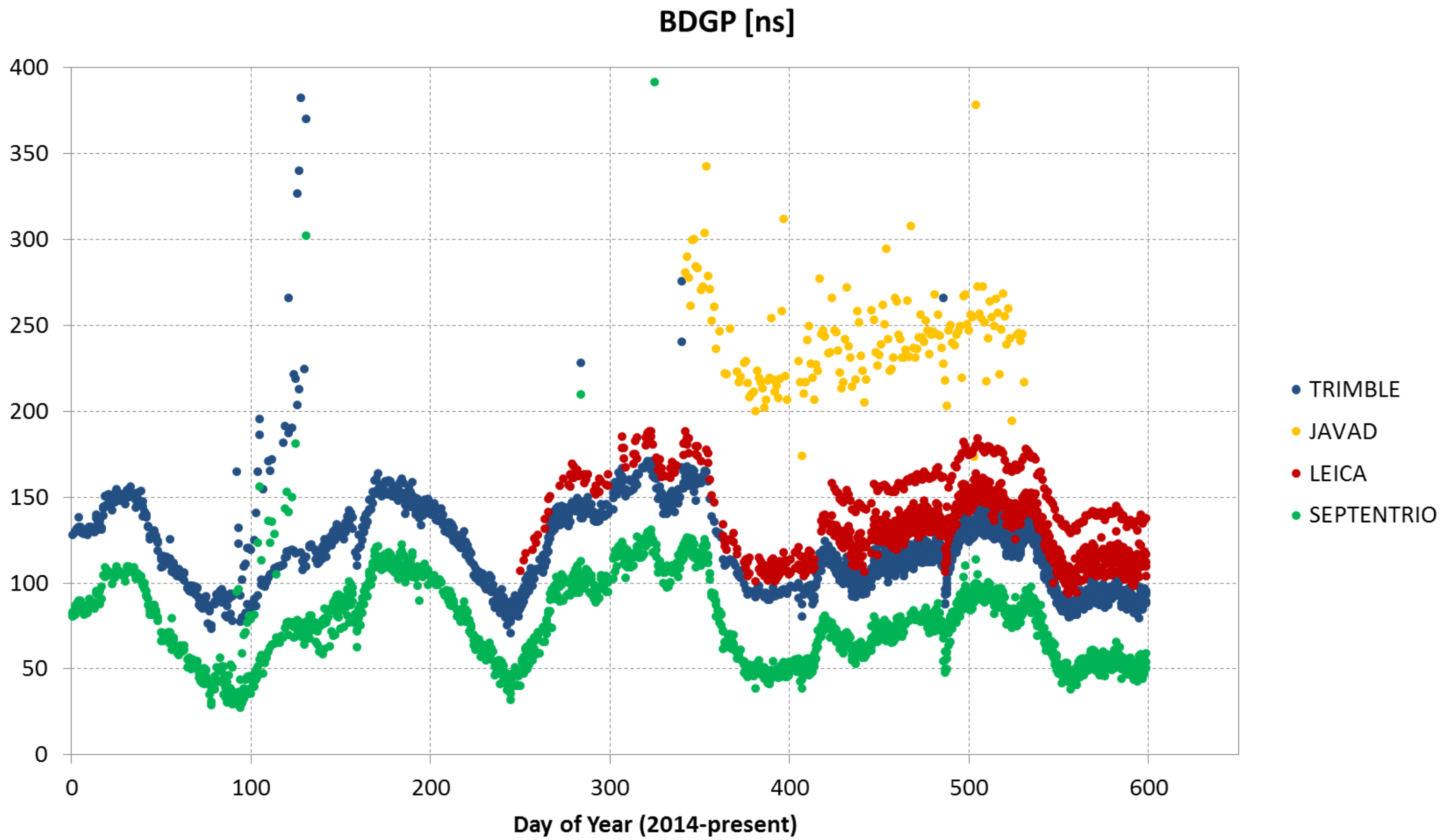
GPGA: Galileo to GPS Time Offset

- Very good performance in 2015
- Receiver dependent biases are clearly visible



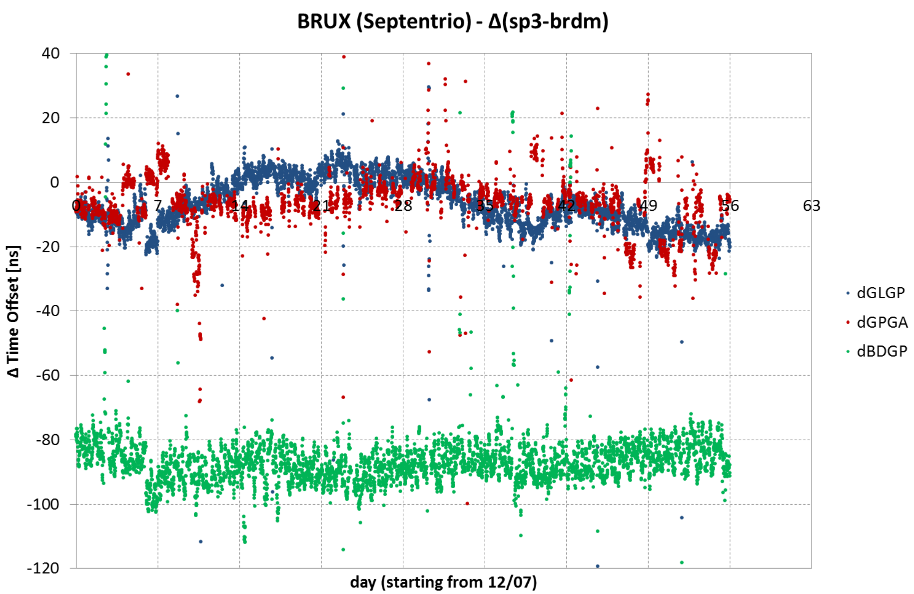
BDGP; BeiDou to GPS Time Offset

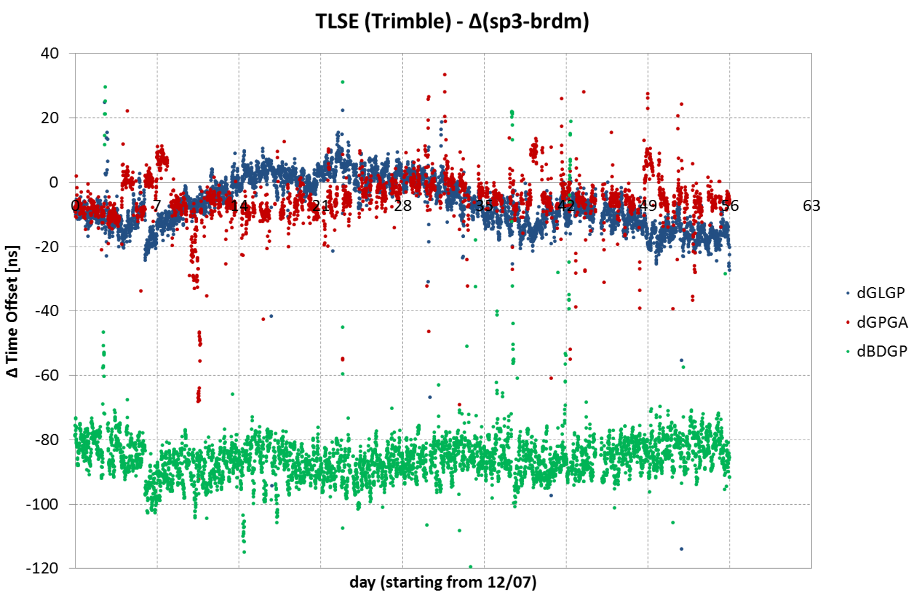
- Contrary to GPGA and GLGP, BDGP seems to vary in time periodically with a large mean value (80-100 ns)
- Receiver dependent biases and site dependent biases are visible



Question: computing GLGP, GAGP, BDGP with broadcast or SP3: how big is the difference?

- dGLGP and dGPGA vary from -20 to +10 ns
- dBDGP vary between -100 and -80 ns, that is exactly the BDGP bias using broadcast ephemeris!
- This means that **the GFZ Sp3 clock is a common 'interGNSS' time scale within +/- 10 ns**
- This statement is receiver independent!





Receiver dependent biases

- We will now examine how different types of receivers introduce time biases for the various GNSS

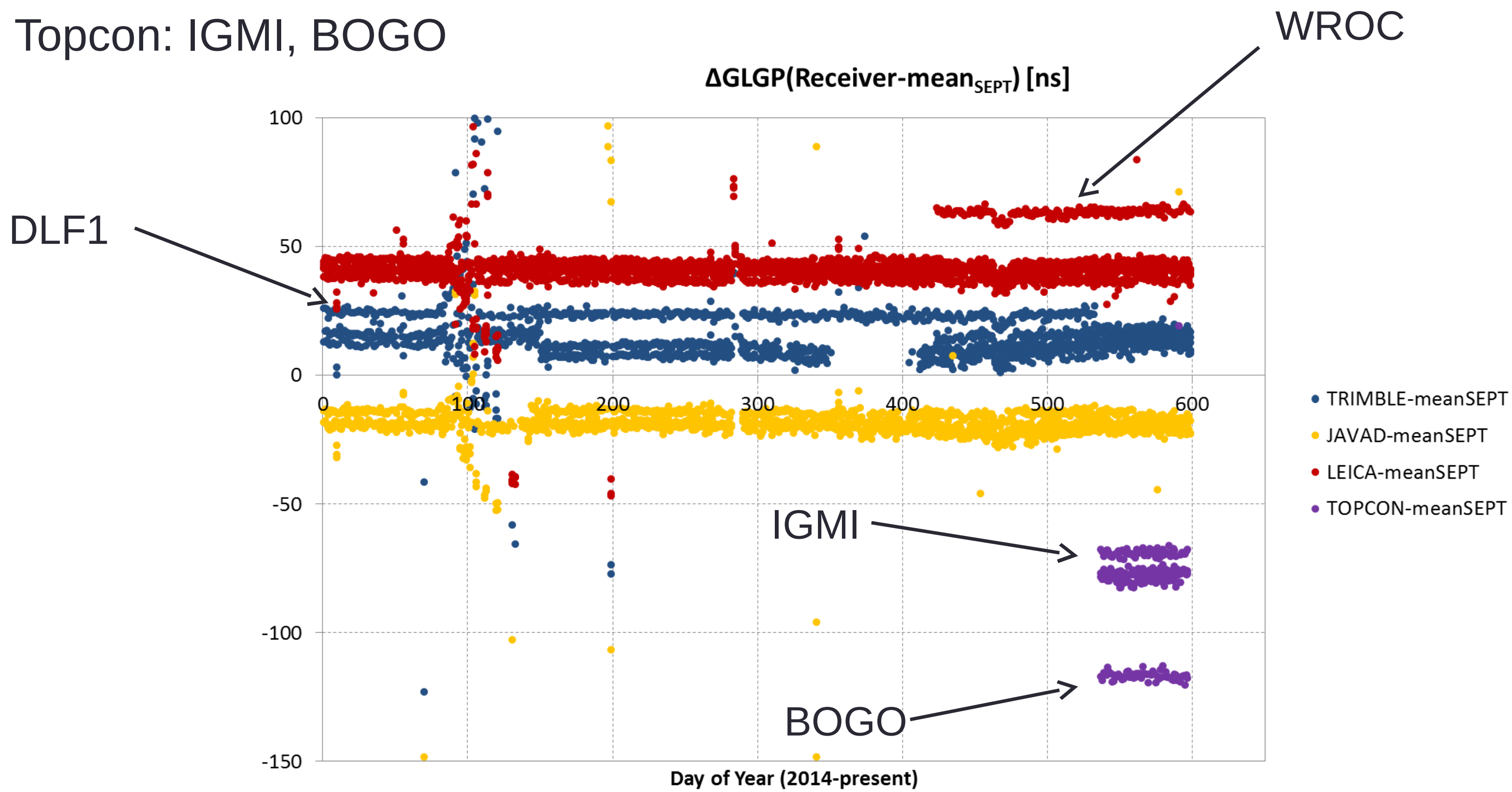
- We will also see that the same receiver brand at different sites can have different bias (Firmware dependence? Antenna dependence? Receiver architecture dependence?)

- We will conclude by proposing a preliminary table of calibration coefficients for the time offsets relative to GPS, for each receiver relative to Septentrio (=mean of 4 receivers BRUX CEBR KIRU REDU)

dGLGP (Receiver - Septentrio)

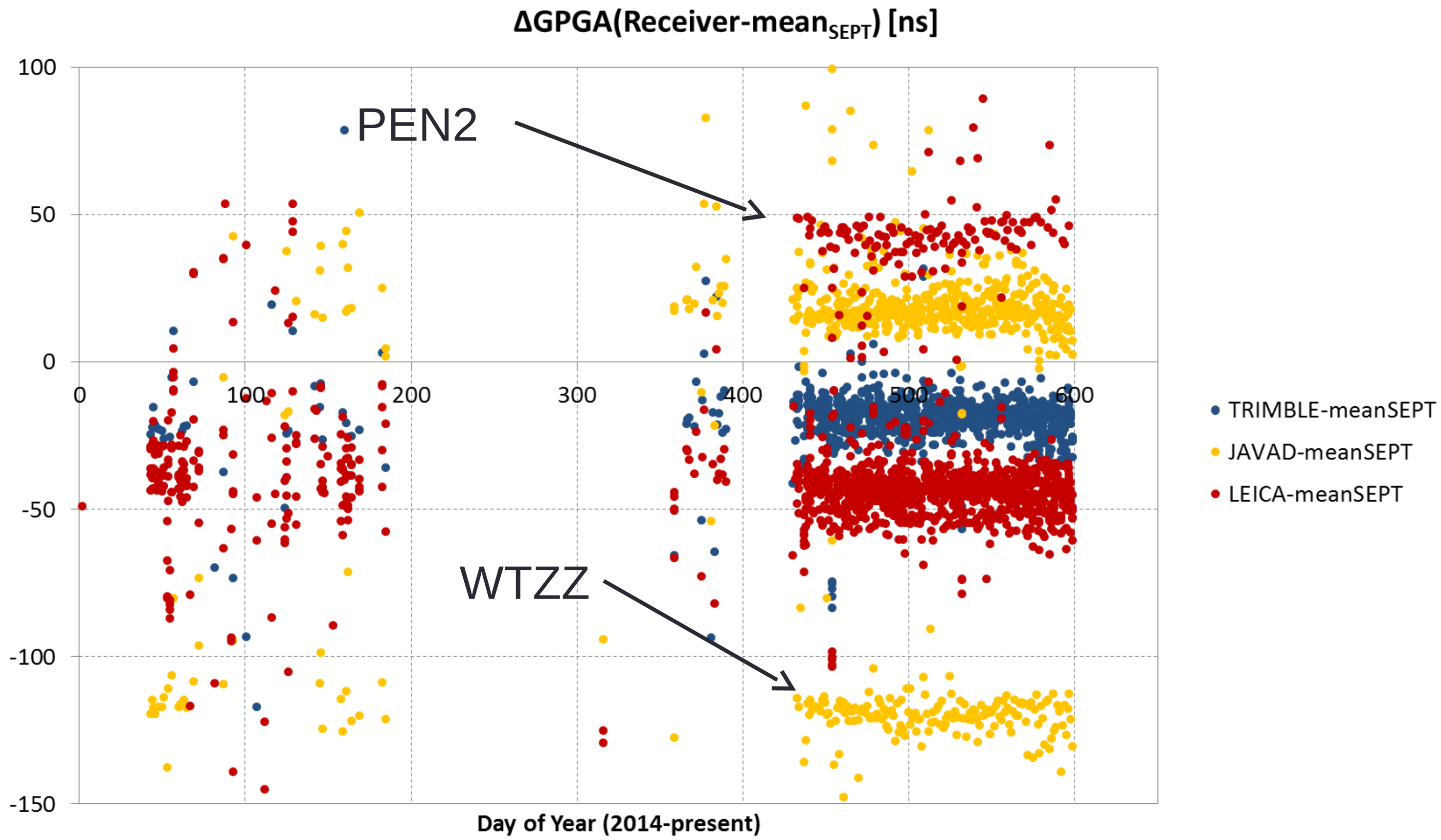
UNAVCO mail 25/08/2015: Septentrio Chosen as Preferred Vendor for Reference Stations

- Trimble: DLF1
- Leica: WROC
- Topcon: IGMI, BOGO



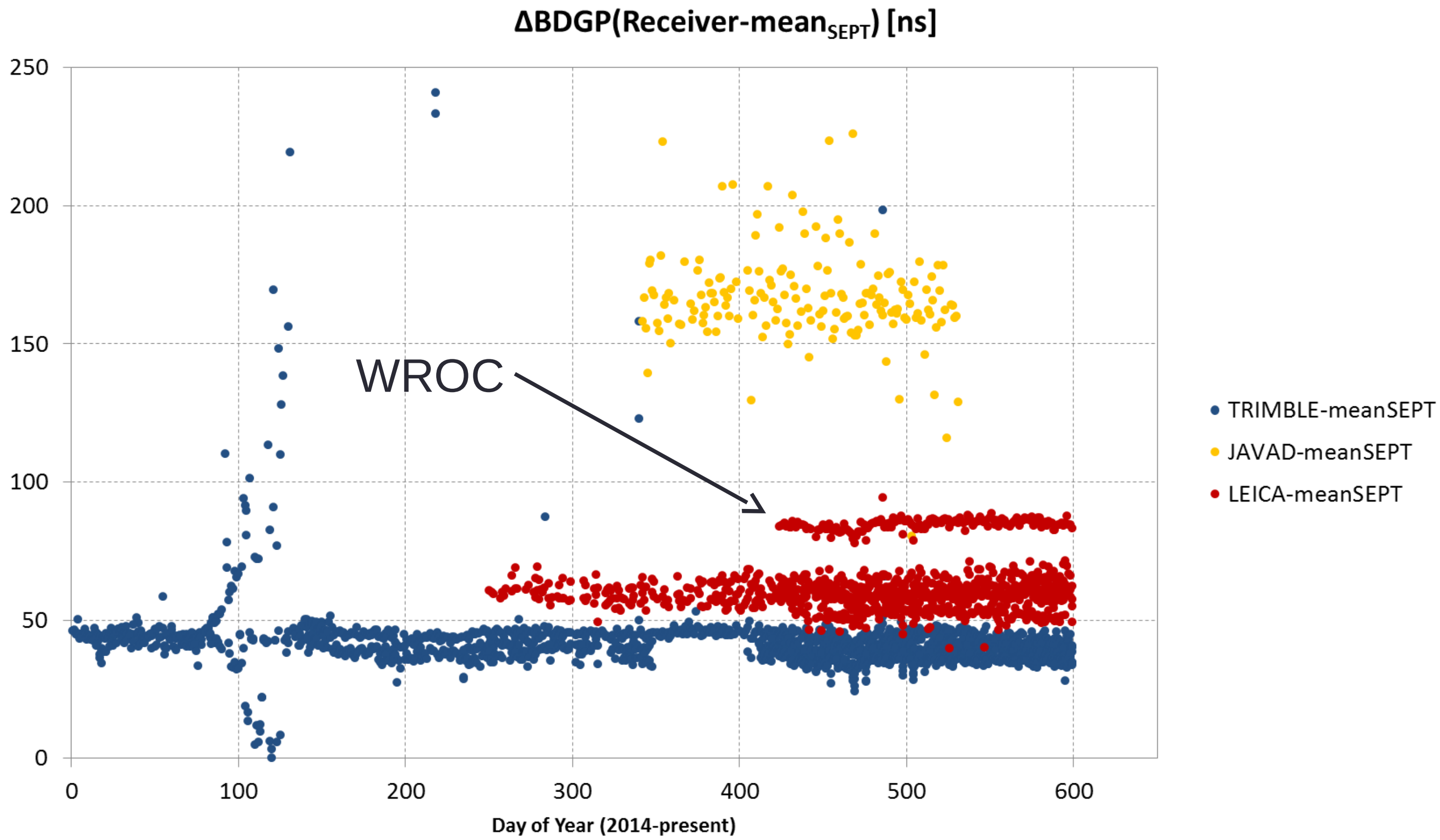
dGPGA (Receiver - Septentrio)

- Javad: WTZZ
- Leica: PEN2



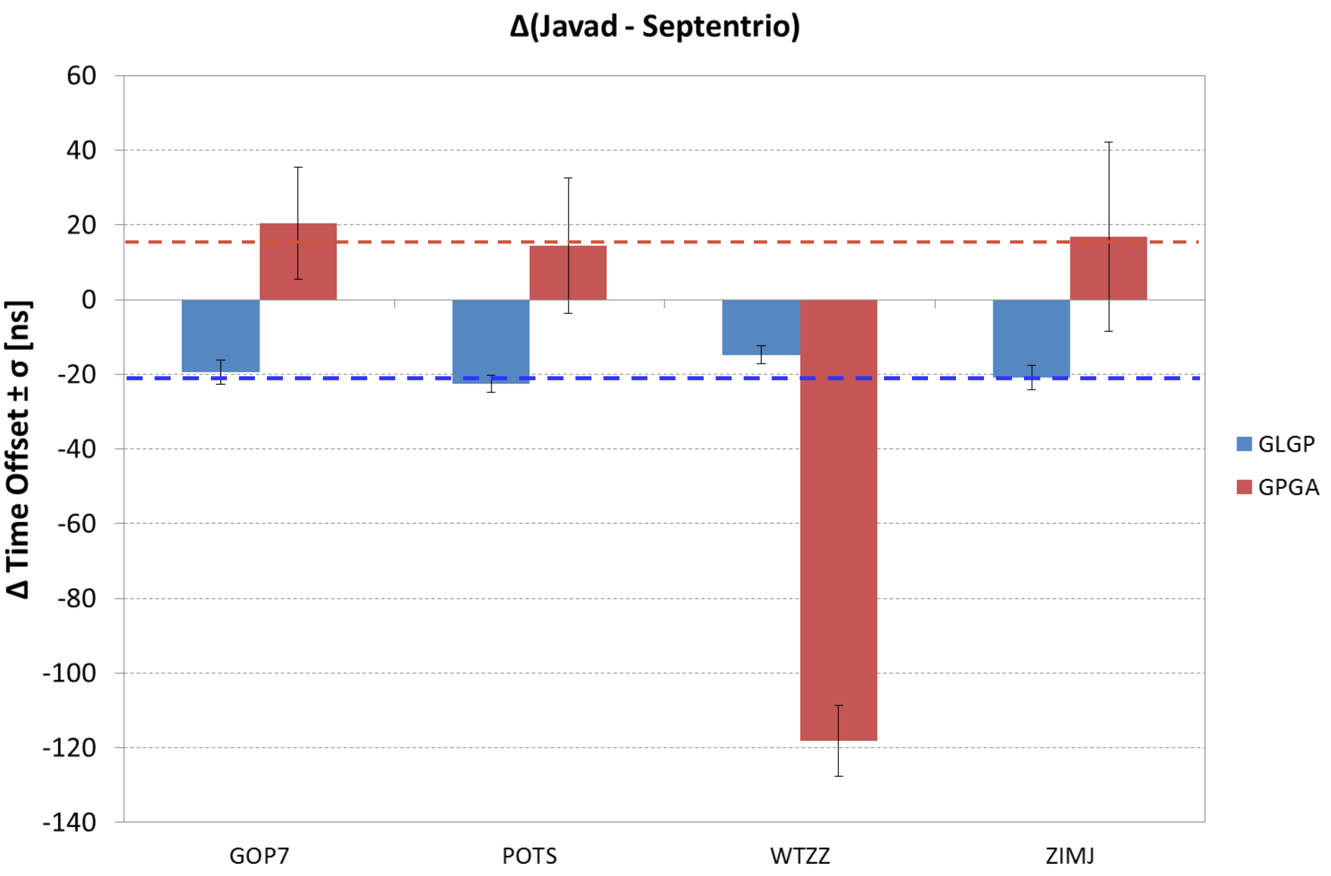
dBDGP (Receiver - Septentrio)

- Leica: WROC



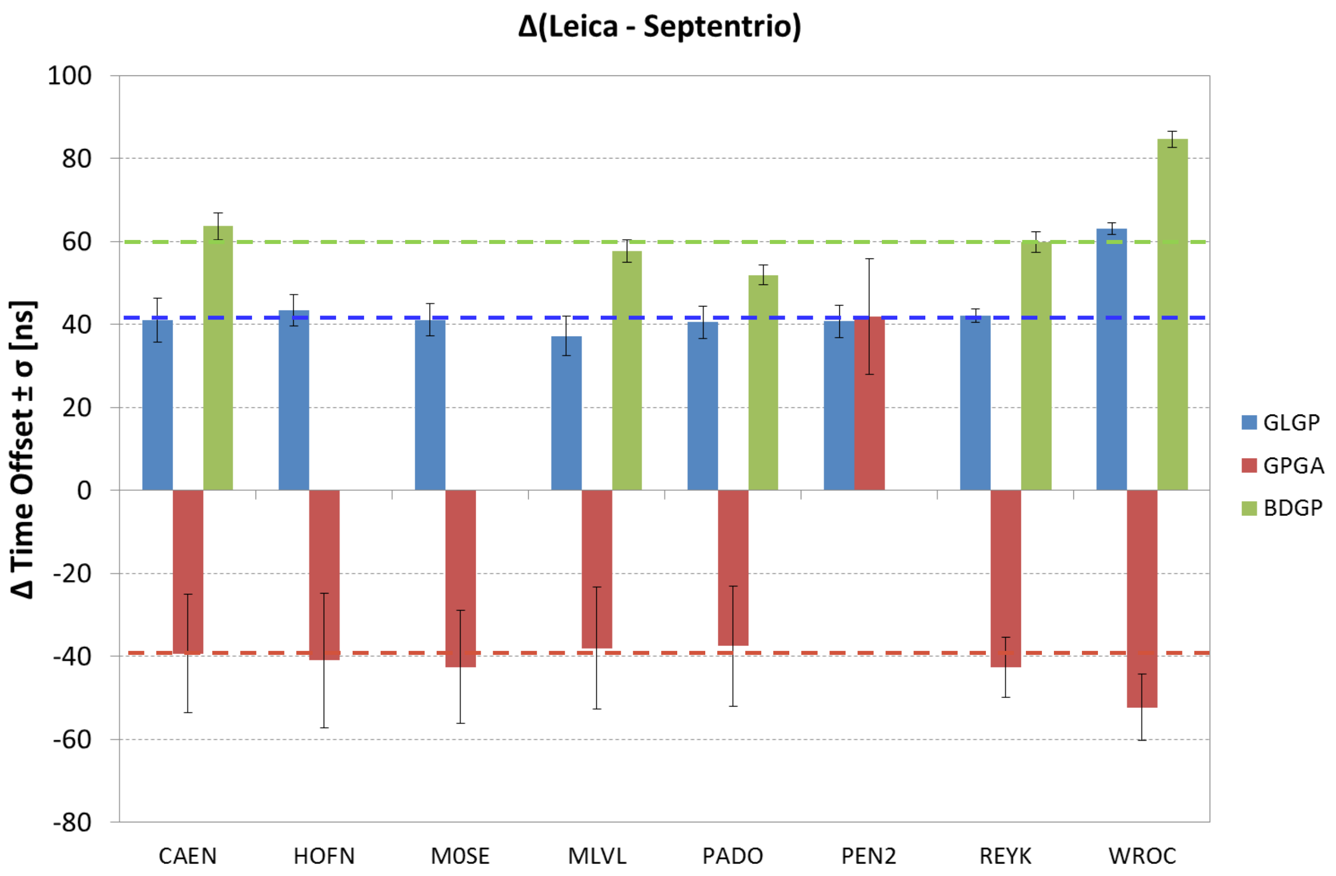
Javad - Septentrio

- WTZZ: GPGA (WTZZ behaviour is due to bad tracking of E5b frequency)



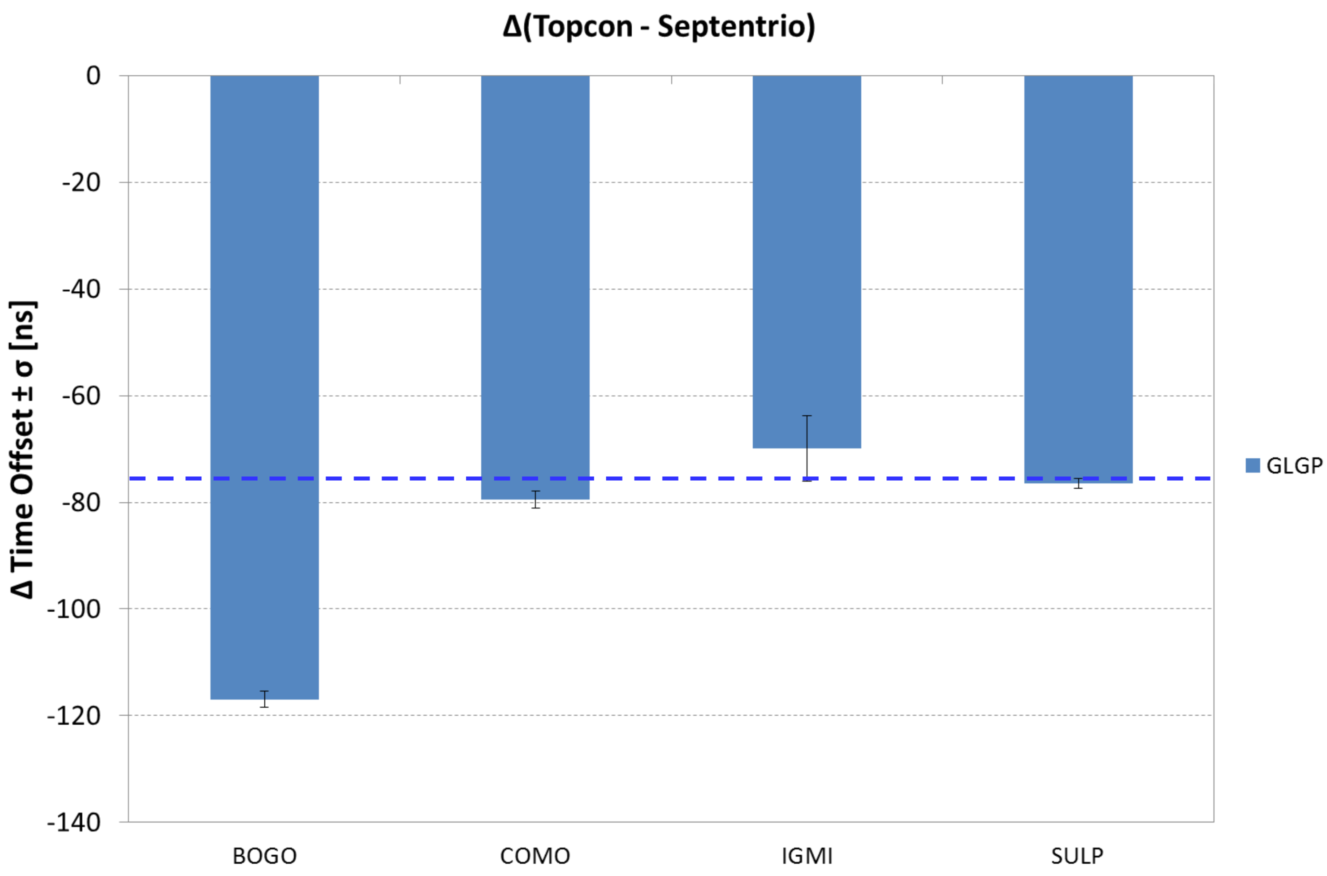
Leica - Septentrio

- PEN2: GPGA
- WROC: GLGP+GPGA+BDGP



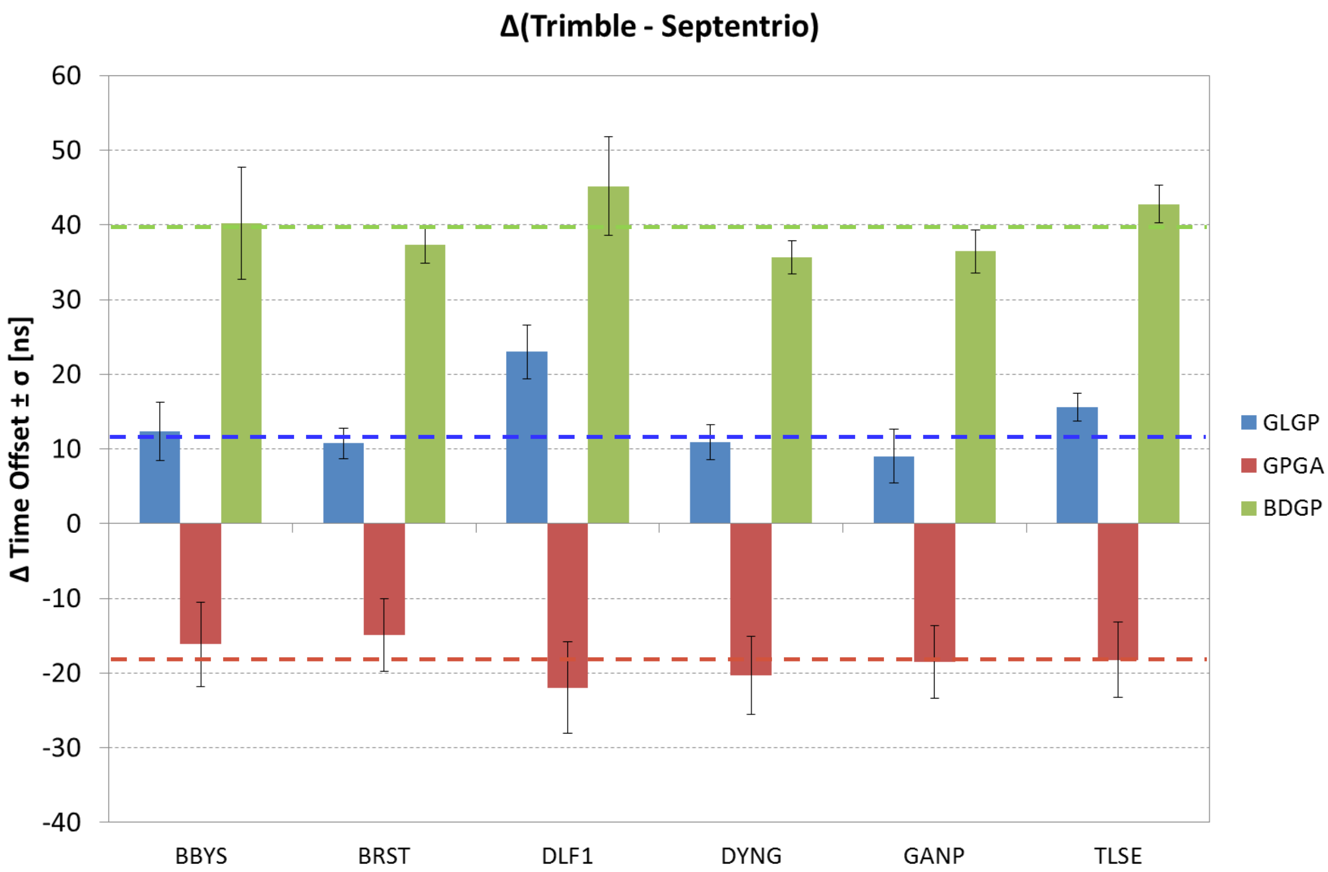
Topcon - Septentrio

- BOGO: GLGP



Trimble - Septentrio

- DLF1: GLGP



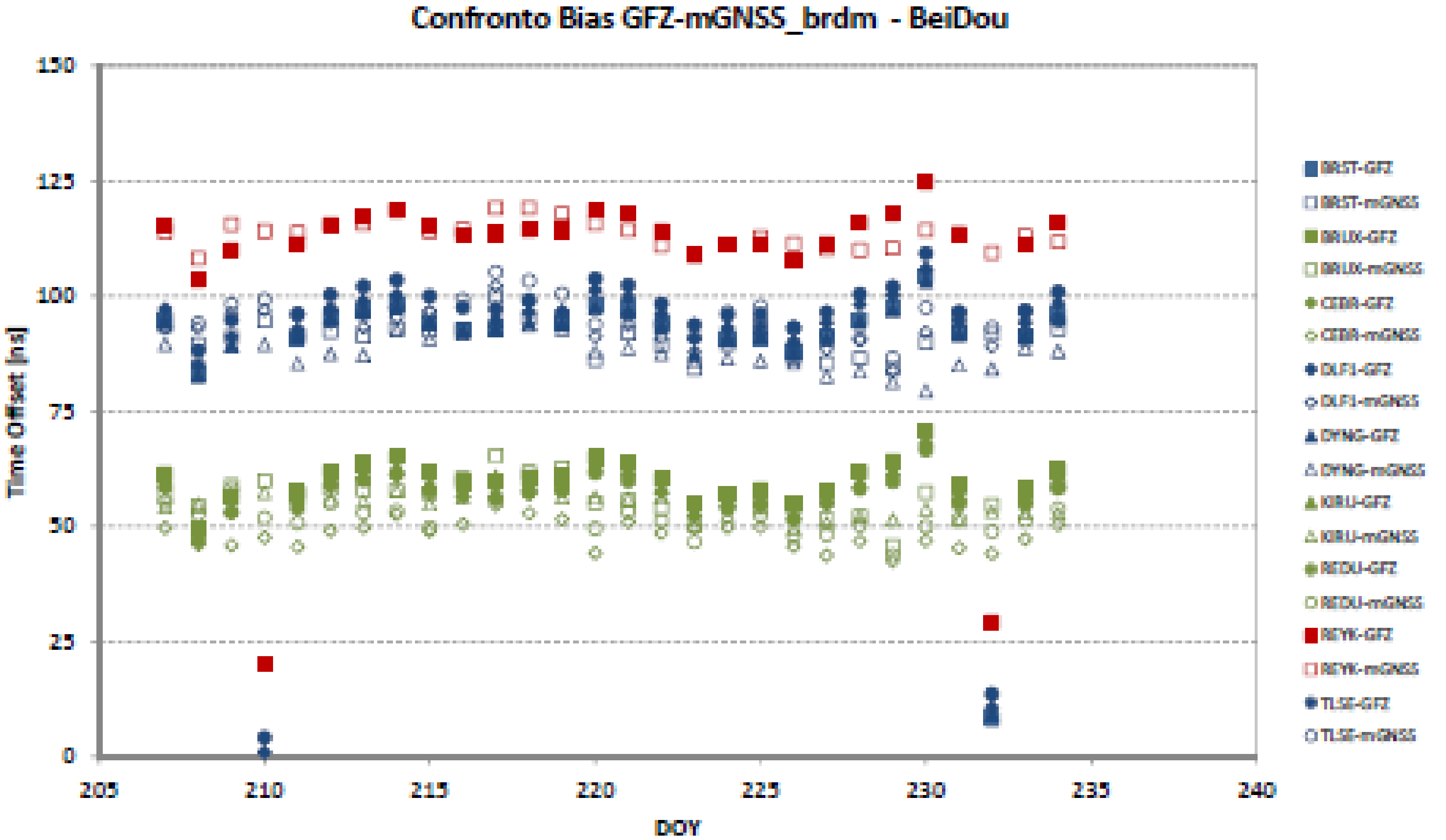
Summary table

STATION	RECEIVER			ANTENNA		CALIBRATION [ns]		
ID	RECEIVER	TYPE	FIRMWARE	ANTENNA TYPE	RADOME	GLGP	GPGA	BDGP
GOP7	JAVAD	TRE_G3TH DELTA	3.5.1	LEIAR25.R4	LEIT	-19.4 ± 3.2	20.4 ± 15.0	
POTS	JAVAD	TRE_G3TH DELTA	3.4.7	JAV_RINGANT_G 3T	NONE	-22.5 ± 2.4	14.5 ± 18.2	
WTZZ	**JAVAD**	**TRE_G3TH DELTA**	**3.6.2 APR,08,2015**	**LEIAR25.R3**	**LEIT**	**-14.8 ± 2.4**	**-118.2 ± 9.5**	
ZIMJ	JAVAD	TRE_G3TH DELTA	3.4.9 Apr,18,2013	JAVRINGANT_DM	NONE	-20.8 ± 3.3	16.9 ± 25.3	
CAEN	LEICA	GR25	3.11	TRM57971.00	NONE	41.0 ± 5.3	-39.3 ± 14.3	63.7 ± 3.3
HOFN	LEICA	GR25	3.11.1639/6.403	LEIAR25.R4	LEIT	43.4 ± 3.9	-41.0 ± 16.3	
M0SE	LEICA	GR25	3.20.B1759/6.403	LEIAR25.R4	LEIT	41.1 ± 3.9	-42.6 ± 13.6	
MLVL	LEICA	GR25	3.11	TRM57971.00	NONE	37.2 ± 4.8	-38.0 ± 14.7	57.6 ± 2.7
PADO	LEICA	GR10	3.10.1633/6.403	LEIAR25.R4	NONE	40.5 ± 4.0	-37.5 ± 14.5	51.9 ± 2.3
PEN2	**LEICA**	**GRX1200+GNSS**	**8.51/6.110**	**LEIAR25.R4**	**LEIT**	**40.7 ± 3.9**	**41.8 ± 13.9**	
REYK	LEICA	GR25	3.11.1639/6.403	LEIAR25.R4	LEIT	42.1 ± 1.6	-42.6 ± 7.2	59.9 ± 2.5
WROC	**LEICA**	**GR25**	**3.11.1639/6.403**	**LEIAR25.R4**	**LEIT**	**63.1 ± 1.5**	**-52.3 ± 8.1**	**84.7 ± 2.0**
BRUX	SEPTENTRIO	POLARX4TR	2.5.2	JAVRINGANT_DM	NONE	± 8.1	± 8.7	± 7.7
CEBR	SEPTENTRIO	POLARX4	2.5.2-esa3	SEPCHOKE_MC	NONE	± 7.0	± 11.1	± 4.8
KIRU	SEPTENTRIO	POLARX4	2.5.2-esa3	SEPCHOKE_MC	SPKE	± 6.4	± 12.8	± 7.0
REDU	SEPTENTRIO	POLARX4	2.5.2-esa3	SEPCHOKE_MC	NONE	± 1.1	± 7.3	± 2.1
			2.6.1	**ASH700936C**		**-116.9 ±**		

Updated to 2015-08-20 (Javad DELTA GT3 receiver at GOP7 station was replaced by Trimble NetR9 receiver on 2015-08-21)

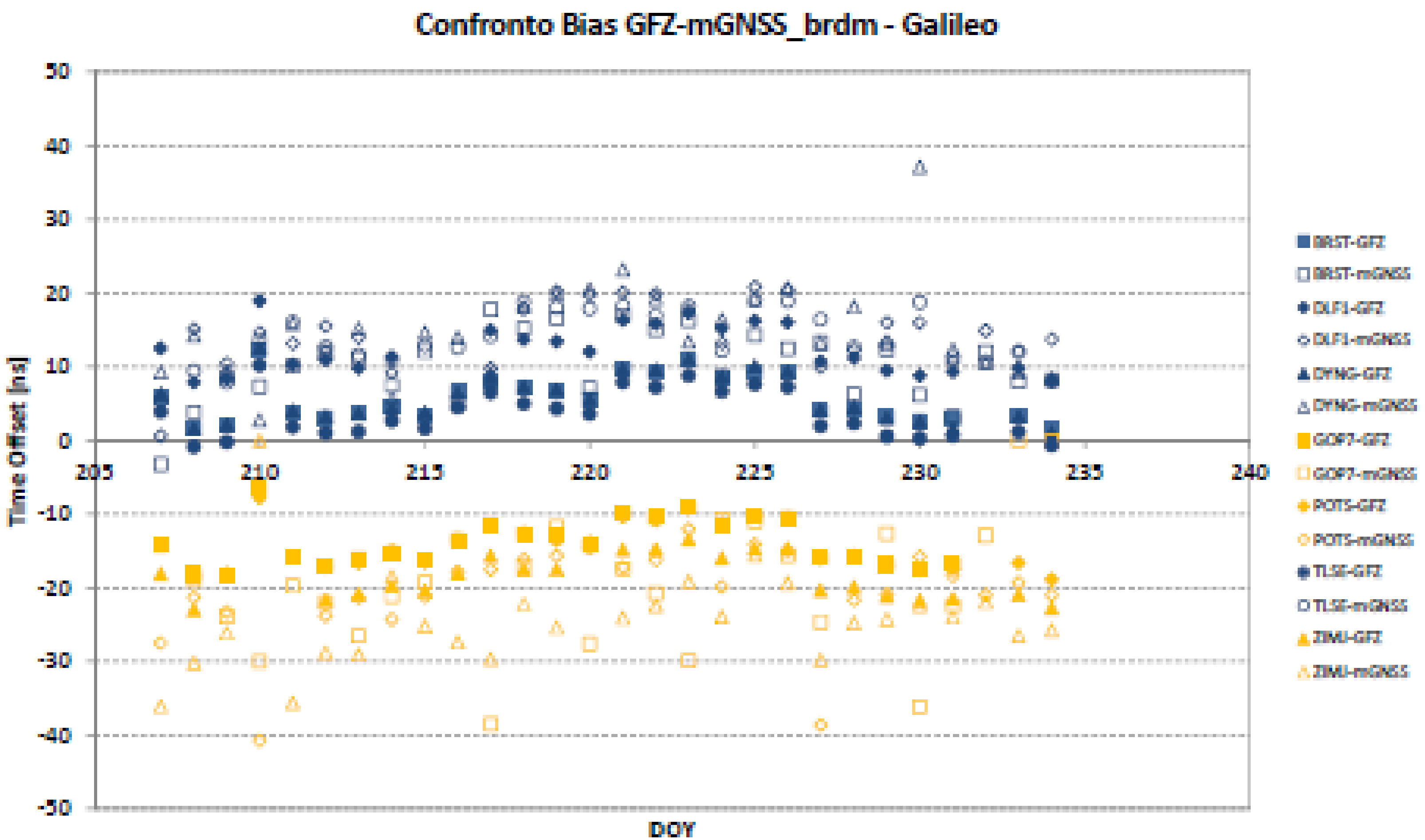
BeiDou to GPS time offset: GFZ vs. UPA/brdc

based on gbz<wwww><d>.bias at cddis.gsfc.nasa.gov/mgex



- Unkown calculation method. reference receiver? Orbits?
- Solid (GFZ) and open (us) symbols agree well

Galileo to GPS Time Offset: GFZ vs.UPA/brdc



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
- Our analysis suggests that the SP3 ephemeris generated by GFZ for GPS Glonass Galileo and Beidou has a clock correction which defines a homogeneous time scale to within +/- 10 ns. Positioning with brdc and sp3 ephemeris yields differences to within +/- 1 m rms and TZD to within 0.1 m rms. However the clock model still reflects the biases of the receivers which were used!
- We present a first analysis of calibration constants which are specific of receivers at the various sites. We use Septentrio as reference.
- 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.