Relative positioning with Galileo E5 AltBOC code measurements

Dissertation submitted to the University of Liège in requirements for a Master's degree in Geomatics and Geometrology

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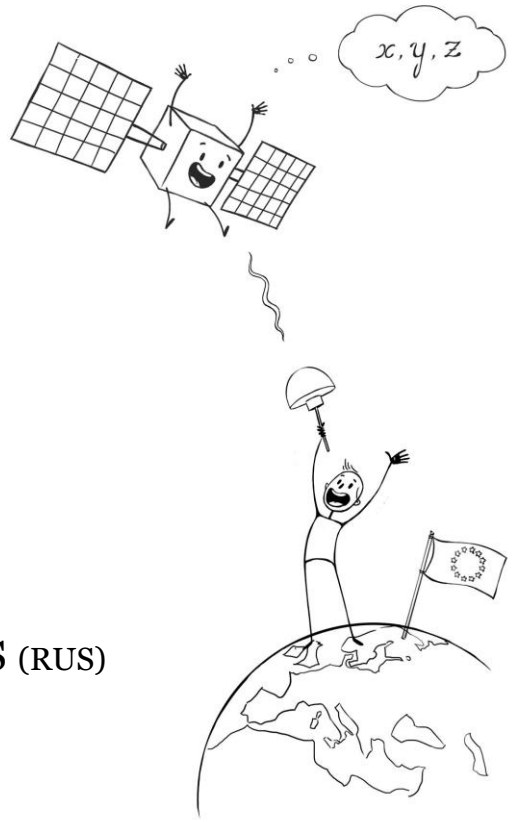
Galileo

European Global Navigation Satellite System (GNSS)

- **New technologies**
  Atomic clocks, signals, frequencies

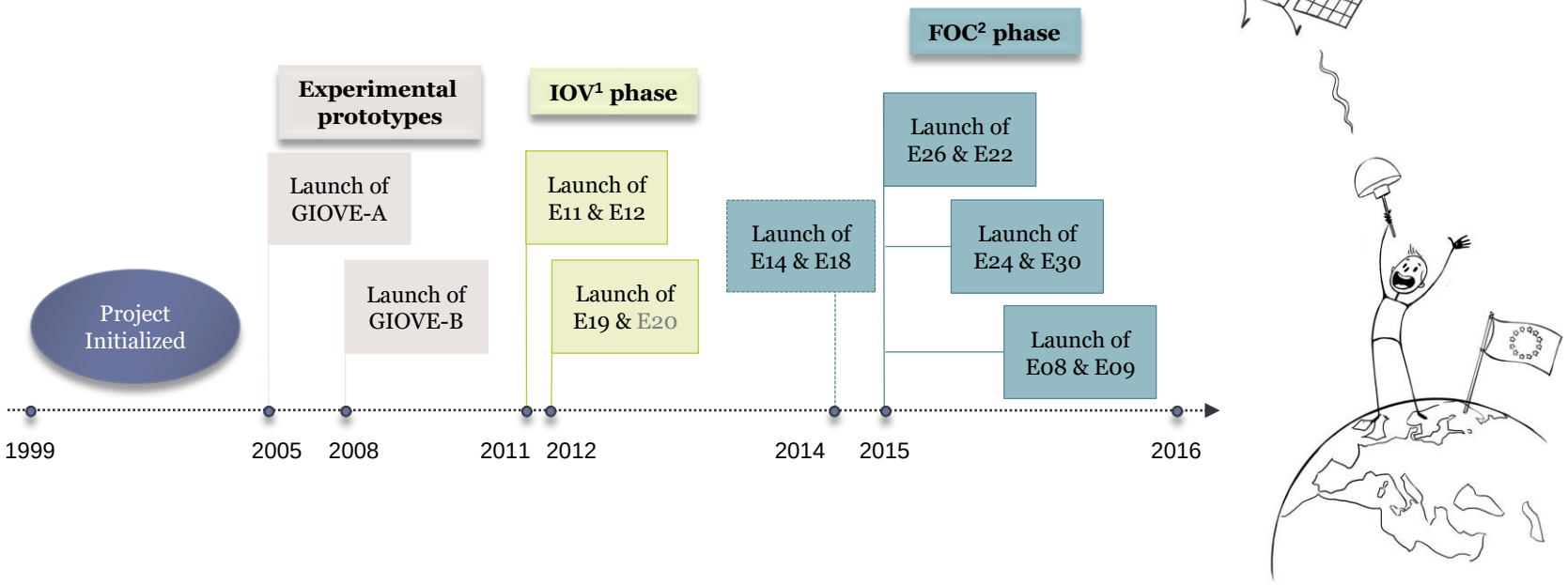
- **Europe space independence**
  Full operational GNSS for European citizens

- **Compatibility and interoperability**
  Use combined with GPS (USA), BeiDou (CHN), GLONASS (RUS)



Constellation

- **Full constellation:** 30 satellites
- **Today:** 9 operational satellites



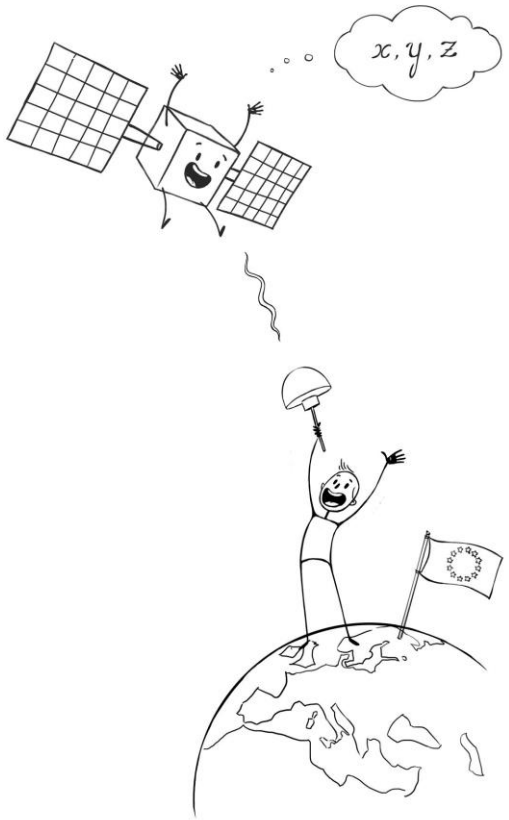
[1]: In Orbit Validation

[2]: Full Operational Capability

Signals

10 navigation signals modulated on **4 carrier frequencies**

Carrier	Signals
E1	E1A E1B E1C
E6	E1A E1B E1C
E5[1]	E5a-I E5a-Q E5b-I E5b-Q

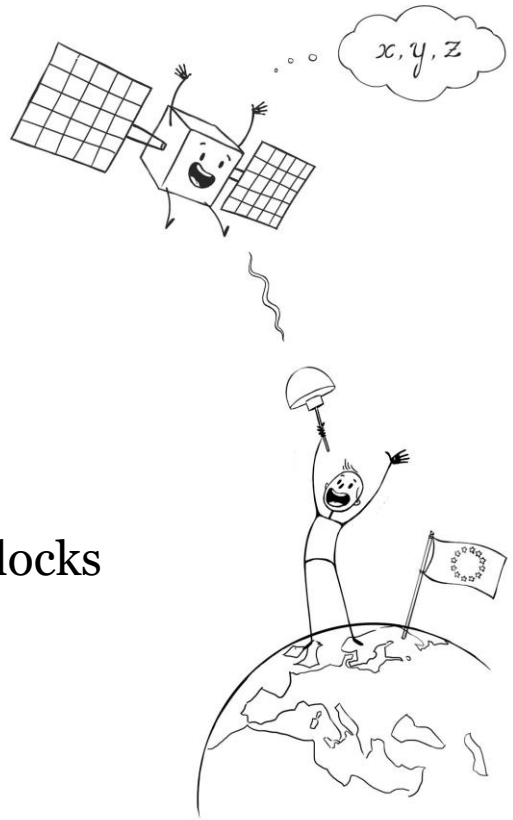


AltBOC Modulation: Improves signal's resistance to multipath and provides high code tracking accuracy

[1]: **Galileo E5** signal is also called **Galileo E5a+b** and **Galileo E5 AltBOC**

Positioning

Time difference between the reception and the emission time of a signal broadcast from a satellite to a receiver:



$$R^{i}{}_{p=}(t_p - t^{i}).c$$

Time difference= **synchronisation** of the clocks

Never reached in practice!

Clock error!

Position equation

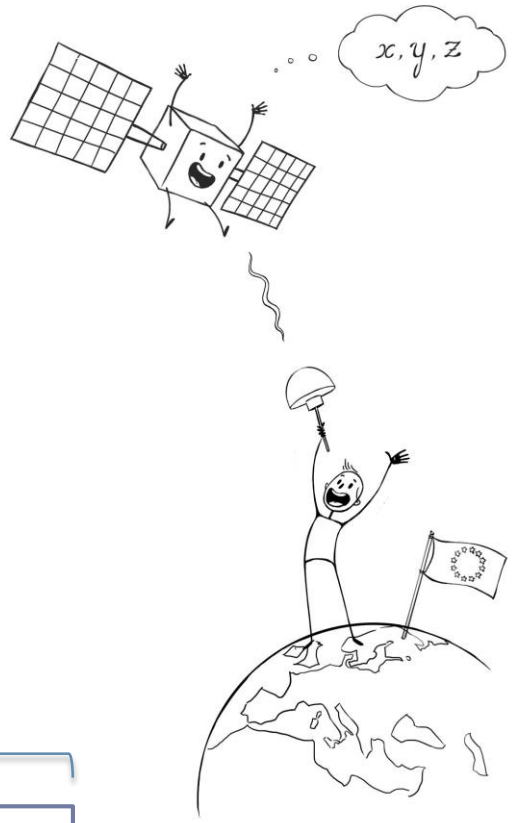
4 unknowns :

- The 3 components of the receiver position : X_p,Y_p,Z_p
- The clock error

Computing a position

=

At least 4 visible satellites!

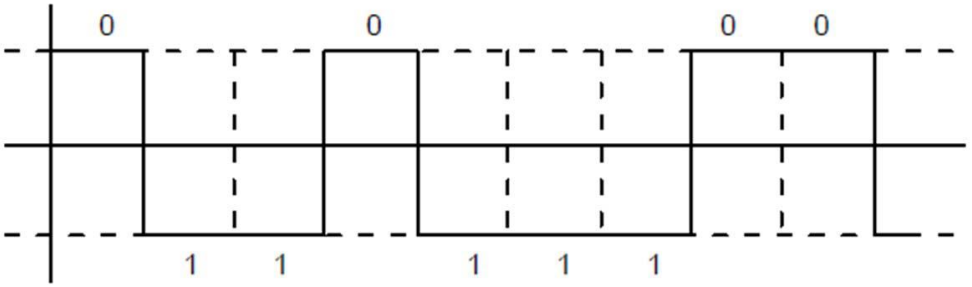


Errors

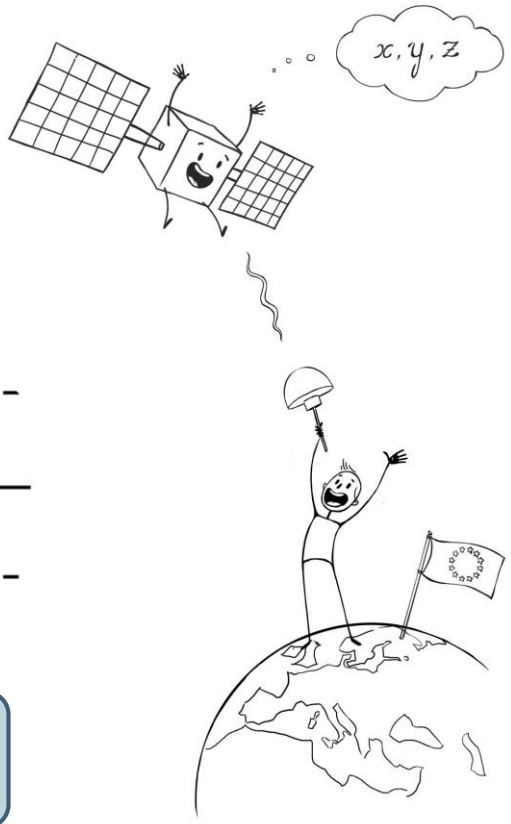
$$P^i_p = D^i_p + T^i_p + I^i_p + M^i_{p,m} + c(\Delta t^i - \Delta t_p) + \varepsilon$$

Code observable

- Basic observable
- Most common for mass market
- Expected precision: a few **metres**
  - ⇨ Usually not sufficient for applications that require **decimetres** precision



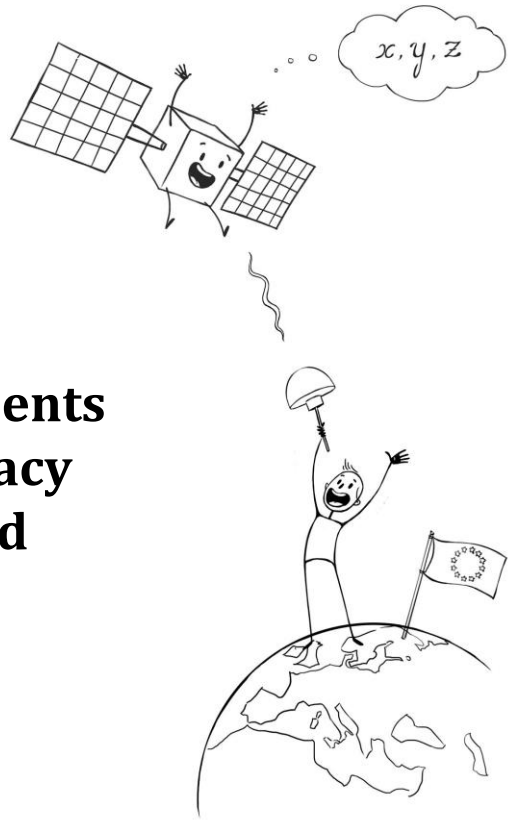
Observable used by **basic** receivers



Hypothesis

Galileo E5 AltBOC outperforms other GPS and Galileo signals:

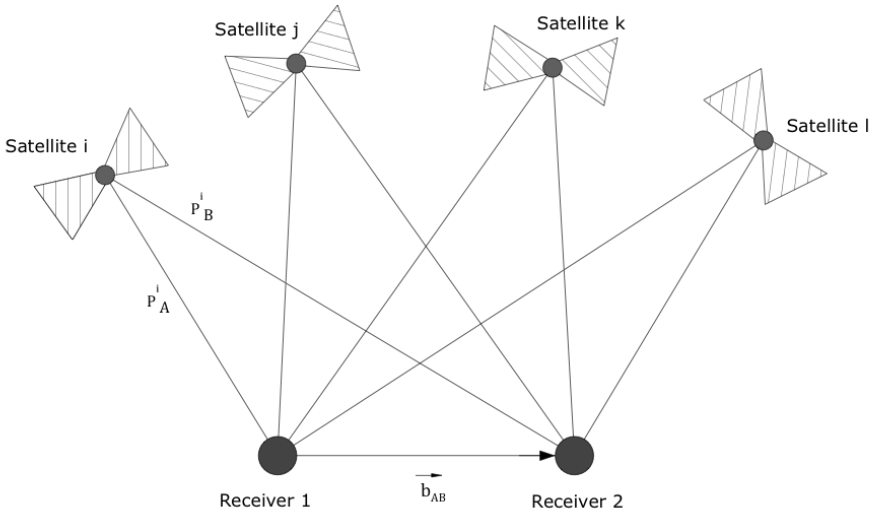
- lower observation noise
- better multipath mitigation

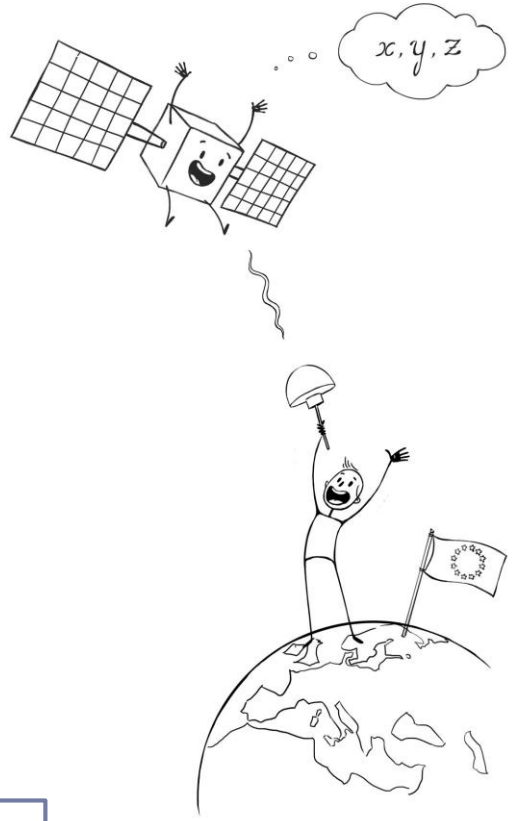


Could Galileo E5 AltBOC code measurements be used to reach decimetre-level accuracy with basic receivers on satellite-based position estimations?

Relative positioning

Principle : Two receivers **simultaneously** track the same satellites.





Double difference :
Difference between two receivers' observations of the two same satellites.

$$P^{ij}{}_{AB}(t) = P^{i}{}_{AB}(t) - P^{j}{}_{AB}(t)$$

Double difference

Configurations

Zero baseline:

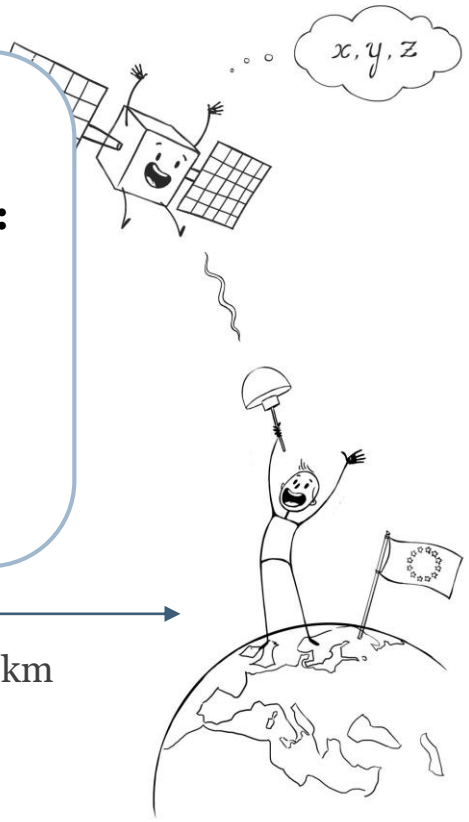
All errors eliminated

Short baseline:

Multipath + Noise errors remaining

Medium baseline:

Multipath + Noise + Atmospheric errors remaining

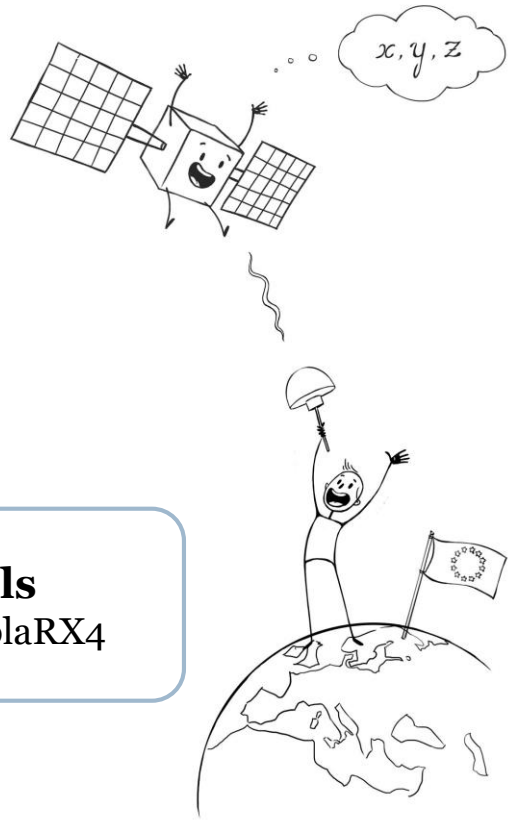


0 m 5 m 10 km 100 km

Experimental conditions

Zero/Short baselines:

ULg ⟺ ULg
- 2 x Trimble NetR9
- 2 x Septentrio PolaR (X4 & XS)



Medium baselines:

ULg ⟺ Waremme
- 2 x Septentrio PolaR (X4 & X4TR)

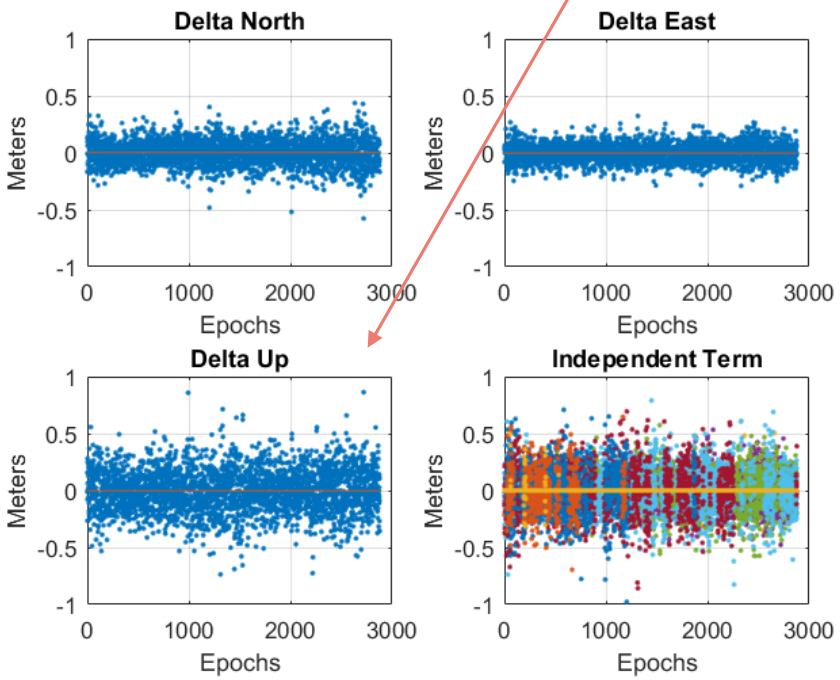
ULg ⟺ Brussels
- 2 x Septentrio PolaRX4

Zero baseline

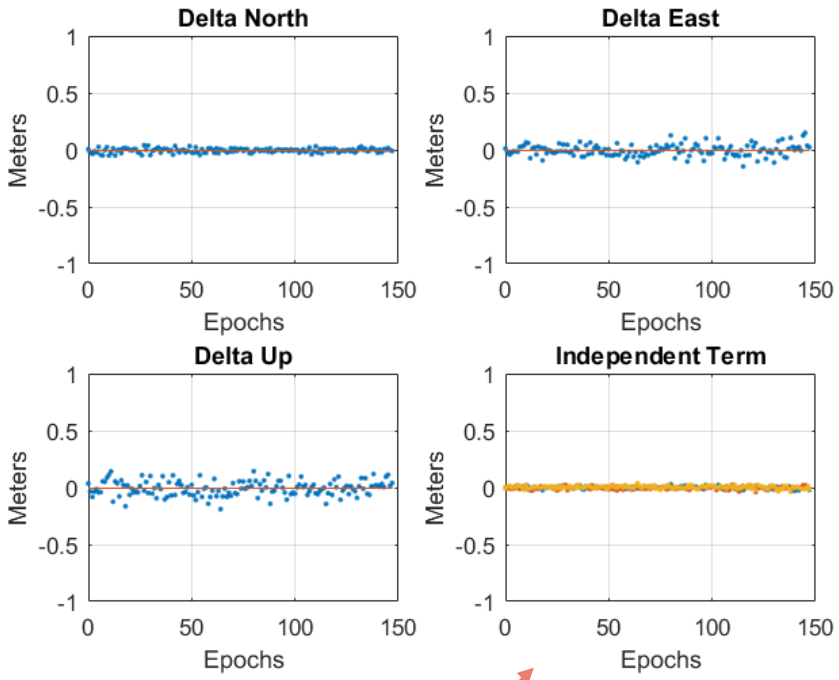
Position precision : influenced by the number of satellites and their geometry

Comparison between GPS L1 and Galileo E5 AltBOC

GPS L1



Galileo E5a+b



Observation precision : measure of the precision of the raw incoming signal

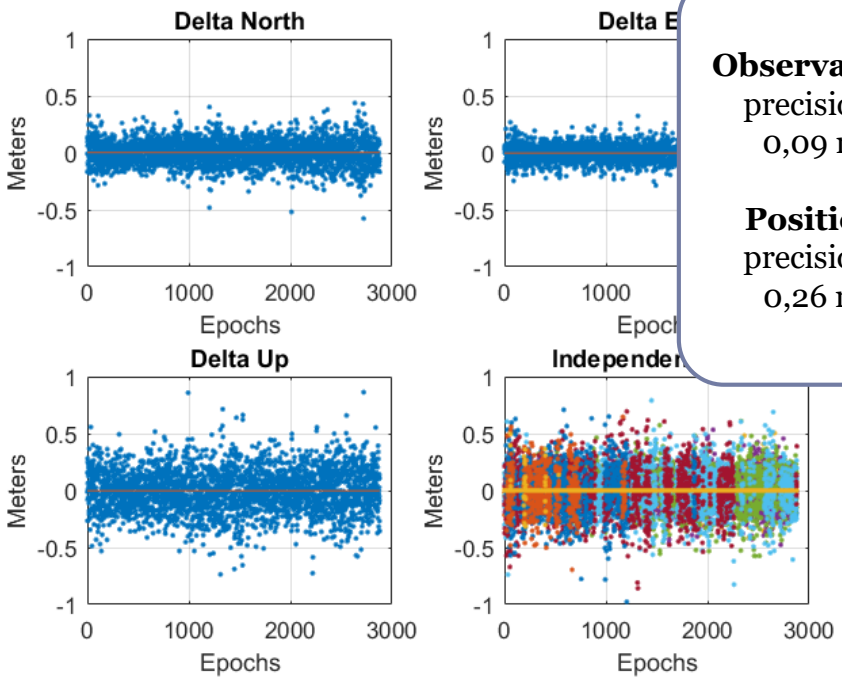
Zero baseline

Observation precision: 0,01 m

Position precision: 0,19 m

Comparison between GPS L1 and Galileo E5 AltBOC

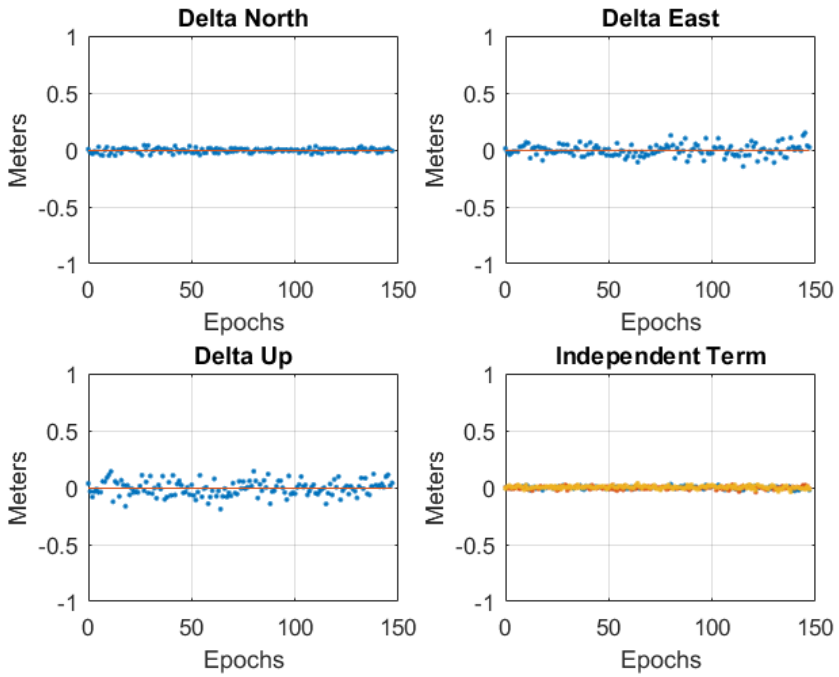
GPS L1



Observation precision: 0,09 m

Position precision: 0,26 m

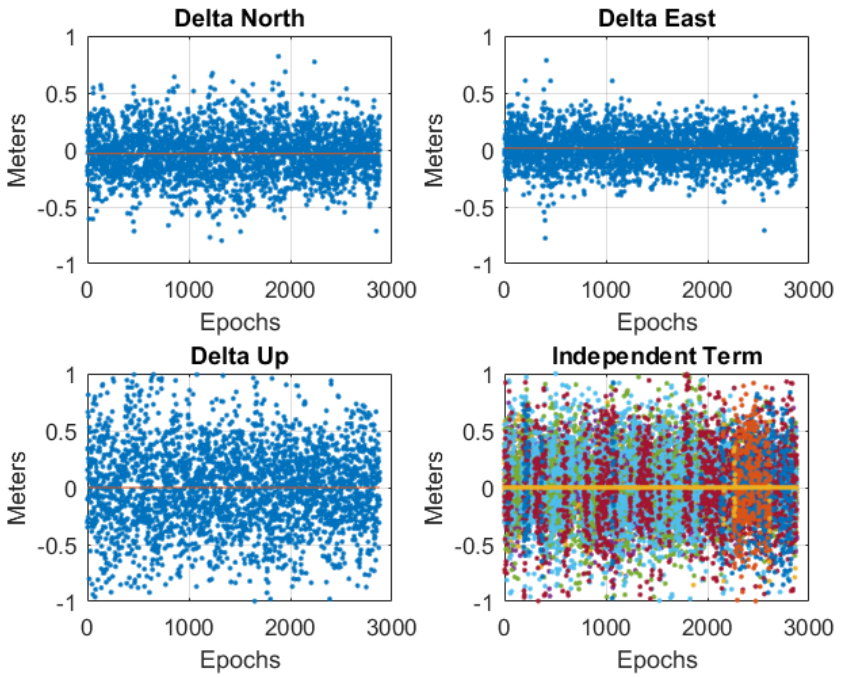
Galileo E5a+b



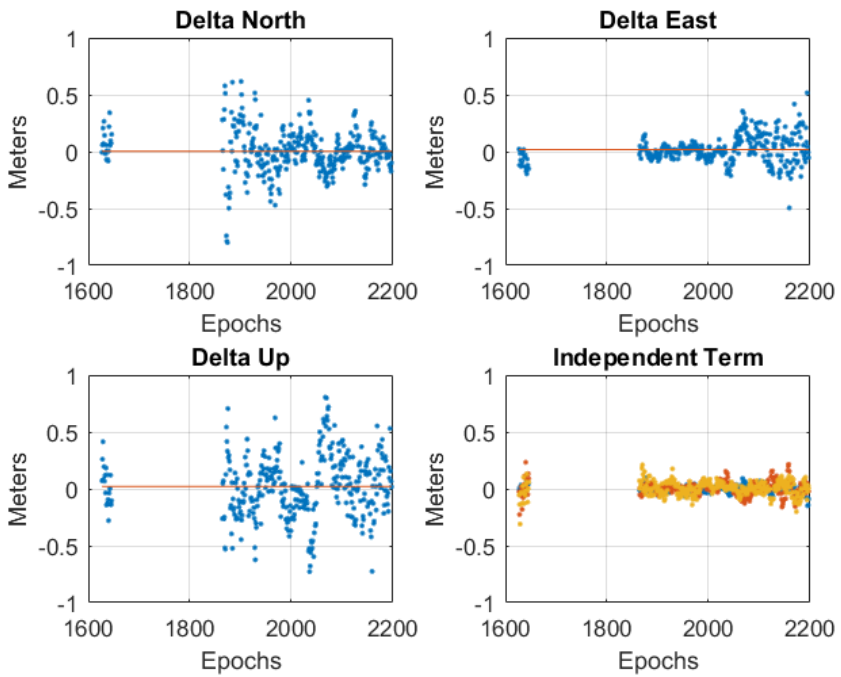
Short baseline

Comparison between GPS L1 and Galileo E5 AltBOC

GPS L1



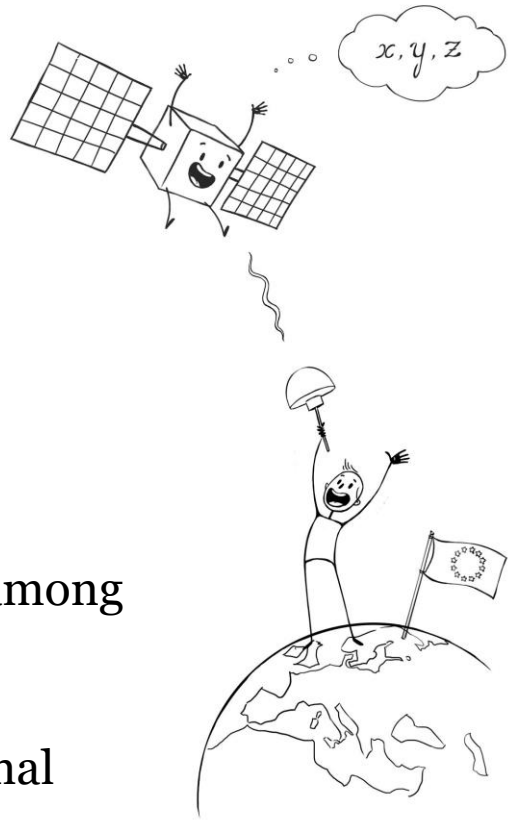
Galileo E5a+b



Short baseline

Statistics

GPS L1	Galileo E1	Galileo E5
Observation precision: 0,15 m	**Observation** precision: 0,10 m	**Observation** precision: 0,04 m
Position precision: 0,46 m	**Position** precision: 1,79 m	**Position** precision: 0,60 m



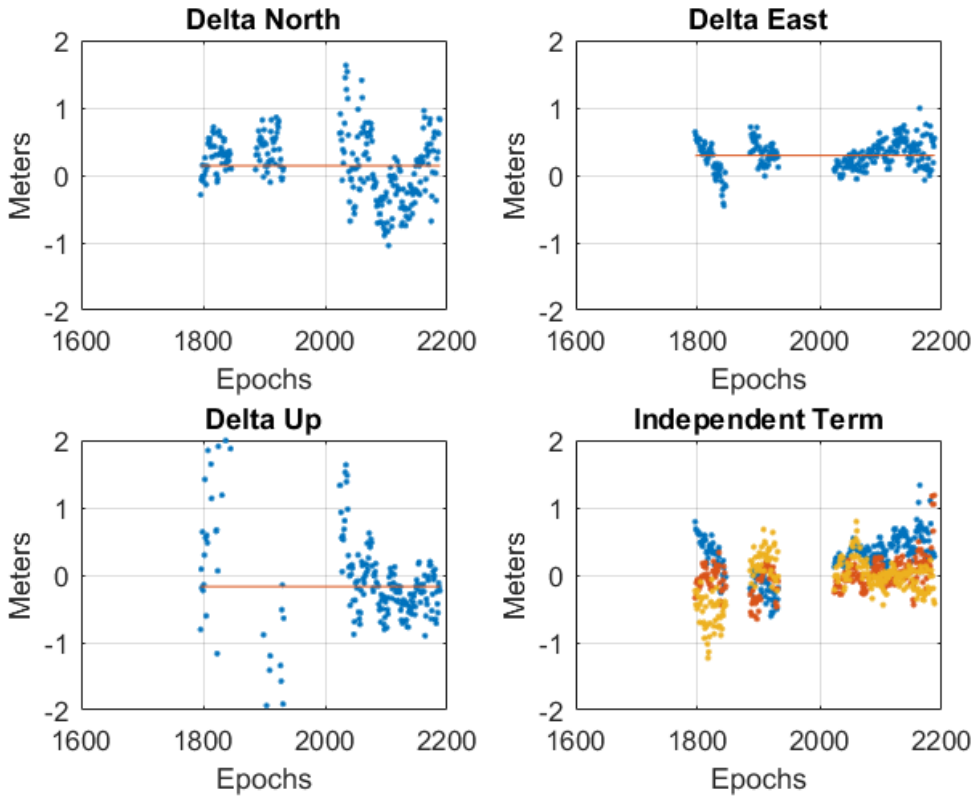
- Galileo E5 shows the best **observation** precision among all GPS and Galileo signals
- For the present time, the small number of operational Galileo satellites reduces the **position** precision

Medium baseline 1

25 kilometres

ULg - Waremme

Galileo E5a+b



Statistics

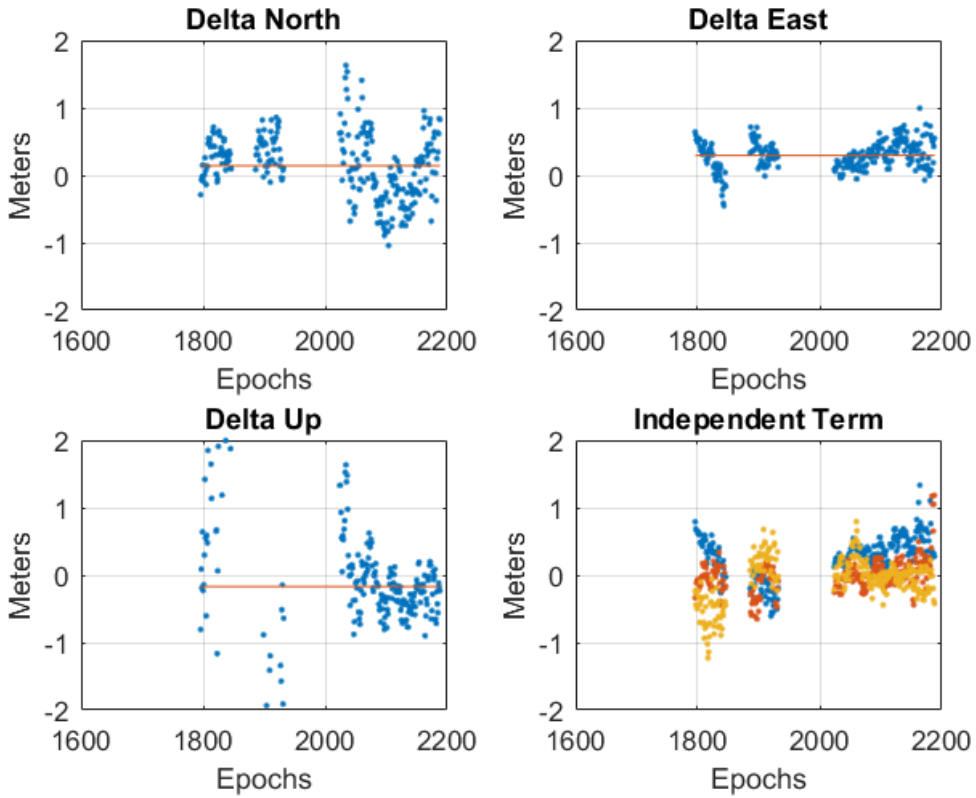
GPS L1	Galileo E5
Position precision: 0,88 m	**Position** precision: 0,40 m

Medium baseline 2

90 kilometres

ULg - Brussels

Galileo E5a+b



Statistics

GPS L1	Galileo E5
Position precision: 1,09 m	**Position** precision: 1,15 m

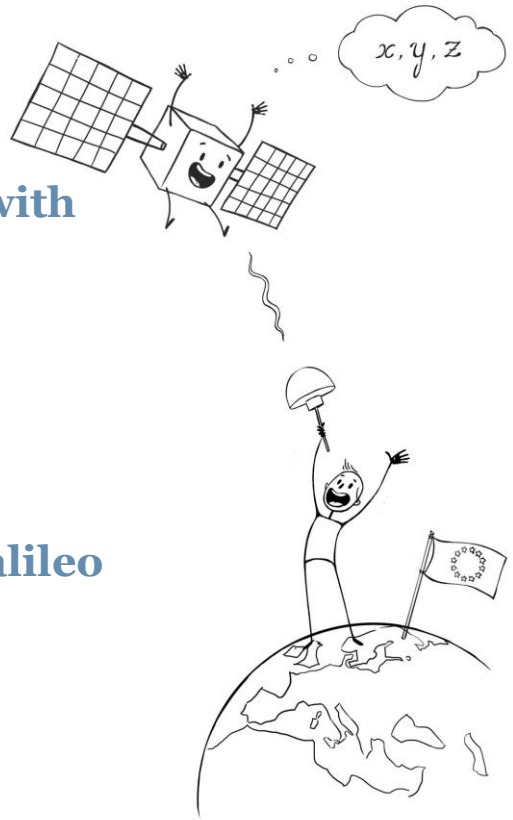
Conclusion

• **Observation precision**
A few centimetres with all Galileo signals

The best results (GPS, Galileo) are obtained with Galileo E5 AltBOC

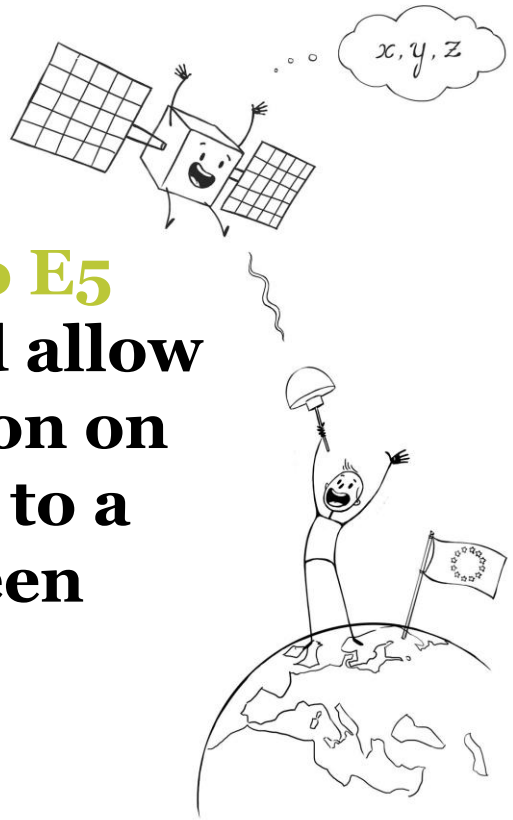
• **Position precision**
A few decimetres with all Galileo signals

The best results (Galileo) are obtained with Galileo E5 AltBOC



Conclusion

Relative positioning with Galileo E5 AltBOC code measurements should allow reaching a few decimetres precision on positions with basic receivers up to a distance of 25 kilometres between receivers.



Thank you for your attention!

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