INTEROPERABILITY OF THE GNSS'S FOR POSITIONING AND TIMING

A. Caporali , L. Nicolini

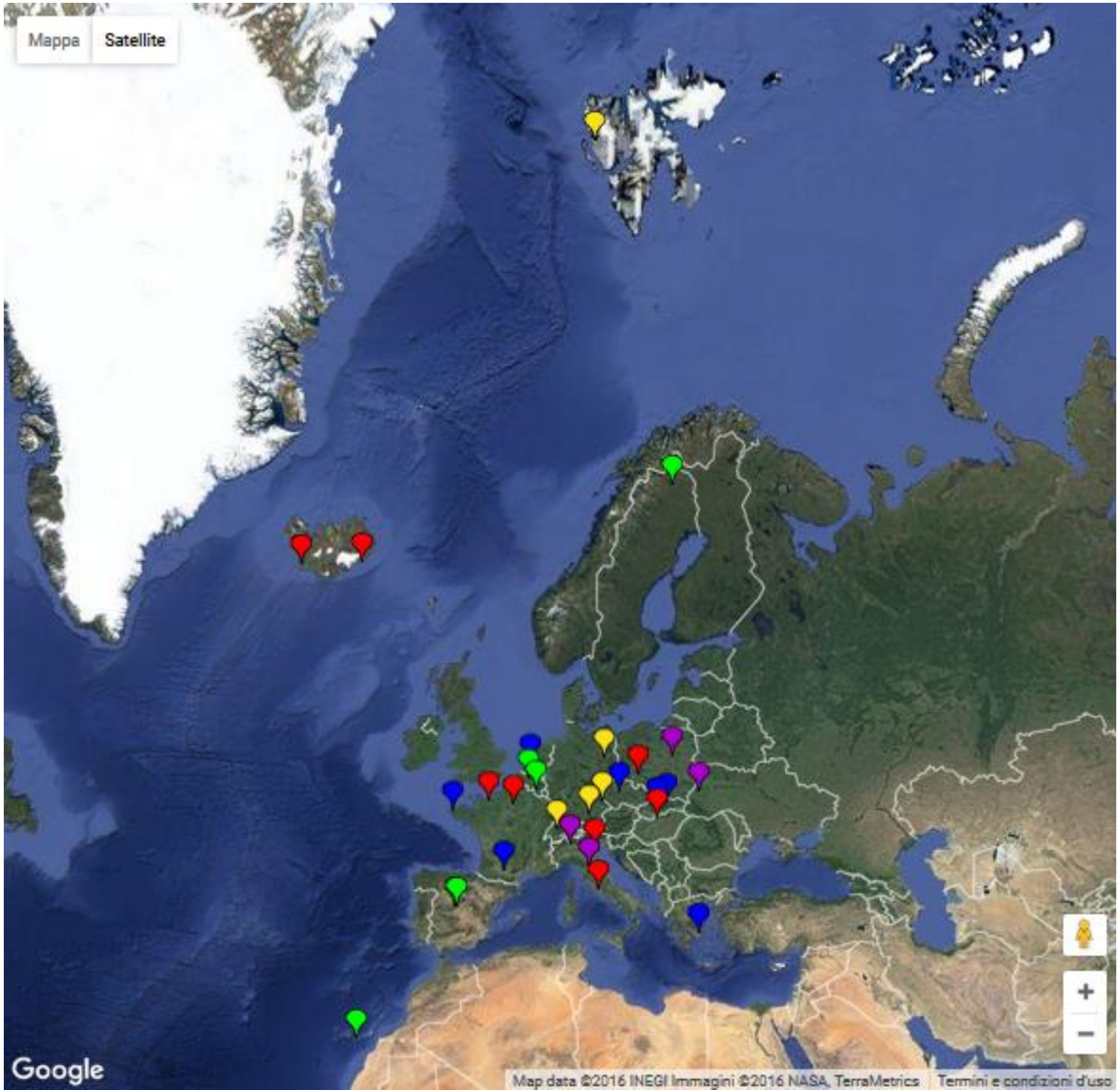
University of Padova, Italy

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 taking GPS as reference
- Use Broadcast ephemeris, and SP3 from GFZ and CODE

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 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)

	E08[2]	E09[2]	E11	E12	E14[3]	E18[3]	E19	E20[1]	E22	E24	E26	E30
obs			✓	✓	✓		✓	✓	✓	✓	✓	✓
brdm			✓	✓			✓		✓	✓	✓	✓
sp3			✓	✓			✓		✓	✓	✓	✓

[1] Unavailable

[2] In Commissioning

[3] Incorrect orbit

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

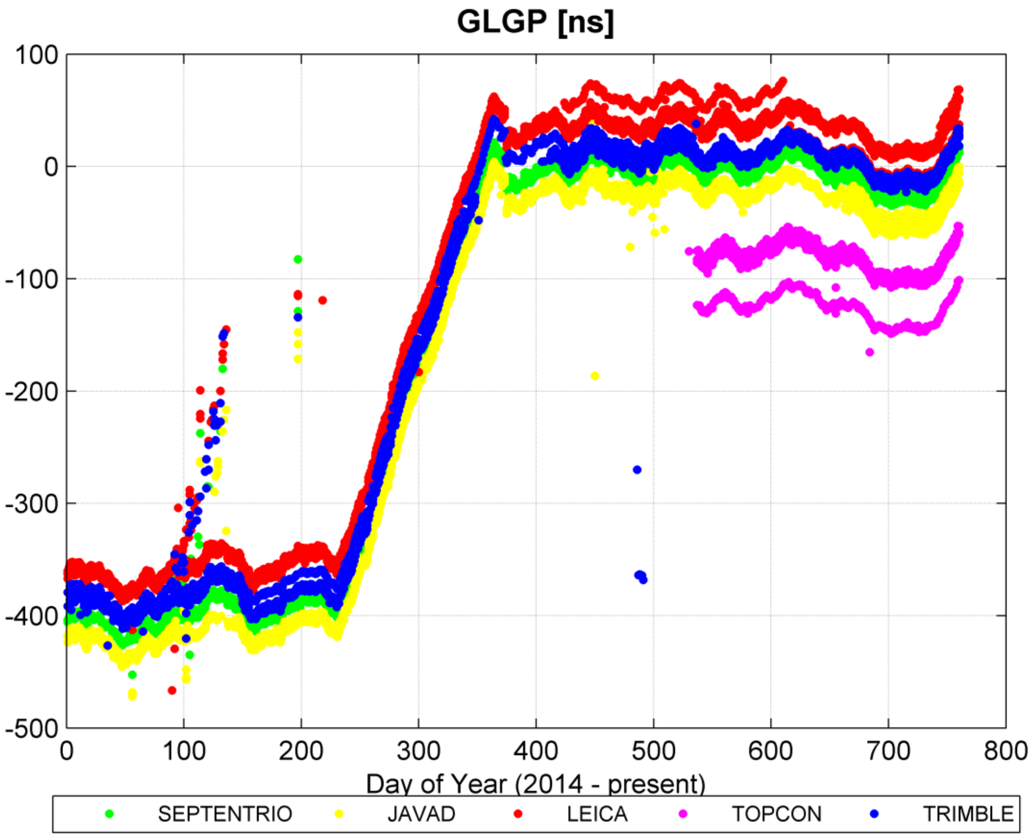
$$GLGP = c \cdot (TSC_R + dT_{Rec}) - c \cdot (TSC_G + dT_{Rec})$$

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

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

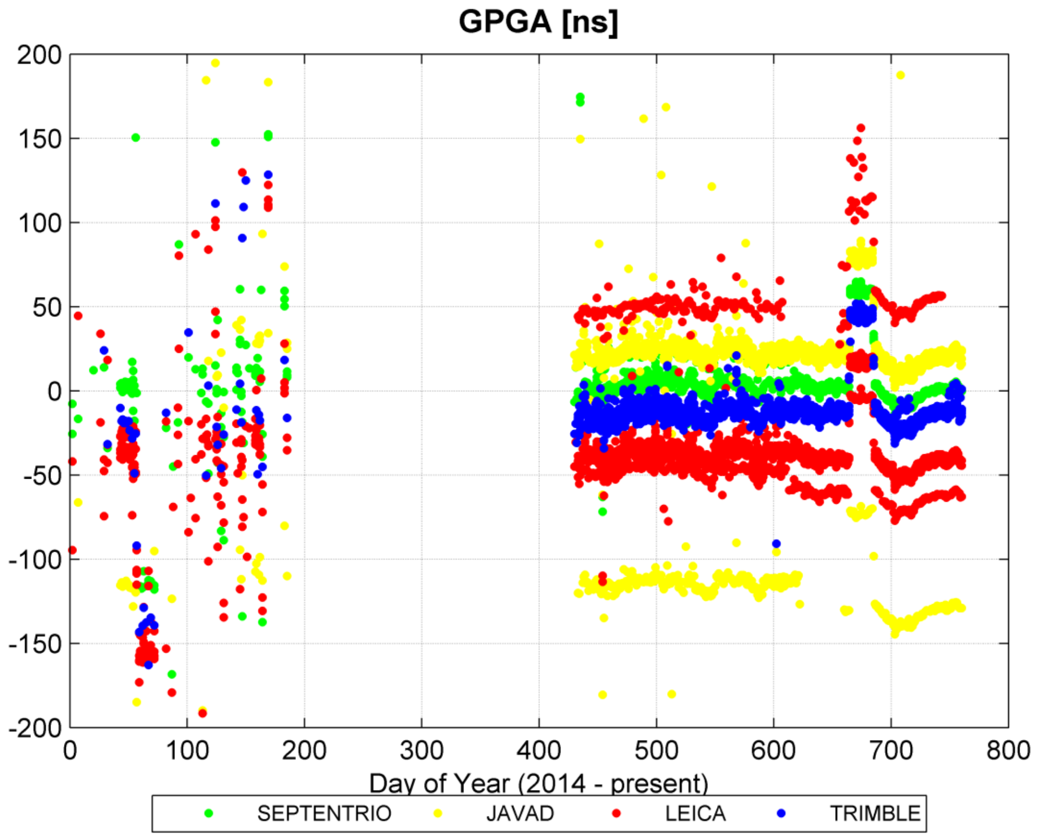
GLGP: Glonass to GPS Time Offset

- 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



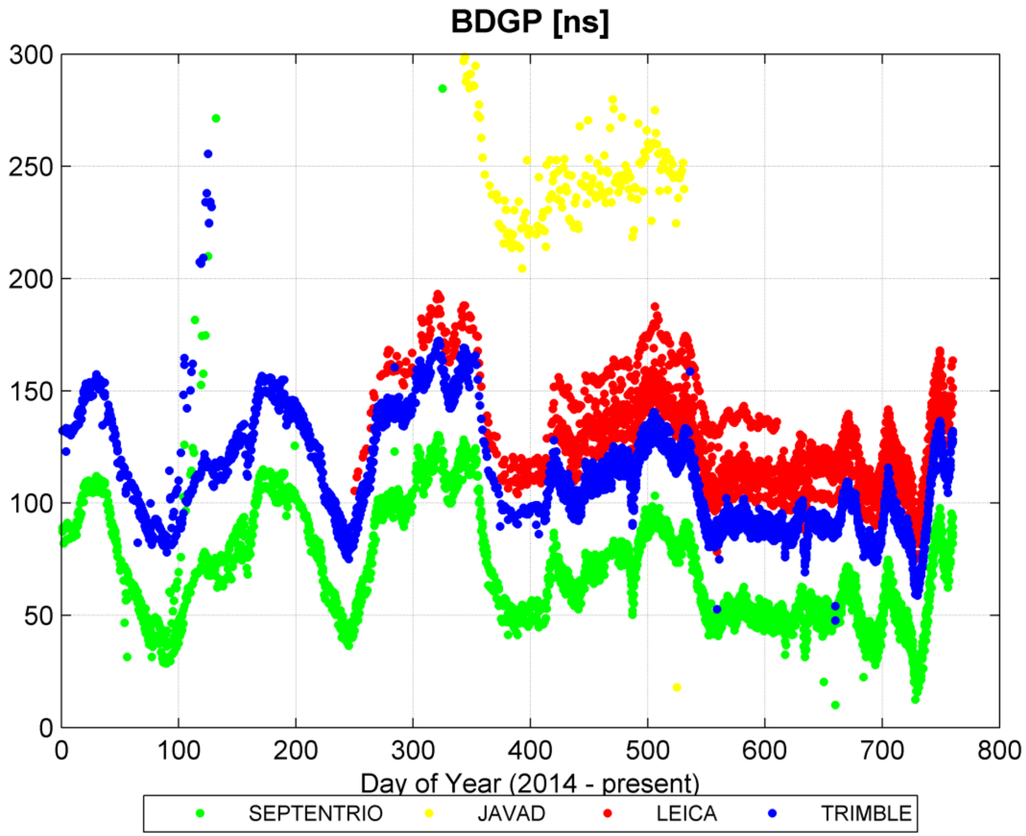
GPGA: Galileo to GPS Time Offset

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



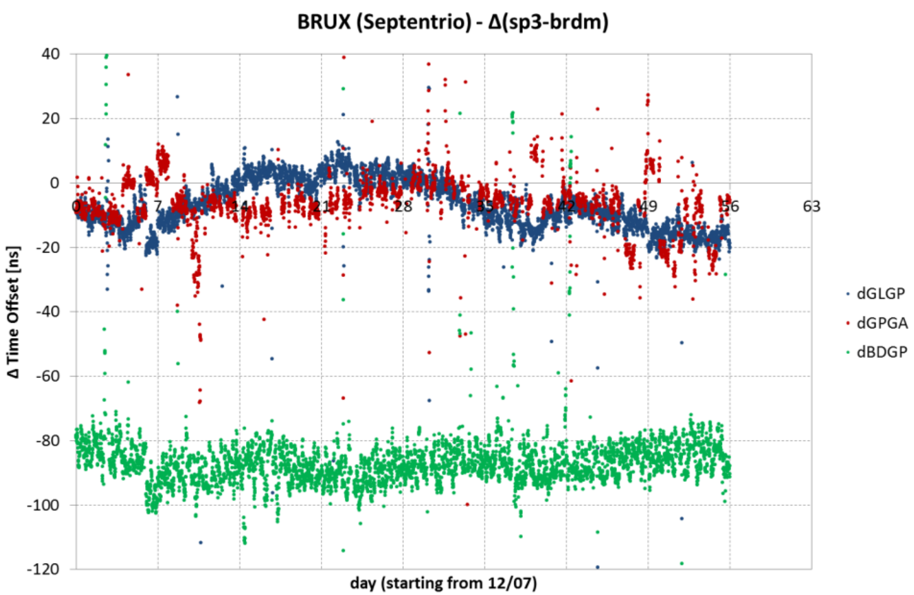
BDGP; BeiDou to GPS Time Offset

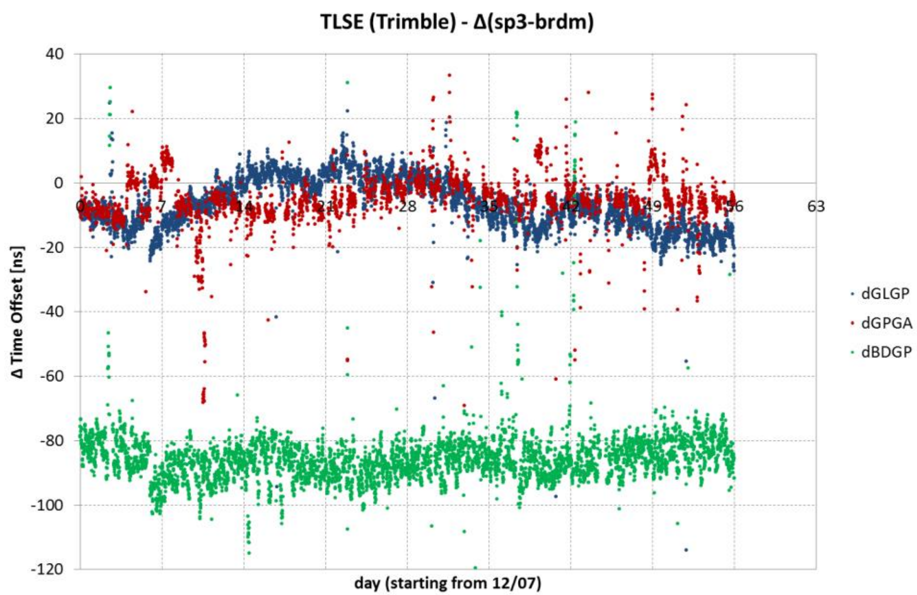
- Contrary to GPGA and GLGP, BDGP seems to vary in time periodically with a large mean value (80-100 ns)
- Receiver dependent biases and site dependent biases are visible



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 **<u>the GFZ Sp3 clock is a common ‘interGNSS’ time scale within +/- 10 ns</u>**
- This statement is receiver independent!





Receiver dependent biases

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

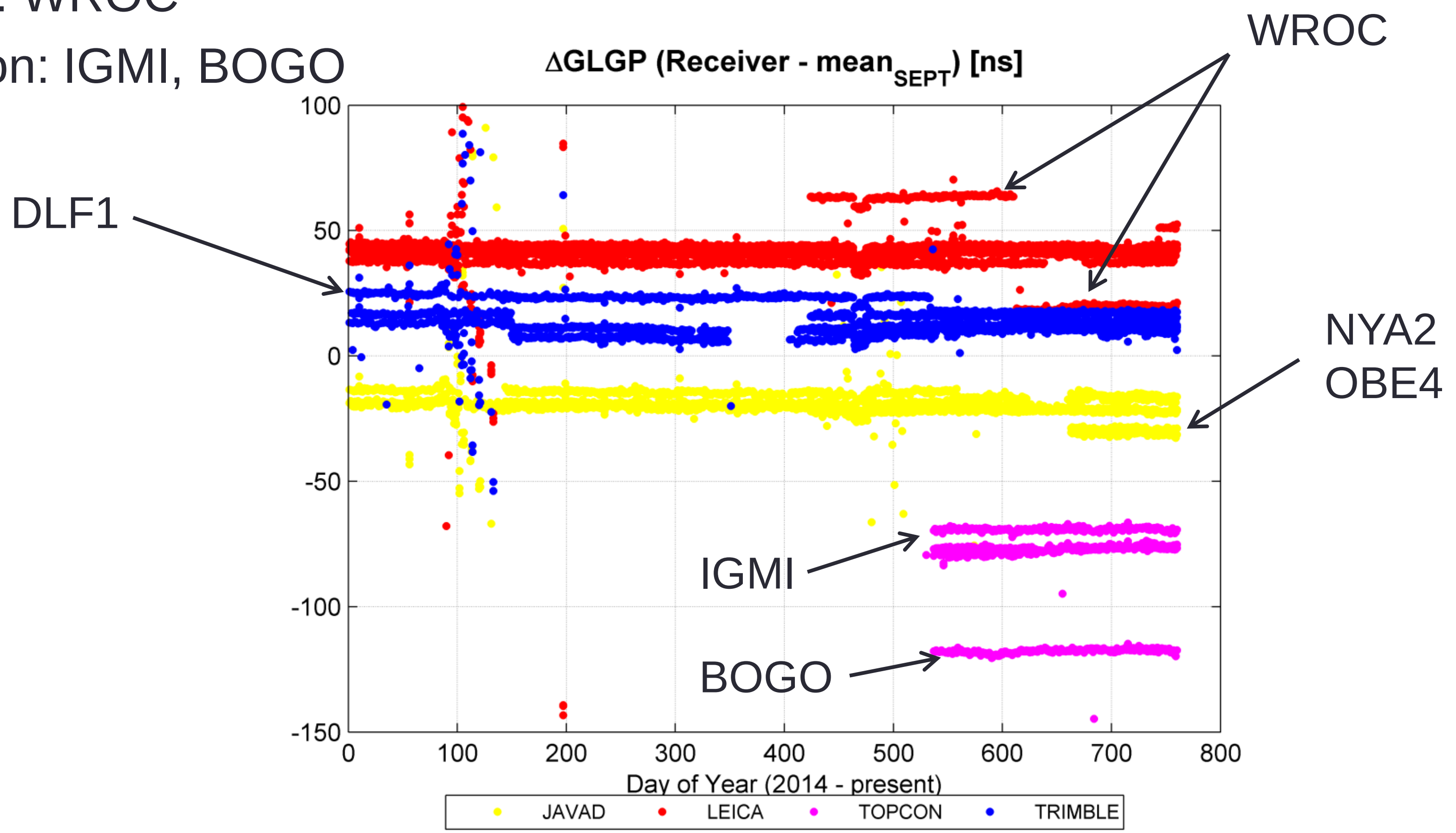
- We will also see that the same receiver brand at different sites can have different bias (Firmware dependence? Antenna dependence? Receiver architecture dependence?)

- 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 6 receivers BRUX CEBR KIRU MAS1 REDU VILL)

dGLGP (Receiver - Septentrio)

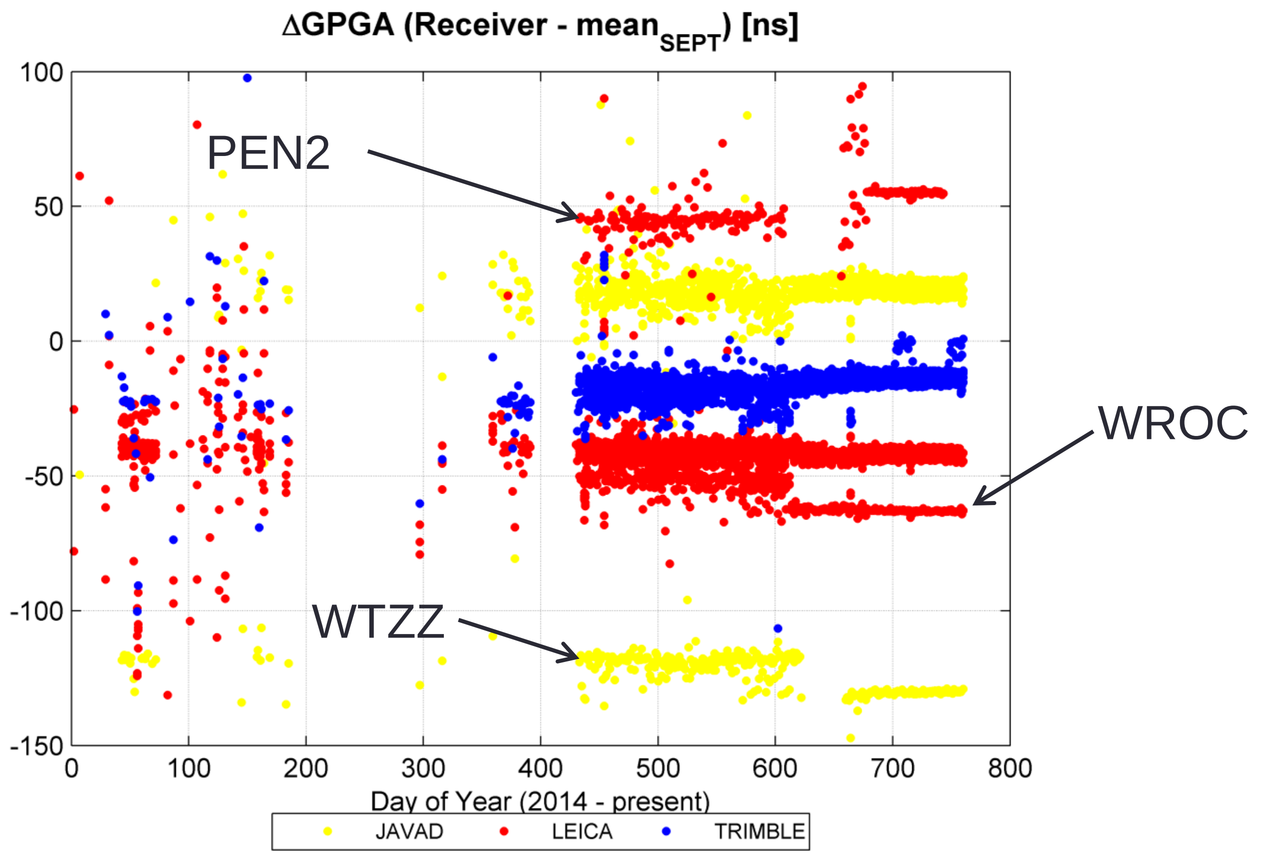
- Javad: NYA2, OBE4
- Trimble: DLF1
- Leica: WROC
- Topcon: IGMI, BOGO

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



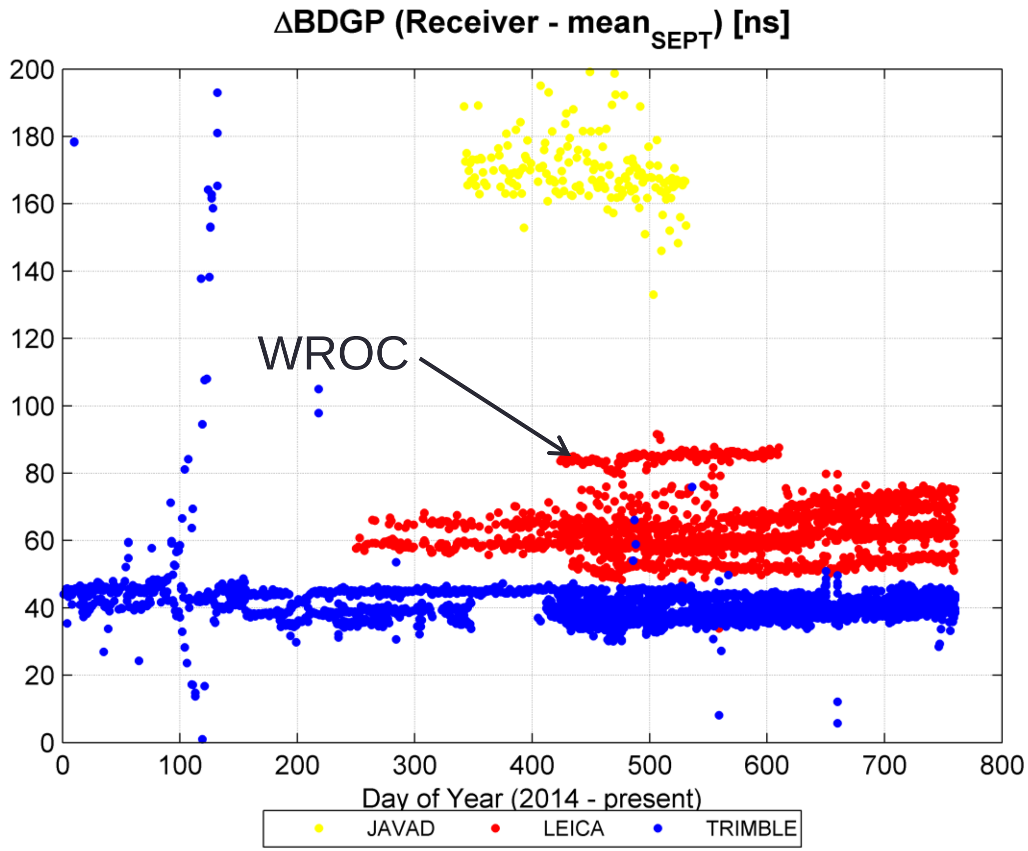
dGPGA (Receiver - Septentrio)

- Javad: WTZZ
- Leica: PEN2, WROC



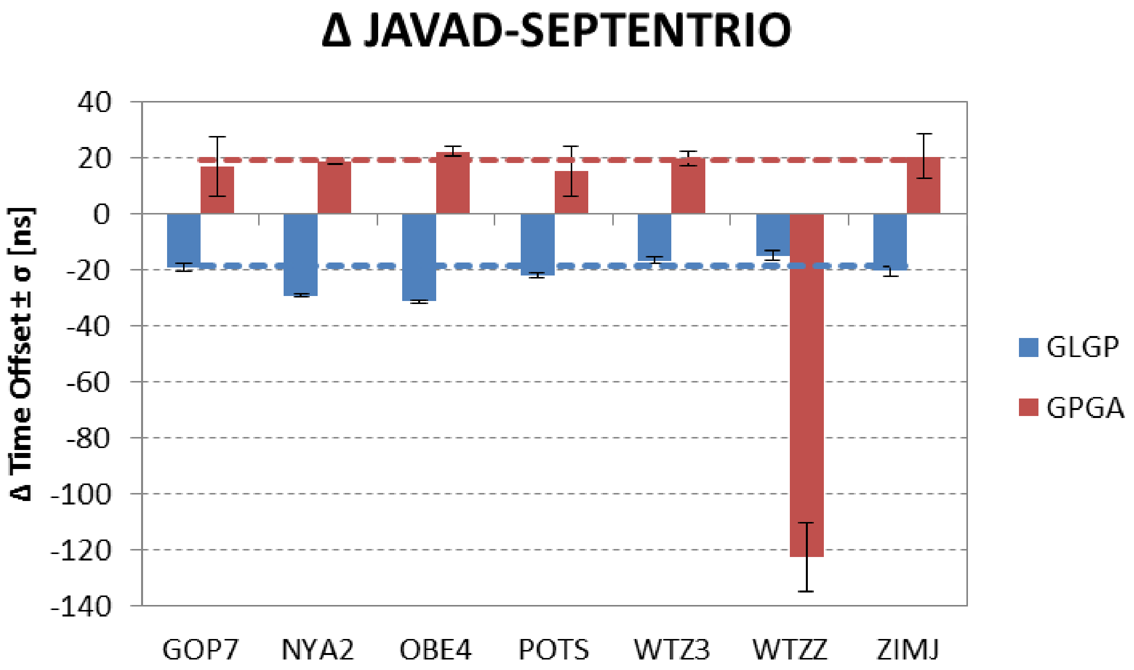
dBDGP (Receiver - Septentrio)

- Leica: WROC



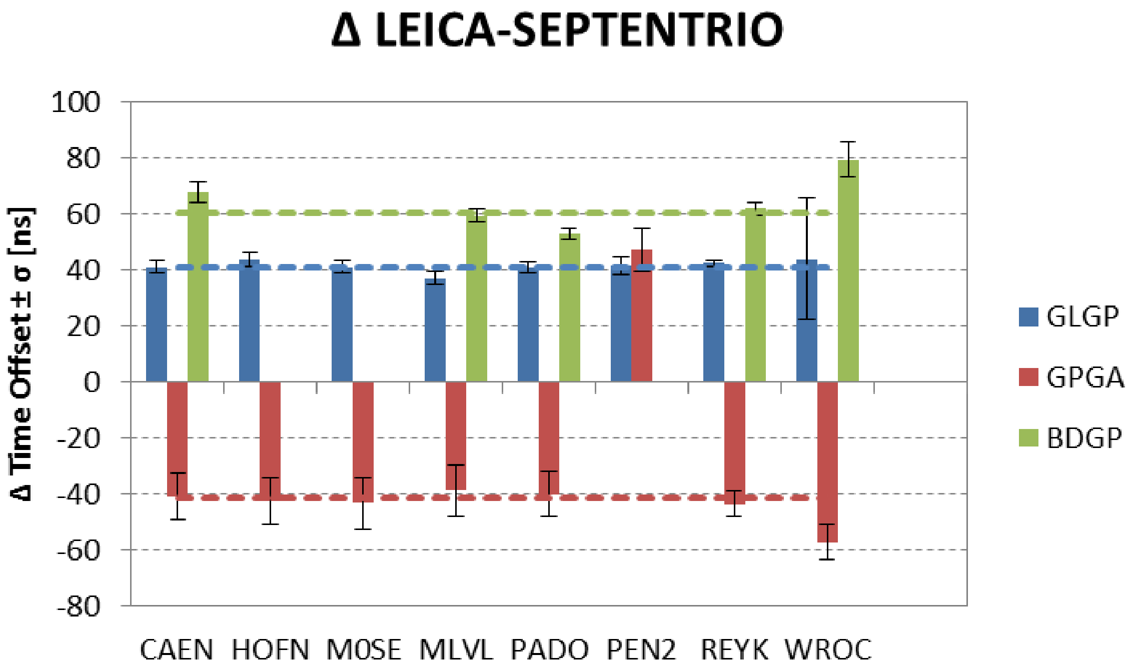
Javad - Septentrio

- WTZZ: GPGA (WTZZ behaviour is due to bad tracking of E5b frequency)
- NYA2, OBE4: GLGP



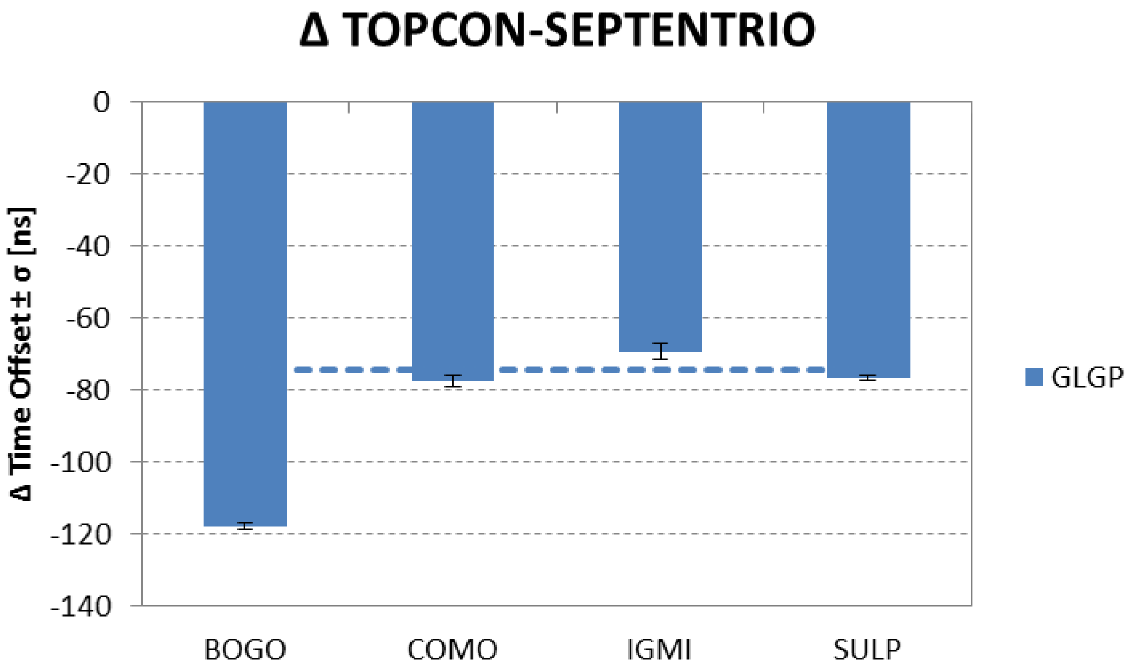
Leica - Septentrio

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



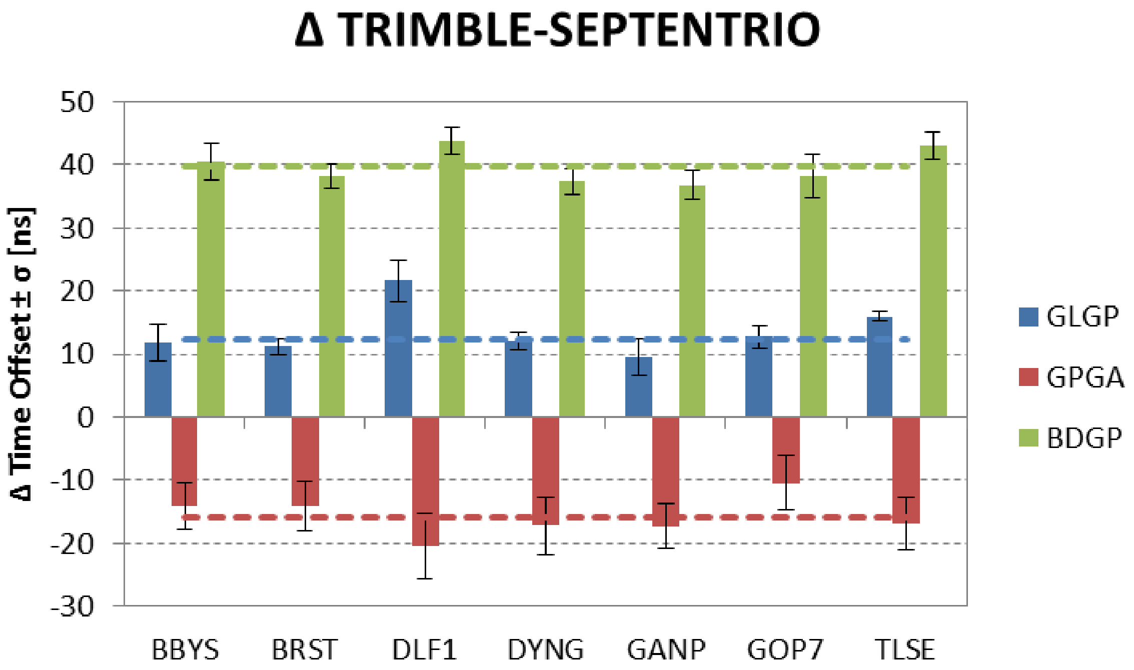
Topcon - Septentrio

- BOGO: GLGP



Trimble - Septentrio

- DLF1: GLGP



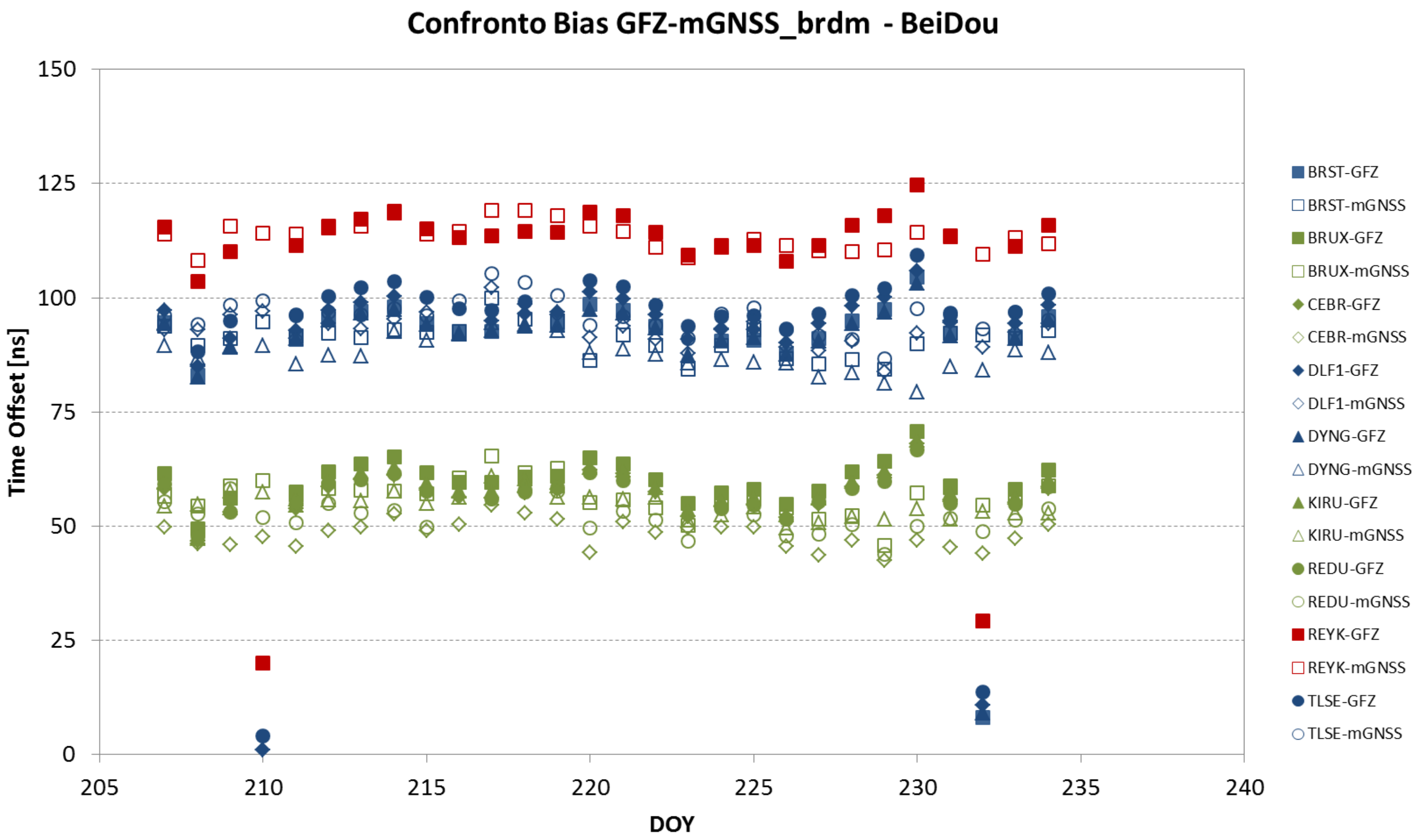
Summary table

STATION	RECEIVER			ANTENNA		CALIBRATION [ns]		
ID	RECEIVER	TYPE	FIRMWARE	ANTENNA TYPE	RADOME	GLGP	GPGA	BDGP
NYA2	JAVAD	TRE_G3TH DELTA	3.5.10	JAV_RINGANT_G3T	NONE	-29.2±0.6	18.9±1.2	
OBE4	JAVAD	TRE_G3TH DELTA	3.5.10	JAV_RINGANT_G3T	NONE	-31.1±0.6	22.3±1.7	
POTS	JAVAD	TRE_G3TH DELTA	3.4.7	JAV_RINGANT_G3T	NONE	-22±0.9	15.4±8.9	
WTZ3	JAVAD	TRE_G3TH DELTA	3.6.1b1-68-7da1	LEIAR25.R3	LEIT	-16.7±1.2	19.9±2.5	
WTZZ	**JAVAD**	**TRE_G3TH DELTA**	**3.6.2 APR,08,2015**	**LEIAR25.R3**	**LEIT**	**-14.9±1.7**	**-122.3±12.3**	**169.7±9.4**
ZIMJ	JAVAD	TRE_G3TH DELTA	3.4.9 Apr,18,2013	JAVRINGANT_DM	NONE	-20.4±1.9	20.5±8.1	
CAEN	LEICA	GR25	3.11	TRM57971.00	NONE	41.2±2.4	-40.9±8.3	67.7±3.7
HOFN	LEICA	GR25	3.11.1639/6.403	LEIAR25.R4	LEIT	43.7±2.6	-42.4±8.2	
MOSE	LEICA	GR25	3.20.B1759/6.403	LEIAR25.R4	LEIT	41.2±2.5	-43.2±9.2	
MLVL	LEICA	GR25	3.11	TRM57971.00	NONE	37.2±2.5	-38.7±9.3	59.3±2.2
PADO	LEICA	GR10	3.10.1633/6.403	LEIAR25.R4	NONE	41.1±2.1	-39.9±8	53.1±2.1
PEN2	**LEICA**	**GRX1200+GNSS**	**8.51/6.110**	**LEIAR25.R4**	**LEIT**	**41.5±3.1**	**47.2±7.6**	
REYK	LEICA	GR25	3.11.1639/6.403	LEIAR25.R4	LEIT	42.6±1.1	-43.4±4.6	61.9±2.3
WROC	**LEICA**	**GR25**	**3.11.1639/6.403**	**LEIAR25.R4**	**LEIT**	**43.9±21.7**	**-57.2±6.3**	**79.4±6.2**
BRUX	SEPTENTRIO	POLARX4TR	2.5.2	JAVRINGANT_DM	NONE	2.9±3.5	1±4.1	3.3±4.3
CEBR	SEPTENTRIO	POLARX4	2.5.2-esa3	SEPCHOKE_MC	NONE	-0.6±3.5	-0.7±5.8	-4.4±3.2
KIRU	SEPTENTRIO	POLARX4	2.5.2-esa3	SEPCHOKE_MC	SPKE	-2.9±2.6	0.2±5.5	2.1±4.8
MAS1	SEPTENTRIO	POLARX4	2.9.0	LEIAR25.R4	NONE	-1.5±0.3	0.1±0.9	-6.2±1.8
REDU	SEPTENTRIO	POLARX4	2.5.2-esa3	SEPCHOKE_MC	NONE	0.2±0.5	-0.3±4	-0.7±1.4
VILL	SEPTENTRIO	POLARX4	2.9.0	SEPCHOKE_MC	NONE	2.6±0.3	-0.4±1.5	-1.7±0.9
BOGO	**TOPCON**	**EUROCARD**	**2.6.1 Jan,10,2008**	**ASH700936C_M**	**SNOW**	**-117.7±0.8**		
COMO	TOPCON	E_GGD	3.4 Dec,12,2009 p2	TPSCR3_GGD	CONE	-77.5±1.6		
IGMI	TOPCON	ODYSSEY_E	3.3 JUL,10,2008 P4	TPSCR.G3	TPSH	-69.3±2.1		
SULP	TOPCON	NET-G3A	4.1 May,31,2013	TPSCR.G5	TPSH	-76.7±0.7		
BBYS	TRIMBLE	NETR9	4.85/4.71	TRM59800.00	NONE	11.8±2.9	-14.1±3.7	40.6±2.9
BRST	TRIMBLE	NETR9	4.85	TRM57971.00	NONE	11.2±1.2	-14±3.9	38.2±1.9
DLF1	**TRIMBLE**	**NETR9**	**5.01**	**LEIAR25.R3**	**LEIT**	**21.6±3.2**	**-20.4±5.1**	**43.8±2.1**
DYNG	TRIMBLE	NETR9	5.01	TRM59800.00	NONE	12.1±1.5	-17.2±4.6	37.4±2
GANP	TRIMBLE	NETR9	4.93/4.93	TRM55971.00	NONE	9.6±2.9	-17.3±3.6	36.8±2.3
GOP7	TRIMBLE	NETR9	5.01	LEIAR25.R4	LEIT	-19±1.3	16.9±10.3	38.2±3.4
TLSE	TRIMBLE	NETR9	5.01	TRM59800.00	NONE	16±0.8	-16.9±4.2	43±2.1

Updated to 2016-01-30

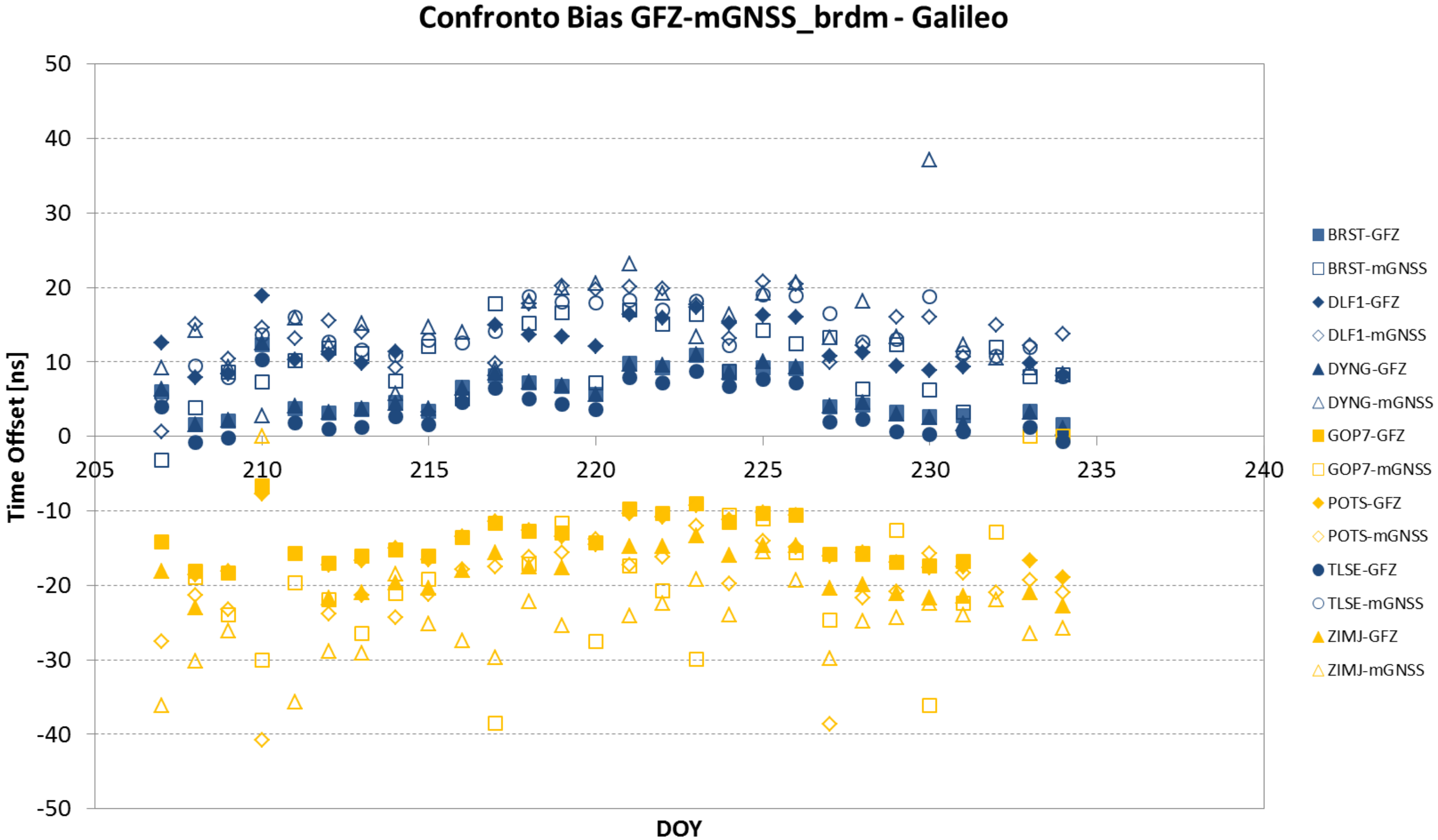
BeiDou to GPS time offset: GFZ vs. UPA/brdc

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.
- 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.