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Time Divergence in Multi-constellation GNSS Receivers – an investigation into risks and resilience

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How accurate is GPS time?

UTC as maintained by the U.S. Naval Observatory (USNO) via the GPS signal in space with a time transfer accuracy relative to UTC(USNO) of

≤30 nanoseconds (billionths of a second), 95% of the time.

This performance standard assumes the use of a specialized time transfer receiver at a fixed location.

Question – *is precision timing data from GPS sufficient or do we need to be able to process timing data from other constellations to complement GPS time?*

Figure 5-3 Time Transfer Error

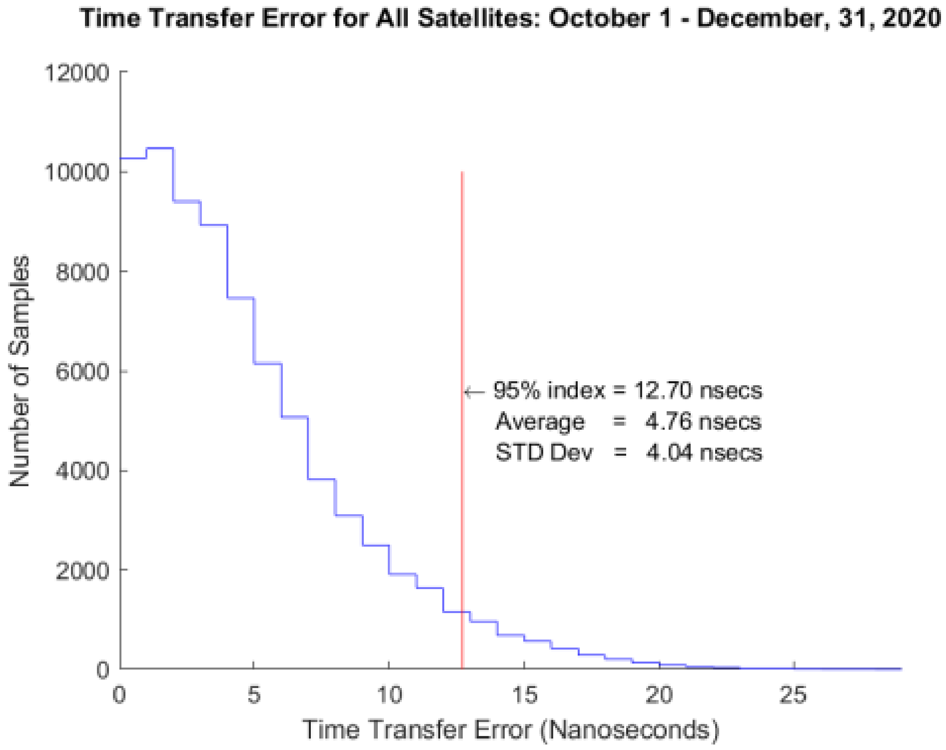

Image: FAA Satellite Navigation Branch

Need for timing using multi-constellation GNSS receivers (1)

- *April 2014:* All GLONASS satellites broadcast corrupt information for 11 hours, from just past midnight until noon Russian time. The effect of this was to render the system completely unusable to all worldwide GLONASS receivers. Many reports were also received of Multi-Constellation Multi-Frequency (MCMF) receivers using GLONASS becoming unusable during this episode

A UK GLONASS receiver with true position given by red dot, reports its position as being coincident with blue triangles on map

- Image from BBC

Need for timing using multi-constellation GNSS receivers (2)

- *January 2016* Errors in the Coordinated Universal Time (UTC) offset parameters broadcast by Global Positioning System (GPS) satellites caused many thousands of GPS clocks to be in error by approximately -13 microseconds. The incorrect UTC offset information was broadcast by 15 GPS satellites, half of the available constellation, throughout the anomaly

- *May 2017* Galileo hardware equipment failure in the ground segment – navigation messages not refreshed from 14 May at 15:50 to 6 May at 12:44 - Galileo Service Notice #01 covers..


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Technology

GPS error caused '12 hours of problems' for companies

By Chris Baraniuk
Technology reporter

4 February 2016 | Technology

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System engineers were "called out of bed" over the problems

Image: BBC

Need for timing using multi-constellation GNSS receivers (3)

Galileo, GPS and GLONASS have all experienced major constellation issues

- Reliance on a single constellation as source for UTC traceable time introduces unnecessary risk
- Receiver implementation is also a factor
  - GPS timing error – data was flagged as being out of date but many receivers processed it as current data (*GPS Receiver Impact from the UTC Offset (UTCO) Anomaly of 25-26 January 2016, Karl Kovach et al is a recommended read to understand what exactly happened and why some receivers exhibited timing errors)*
  - Leap Second implementation – Jan 2015 GPS broadcast future leap second data
    - Some receivers implemented this immediately
    - Resulted in a negative one second offset in affected receivers…

How does GNSS time trace to UTC?

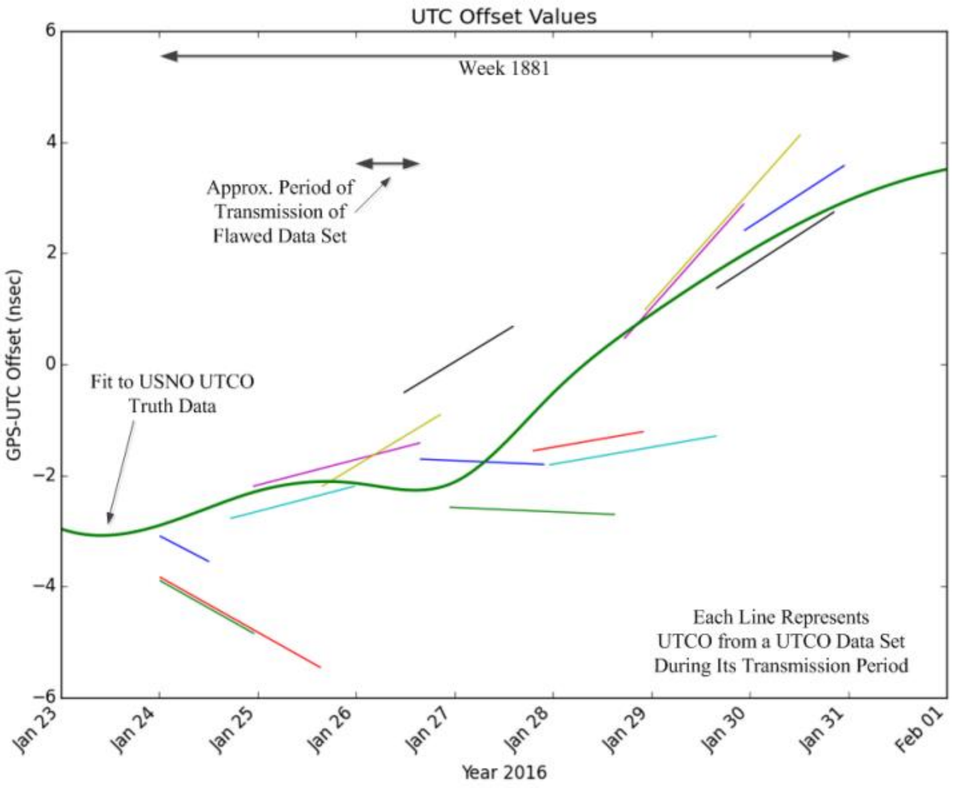


Figure 4 - UTC Offset As a Function of Time for Various UTC Data Sets (Flawed Set Excluded)

- "USNO estimates the timing difference between GPS Time and UTC(USNO)
- This data is provided to GPS operations daily, which is used to align GPS Time (modulo whole second differences) and build the UTCO correction message.
- GPS Time is specified to be kept within one microsecond of UTC(USNO) modulo whole second offset.
- Over the past 20 years GPS Time has been kept within 10 nanoseconds of UTC(USNO) modulo whole second differences."

From "GPS Receiver Impact from the UTC Offset (UTCO) Anomaly of 25-26 January 2016", Karl Kovach, The Aerospace Corporation Philip J. Mendicki, The Aerospace Corporation Edward D. Powers, United States Naval Observatory (USNO) Brent Renfro, Applied Research Laboratories, The University of Texas at Austin

Relationship between Galileo and GPS Time

- Galileo uses Galileo System Time (GST)
- Generated by the Precise Timing Facility (PTF) at the Galileo Control Centre (GCC), Fucino. Based on averages of different atomic clocks.
- GPS time is computed by the GPS control segment
- GPS and Galileo time derived independently of one another
- Both are kept close to UTC
- The offset between the two is precisely calculated on a continuous basis by the PTF
- Resulting GGTO distributed through Galileo Open Service Navigation Message

Image: ESA

The GPS to Galileo Time Offset (GGTO)

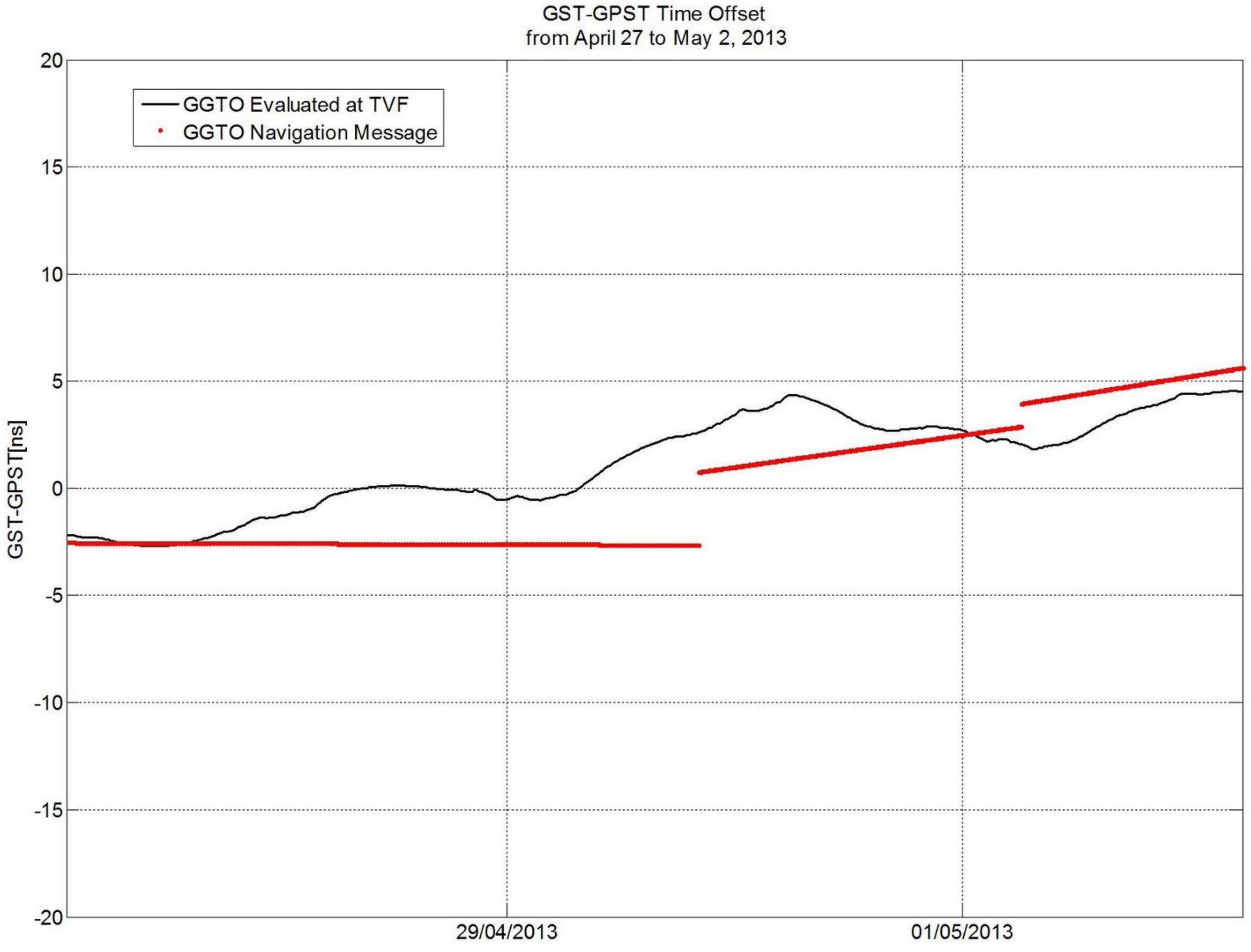


Image: ESA

- GGTO determination methods and interface design were agreed on a preliminary basis between the Galileo Project and the US Naval Observatory back in 2003
- The accuracy of the GGTO has been benchmarked by ESA at 5ns or less
- What happens if there is a serious constellation error (such as the UTC Offset (UTCO) Anomaly of 25-26 January 2016?

GPS Receiver Operation – A refresher

- A GNSS Receiver has different modes (states) of operation – these modes of operation affect the vulnerability level of the receiver. The US Air Force defined these modes of operation (for military Receivers) as:

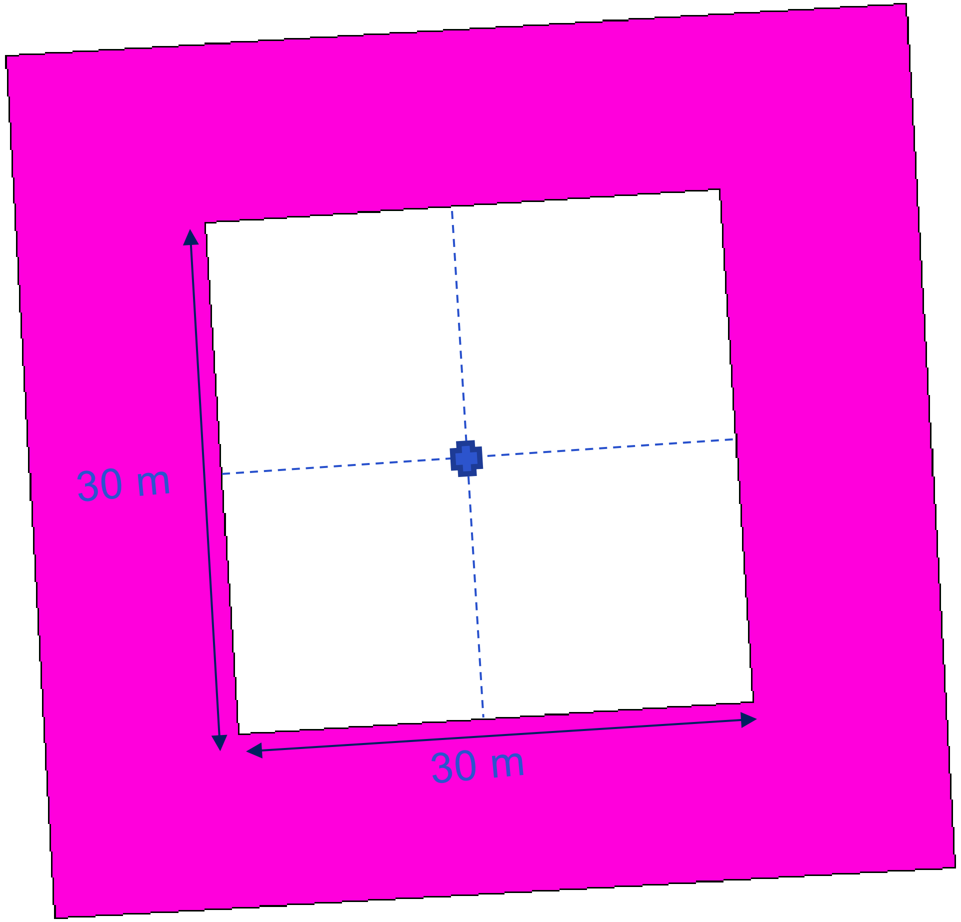
  - **State 1: Normal Acquisition** (L1 C/A code)
  - **State 2: Direct Acquisition** (applies to GPS L2 P(Y)frequency)
  - **State 3: Code lock** (Receiver maintains code lock, but cannot maintain precise carrier tracking)
  - **State 4: Carrier lock** (Receiver locks on carrier, but pseudorange and pseudorange delta values may be inaccurate)
  - **State 5: Carrier Track/Data demodulation** (Receiver tracks carrier and demodulates signal, accurate pseudorange and pseudorange delta values)
  - **State 6: Sequential resynchronisation** (N/A for receivers with continual tracking)
  - **State 7: Signal reacquisition** (Receiver that was tracking in State 5 but lost lock on GPS signals and is in search mode

The operation mode of the receiver is always important to consider – especially with multi-constellation, multi-frequency receivers where State 1 or State 7 might be constrained to a single constellation/frequency – e.g., GPS L1

MCMF Receiver considerations

- Multi constellation receivers might need to acquire signals on GPS L1 C/A frequency
- This means that advantages of MCMF operation when processing precise timing data do not apply if the receiver is in State 1 or State 7
- Not clear how the receiver under test uses GGTO with GPS to drive the 1PPS output. Need to investigate using a selection of realistic test scenarios
- How does GGTO drive solution accuracy in different environments – urban vs suburban to assess the impact of multipath? (Note this particular set of tests is limited to using the GGTO message broadcast by Galileo constellation)
- Assessment of GGTO effectiveness in scenarios with differing satellite availability (large number of visible satellites vs low number of visible satellites in solution)

GGTO Test Set-up



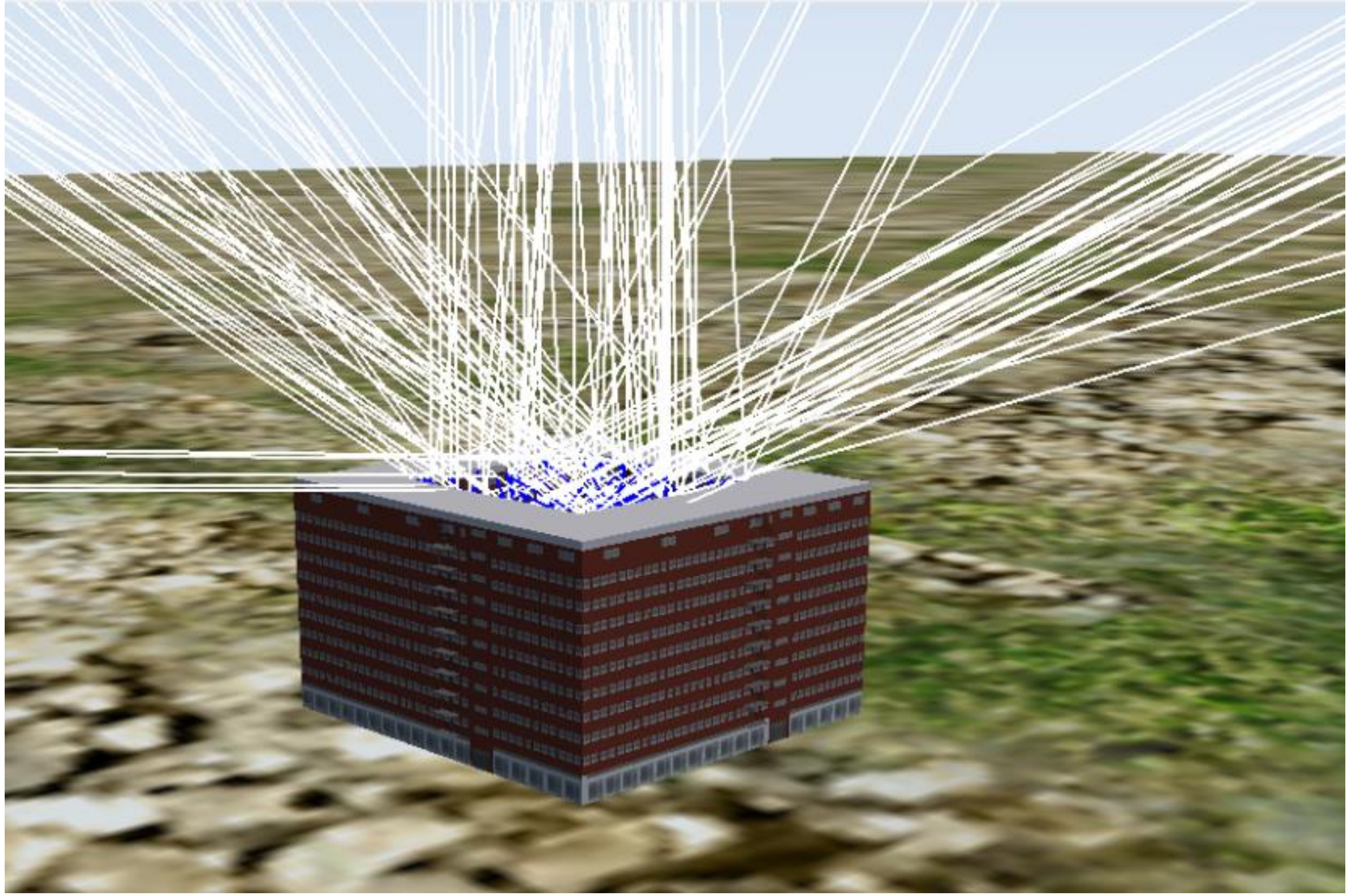


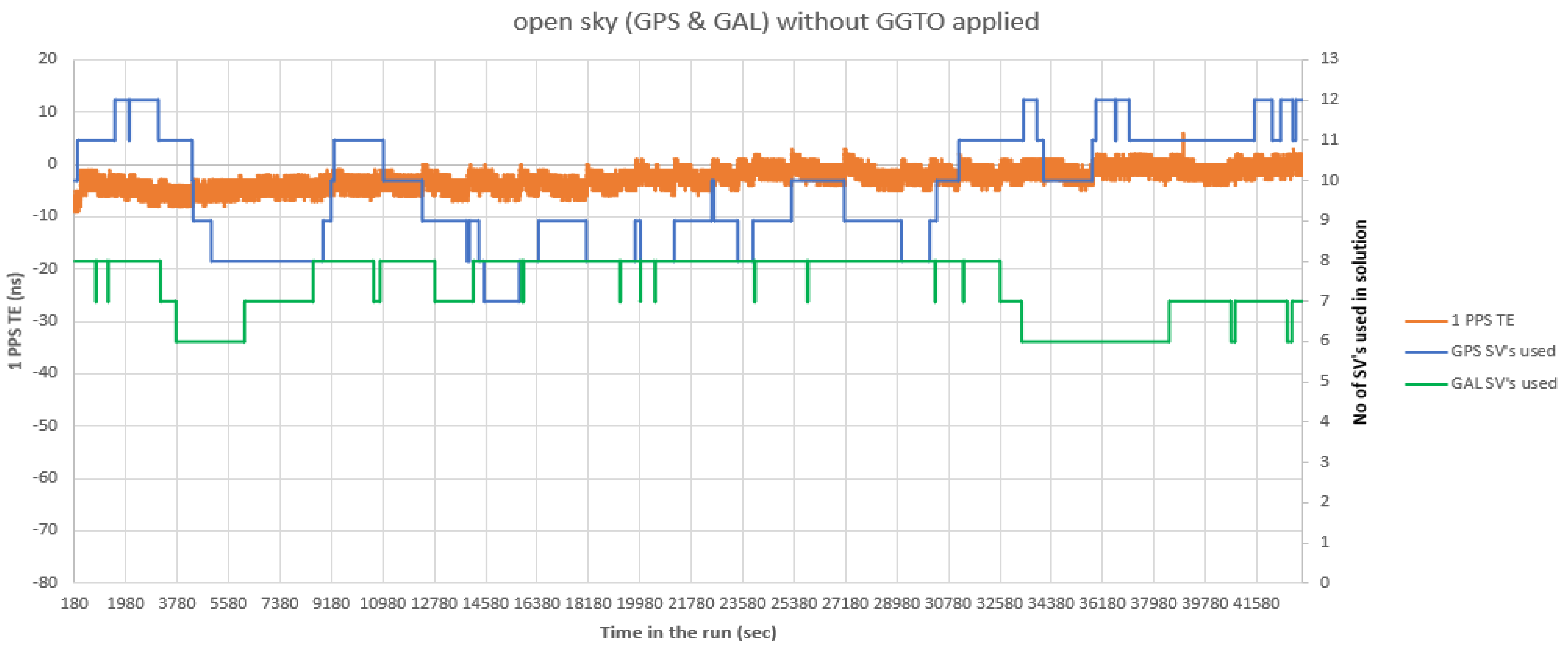
Figure 1: Sim3D scene with ~60 degrees obscuration

Obscuration geometry profile

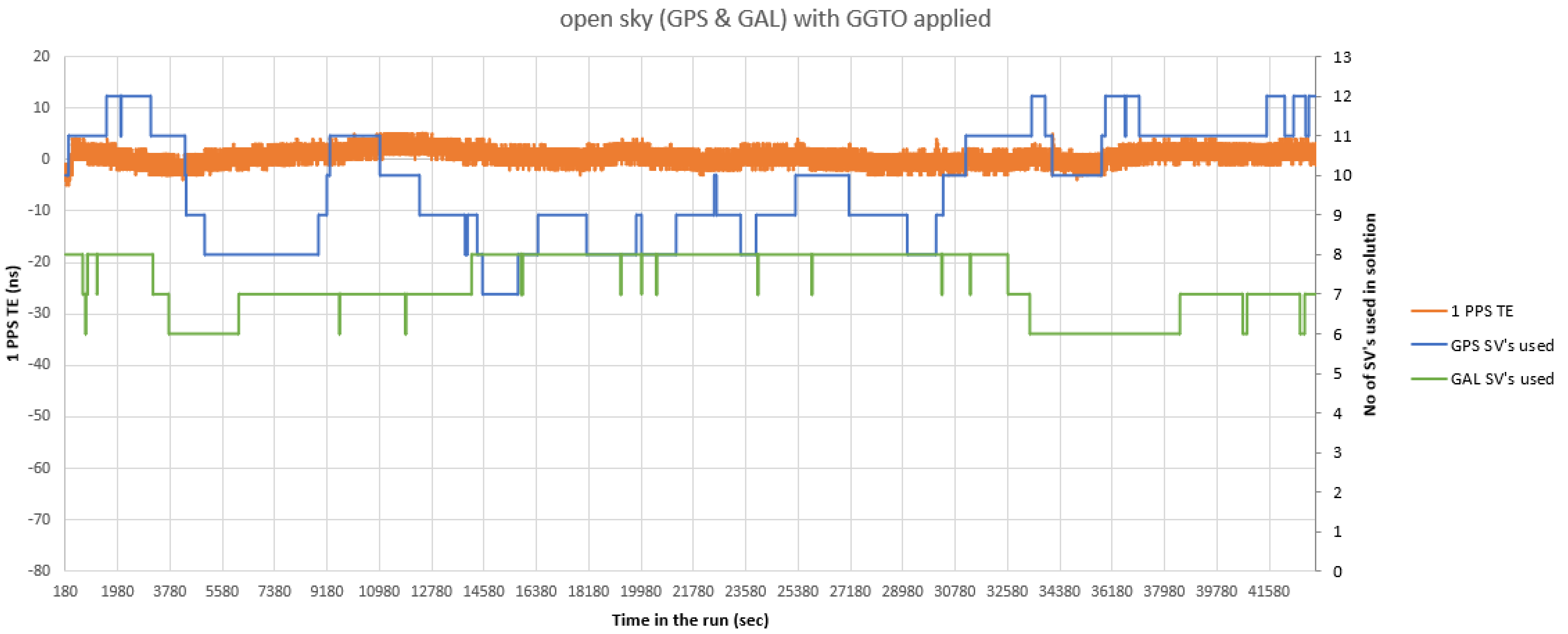
Parameters	Description	Values			
		Reference	Low obscuration	Medium obscuration	High obscuration
hr	Height of the APC w.r.t. the WGS ellipsoid, in meters	2.49 + 1.5 antenna offset			
hb	Height of the building w.r.t. the WGS ellipsoid, in meters	12.66	21.86	30	45.2
drb	Distance between the APC and the building, in meters	15	15	15	15
ε	The elevation angle, in degrees	30	50	60	70

Table 1: Obscuration geometry profile

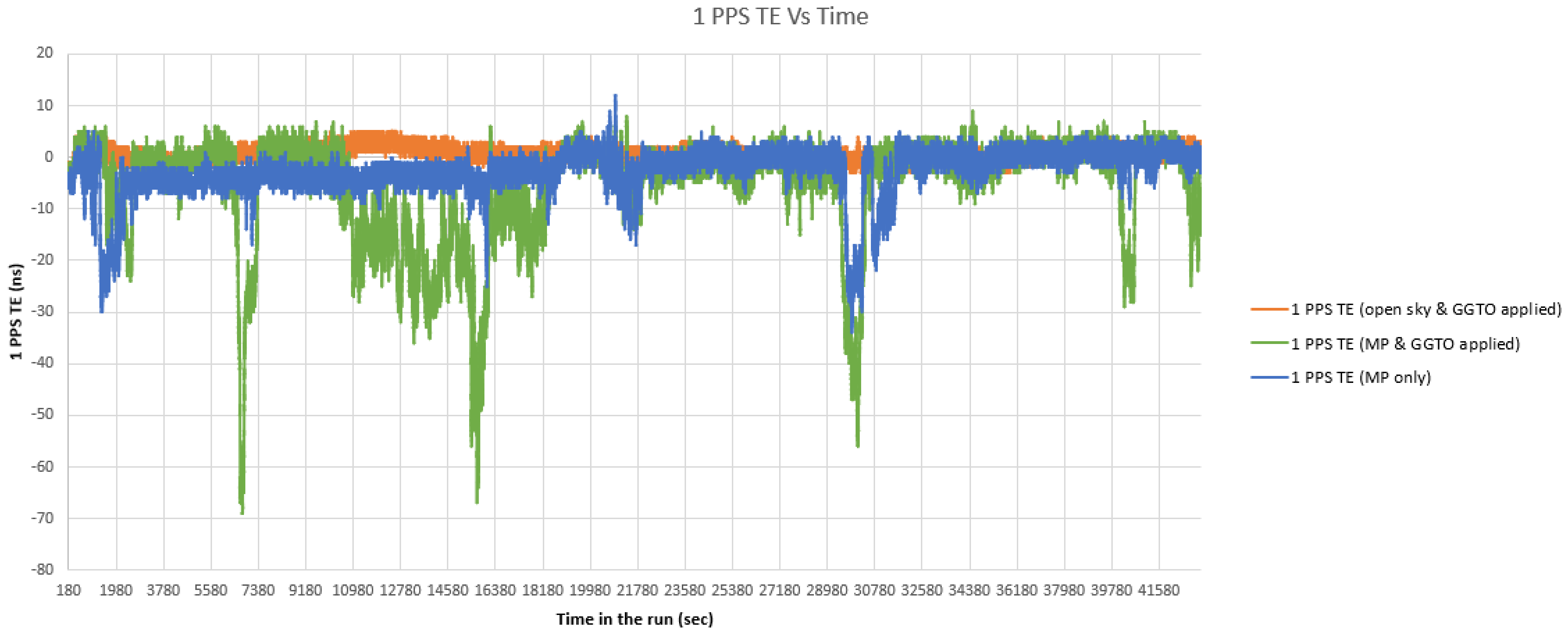
Open sky run without any GGTO applied



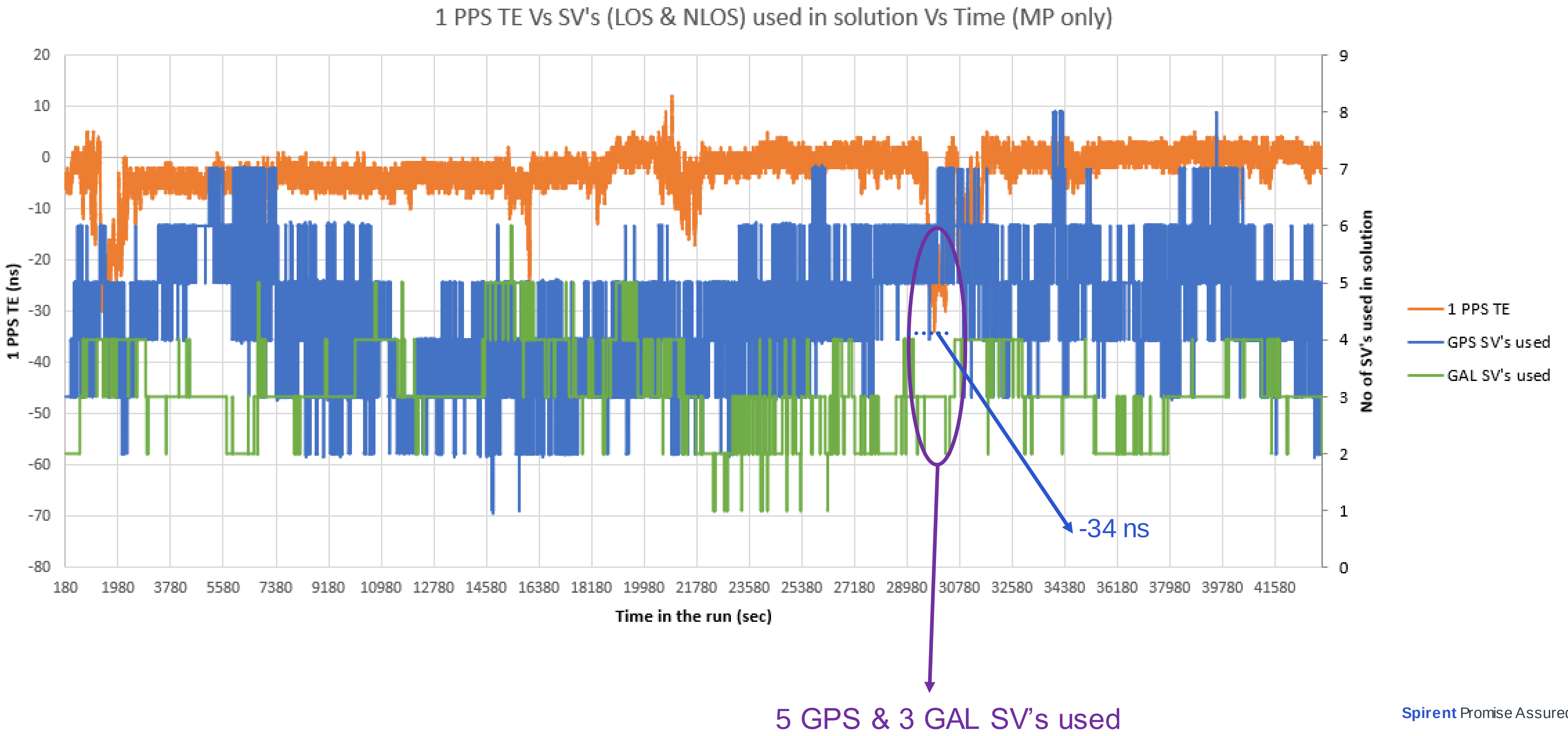
Open sky run with GGTO applied



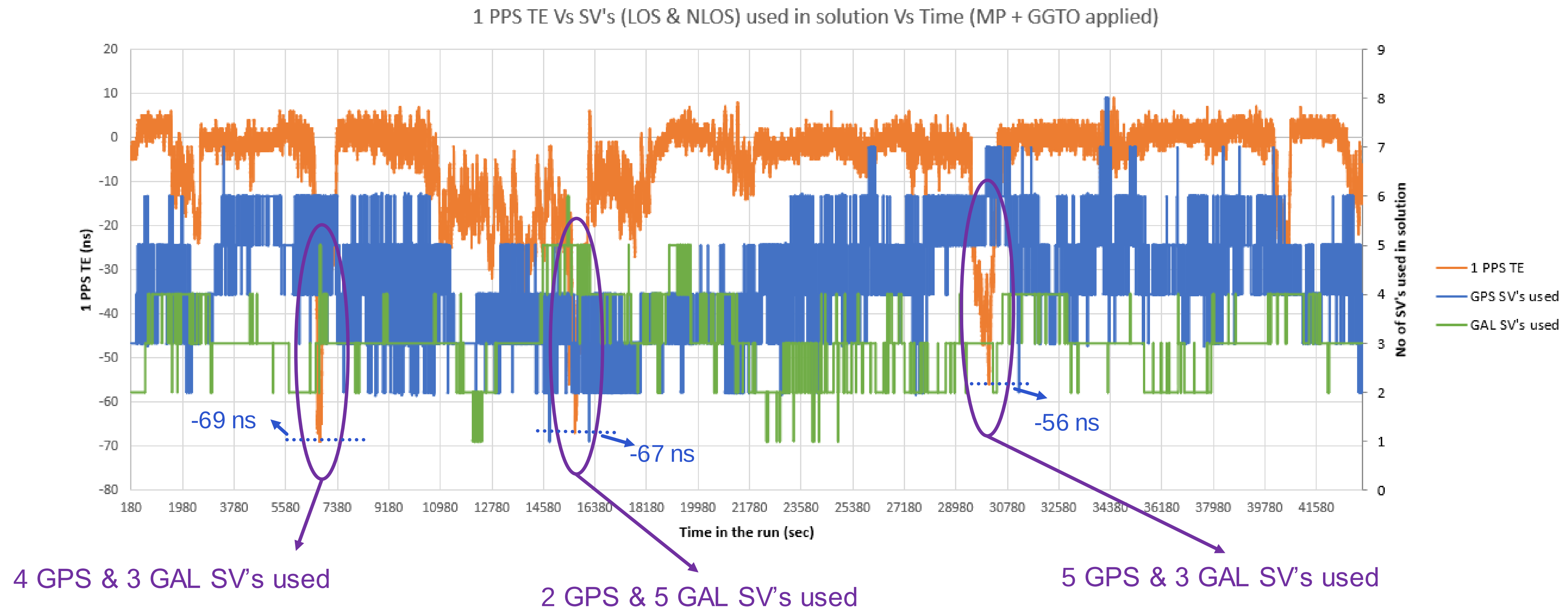
1 PPS TE Vs Time in the run



1 PPS TE under MP conditions only



1 PPS TE under MP conditions and with GGTO applied

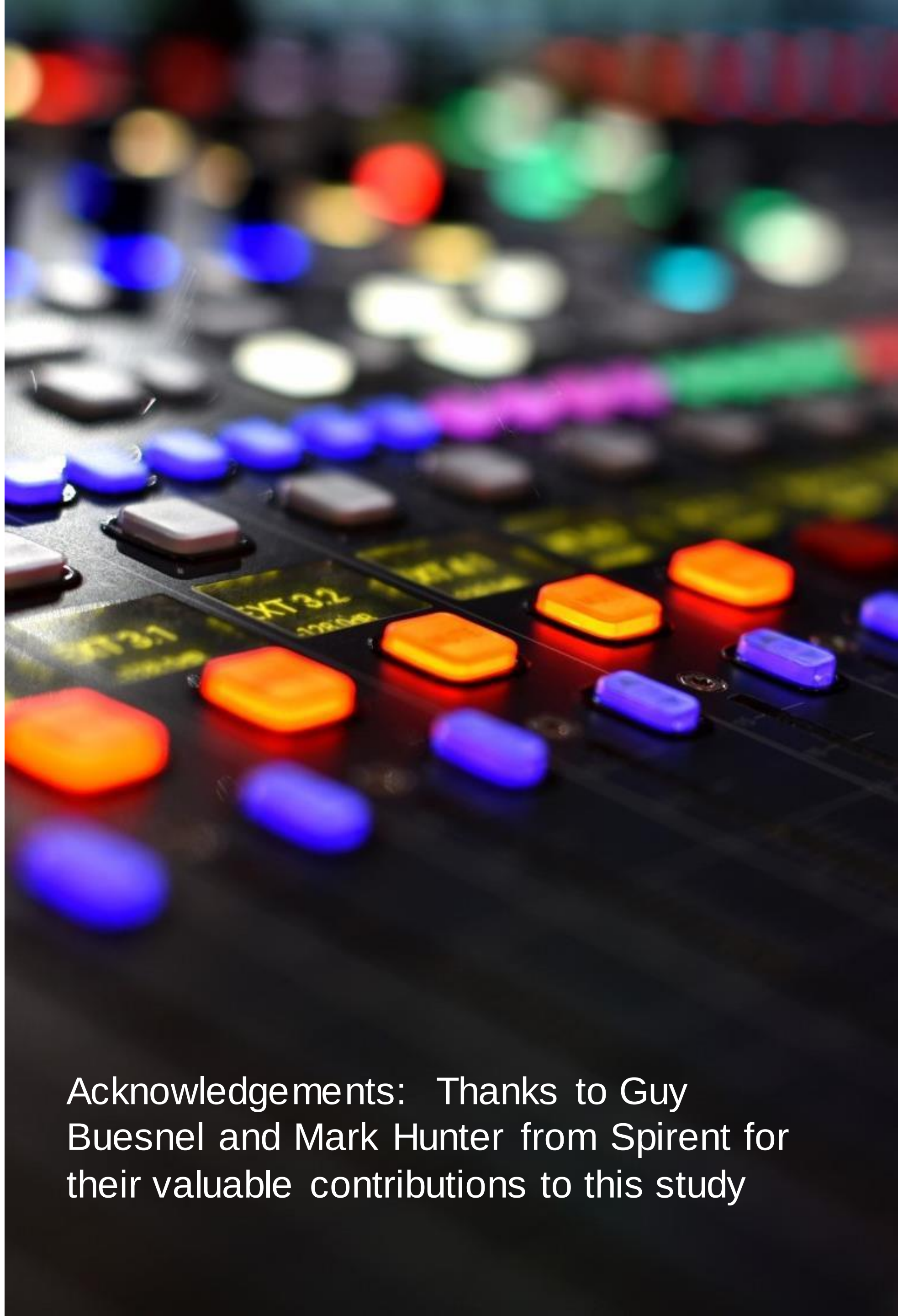


Insights/further work

- GGTO divergence **only** becomes an **issue** with low numbers of satellites available (e.g. due to multipath)
  - This might be the case where users would place most reliance on GGTO to help with provision of precise, traceable time data

- Results showed that with 8 or less satellites (LOS & NLOS) available to the receiver, GGTO divergence led to a degradation in accuracy of the Receiver PPS output

- Clear need to understand how GGTO works in multi-constellation multi-frequency receivers
  - Users need to evaluate how their multi-constellation solutions work against relevant scenarios



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