

GPS, Galileo and BeiDou inter-system biases estimation in relative positioning with code and phase pseudoranges

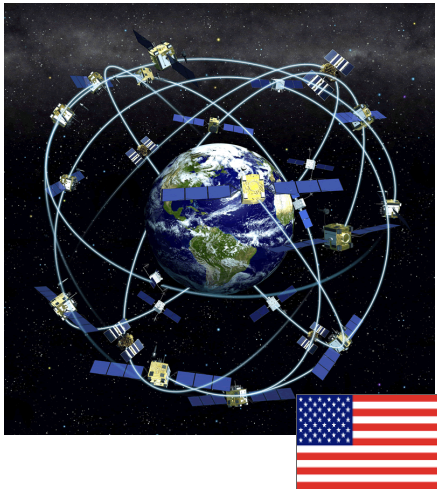
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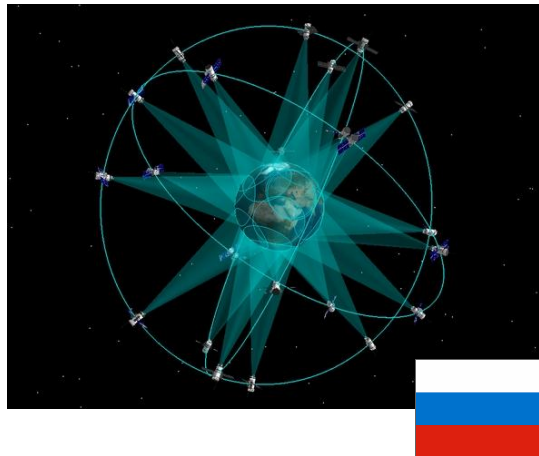
Multi-GNSS

- ▶ Many systems : GPS, GLONASS, Galileo, BeiDou, QZSS, IRNSS

GPS



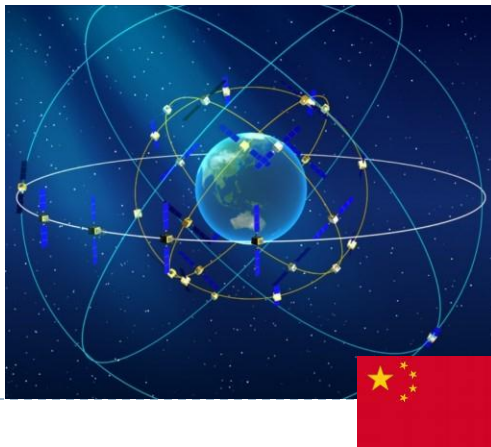
GLONASS



Galileo



BeiDou



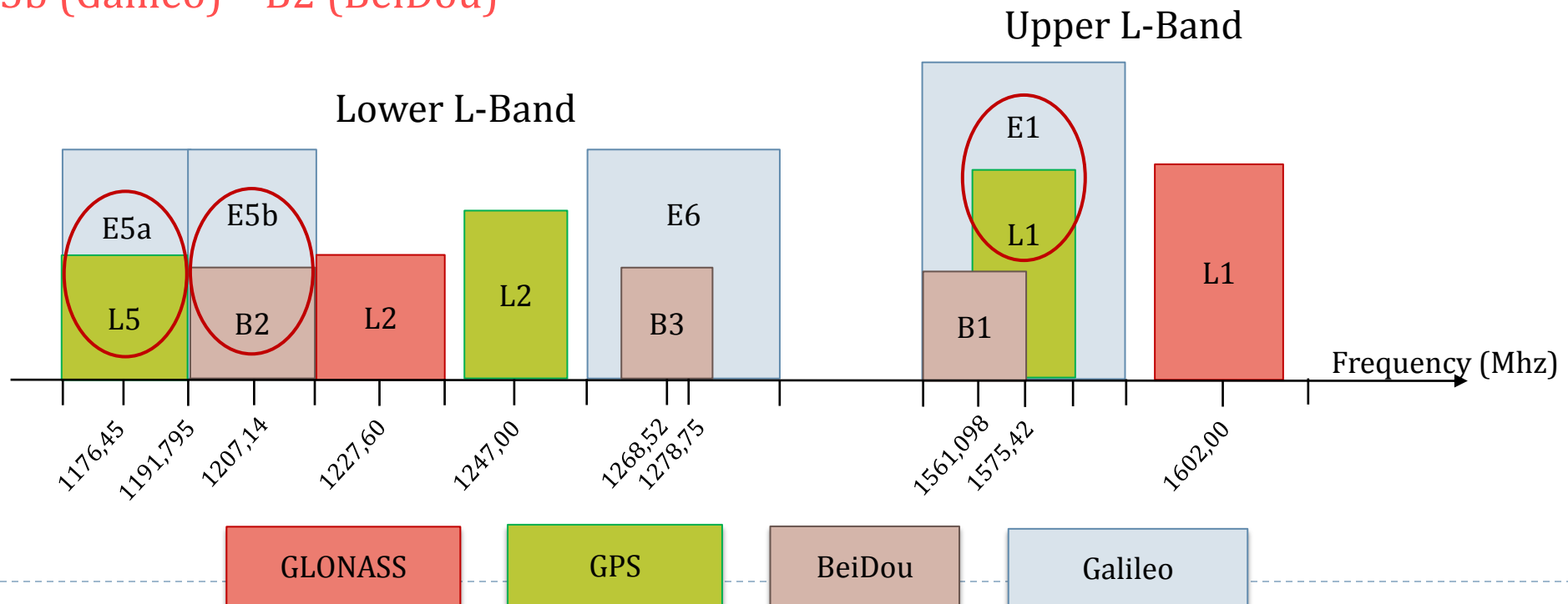
QZSS



Multi-GNSS

▶ Overlapping frequencies :

- ▶ L1 (GPS) – E1 (Galileo) – B1 (BeiDou Phase III) – L1 (QZSS)
- ▶ L5 (GPS) – E5a (Galileo) – L5 (QZSS) – L5 (IRNSS)
- ▶ L2 (GPS) – L2 (QZSS)
- ▶ E5b (Galileo) – B2 (BeiDou)



Inter-system biases (ISBs)

► One way code observation model

$$\text{GPS: } P_{1,k}^G = D_1^G + T_1^G + I_{1,k}^G + M_{1,k,m}^G + c \cdot (\delta t_1^{(G)} - \delta t^G) + d_1 - d^G + \epsilon_{1,k,m}^G$$

$$\text{Galileo: } P_{1,k}^E = D_1^E + T_1^E + I_{1,k}^E + M_{1,k,m}^E + c \cdot (\delta t_1^{(E)} - \delta t^E) + d_1 - d^E + \epsilon_{1,k,m}^E$$

$$+ c \cdot (\delta t_1^{(E)} - \delta_{GGTO} - \delta t^E)$$

$P_{1,k}^*$: Pseudo-range δt_1 : Receiver clock errors
 D_1^* : Geometric distance δt^* : Satellite clock errors
 T_1^* : Tropospheric delay d_1 : Receiver hardware delay
 $I_{1,k}^*$: Ionospheric delay d^* : Satellite hardware delay
 $M_{1,k,m}^*$: Multipath $\epsilon_{1,k,m}^*$: Code noise

Galileo to GPS
Time Offset
=
Different Time
Systems

Inter-system biases (ISBs)

- ▶ In a **zero baseline** case :

- ▶ Single difference :

$$P_{12,k}^G = D_{12}^G + \delta t_{12}^{(G)} - d_{12}^{(G)} + \epsilon_{12,k,m}^G$$

$$P_{12,k}^E = D_{12}^E + \delta t_{12}^{(E)} - d_{12}^{(E)} + \epsilon_{12,k,m}^E$$

The GGTO
term
disappears

- ▶ Double difference :

$$P_{12,k}^{GG} = D_{12}^{GG} + \epsilon_{12,k,m}^{GG}$$

$$P_{12,k}^{GE} = D_{12}^{GE} - d_{12}^{(GE)} + \epsilon_{12,k,m}^{GE}$$

Differential
hardware delay
between GPS and
Galileo (ISB)

Single reference satellite for all
observations

Equipment

▶ Antennae :

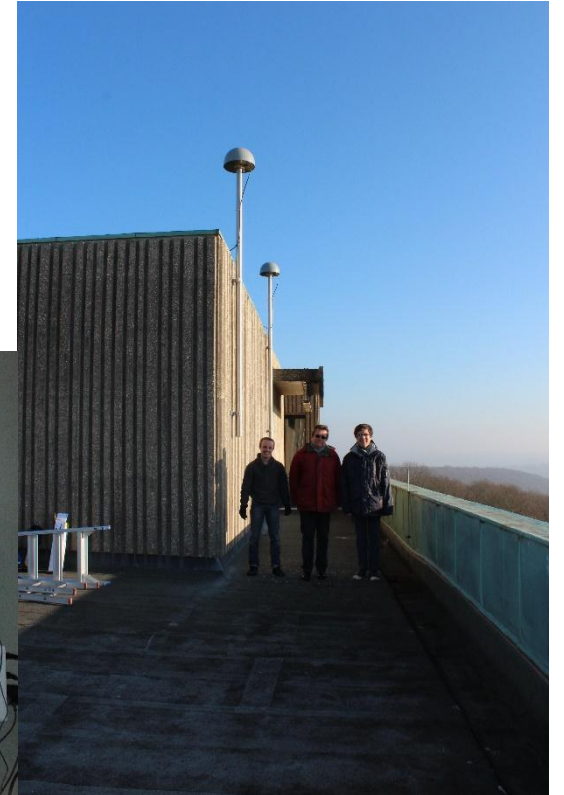
- ▶ 2 x TRIMBLE TRM 59800 SCIS (chock ring antenna) (ULG0 & ULG1)

▶ Receivers :

- ▶ 2 x Trimble NetR9 (TRM 1 & TRM 2)
- ▶ 2 x Septentrio PolaRx4 (Sept1 & Sept2)
- ▶ 1 x Septentrio PolaRxS (Sept 3)
- ▶ 1 x Septentrio PolaRx5 (Sept 4)

▶ Splitters :

- ▶ 1 x 2-way splitter
- ▶ 1 x 4-way splitter



Results

CODE PSEUDORANGES

Code ISBs (m) in zero baseline mode (2014-2015-2016)

2014

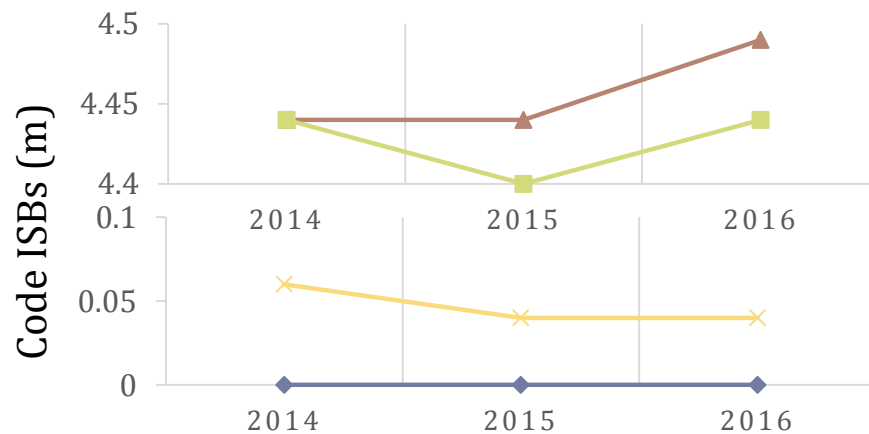
	TR	X4	XS
TR	0,00	-4,44	-4,44
X4	4,44	-	-0,06
XS	4,44	0,06	-

2015

	TR	X4	XS
TR	0,00	-4,40	-4,44
X4	4,40	0,00	-0,04
XS	4,44	0,04	-

2016

	TR	X4	XS	X5
TR	0,00	-4,44	-4,49	-4,48
X4	4,44	0,00	-0,04	-0,03
XS	4,49	0,04	-	-0,02
X5	4,48	0,03	0,02	-



VERY STABLE RESULTS

Galileo E5a / GPS L5

Code ISBs (m) in zero baseline mode (2014-2015-2016)

2014

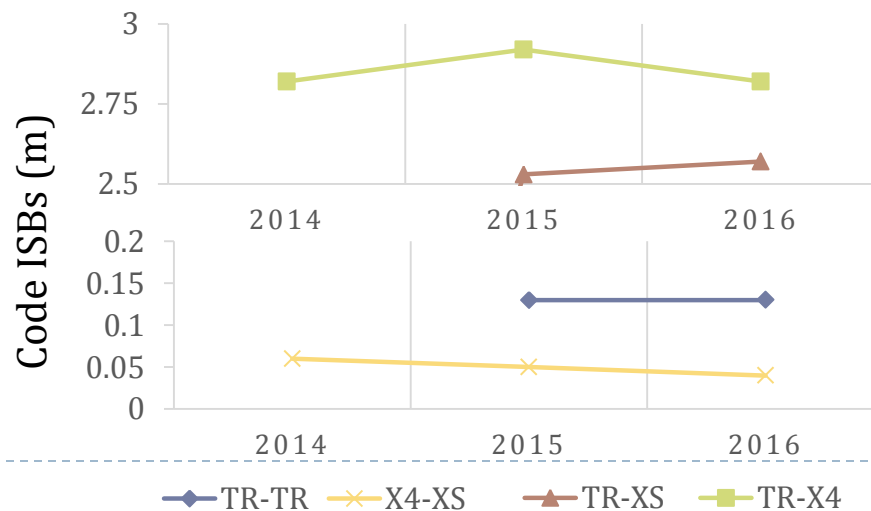
	TR	X4	XS
TR	-	-2,82	-
X4	2,82	-	-0,06
XS	-	0,06	-

2015

	TR	X4	XS
TR	0,13	-2,92	-2,53
X4	2,92	0,02	-0,05
XS	2,53	0,05	-

2016

	TR	X4	XS
TR	0,13	-2,82	-2,57
X4	2,82	0,02	-0,04
XS	2,57	0,04	-

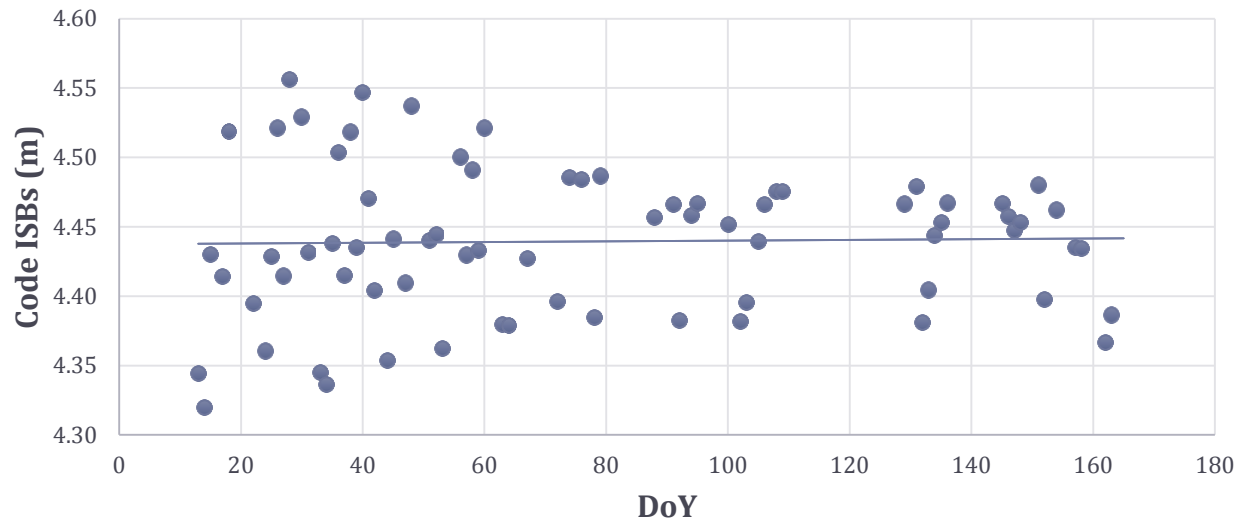


VERY STABLE RESULTS

Galileo E5b / BeiDou B2

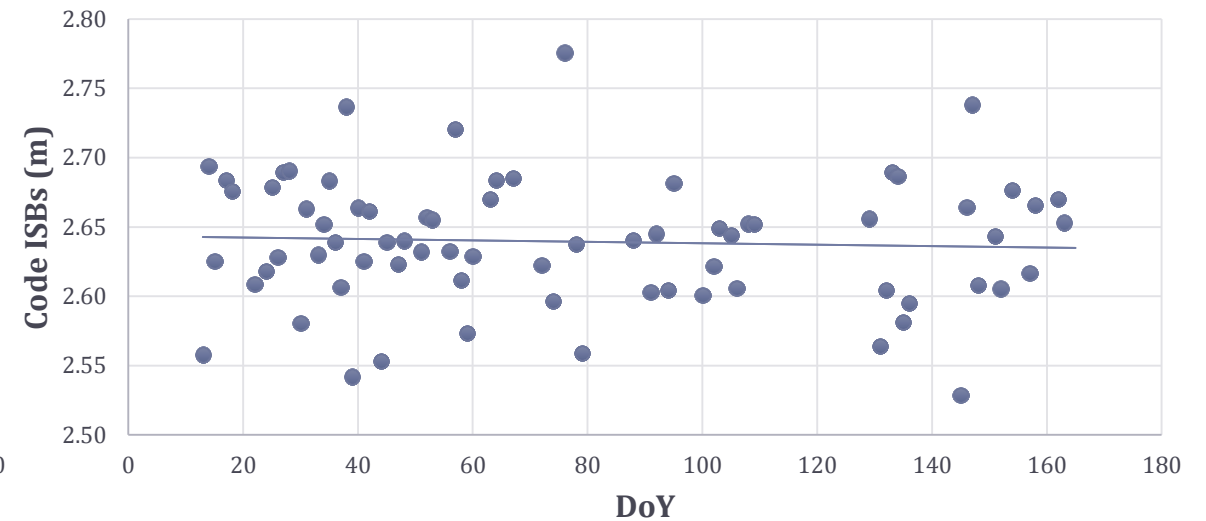
Code ISBs (m) in zero baseline mode (2016)

**TRIMBLE Net R9 - Septentrio X4
Galileo E5a/GPS L5**



Mean = 4,439
StD = 0,053

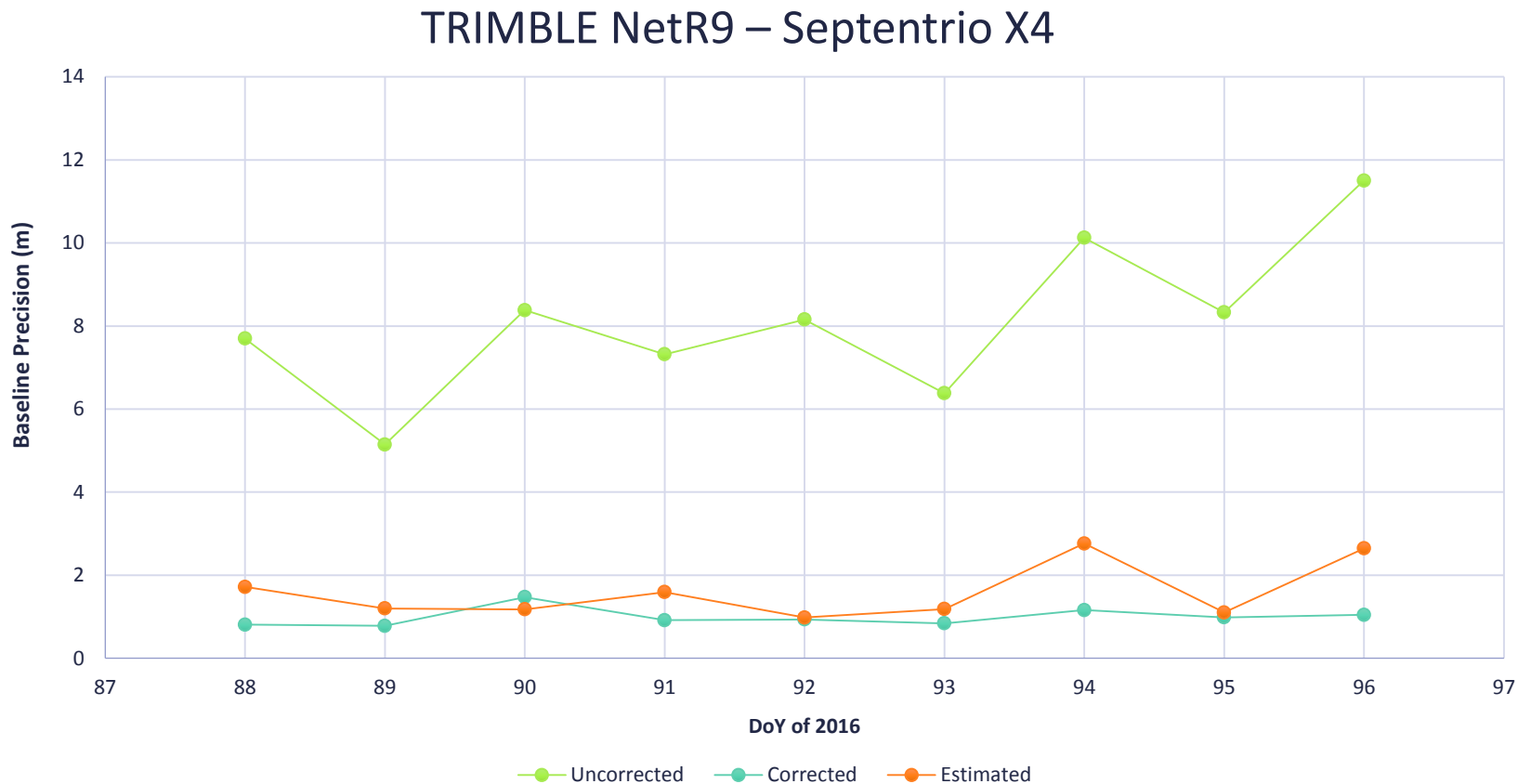
**TRIMBLE Net R9 - Septentrio X4
Galileo E5b/BeiDou B2**



Mean = 2,639
StD = 0,046

Multi-GNSS positioning

Precision of the computed positions with Galileo E5a/ GPS L5 in zero baseline



Uncorrected:
Mean: 8,11 m

Estimated:
Mean: 1,60 m

Corrected:
Mean: 1,49 m

Trimble multipath filter ON

Septentrio multipath filter
ON and OFF does not
impact ISBs

E5a/L5

2016a

	TR	X4	XS	X5
TR	0,00	-4,44	-4,49	-4,48
X4	4,44	0,00	-0,04	-0,03
XS	4,49	0,04	-	-0,02
X5	4,48	0,03	0,02	-



2016b

	TR	X4	XS	X5
TR	-	-5,98	-6,03	-6,03
X4	5,98	-	-0,05	-0,04
XS	6,03	0,05	-	-0,01
X5	6,03	0,04	0,01	-

E5b/B2

	TR	X4	XS
TR	0,13	-2,82	-2,57
X4	2,82	0,02	-0,04
XS	2,57	0,04	-

Not
influenced
by the filter
activation

	TR	X4	XS
TR	-	-2,87	-2,57
X4	2,87	-	-0,04
XS	2,57	0,04	-

Code ISBs (m) in zero baseline mode (2014-2015-2016)

2014

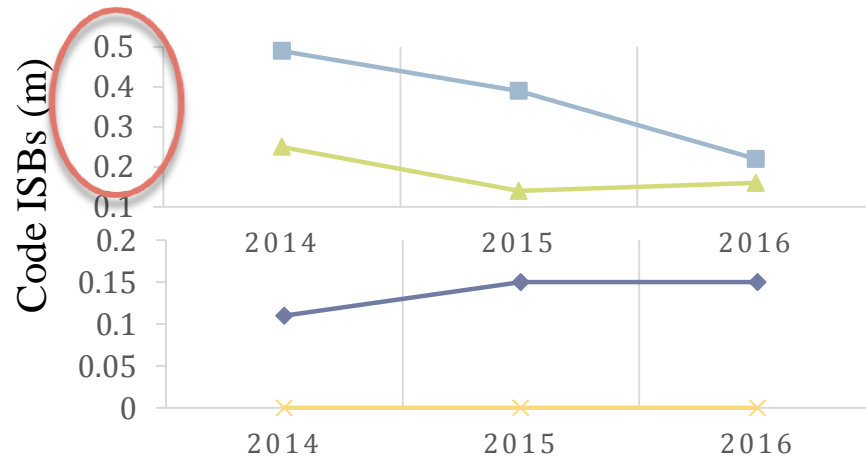
	TR	X4	XS
TR	0,11	-0,49	-0,25
X4	0,49	-	0,00
XS	0,25	0,00	-

2015

	TR	X4	XS
TR	0,15	-0,39	-0,14
X4	0,39	0,00	0,00
XS	0,14	0,00	-

2016

	TR	X4	XS	X5
TR	0,15	-0,22	-0,16	-0,02
X4	0,22	0,00	0,00	-0,17
XS	0,16	0,00	-	-0,17
X5	0,02	0,17	0,17	-

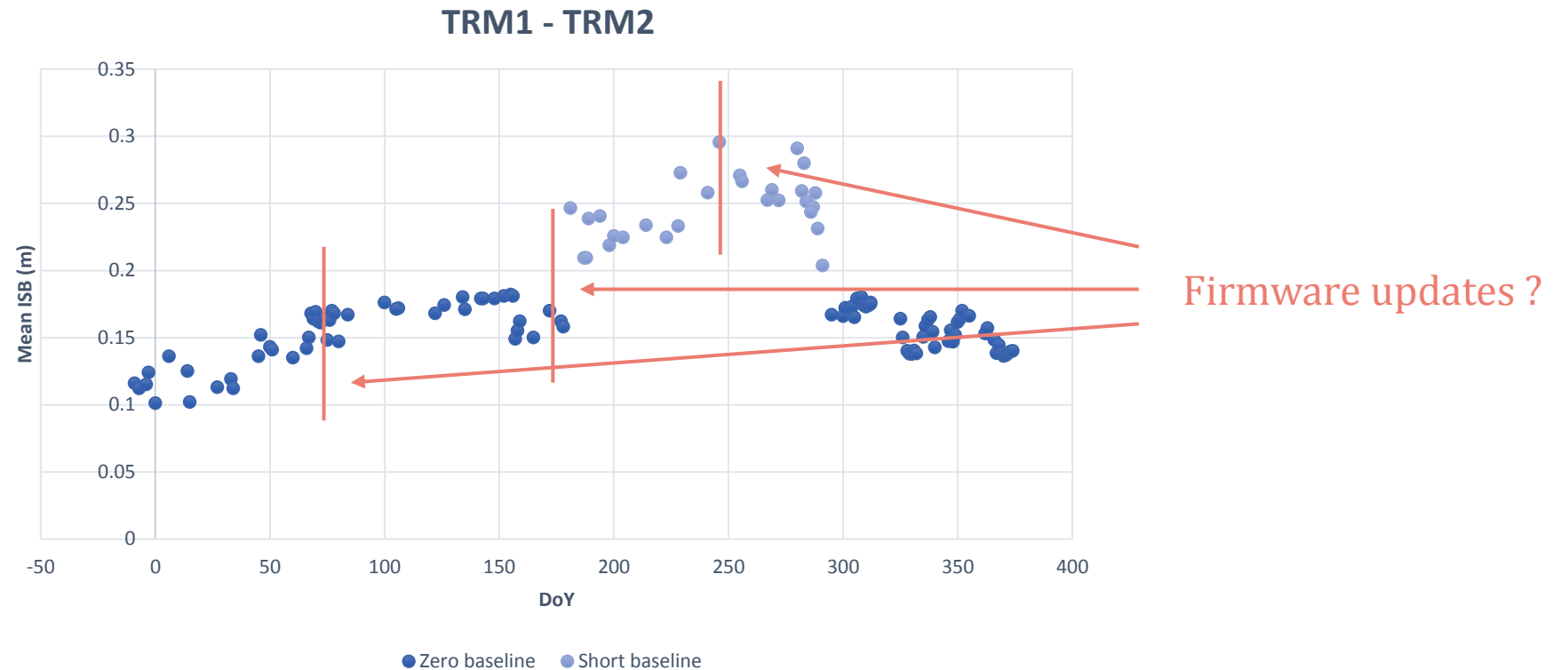


VARYING RESULTS

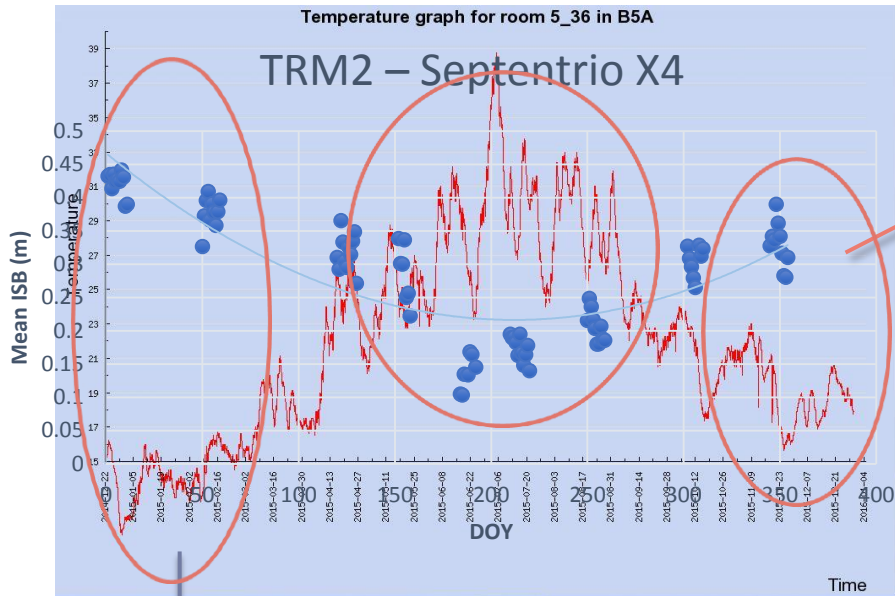
Galileo E1 / GPS L1

Code ISBs (m) in zero baseline with identical receiver-types

Analysis over the year 2015

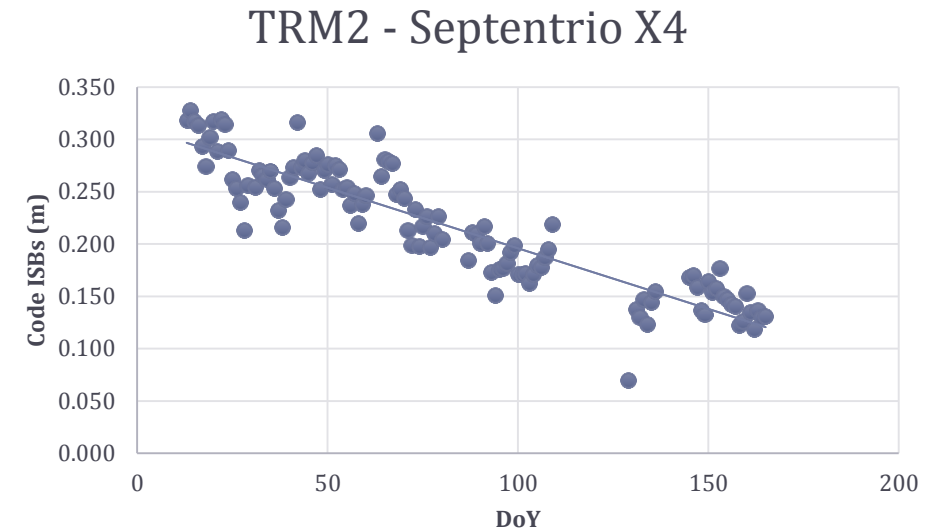


Code ISBs (m) in zero baseline with different receiver-types



Influence of the temperature?

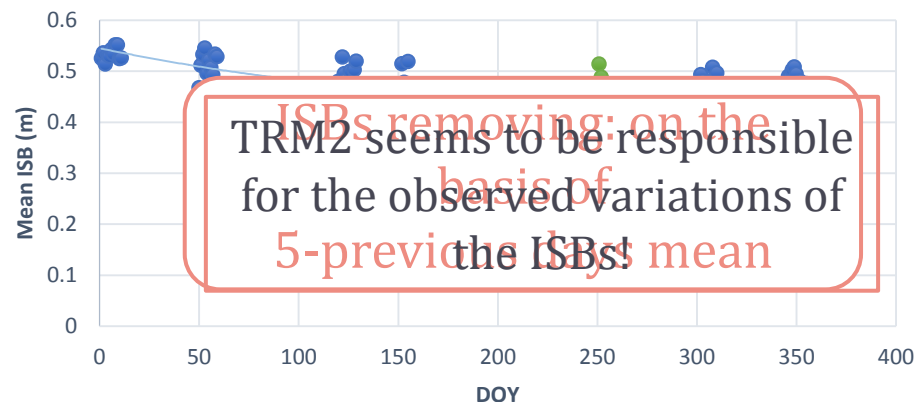
Analysis over year 2015
Galileo E1/GPS L1



Analysis over year 2016

Temperature registered inside the receiver's room

TRM1 – Septentrio X4



Trimble multipath filter ON

E1/L1

2016a

	TR	X4	XS	X5
TR	0,15	-0,22	-0,16	-0,02
X4	0,22	0,00	0,00	-0,17
XS	0,16	0,00	-	-0,17
X5	0,02	0,17	0,17	-



2016b

	TR	X4	XS	X5
TR	-	-1,62	-1,65	-1,80
X4	1,62	0,00	0,00	-0,17
XS	1,65	0,00	-	-0,17
X5	1,80	0,17	0,17	-

Results

CARRIER PHASES



Phase ISBs (cycle) in zero baseline mode (2015-2016)

2015

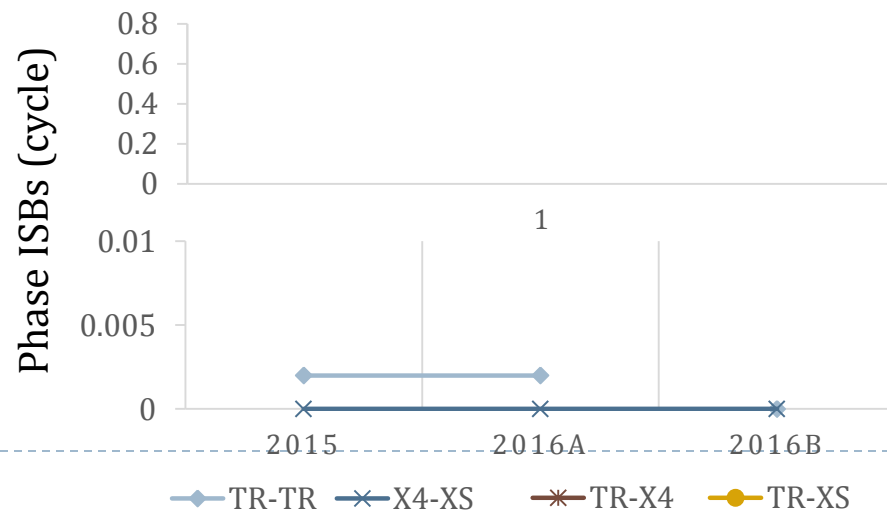
	TR	X4	XS
TR	0,00	-0,24	-0,24
X4	0,24	0,00	0,00
XS	0,24	0,00	-

2016a

	TR	X4	XS
TR	0,00	-0,24	-0,24
X4	0,24	0,00	0,00
XS	0,24	0,00	-

2016b

	TR	X4	XS
TR	-	-0,24	-0,24
X4	0,24	-	0,00
XS	0,24	0,00	-



No firmware update influence

Not influenced by the activation of the Trimble multipath filter

Galileo E5b / BeiDou B2

Conclusions and prospects

Conclusions

- ▶ Code ISBs
 - ▶ Galileo E5a/GPS L5, Galileo E5b/BeiDou B2 show very stable values
 - ▶ Galileo E1/GPS L1 ISBs are varying with some receiver models (temperature influence?)
 - ▶ The activation of multipath filters might have an impact on ISBs (Galileo E5a/GPS L5, Galileo E1/GPS L1)
 - ▶ Identical receivers show close to 0 ISB values
 - ▶ Not influenced by firmware updates
- ▶ Phase ISBs
 - ▶ Firmware updates of 2015/2016 do not impact Galileo E5b/ BeiDou B2 phase ISB values
 - ▶ The activation of multipath filters has also no effect on Galileo E5b/ BeiDou B2 phase ISBs
- ▶ Positioning
 - ▶ Removing mean ISBs on the basis of previous days analysis improve positioning results

Prospects

- ▶ Compute BeiDou B1 (III)/ Galileo E1/ GPS L1 ISBs
- ▶ Process longer baselines

Thank you for your attention

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