Use of current broadcast time-offsets for multi-constellation users in harsh environments

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Background

- At the June 2019 Timing Workshop, the point was made that the broadcast value of XYTO* should be used only when the number of satellites available prevents its determination.

- At the September 2019 WG-S Intersessional Meeting, results were presented showing that the broadcast XYTO values (e.g. GGTO for GPS and Galileo) brings benefits to a majority of users (in particular smartphones) when compared to the use of only an estimation of XYTO in the receiver.

- These results appear to confirm the view of the mass-market GNSS chip manufacturers

- Furthermore, specific classes of receivers, such as mass-market ones operating with coarse time assistance, might be less inclined to estimate inter-system time biases since they already have to estimate the precise time of week as an additional unknown in the navigation solution.

- The ICG WG-S was encouraged to continue its work and:
    - Organization of a workshop on XYTO mass-market user needs
    - Experimental work on using UTC as a pivot to estimate XYTO

*XYTO = Inter-System Time Offsets, e.g. via GGTO, via UTC broadcast, ….

Content

- This presentation provides an update on the results presented in September, correcting for a bias found on the software and applied to the broadcast XYTO. This improves the broadcasted XYTO results (in particular in good visibility conditions).

- Provides additional results using UTC as a pivot:
    - GPS + Galileo
    - GLONASS + Galileo

- Results on multi-constellation solutions using BeiDou are ongoing

- Results are based on processing of **live signals** using three different types of receivers
    - Professional receiver + professional antenna
    - Mass-market receiver: Evaluation kit + external antenna
    - Smartphone

GPS + Galileo considerations

- Computing PVT using only **GPS + Galileo**
- Two ways of determining XYTO*

    1. By using the broadcasted **XYTO*** (GAGP) directly
    2. By using **UTC** as a pivot ($\mathrm{XYTO} = \mathrm{GAUT} - \mathrm{GPUT}$)

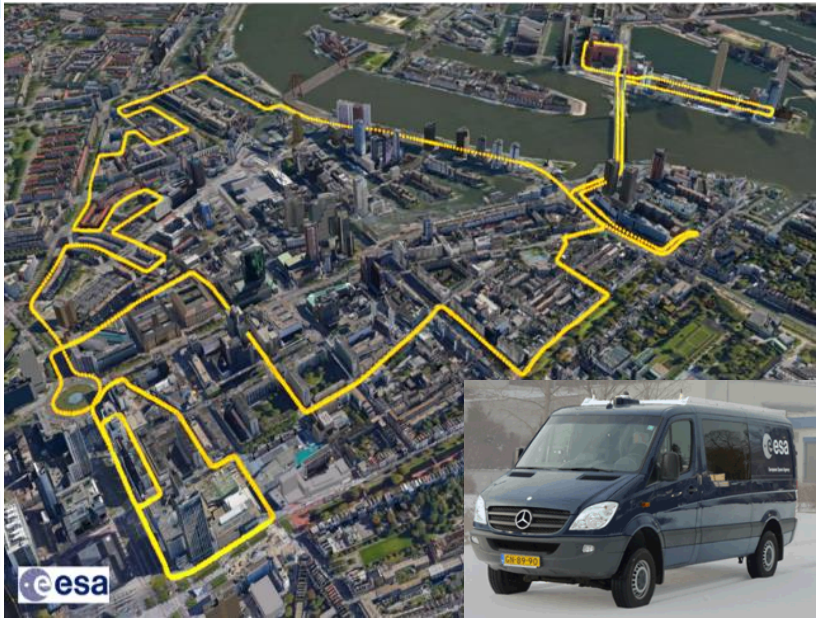
RINEX time-offset labels

- **GPUT**: GPS to UTC(USNO)
- **GAUT**: Galileo to UTC(Europe)
- **GAGP**: Galileo to GPS

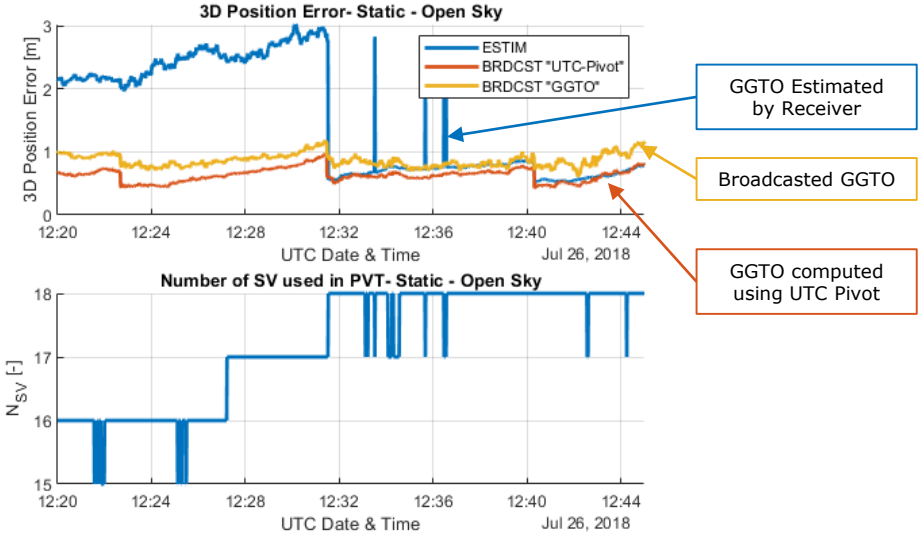
*XYTO = Galileo to GPS Time-Offset

Test Setup (Professional Receiver)

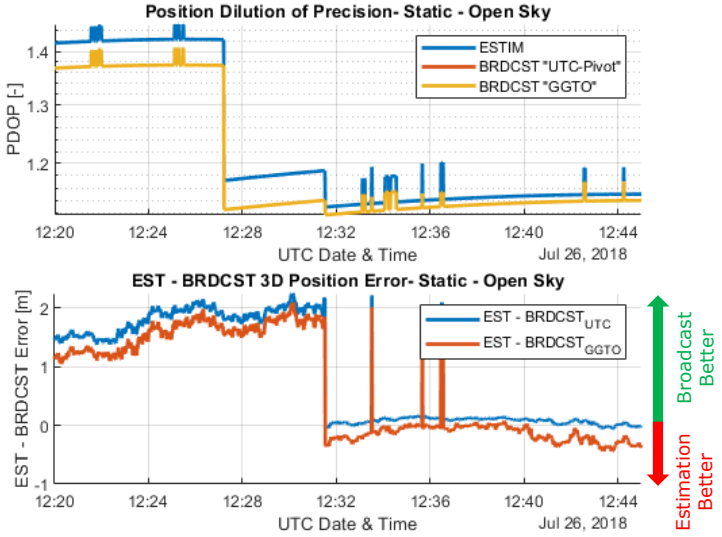
Test Setup	
Date	7 July 2018
Duration	12:20:00 – 14:30:00 (2:10 hours)
Constellation	GPS + Galileo
Elevation Mask	5 degrees
Smoothing	Carrier Phase Based Hatch Filter
PNT algorithm	Weighted Least Squares
Receiver	Professional Antenna + Receiver
Environment	Open Sky (25 minutes) -> Urban (1:45 hr)



Professional Receiver – Static – Open Sky



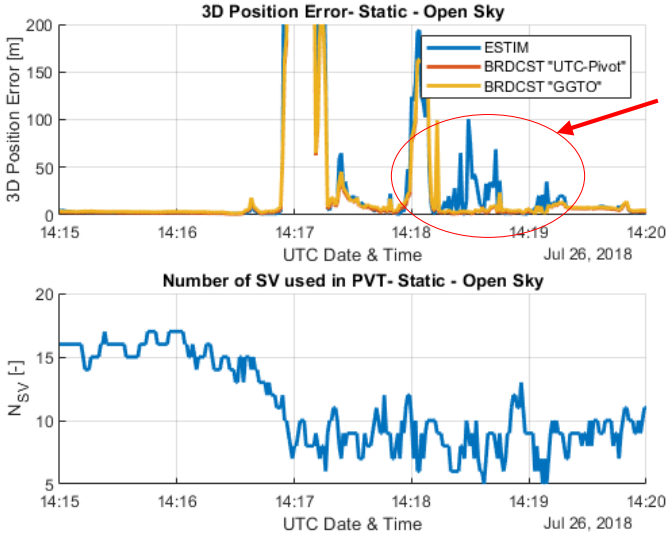
GPS + GAL



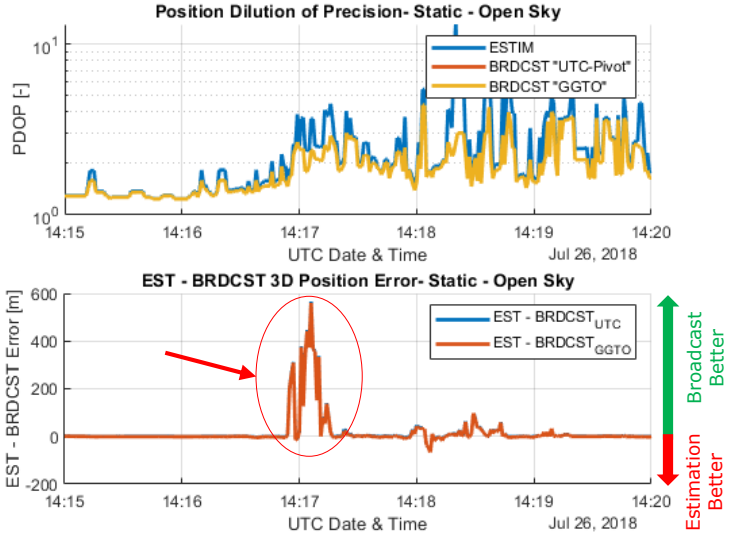
GPS + GAL

- In **good visibility conditions** there seems to be a clear dependency between the accuracy of the estimate and the **number of satellites** and/or **satellite geometry** (DOP)

Professional Receiver – Dynamic – Deep Urban (1)



GPS + GAL

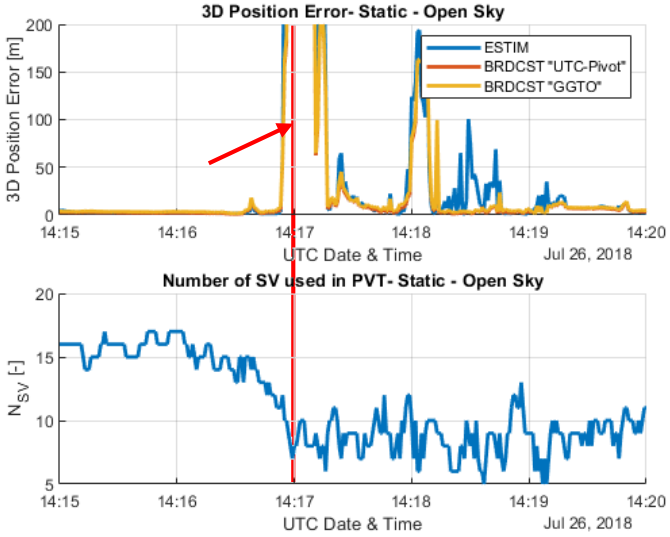


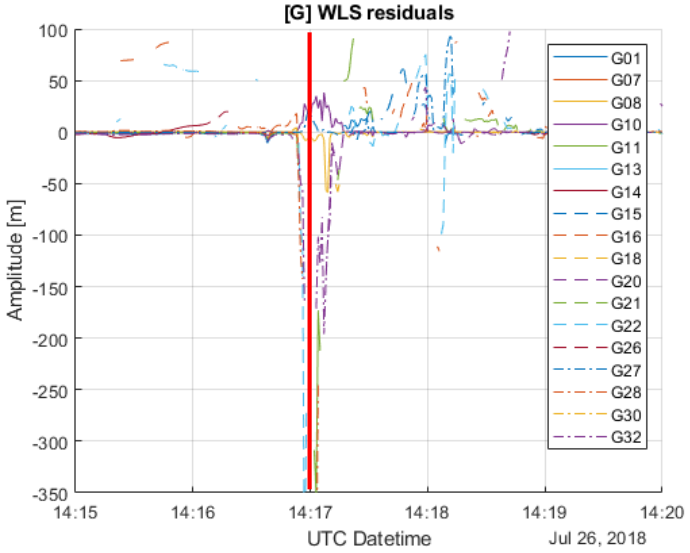
GPS + GAL

- In good conditions (number of SV > 10) there seems to be no difference between the estimate and broadcast results
- In poor visibility (number of SV < 8) there seems to be a **benefit** of using the broadcasted value of the GGTO

See additional material slide 21 for full time series

Professional Receiver – Dynamic – Deep Urban (2)





3D Error

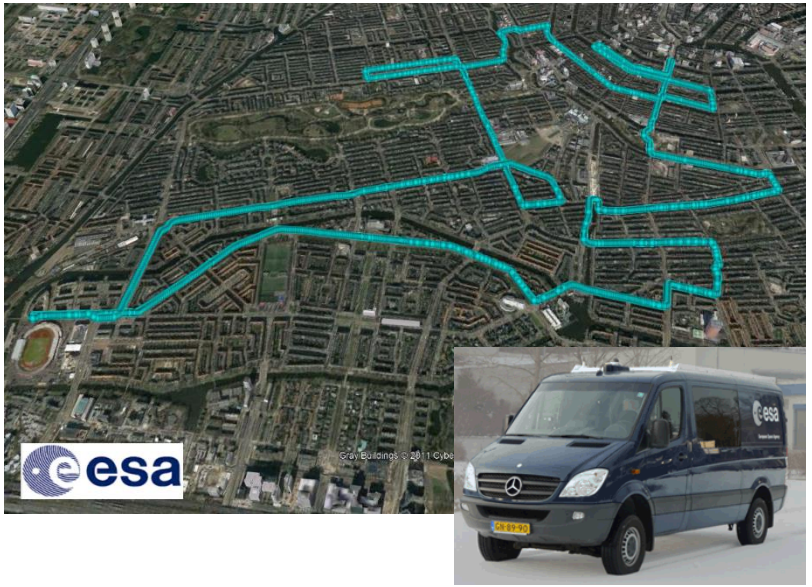
Scenario

WLS Residuals

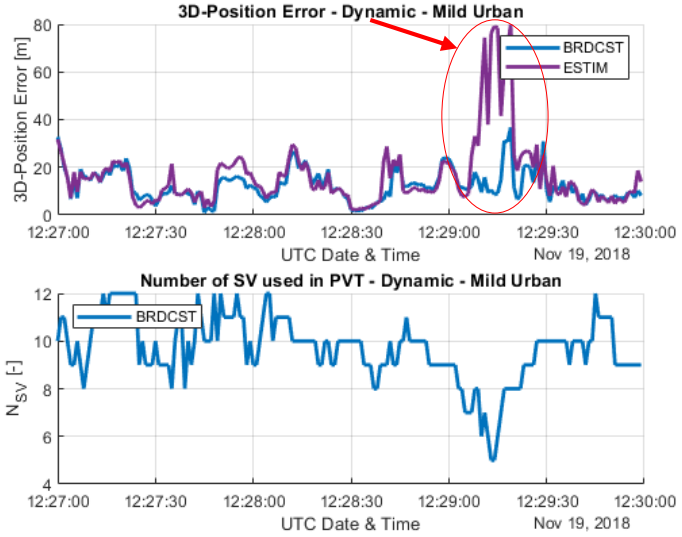
- Around 14:17 both the solution for both the estimated and broadcasted XYTO has **peaks**. This is related to the fact the receiver is located in an **urban canyon**, such that the **signals** are **reflected** and affected by **multipath** (which is confirmed by the **residuals**).

Test Setup (Mass-Market Receiver)

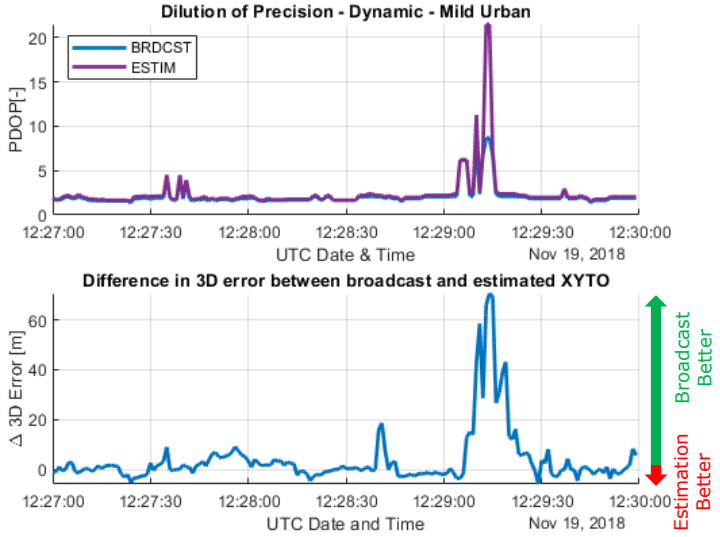
Test Setup	
Date	19 September 2018
Duration	11:00:00 – 14:00:00 (3 hours)
Constellation	GPS + Galileo
Elevation Mask	5 degrees
Smoothing	Carrier Phase Based Hatch Filter
PNT algorithm	Weighted Least Squares
Receiver	Mass Market Antenna + Receiver
Environment	Mild Urban



Mass-Market Receiver – Dynamic – Mild Urban



GPS + GAL



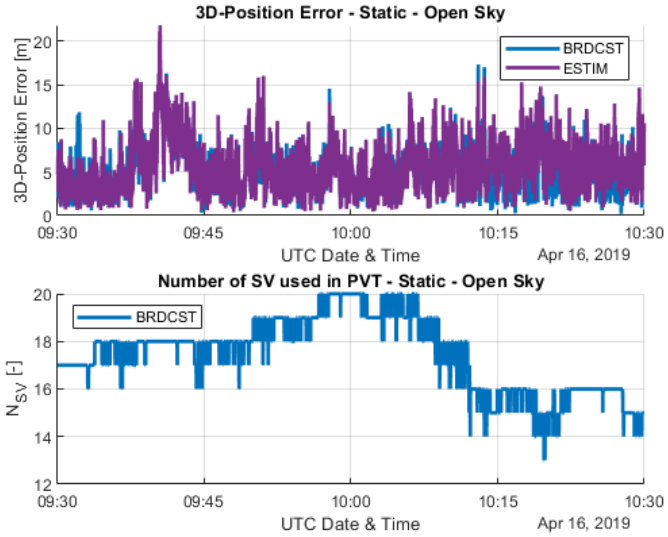
GPS + GAL

- In good conditions (number of SV > 10) there seems to be **no/limited difference** between the estimate and broadcast results
- In poor visibility (number of SV < 8) there seems to be a **clear benefit** using the broadcasted value of the GGTO

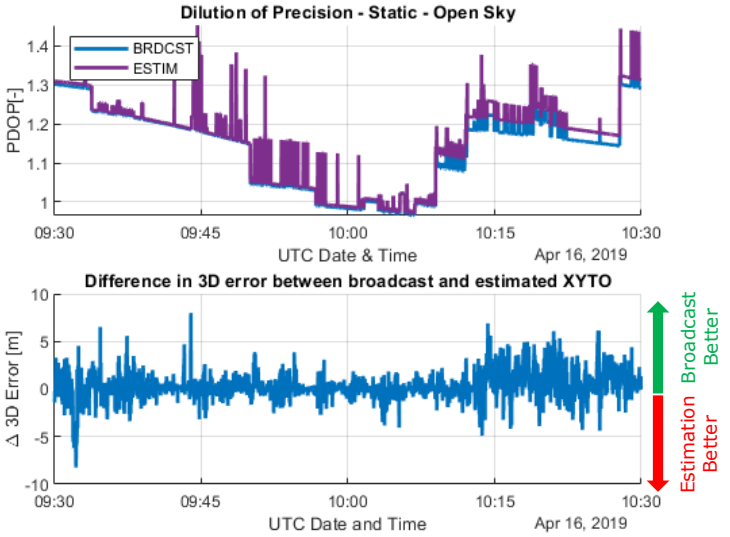
Test Setup (Smartphone)

Test Setup	
Date	16 April 2019
Duration	09:30:00 – 10:30:00 (1 hours)
Constellation	GPS + Galileo
Elevation Mask	5 degrees
Smoothing	None
PNT algorithm	Weighted Least Squares
Receiver	Smartphone Antenna + Receiver
Environment	Static Open Sky

Smartphone – Static – Open Sky



GPS + GAL



GPS + GAL

- In good visibility the difference between estimating the GGTO or using its broadcasted value is limited

Galileo + GLONASS considerations

- Computing PVT using only **Galileo + GLONASS**
- Two ways of determining XYTO* as **no direct broadcast** is available
    1. By using **UTC** as a pivot ($\mathrm{XYTO} = \mathrm{GLUT} - \mathrm{GAUT}$)
    2. By using **GPS** as a pivot ($\mathrm{XYTO} = \mathrm{GLGP} - \mathrm{GAGP}$)

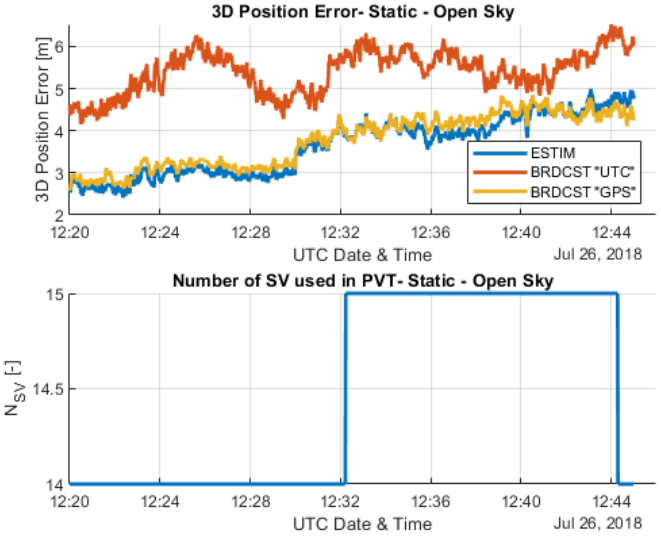
RINEX time-offset labels

- **GLUT**: GLONASS to UTC(SU)
- **GAUT**: Galileo to UTC(Europe)
- **GLGP**: GLONASS to GPS
- **GAGP**: Galileo to GPS

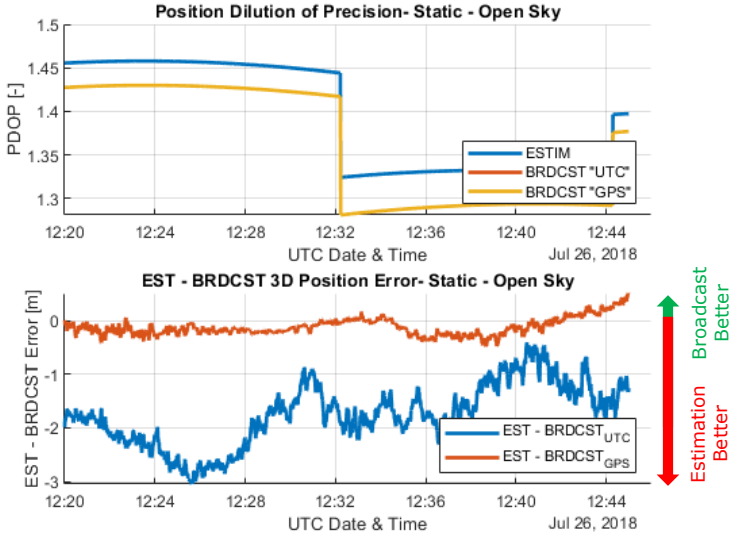
- In case less than 2 Galileo satellites are observed, in the tool used for this study XYTO was not computed and PVT switches to GLONASS only

*XYTO = GLONASS to Galileo Time-Offset

Professional Receiver – Static – Open Sky



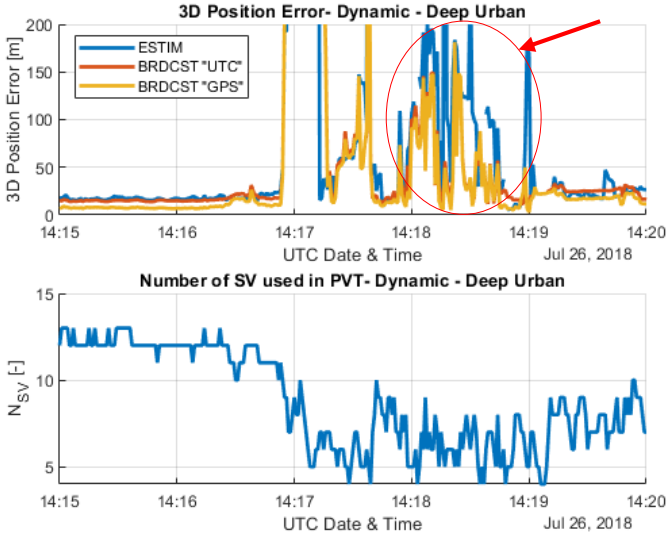
GAL + GLO



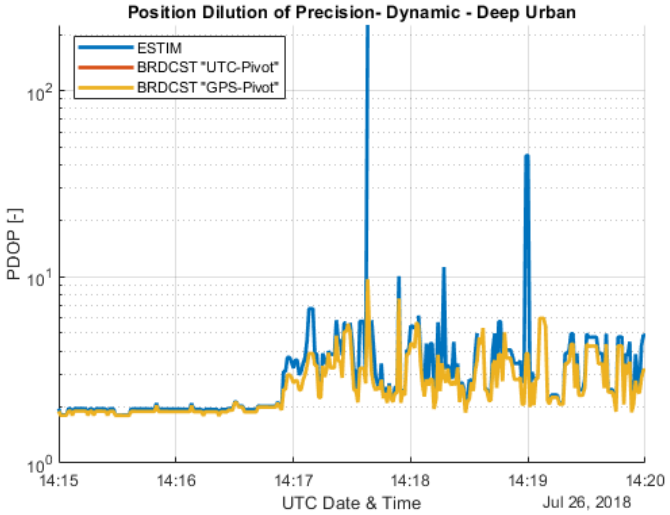
GAL + GLO

Broadcast **"UTC Pivot"** is less accurate than broadcast **"GPS Pivot"** for this particular day (July 26, 2018)

Professional Receiver – Dynamic – Deep Urban



GAL + GLO

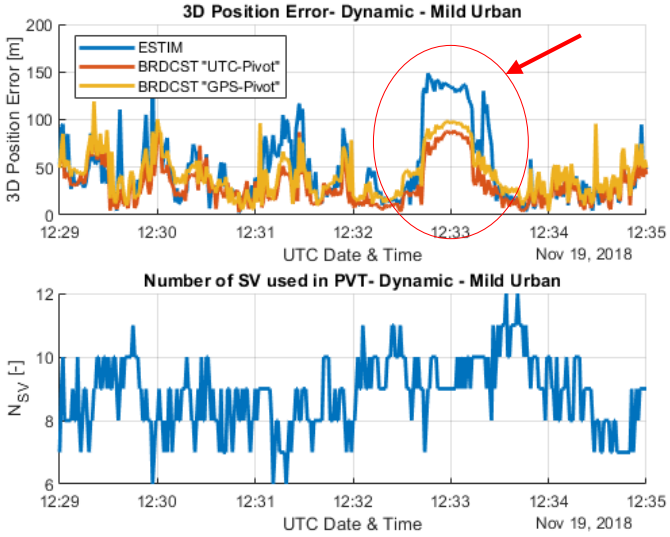


GAL + GLO

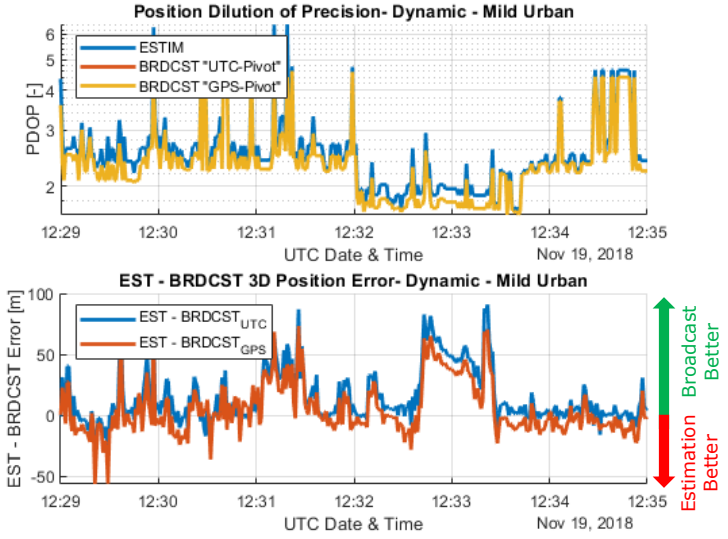
Broadcast **"UTC Pivot"** is less accurate than broadcast **"GPS Pivot"** for this particular day (July 26, 2018)

See additional material slide 22 for full time series

Mass-Market Receiver – Dynamic – Mild Urban



GAL + GLO



GAL + GLO

The position error seems to be smaller using the **UTC pivot** compared to the **GPS pivot** for this particular day (Nov 19, 2018)

Conclusions (1/2)

- In good visibility conditions there is no substantial difference between estimating XYTO or using its broadcasted value.

- In poor visibility conditions, there appears to be a clear benefit using the broadcasted XYTO compared to estimating its value due to the limited number of satellites and the quality of the observations. Therefore, system providers are encouraged to continue broadcasting the intersystem time-offsets.

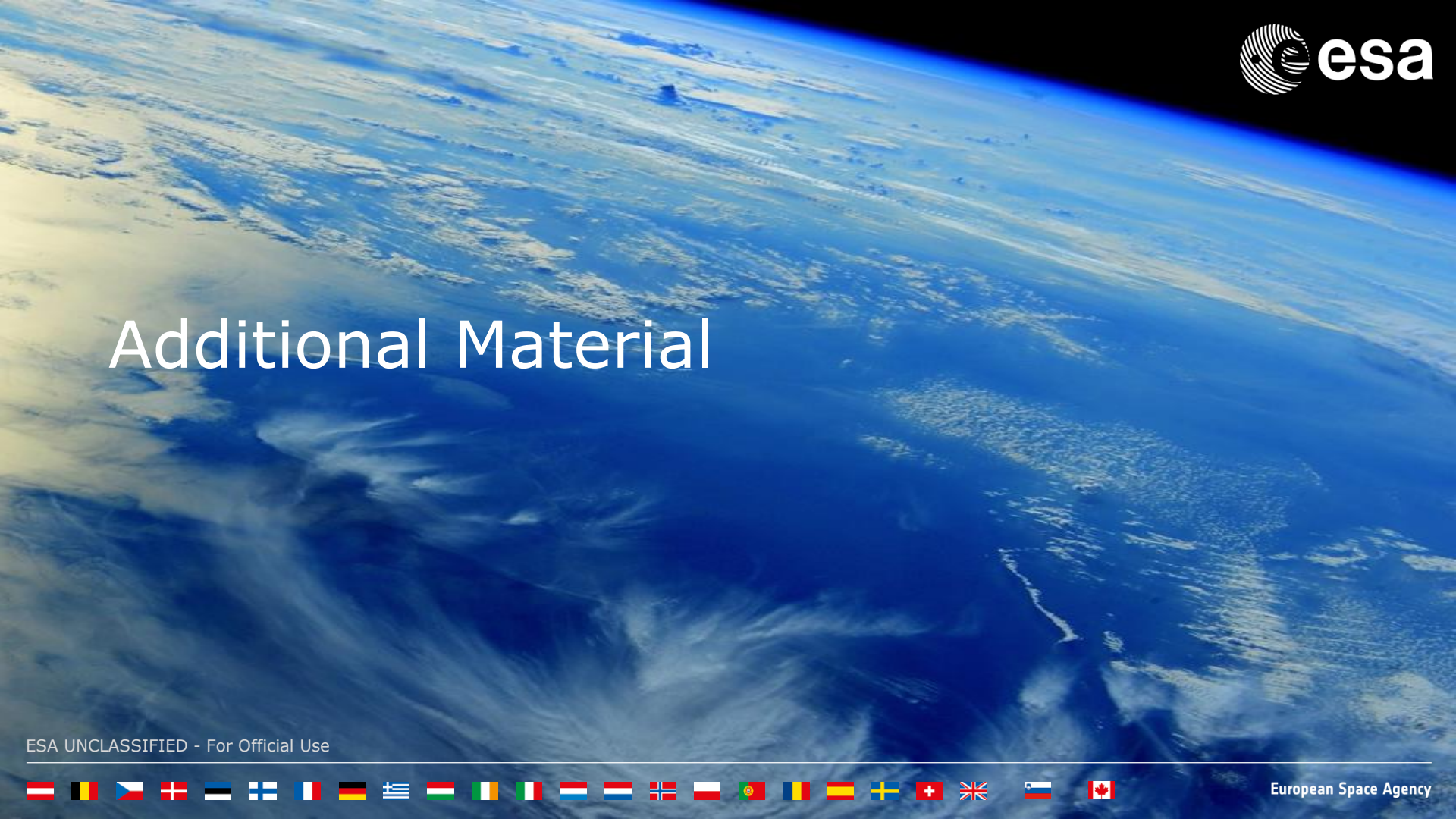
- Estimating XYTO in good visibility conditions and using this value at a later time might be a viable option for some use cases. For mass-market users this is not applicable as they switch on and off at random times such that the validity of the estimated XYTO cannot be guaranteed.

Conclusions (2/2)

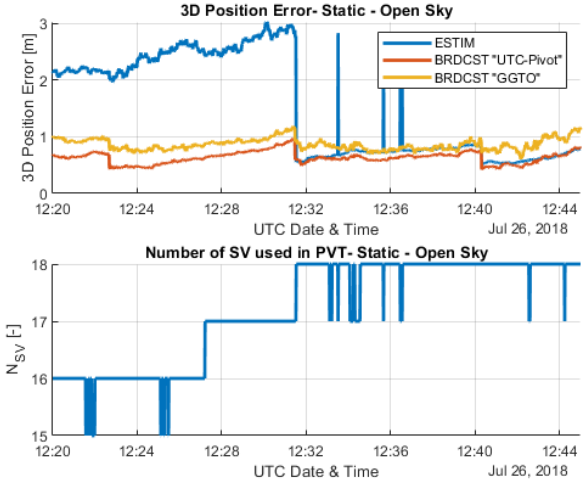
- Using UTC as a pivot appears to be viable option in case the direct XYTO broadcast is not available. Further analysis (longer time series and different locations around the world) required to confirm.

- Considering the results presented here, it is not recommended to force/recommend the manufacturer to use the estimated XYTO as primary source in case broadcast values are available. The final choice should be left to the manufacturer (considering the specific application).

- To confirm this conclusion a workshop with receiver manufacturers is recommended.



Professional Receiver – Static – Open Sky



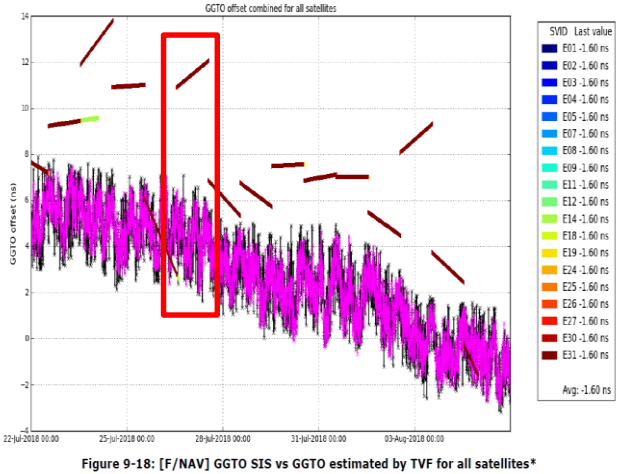
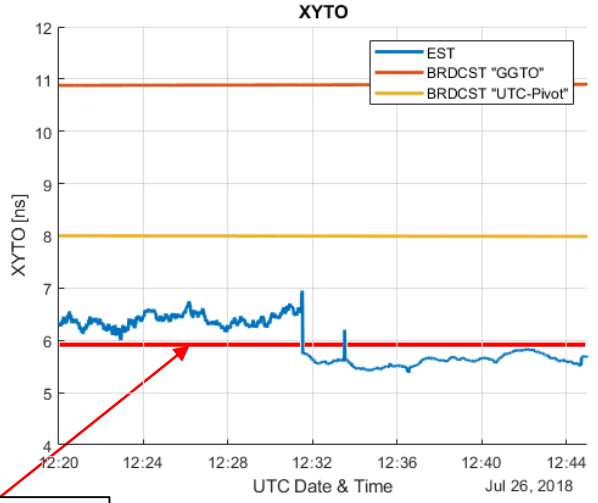


Figure 9-18: [F/NAV] GGTO SIS vs GGTO estimated by TVF for all satellites*



Actual GGTO (from TGVF)

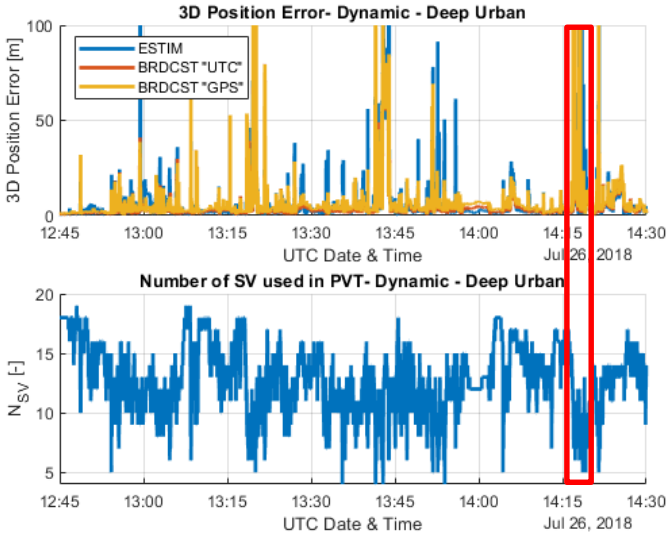
3D Error

GGTO Accuracy

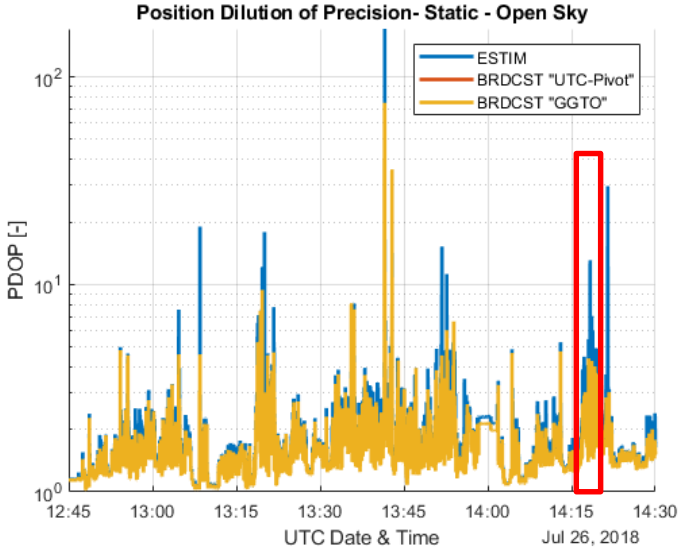
GGTO Values

- During this scenario the **accuracy** of the **GGTO** is close to its 1 sigma value (+ 5 ns)
- The error of **Galileo to UTC** and **GPS to UTC** combined is less (+ 2 ns) resulting in better performance of **BRDCST "UTC"** for this particular day

Professional Receiver – Dynamic – Deep Urban



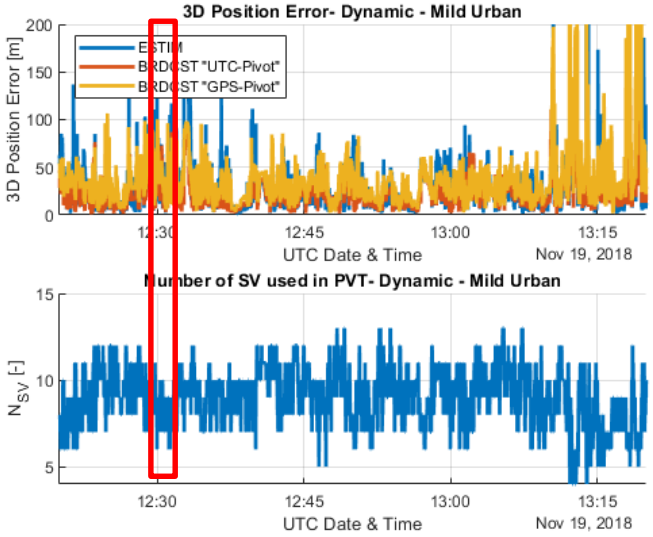
GPS + GAL



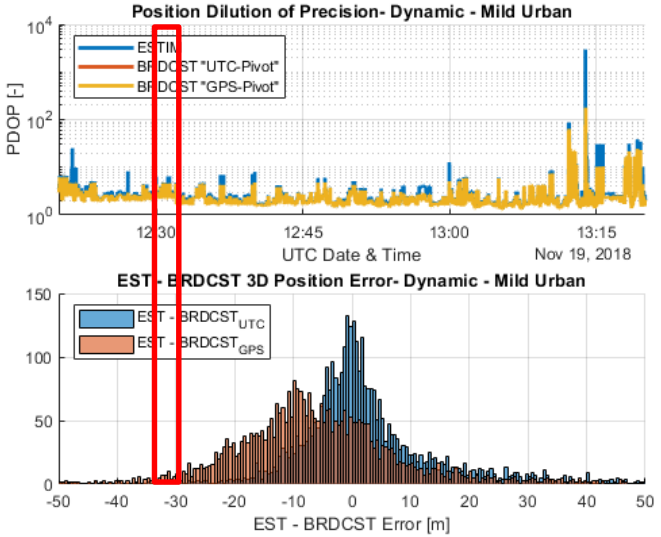
GPS + GAL

- In a deep urban canyon scenario there seems to be clear benefit of using the broadcasted GGTO in case the number of SVs < 8
- In case of a large number of satellite the position accuracy does not suffer using the broadcasted GGTO

Mass-Market Receiver – Dynamic – Mild Urban



GAL + GLO



GAL + GLO

The position error seems to be smaller using the **UTC pivot** compared to the **GPS pivot** for this particular day (Nov 19, 2018)