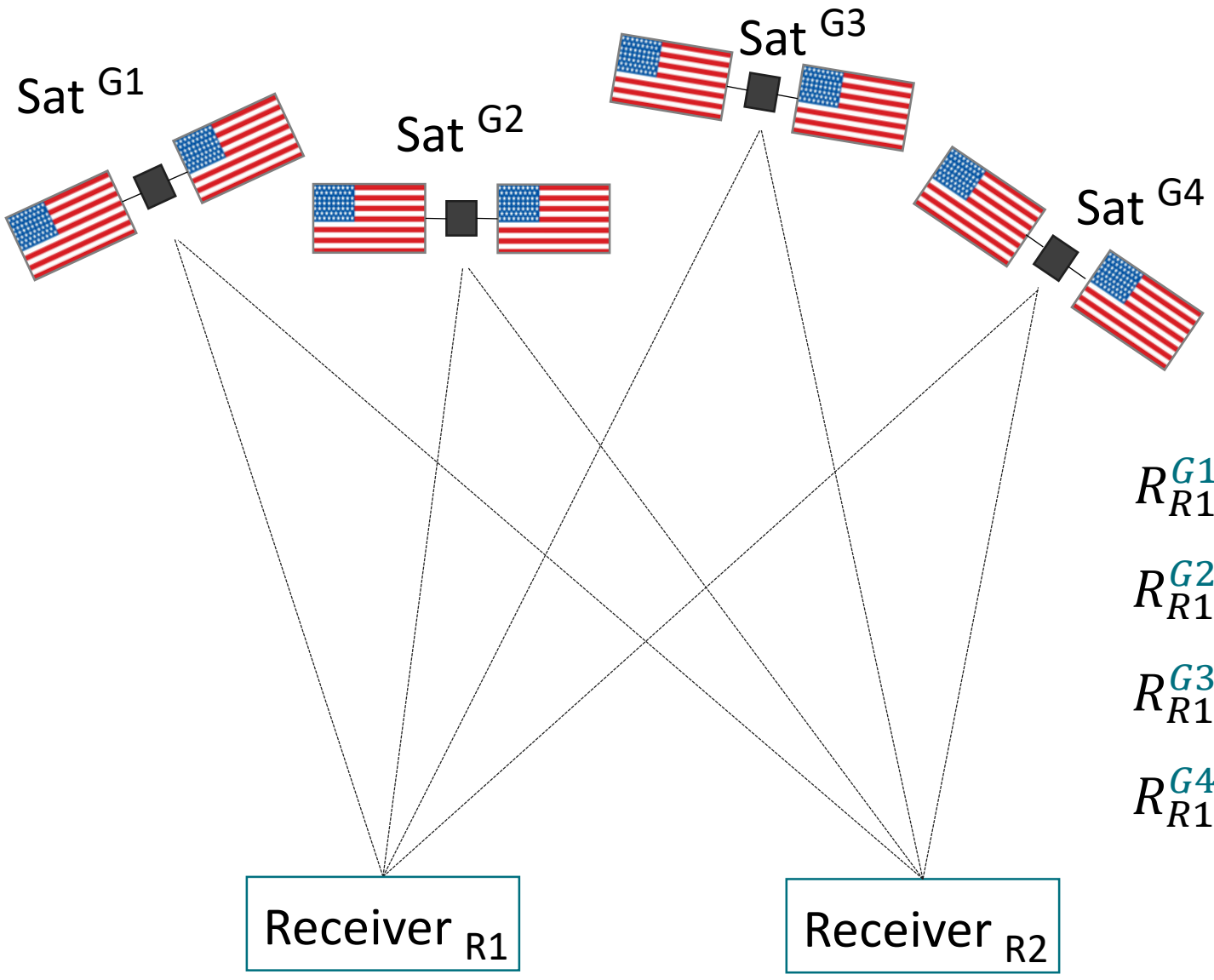
LIÈGE université
Geomatics

GPS + Galileo
Single-Frequency Relative Positioning
with Low-Cost Receivers

Deprez Cécile
PhD Candidate
University of Liège

Warnant René
Head of Geodesy Department
University of Liège

fnrs
FREEDOM TO RESEARCH



Single-GNSS Relative Positioning

Single Differences:

$$R_{R1R2}^{G1}(t) = R_{R1}^{G1}(t) - R_{R2}^{G1}(t)$$

Codes:

$R_{R1R2}^{G2}(t)$

$R_{R1R2}^{G3}(t)$

$R_{R1R2}^{G4}(t)$

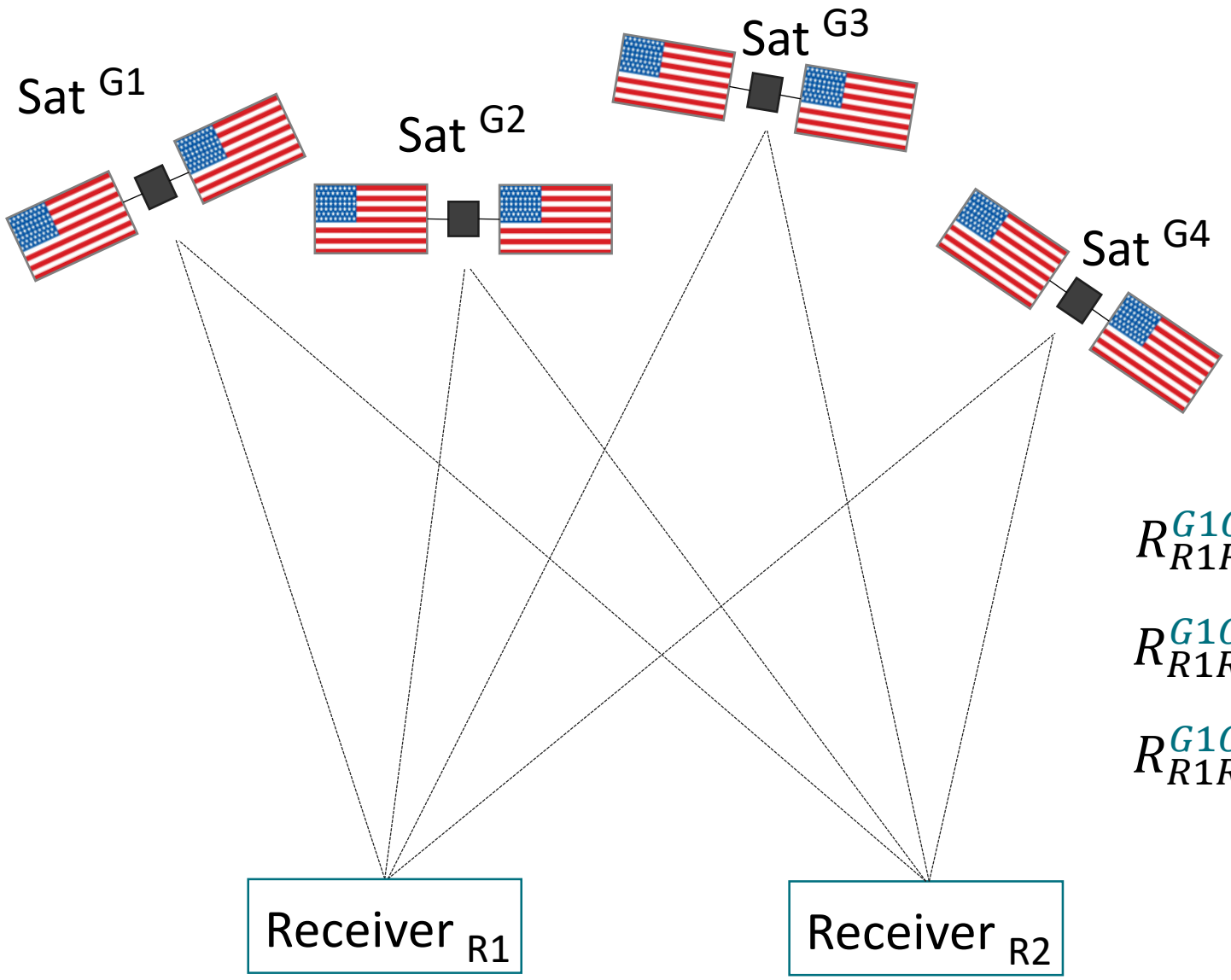
Phases:

$\Phi_{R1R2}^{G1}(t)$

$\Phi_{R1R2}^{G2}(t)$

$\Phi_{R1R2}^{G3}(t)$

$\Phi_{R1R2}^{G4}(t)$



SINGLE-GNSS RELATIVE POSITIONING

Double Differences:

$$R_{R1R2}^{G1G2}(t) = R_{R1R2}^{G1}(t) - R_{R1R2}^{G2}(t)$$

Codes:

$$R_{R1R2}^{G1G3}(t)$$

$$R_{R1R2}^{G1G4}(t)$$

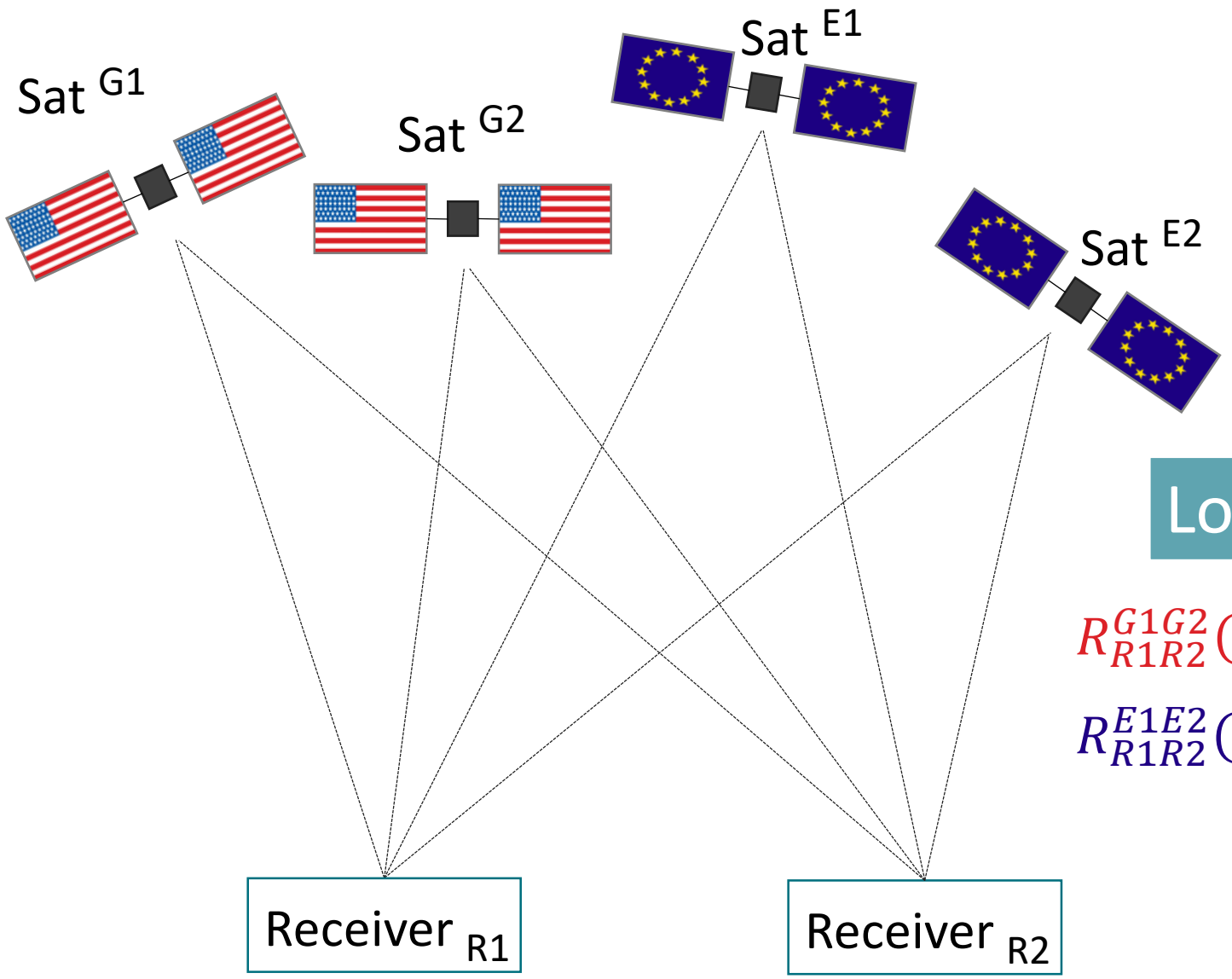
Phases:

$$\Phi_{R1R2}^{G1G2}(t)$$

$$\Phi_{R1R2}^{G1G3}(t)$$

$$\Phi_{R1R2}^{G1G4}(t)$$

Multi-GNSS Relative Positioning



Double Differences:

Loose combining:

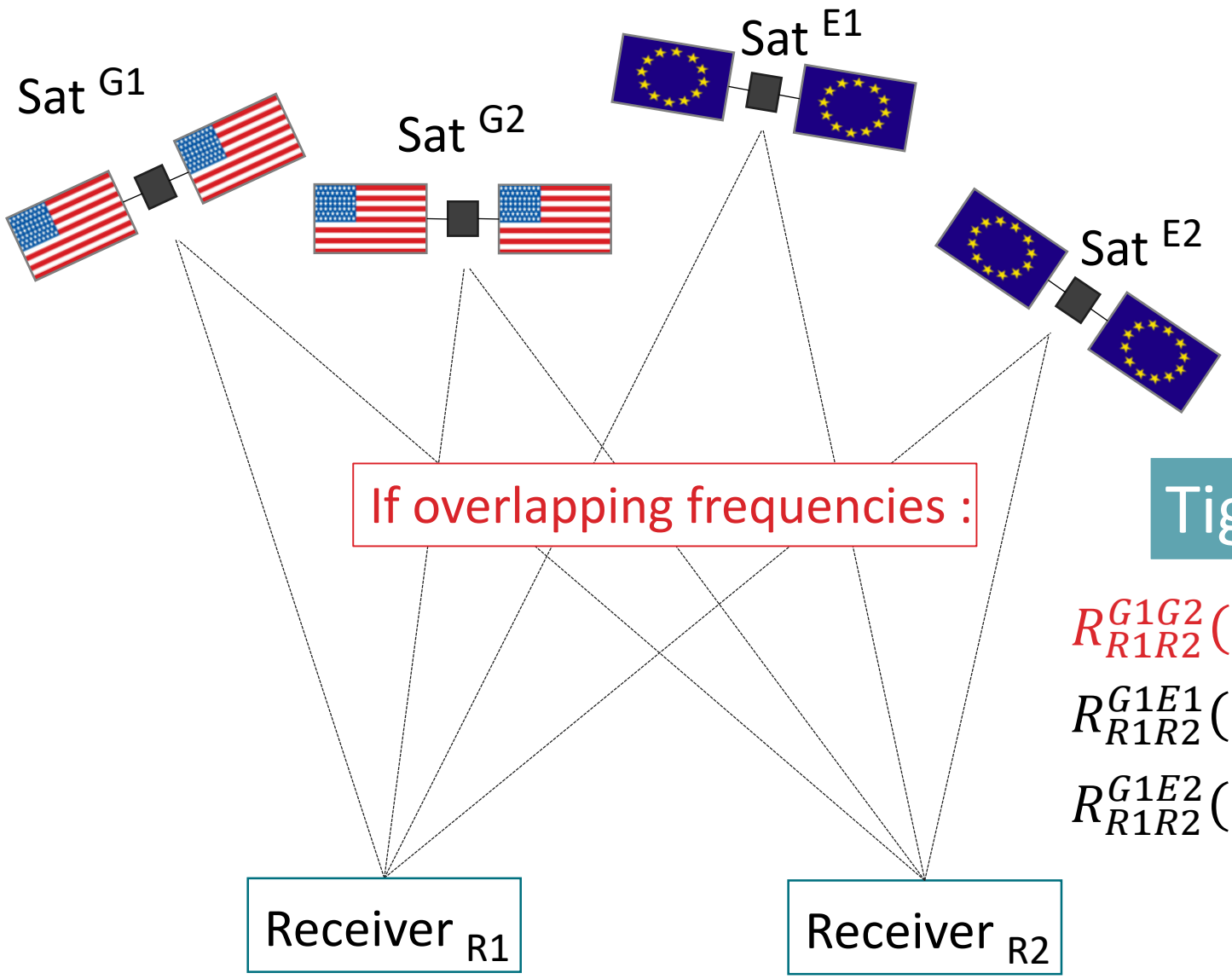
$$R_{R1R2}^{G1G2}(t) = R_{R1R2}^{G1}(t) - R_{R1R2}^{G2}(t)$$
$$R_{R1R2}^{E1E2}(t) = R_{R1R2}^{E1}(t) - R_{R1R2}^{E2}(t)$$

Codes

Phases

$$\Phi_{R1R2}^{G1G2}(t)$$
$$\Phi_{R1R2}^{E1E2}(t)$$

Multi-GNSS Relative Positioning



Double Differences:

Tight combining:

$$R_{R1R2}^{G1G2}(t) = R_{R1R2}^{G1}(t) - R_{R1R2}^{G2}(t)$$
$$R_{R1R2}^{G1E1}(t) = R_{R1R2}^{G1}(t) - R_{R1R2}^{E1}(t)$$
$$R_{R1R2}^{G1E2}(t) = R_{R1R2}^{G1}(t) - R_{R1R2}^{E2}(t)$$

Codes

Phases

$$\Phi_{R1R2}^{G1G2}(t)$$
$$\Phi_{R1R2}^{G1E1}(t)$$
$$\Phi_{R1R2}^{G1E2}(t)$$

Multi-GNSS Relative Positioning

Double Differences:

Tight combining:

+

Maximizes the redundancy

Multi-GNSS Relative Positioning

Double Differences:

Tight combining:

\+

~~Maximizes the redundancy~~

\-

Introduces additional unknowns:

Differential receiver hardware delays

= Phase and code inter-system biases

= ISBs

ISBs ON GEODETIC RECEIVERS

ISBs are **receiver-dependent** *(Odijk & Teunissen, 2013 – Pazeiwski & Wieglosz, 2015)*

Trimble NetR9

(a)

+

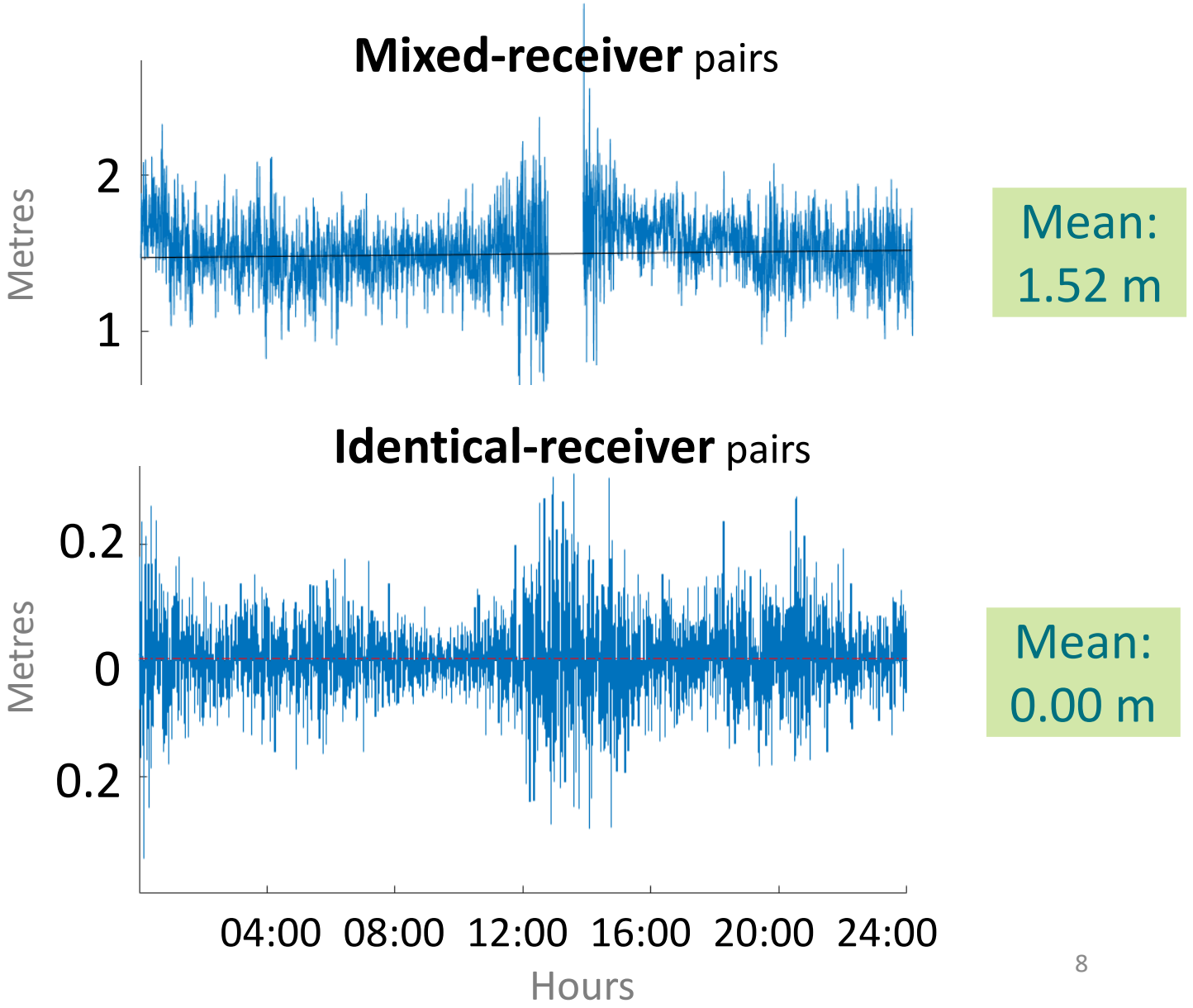
Septentrio X4

Septentrio X4

(b)

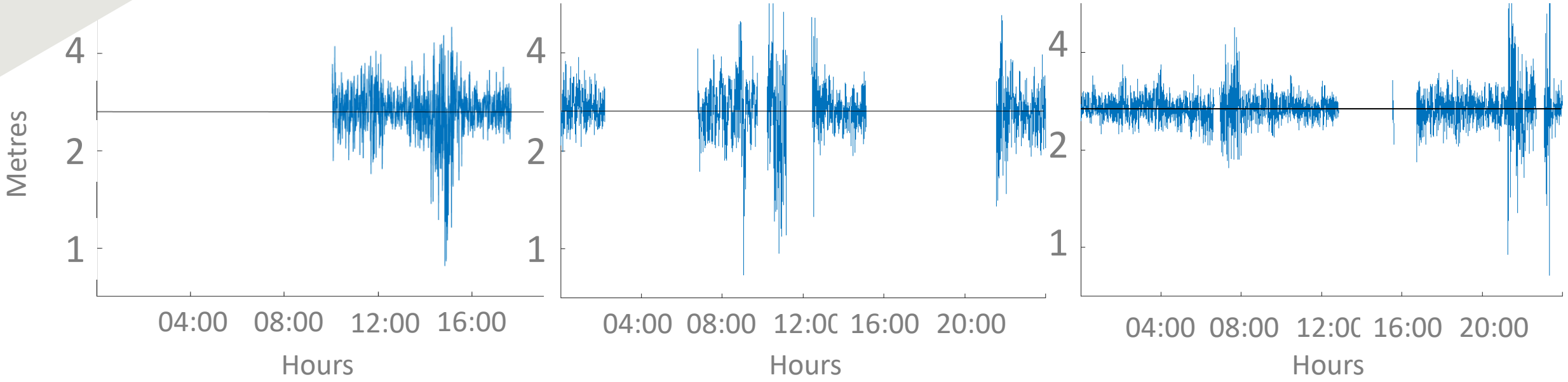
+

Septentrio X4



(a) Code ISBs (DD ZB) Galileo E1/GPS L1 (DOY 9 2016)
(b) Code ISBs (DD ZB) Galileo E1/GPS L1 (DOY 212 2016)

ISBs are stable over time *(Odijk & Teunissen, 2013 – Pazeiwski & Wieglosz, 2015)*



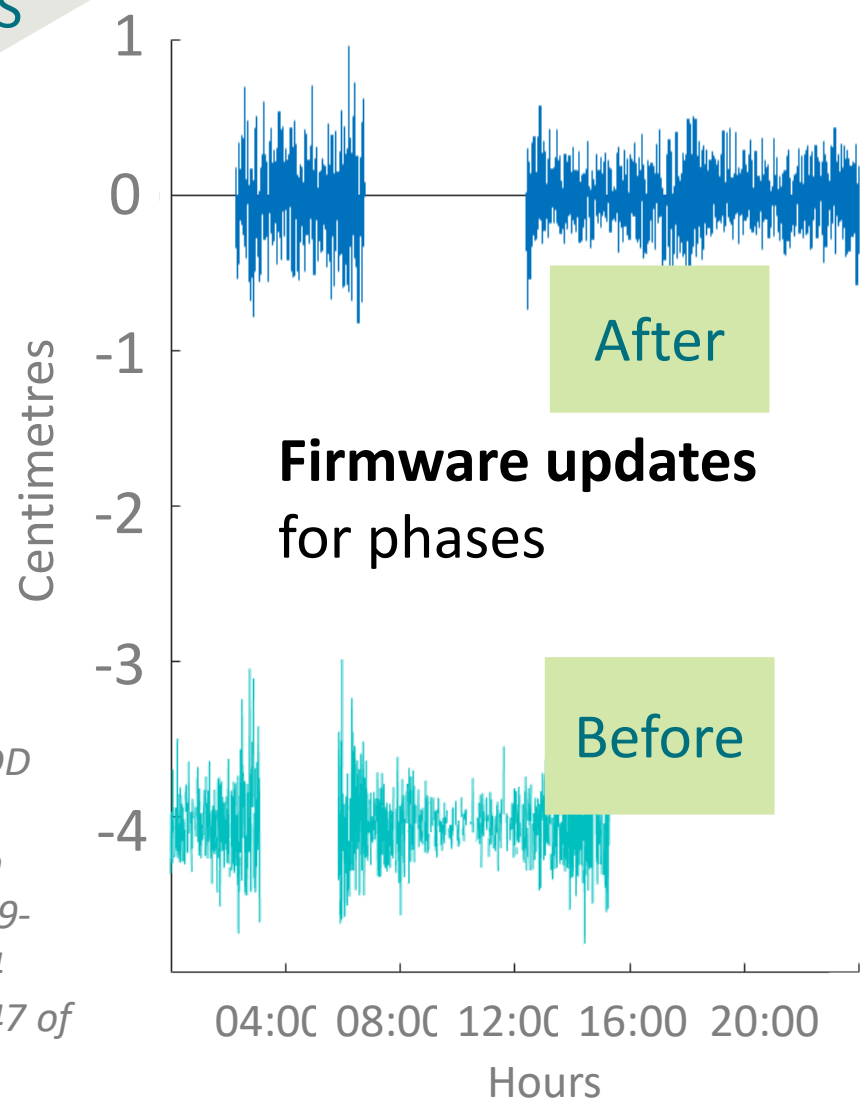
Mean: 2.82 m	Std/$\sqrt{n}$: 1 cm	Mean: 2.86 m	Std/$\sqrt{n}$: 2 cm	Mean: 2.84 m	Std/$\sqrt{n}$: 1 cm

2014 (a) **2015** (b) **2016** (c)

Code ISBs (DD ZB) Galileo E5b/BeiDou B2 on Trimble NetR9-Septentrio X4 :
(a) DOY 310 2014 (b) DOY 198 2015 (c) DOY 212 2016

ISBs ON GEODETIC RECEIVERS

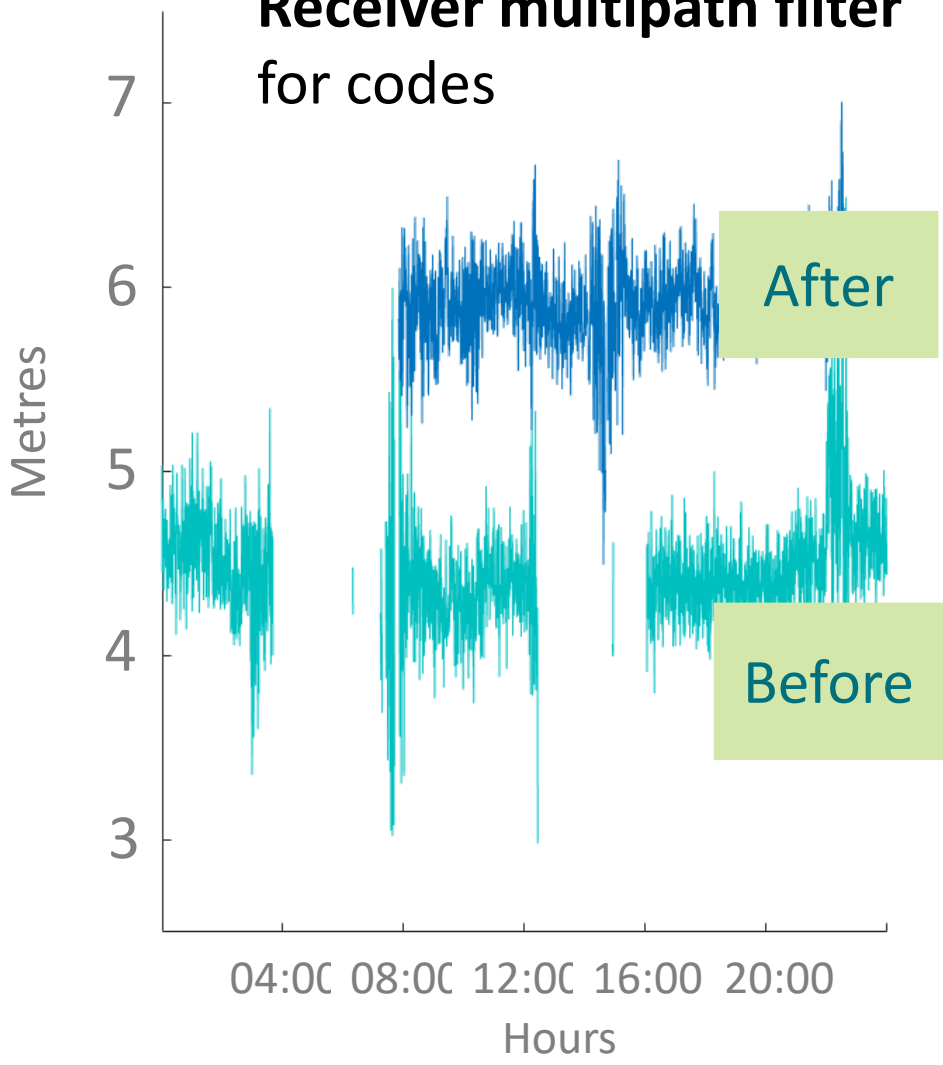
ISBs might be **affected** by



Firmware updates for phases

Phase ISBs (DD ZB) Galileo E1/GPS L1 on Trimble NetR9-Septentrio X4 (DOYs 245-247 of 2015)

Receiver multipath filter for codes



Codes ISBs (DD ZB) Galileo E5A/GPS L5 on Trimble NetR9-Septentrio X4 (DOYs 165-167 of 2016)

Multi-GNSS Relative Positioning

Double Differences:

Tight combining:

\+

Maximizes the redundancy

Constant value for geodetic receivers :

(Odijk & Teunissen, 2013 – Pazeiwski & Wieglosz, 2015)

Once estimated,
can be removed from equations

\-

Introduces additional unknowns:

Differential hardware delays

= Phase and code inter-system biases

= ISBs

Receiver's Features

Geodetic receivers

$$$ (Thousands USDs)

Trimble image

Septentrio image

- Multi-GNSS
- Multi-Frequency

Low-Cost receivers

$$ (Hundreds USDs)

u-blox image

- Multi-GNSS
- Single-Frequency

Galileo E1 + GPS L1

CODE PRECISIONS

Geodetic receivers

$$$ (Thousands USDs)

Low-Cost receivers

$$ (Hundreds USDs)

Codes precisions (DD SB 5.6m)

- *Geometry-fixed*
- *Geodetic antenna*
- *30s. data*
- *Min elevation: 10°*
- *Multipath filters OFF*

Based on 4 days in 2018 (160-161-162-163 for Trimble, 262-263-264-25 for Septentrio and 129-131-134-135 for u-blox)

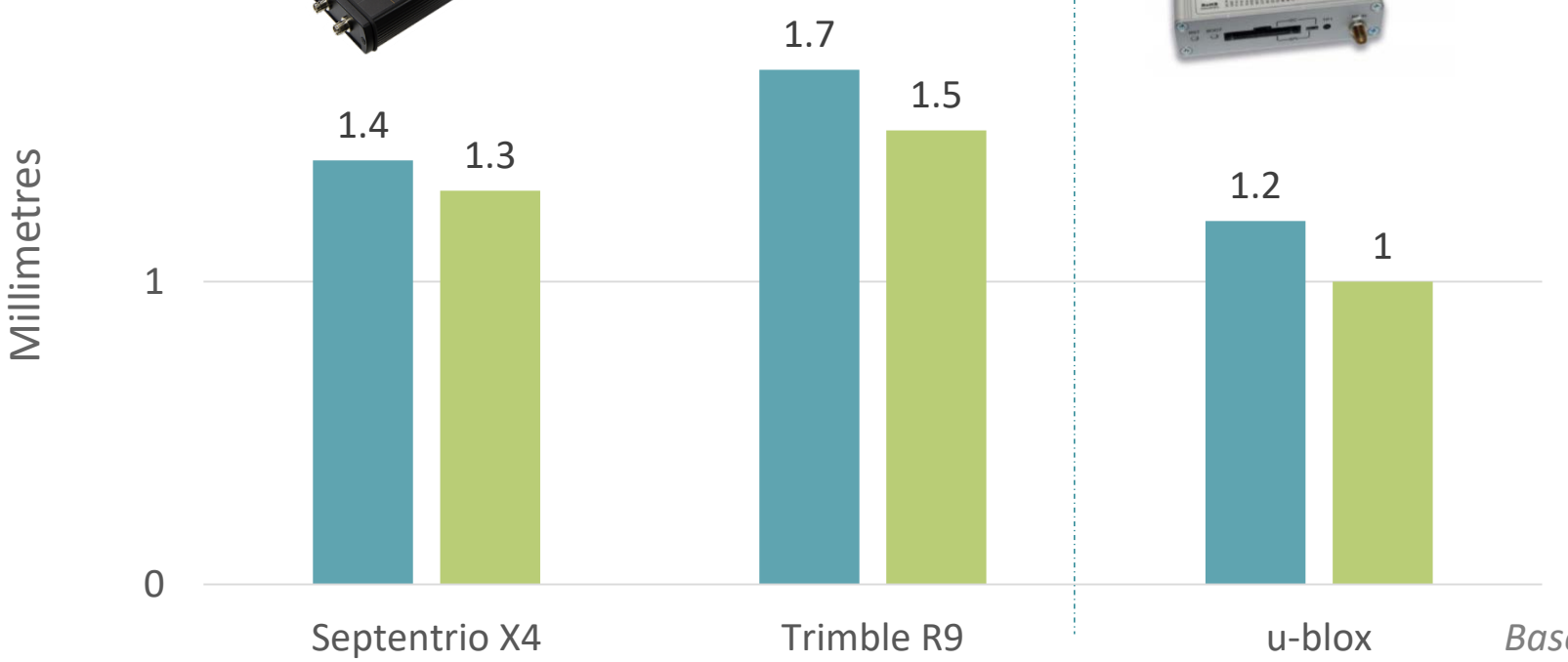
PHASE PRECISIONS

Geodetic receivers

$$$ (Thousands USDs)

Low-Cost receivers

$$ (Hundreds USDs)

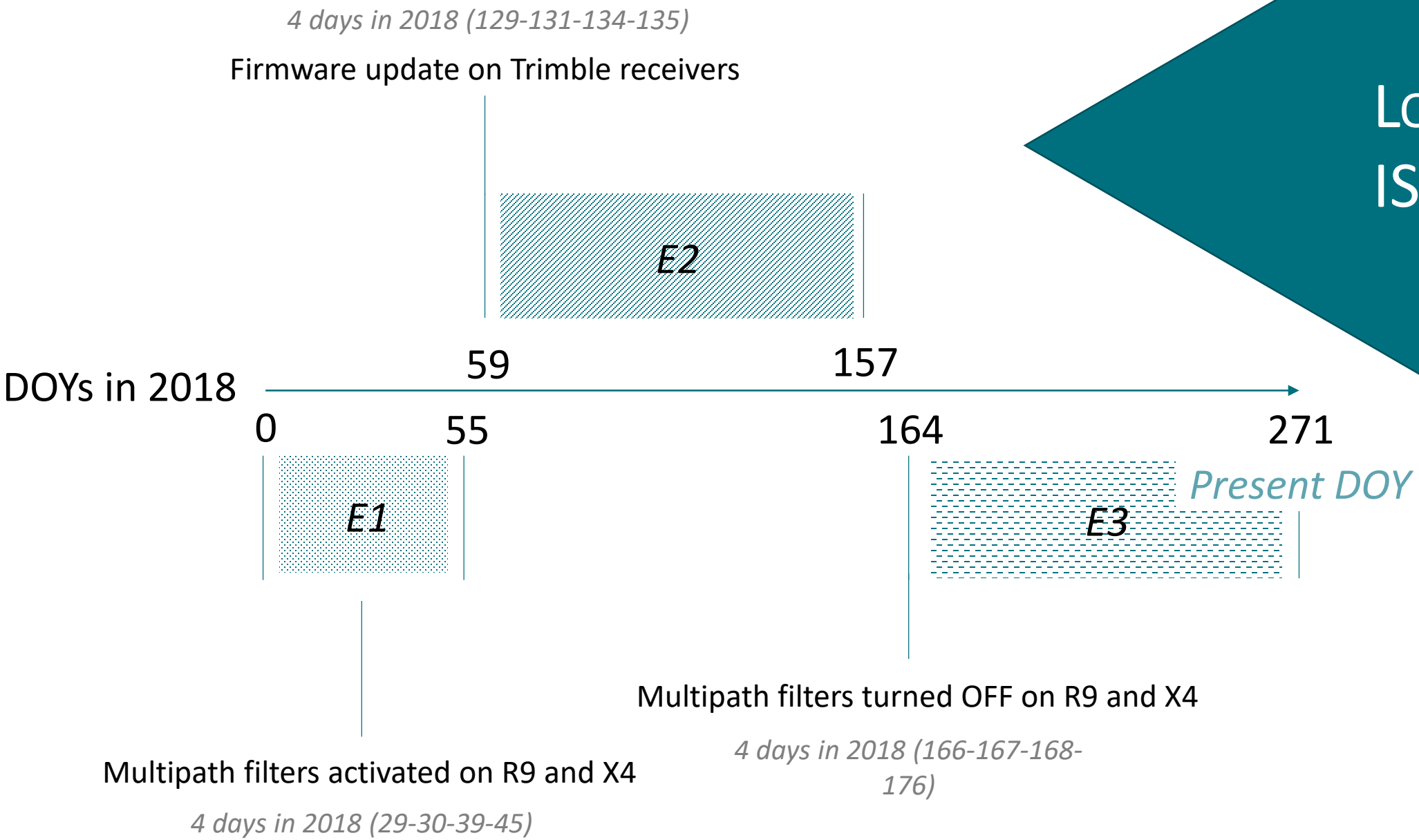


Phase precisions (DD SB 5.6m)

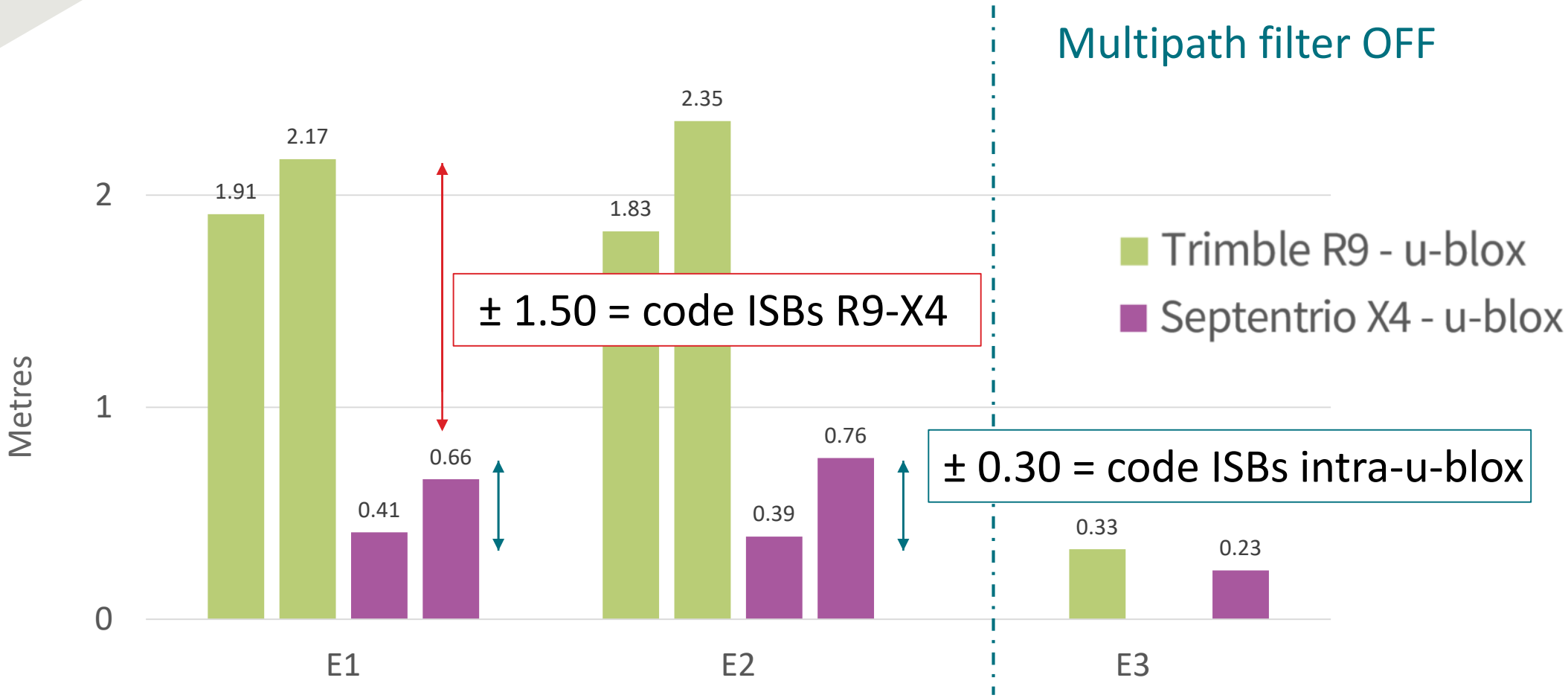
- *Geometry-fixed*
- *Ambiguity-fixed*
- *Geodetic antenna*
- *30s. data*
- *Min elevation: 10°*
- *Multipath filters OFF*

Based on 4 days in 2018 (160-161-162-163 for Trimble, 262-263-264-25 for Septentrio and 129-131-134-135 for u-blox)

Low-Cost ISBs



Mixed-receivers codes ISBs evolution



Code ISBs (DD SB 5.6m) - Geometry-fixed - Geodetic antenna - 30s. data - Min elevation: 10°

- Absence of fractional phase ISBs for all receivers!

  → No impact on RTK!

- Code ISBs present during E1, E2 & E3:

  → DGPS affected!

  - Mixed-receivers ISBs non negligible

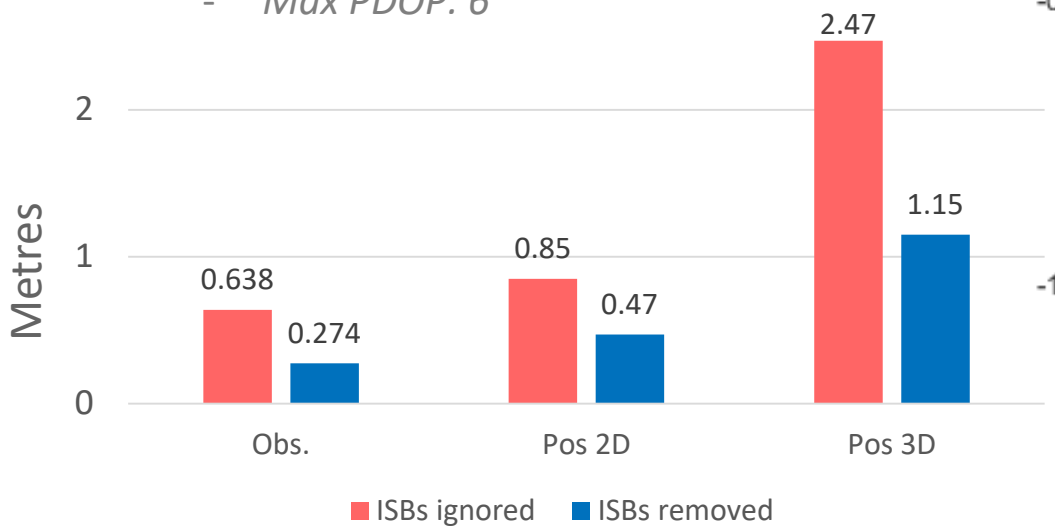
  - Intra u-blox code ISBs different from 0!

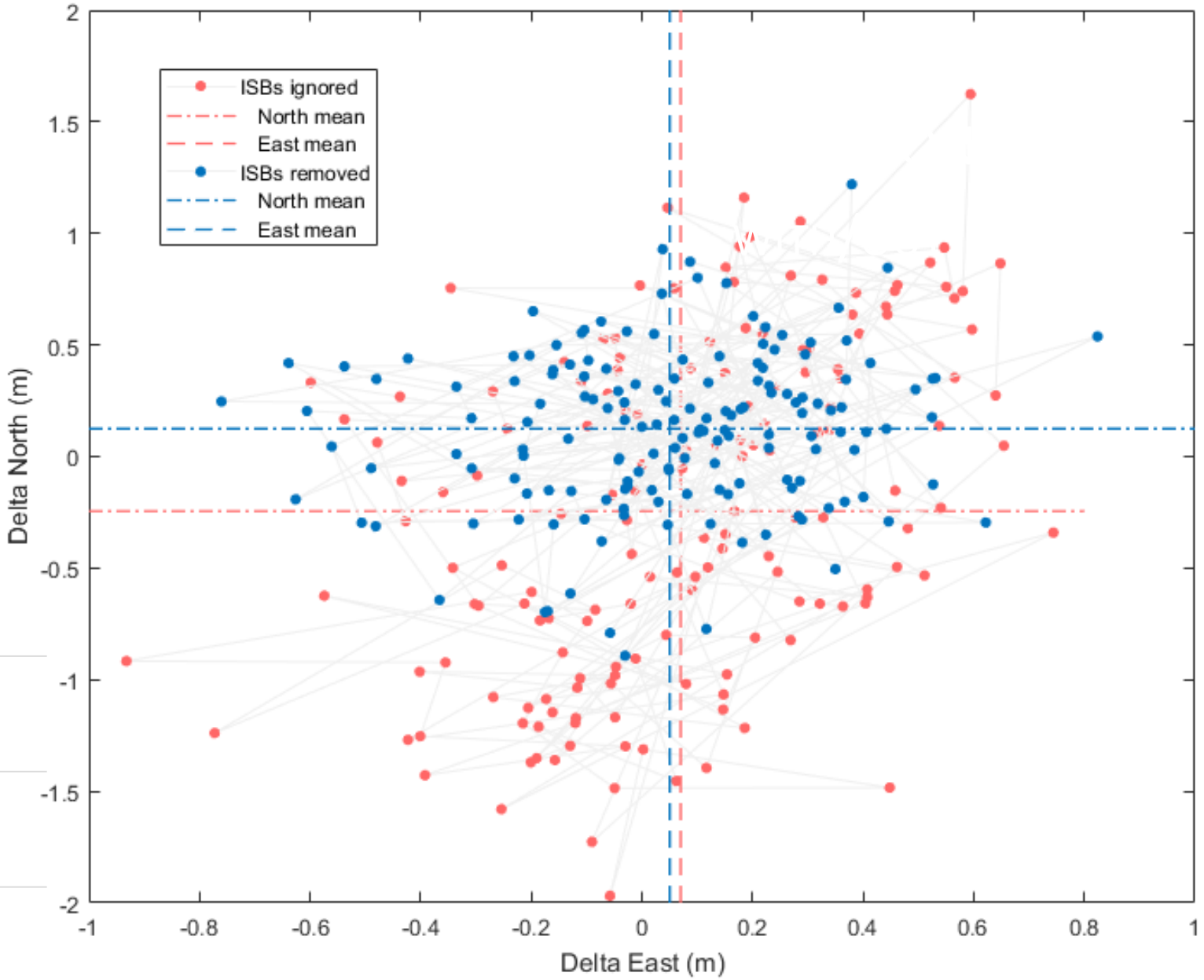
ON SHORT DISTANCES

Impact of ISBs

*ISBs removal on a DD SB **5.6 m** on DOY 32 of 2018 (E1) between u-blox and Trimble R9 :*

- *Geodetic antennas*
- *30s. data*
- *Min elevation: 10°*
- *Multipath filters OFF*
- *Max PDOP: 6*



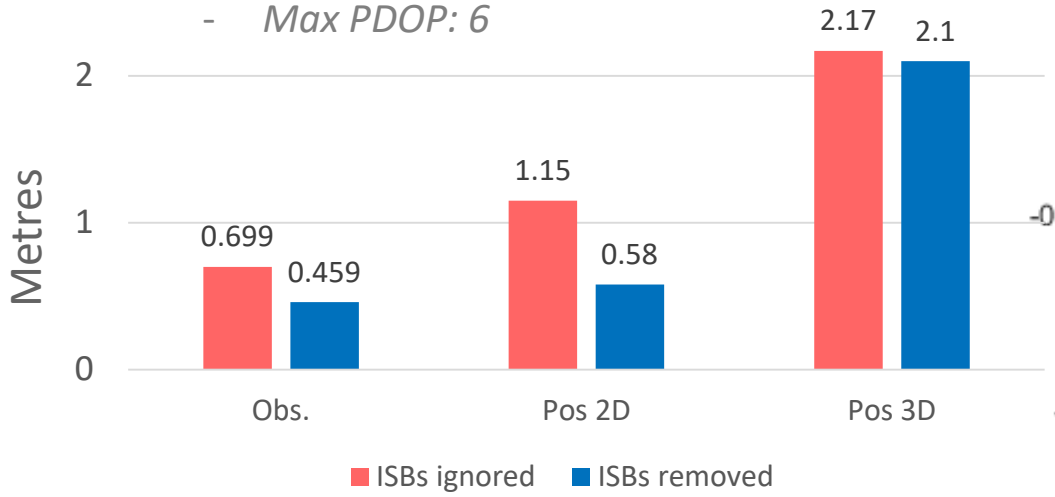


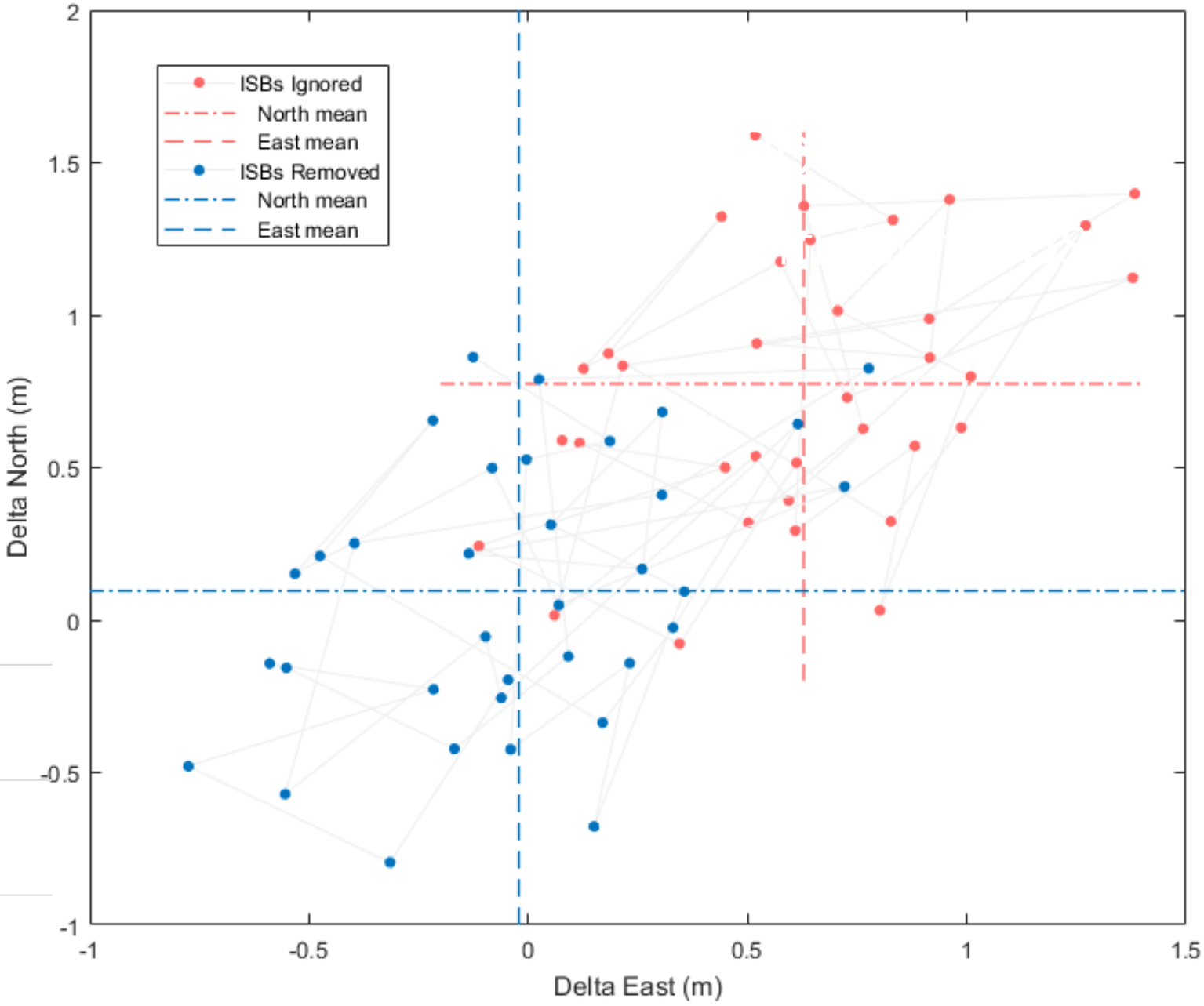
ON LARGER DISTANCES

Impact of ISBs

*ISBs removal on a DD SB **13 km** on DOY 156 of 2018 (E2) between u-blox and Trimble R9 :*

- *Patch antenna + geodetic antenna*
- *30s. data*
- *Min elevation: 10°*
- *Multipath filters OFF*
- *Max PDOP: 6*





CONTACT

LIÈGE université
Geomatics

Deprez Cécile

PhD Candidate
University of Liège

Phone : +32 484 29 61 18
Email: cecile.deprez@uliege.be
LinkedIn

Warnant René

Head of Geodesy Department
University of Liège

Email: rene.warnant@uliege.be

fnrs
FREEDOM TO RESEARCH