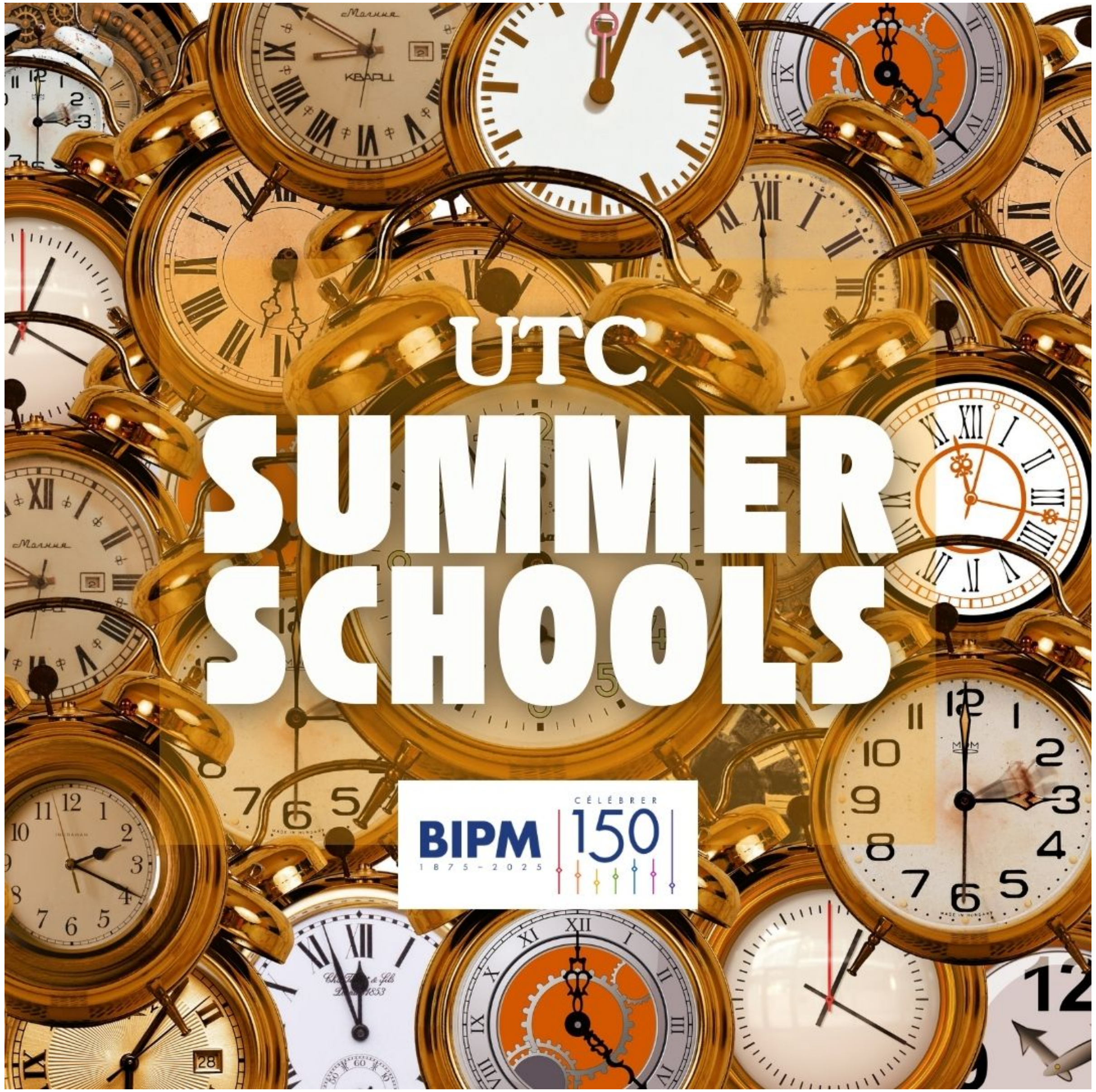

BIPM UTC Summer School

September 9-11th BIPM, Paris

Processing of CGGTTS data

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NPL India

Together with the BIPM Time department

Time Transfer Through GNSS Pseudorange Measurements

Enrolment options

Time Transfer Through GNSS Pseudorange Measurements

This course aims at providing knowledge and processing capacity to obtain time transfer through GNSS measurements using CGGTTS data.

It offers the following content to the user:

1. **Tutorial** on Time Transfer by GNSS Common-View and All-in-View Methods
2. CGGTTS data format description in an Interactive webpage **"CGGTTS format"**
3. A software tool **"CGGTTS Data Analyser"** was developed for the analysis of CGGTTS data All-in-View time transfer
4. **User Manual** of the Software "CGGTTS Data Analyser"
5. Video demonstrating the usage of the **"CGGTTS Data Analyser"**
6. **Git Repository** of the source code of the software
7. **Quiz** on GNSS time Transfer through CV and AV methods
8. **References** for the GNSS Pseudo Range Measurements

Common Generic GNSS Time Transfer Standard (CGGTTS) data format
(CGGTTS standard)

- A **standard data format** for the GNSS time transfer methods based on pseudorange measurements
- Used to perform the **Common–View and All-in-View** time transfer methods
- The observations recorded are at **every 16 minutes** interval as per BIPM tracking schedule
- Time transfer receivers automatically generates the **CGGTTS files** or else you can use the "**r2cggtts**" ROB software to convert Rinex data to CGGTTS (available from BIPM ftp with using UTC(k) lab credentials or asking ROB for a copy).
- **Versions:** CGGTTS V1.0 (GPS),
  CGGTTS V2.0 (GPS, GLONASS),
  CGGTTS V2E (GPS, GLONASS, Galileo, BDS2, QZSS)
- Currently one single frequency and one Iono free combination is **recognized per GNSS system**:
  GPS: L1C/A, L1P and L3P　　Glonass: L1C/A, L1P and L3P
  BDS2 : B1i and L3B　　Galileo: E1 and L3E　　QZSS : L1C and L3Q
- The **antenna location** should be known better than 3 cm accuracy (through PPP) to match the 0.1 ns numeric precision of the format
- UTC(k) labs **share regularly** their CGGTTS files to BIPM for the computation of UTC.

CGGTTS data format

➢ *Interactive description of the data format*

CGGTTS data format: Version 2E

File name

gmpt1060.312

File content

```
CGGTTS GENERIC DATA FORMAT VERSION = 2E
REV DATE = 2022-06-22
RCVR = GTR51 1309042 1.9.0
CH = 20
IMS = GTR51 1309042 1.9.0
LAB = PTB Germany
X = -1432891.86 m
Y = +6050260.21 m
Z = -5739698.67 m
FRAME = ITRF
COMMENTS = AUSPOS ITRF2014 2020-11-23
INT DLY = 33.2 ns (GPS C1), 31.4 ns (GPS P1), 24.8 ns (GPS P2), CAL_ID = 1001-2020
CAB DLY = 250.0 ns
REF DLY = 36.6 ns
REF = UTC(PTB)
CKSUM = DA
```

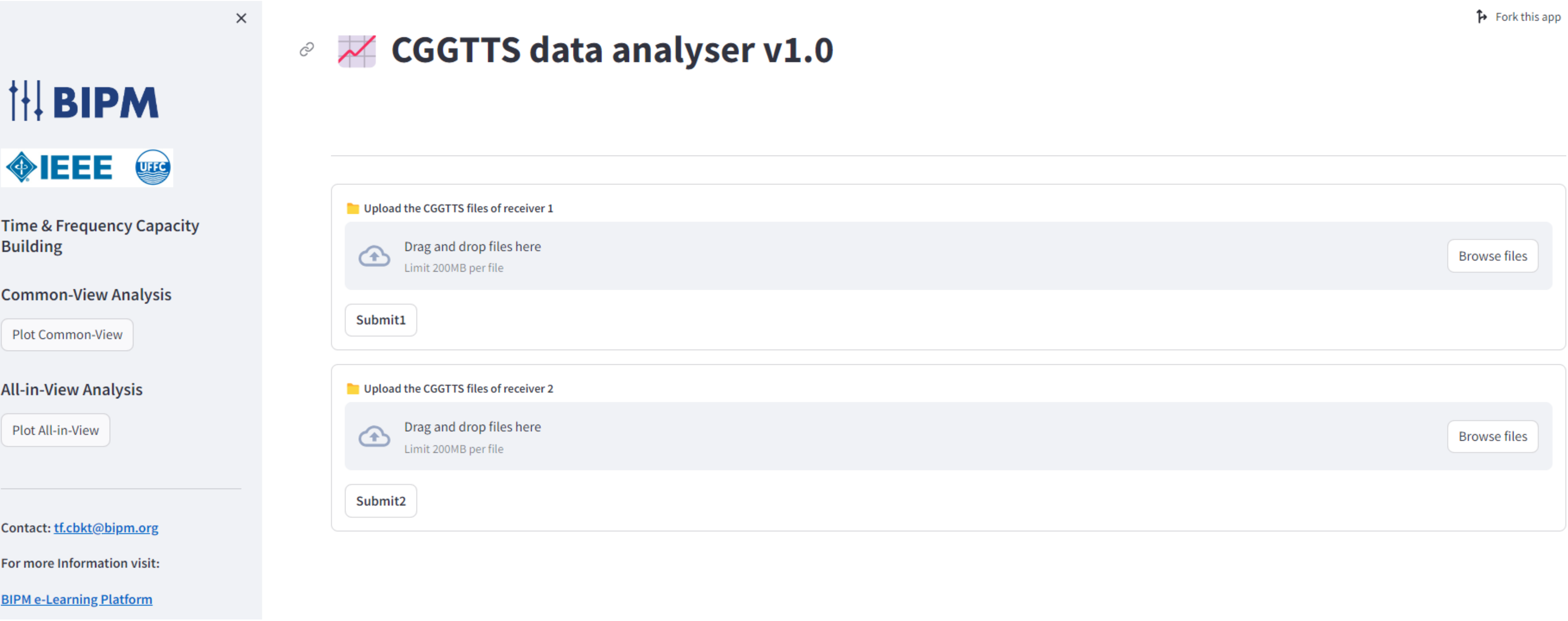
Internal delays of the receiver:

- **For single-frequency CGGTTS:**
  "INT DLY = DDD.D ns (cons code1) CAL_ID = cccccccccccc",
- **For dual-frequency CGGTTS:**
  "INT DLY = DDD.D ns (cons code1), DDD.D ns (cons code2) CAL_ID = cccccccccccc",
- The Internal delays (receiver + antenna) should be entered in ns and given with 1 decimal, only for the constellation and the code(s) used in the file. The parameter 'cons' will be **GPS, GLO, GAL, BDS or QZS**, and 'code1' and 'code2' will follow the convention provided in the third column of Table 1. The parameter **"CAL_ID"** is the reference to the calibration report where the internal delays are provided; its expression is detailed in the BIPM guidelines for calibration.

SAT	CL	MJD	STTIME															SMSI	ISG	FR	HC	FRC	CK
			hhmmss															.1ps/s	.1ns				
G02	FF	60312	000200	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	+10	5	0	0	L1C	AA
G03	FF	60312	000200	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1	9	0	0	L1C	F3
G08	FF	60312	000200	780	410	1811	+1601523	+5	-36	-14	5	014	123	+19	72	+10	61	+9	19	0	0	L1C	CC
G10	FF	60312	000200	780	191	589	+677818	+7	-188	-8	8	036	246	+82	111	+16	52	-33	19	0	0	L1C	02
G14	FF	60312	000200	780	211	2864	-2881624	-79	-76	+25	9	160	223	+23	106	+5	42	+28	30	0	0	L1C	0E
G17	FF	60312	000200	780	192	3153	-7207717	+9	-103	+1	8	046	243	-75	111	-15	28	-8	28	0	0	L1C	00

https://cbkt-time.bipm.org/

Software application: https://cbkt-time.bipm.org/
Source code : https://github.com/TheBIPM/CCTF_CBKT_software



CGGTTS - Analyser:
Demo video : CGGTTS – Analyser: Time & Frequency BIPM CBKT - YouTube

- User can upload multiple CGGTTS files and investigate the details of the data (MJD, REFSYS, frequencies, gaps or jumps in the data)

- The interactive plots helps the user for detailed observations

- Can perform Common-View and All-in-View time transfer between two receivers' data.

- The user has option to perform the CV and AV methods by filtering the data based on
  - GNSS measurement code (L1P, L1C,L2P etc.,)
  - MJD range
  - Satellite selection
  - Outlier selection (as multiples of standard deviation)
  - Elevation mask (0 to 90 degrees)

- The user can download the CSV files of each corresponding plot, for further processing

Calculations

➢ Weighted Refsys of each receiver

Sum of the weighted REFSYS values of all satellites available, with respect to their elevation angles

$$weighted\ Refsys_1 = \sum_{SAT(i=1)}^{n} \frac{Refsys_i \ * \ sin^2(ELV_i)}{\sum_{i=1}^{n} sin^2(ELV_i)} \qquad weighted\ Refsys_2 = \sum_{SAT(j=1)}^{n} \frac{Refsys_j \ * \ sin^2(ELV_j)}{\sum_{j=1}^{n} sin^2(ELV_j)}$$

➢ Common – View method

Average of difference between Refsys values at each epoch

$$Common - View\ at\ each\ epoch = \sum_{SAT(i=1)}^{n} \frac{(Refsys_{(1,i)} - Refsys_{(2,i)})}{n}$$

➢ All - in– View method

All-in-view at each epoch = $weighted\ Refsys_1$ - $weighted\ Refsys_2$

Example for calculating: Performance of Receiver clock - GNSS(time)

CGGTTS data snippet

SAT	MJD	STTIME	ELV	REFSYS	FRC
		hhmmss	.1dg	.1ns	
G10	60269	140000	392	-94	L1C
G10	60269	140000	392	-86	L1P
G10	60269	140000	392	247	L2C
G10	60269	140000	392	-69	L2P
G10	60269	140000	392	159	L5C
G15	60269	140000	351	-25	L1C
G15	60269	140000	351	-8	L1P
G15	60269	140000	351	308	L2C
G15	60269	140000	351	-26	L2P
G18	60269	140000	697	-17	L1C
G18	60269	140000	697	1	L1P
G18	60269	140000	697	339	L2C
G18	60269	140000	697	4	L2P

At each epoch

Sum of the weighted REFSYS values of all satellites available, with respect to their elevation angles

$$sum\ of\ weighted\ Refsys = \sum_{i=1}^{n} \frac{Refsys_i * \sin^2(ELV_i)}{\sum_{i=1}^{n} \sin^2(ELV_i)}$$

$$sum\ of\ weighted\ Refsys = \frac{-8.6 * \sin^2(39.2) - 0.8 * \sin^2(35.1) + 0.1 * \sin^2(69.7)}{\sin^2(39.2) + \sin^2(35.1) + \sin^2(69.7)}$$

= -2.24 ns

Example for calculation: Common-view Performance at each epoch

GPS Receiver 1 data
(CGGTTS V2E)

SAT	MJD	STTIME	ELV	REFSYS	FRC
		hhmmss	.1dg	.1ns	
G10	60269	1400	392	-94	L1C
G10	60269	1400	392	-86	L1P
G10	60269	1400	392	247	L2C
G10	60269	1400	392	-69	L2P
G10	60269	1400	392	159	L5C
G15	60269	1400	351	-25	L1C
G15	60269	1400	351	-8	L1P
G15	60269	1400	351	308	L2C
G15	60269	1400	351	-26	L2P
G18	60269	1400	697	-17	L1C
G18	60269	1400	697	1	L1P
G18	60269	1400	697	339	L2C
G18	60269	1400	697	4	L2P

GPS Receiver 2 data
(CGGTTS V2)

SAT	MJD	STTIME	ELV	REFSYS	FRC
		hhmmss	.1dg	.1ns	
8	60269	1400	188	-80	L1C
32	60269	1400	289	-63	L1C
27	60269	1400	595	-47	L1C
16	60269	1400	451	-23	L1C
23	60269	1400	458	-70	L1P
18	60269	1400	267	-85	L1P
10	60269	1400	835	-122	L1P
26	60269	1400	291	-40	L1P
8	60269	1400	188	-104	L2P
32	60269	1400	289	-88	L2P
27	60269	1400	595	-68	L2P
27	60269	1400	595	-23	L3P
16	60269	1400	451	-4	L3P

Choice of signal Frequency (L1P)

Common Satellites

Refsys values for CV (units: 0.1 ns)

$$\text{CommonView difference} = \sum_{\begin{pmatrix} SAT\ (i=1), \\ frequency\ (f) \\ Receiver\ (1,2) \end{pmatrix}}^{n} \frac{\left(Refsys_{(1,i,f)} - Refsys_{(2,i,f)}\right)}{n} = \frac{[(-8.6) - (-12.2)] + [0.1 \ - (-85)]}{2}$$

$$= 6.1 \text{ ns}$$

Example for calculating: All-in-view Performance at an epoch

At each epoch

GPS Receiver 1 data
(CGGTTS V2E)

SAT	MJD	STTIME	ELV	REFSYS	FRC
		hhmmss	.1dg	.1ns	
G10	60269	1400	392	-94	L1C
G10	60269	1400	392	-86	L1P
G10	60269	1400	392	247	L2C
G10	60269	1400	392	-69	L2P
G10	60269	1400	392	159	L5C
G15	60269	1400	351	-25	L1C
G15	60269	1400	351	-8	L1P
G15	60269	1400	351	308	L2C
G15	60269	1400	351	-26	L2P
G18	60269	1400	697	-17	L1C
G18	60269	1400	697	1	L1P
G18	60269	1400	697	339	L2C
G18	60269	1400	697	4	L2P

GPS Receiver 2 data
(CGGTTS V2)

SAT	MJD	STTIME	ELV	REFSYS	FRC
		hhmmss	.1dg	.1ns	
8	60269	1400	188	-80	L1C
32	60269	1400	289	-63	L1C
27	60269	1400	595	-47	L1C
16	60269	1400	451	-23	L1C
23	60269	1400	458	-70	L1P
18	60269	1400	267	-85	L1P
10	60269	1400	835	-122	L1P
26	60269	1400	291	-40	L1P
8	60269	1400	188	-104	L2P
32	60269	1400	289	-88	L2P
27	60269	1400	595	-68	L2P
27	60269	1400	595	-23	L3P
16	60269	1400	451	-4	L3P

- Choice of signal Frequency (L1P) (yellow)
- Elevation Angle (unit 0.1 degrees) (olive)
- All available Satellites (green)
- Refsys values for AV (units: 0.1 ns) (red)

$$\text{sum of weighted Refsys for receiver 1} = \frac{-8.6 * sin^2(39.2) - 0.8 * sin^2(35.1) + 0.1 * sin^2(69.7)}{sin^2(39.2) + sin^2(35.1) + sin^2(69.7)} = \text{-2.24 ns}$$

$$\text{sum of weighted Refsys for receiver 2} = \frac{-7.0 * sin^2(45.8) - 8.5 * sin^2(26.7) - 12.2 * sin^2(83.5) - 4.0 * sin^2(29.1)}{sin^2(45.8) + sin^2(26.7) + sin^2(83.5) + sin^2(29.1)} = \text{-9.43 ns}$$

All-in-view performance = (-2.24) – (-9.43) = 7.19 ns

Features

- User can **upload multiple CGGTTS files** and investigate the details of the data (MJD, Refsys, frequencies, gaps or jumps in the data)

- The **interactive plots** helps the user to select their choice of frequency and MJD range of the files for detailed observations

- To perform the **common view** and **all in view time transfer**, two sets of CGGTTS files need to be uploaded by the user

- The user can also **select choice of satellites** instead of default ALL option, set elevation mask and outlier filter to evaluate the performance of the CV and AV.

- The user can also **download the CSV files** of each corresponding plots

CGGTTS – Analyser:

Overview of the Course on e-learning

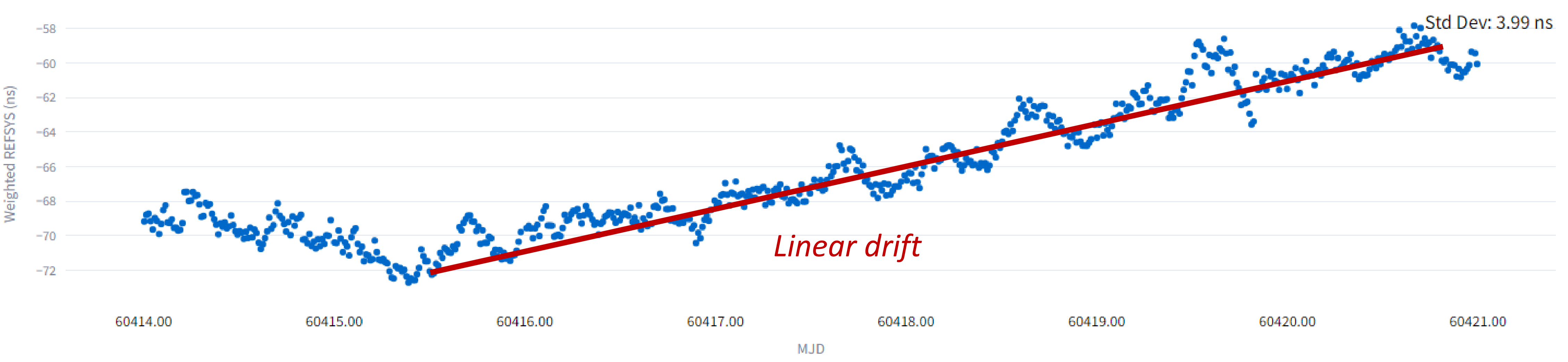
https://e-learning.bipm.org/

Live Demo

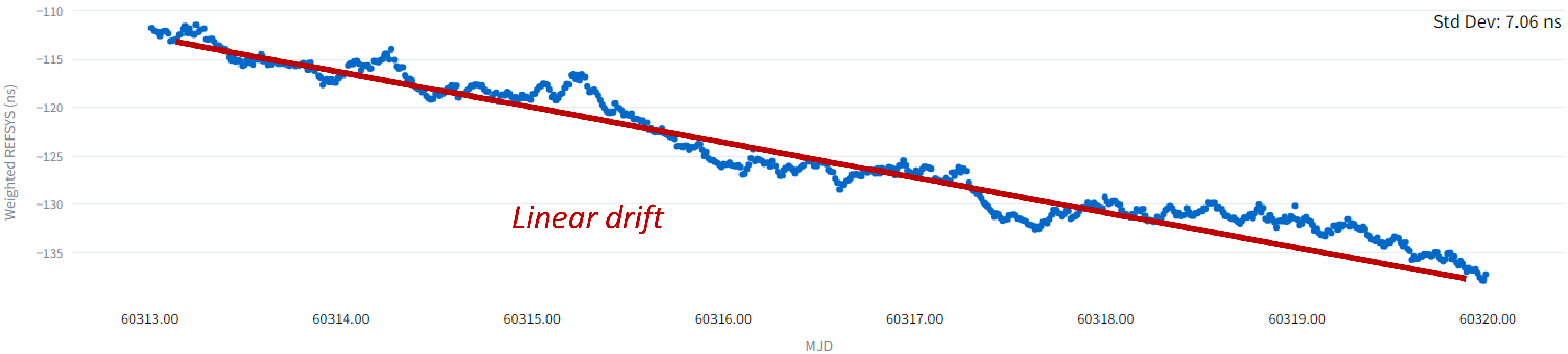
https://cbkt-time.bipm.org/

Use case Example: Drift in UTC(k)

UTC[redacted] - GPS time at Lab[redacted] through L3P. (Each point corresponds to Sum of all satellite weighted refsys per epoch)

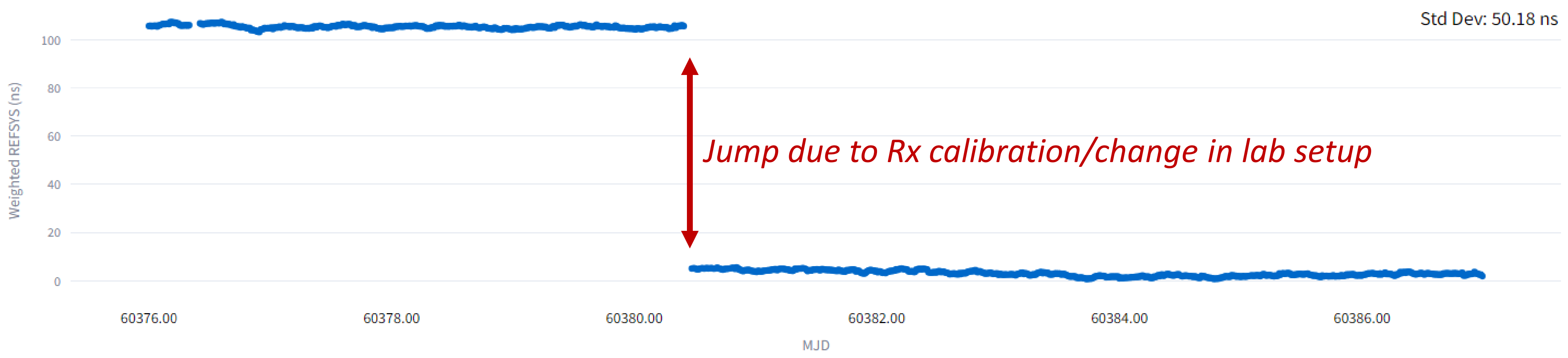


UTC[redacted] - GPS time at Lab[redacted] through L3P. (Each point corresponds to Sum of all satellite weighted refsys per epoch)

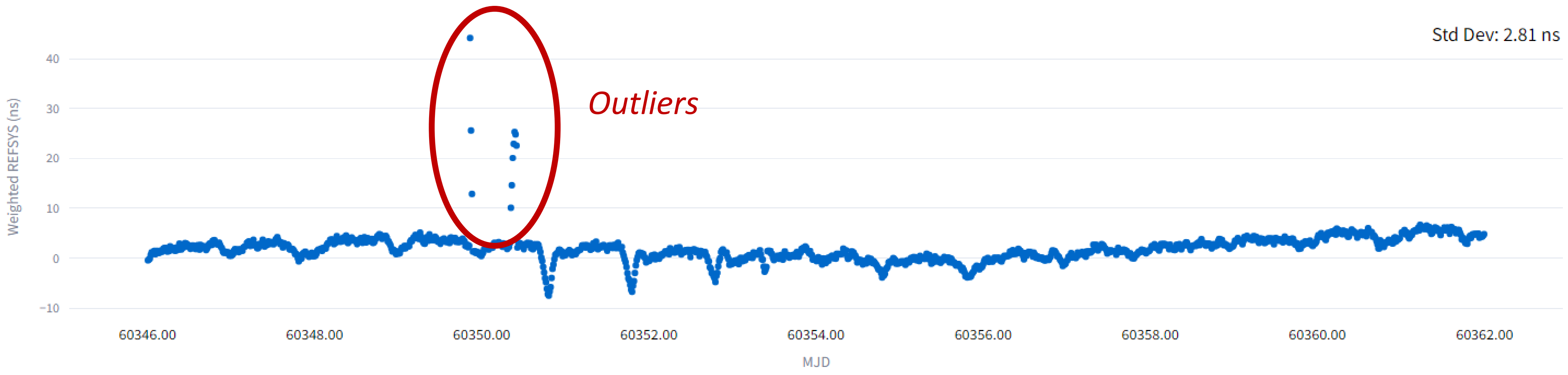


Use case Example: Jump & Outliers

UTC[redacted] - GPS time at Lab: [redacted] through L3P. (Each point corresponds to Sum of all satellite weighted refsys per epoch)

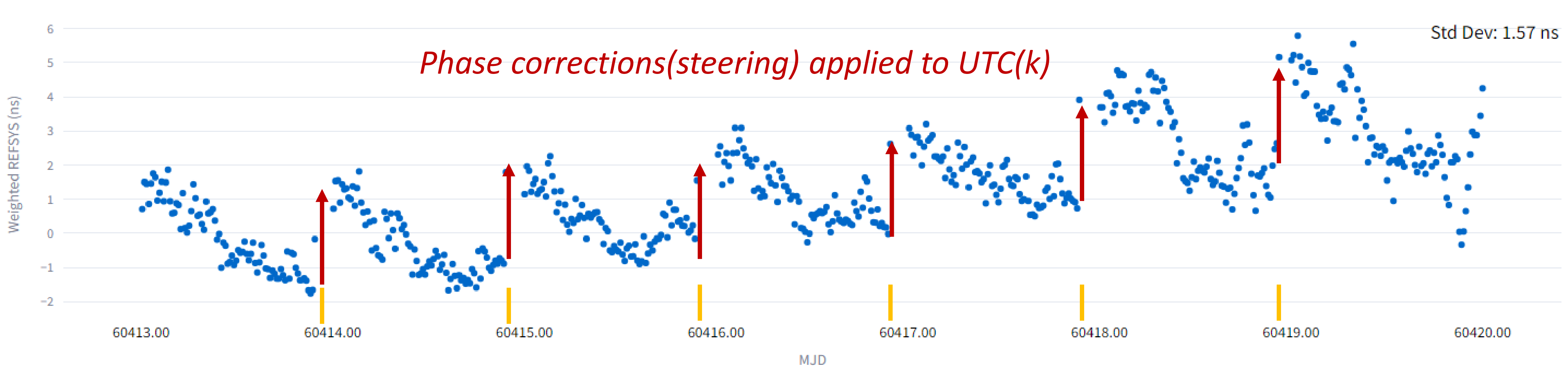


UTC[redacted] - GPS time at Lab: [redacted] through L3P. (Each point corresponds to Sum of all satellite weighted refsys per epoch)

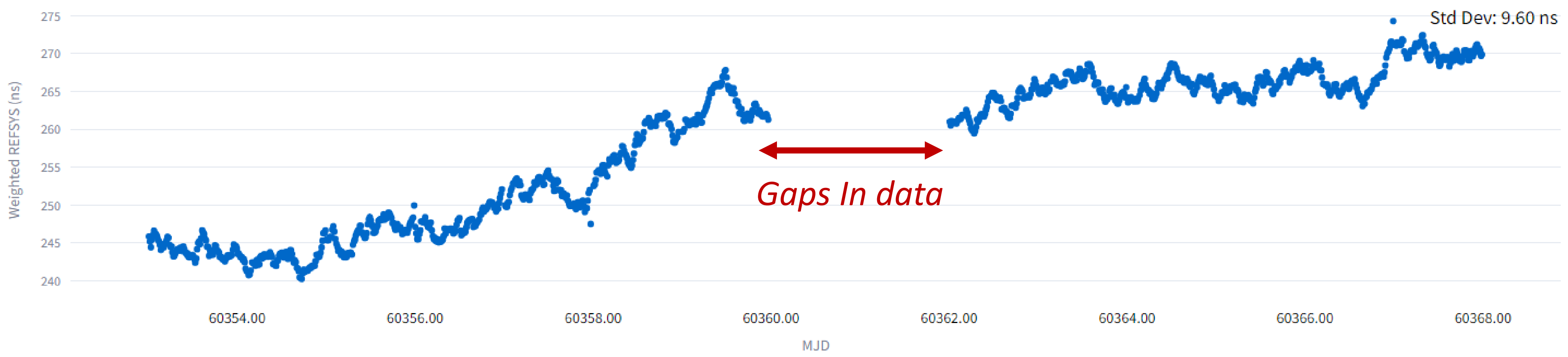


Use case Example: Phase jumps and Gaps

UTC[redacted] - GPS time at Lab:[redacted] through L3P. (Each point corresponds to Sum of all satellite weighted refsys per epoch)

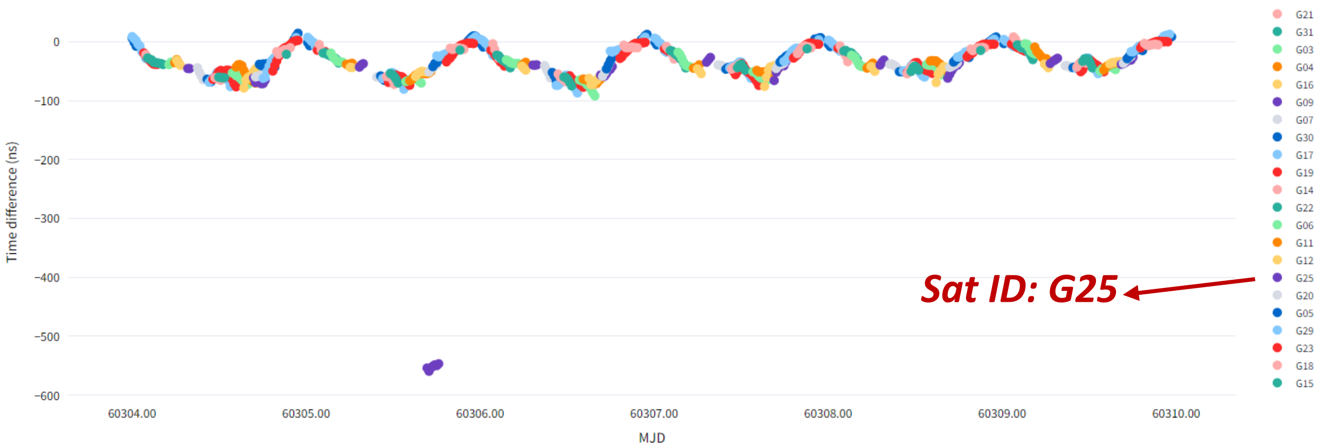


UTC[redacted] - GPS time at Lab:[redacted] through L3P. (Each point corresponds to Sum of all satellite weighted refsys per epoch)

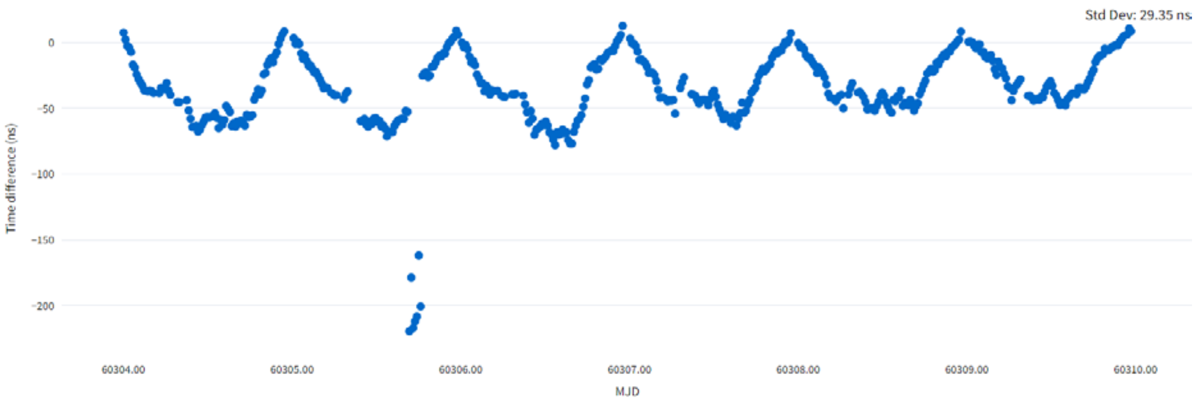


Use case Example: Outlier due to one satellite

GPS satellites in common-view [redacted] (L2P) - [redacted] (L2P)
(Each point corresponds to difference of refsys values for each common satellite in view at each epoch)

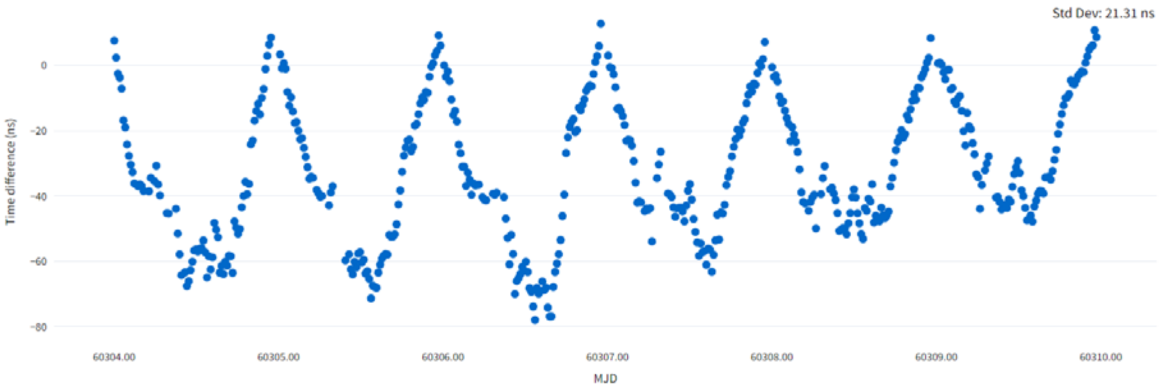


GPS Common-View link [redacted] (L2P) - [redacted] (L2P)
(Each point is average of differences between refsys values of all common satellites at each epoch)



GPS satellites in common-view [redacted] (L2P) - [redacted] (L2P)
(Each point corresponds to difference of refsys values for each common satellite in view at each epoch)

GPS Common-View link [redacted] (L2P) - [redacted] (L2P)
(Each point is average of differences between refsys values of all common satellites at each epoch)

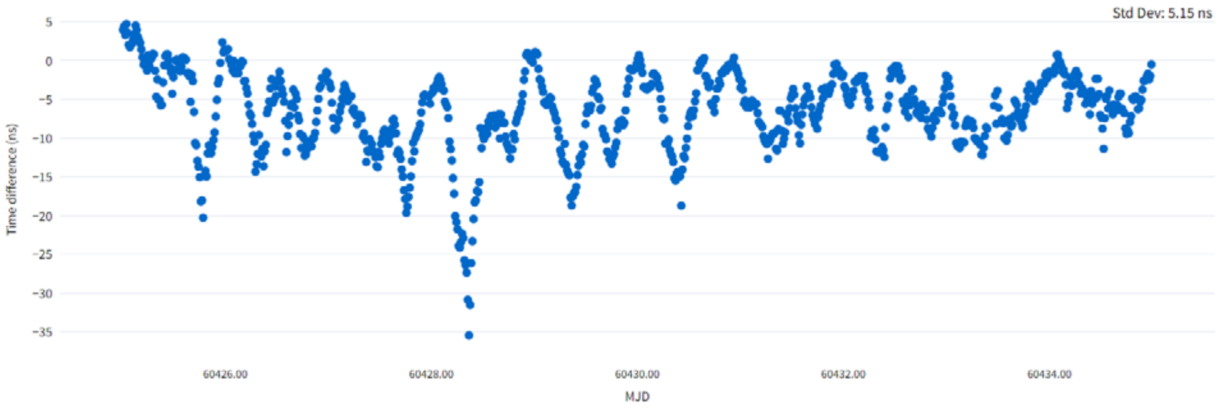


Use case Example: CV with different frequencies

Single frequency (L1P)

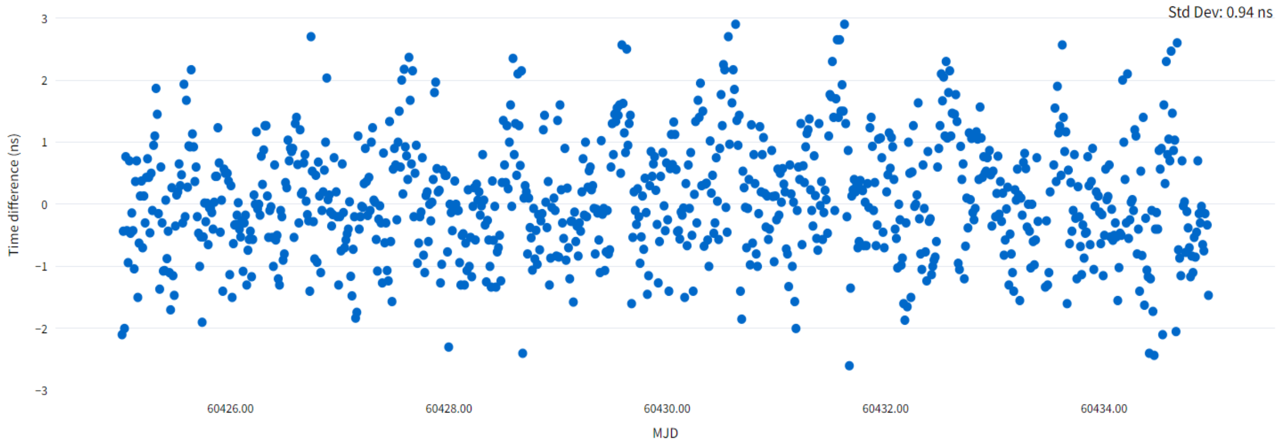
GPS Common-View link[redacted](L1P) -[redacted](L1P)
(Each point is average of differences between refsys values of all common satellites at each epoch)

GPS All-in-View link UTC[redacted]) (L1P) - UTC[redacted] (L1P)
(Each point is the difference of the average weighted refsys of all satellites in view)

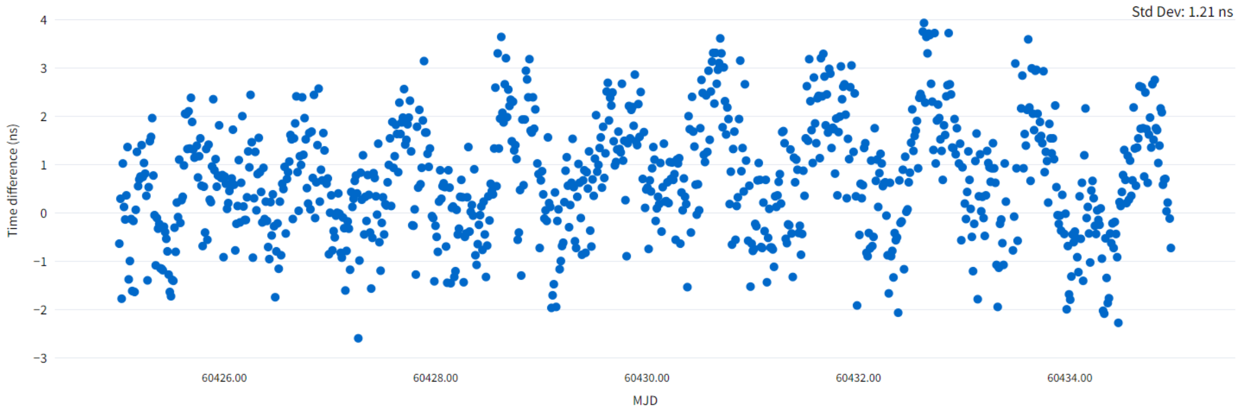


Iono free combination (L3P)

GPS Common-View link[redacted](L3P) -[redacted](L3P)
(Each point is average of differences between refsys values of all common satellites at each epoch)



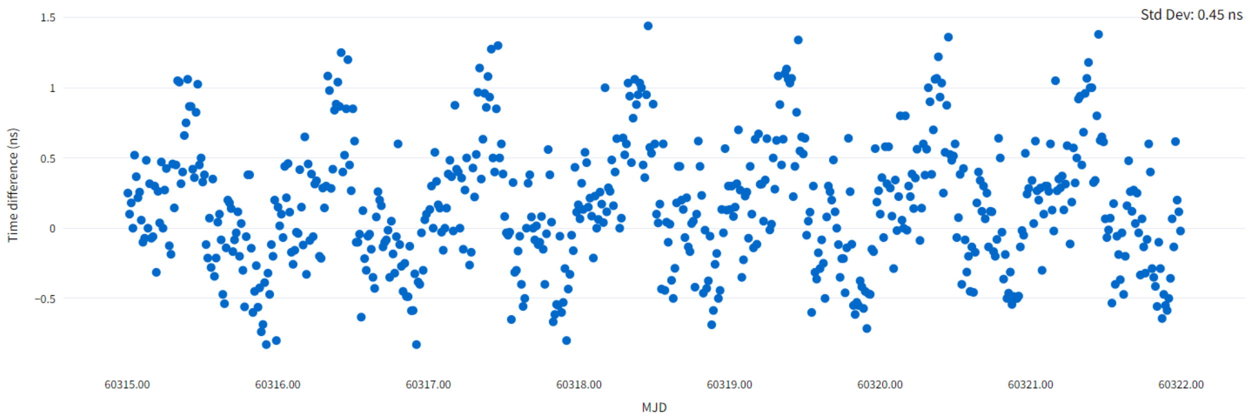
GPS All-in-View link UTC[redacted]) (L3P) - UTC[redacted](L3P)
(Each point is the difference of the average weighted refsys of all satellites in view)



Use case Example: CV & AV with Same receiver itself (atmospheric effects)

Common-View [Same Frequency : Multipath effects]

GPS Common-View link [redacted](L1P) - [redacted](L1C)
(Each point is average of differences between refsys values of all common satellites at each epoch)

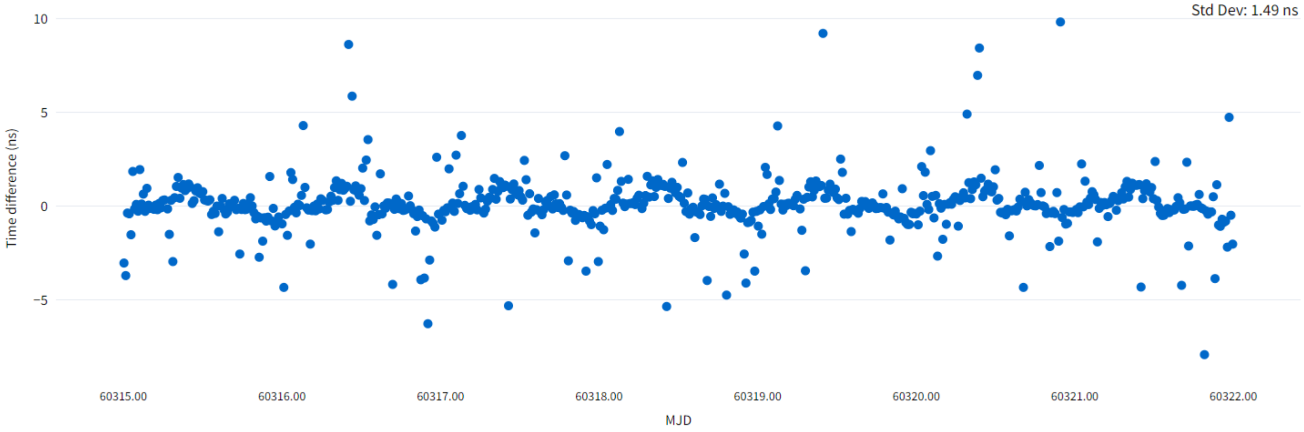


Common –View [different Frequencies : Iono effect]

GPS Common-View link [redacted](L1P) - [redacted](L2P)
(Each point is average of differences between refsys values of all common satellites at each epoch)

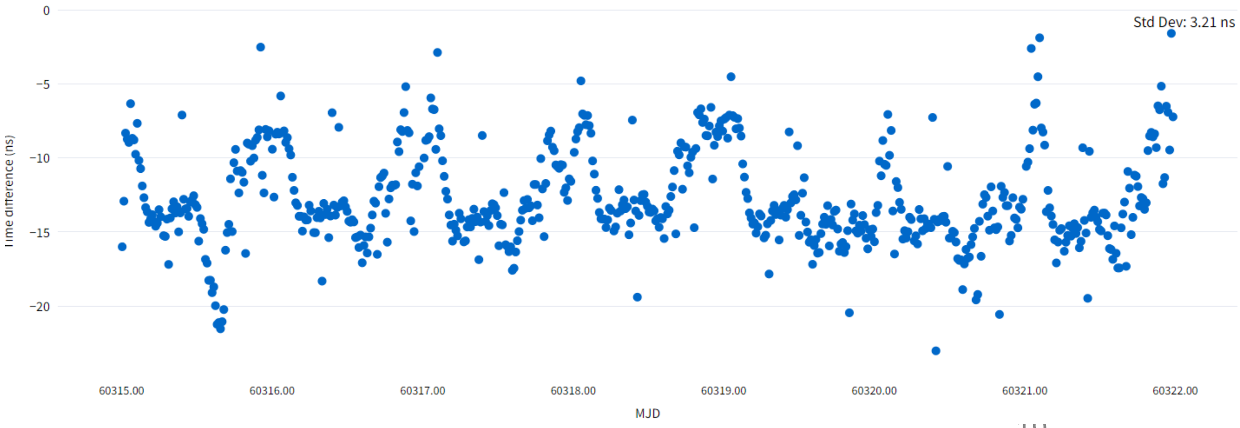
All-in-View [Same Frequency : Multipath effects]

GPS All-in-View link UTC([redacted]) (L1P) - UTC([redacted]) (L1C)
(Each point is the difference of the average weighted refsys of all satellites in view)



All-in-View [different Frequencies : Iono effect]

GPS All-in-View link UTC([redacted]) (L1P) - UTC([redacted]) (L2P)
(Each point is the difference of the average weighted refsys of all satellites in view)



Use cases of CGGTTS Analyser and execution steps (1)

Monitor the Performance of the UTC(k)

a. **Jump in Time Scale**: Jump in weighted Refsys data w.r.t all the constellations at that point of time
b. **Jump in the GNSS system**: No jump in weighted Refsys data w.r.t other GNSS systems at that point of time
c. **Performance of UTC(k) steering** : Drift correction in weighted Refsys data w.r.t all GNSS systems
d. **Accuracy of UTC(k) w.r.t other UTC(k):** Perform CV or AV methods w.r.t another UTC(k) (if you have access to other UTC(k) data}
e. **Outliers in the time scale data**: Vary the outlier filter, if it exits in all the constellations at same time its an outlier in time scale

Satellite based effect on time link

a. **Effect of selected satellites** on the time transfer link: Choose required Satellite’s(PRN) and perform AV and CV methods
b. Does **one satellite is sufficient for time transfer** ? : Select only one satellite and perform the CV and AV method
c. **Effect of low altitude** satellites on time transfer: Vary the Elevation angle filter and observe the CV and AV links
d. **Outliers in a particular satellite data**: Vary the outlier limit and select the satellite causing outliers in the link

If you have only one time transfer receiver

a. **Atmospheric effects on GNSS signals**: Perform CV and AV with different frequencies (Ex: L1C & L2C or L1C & L2P) of same GNSS system of same receiver of same CGGTTS files
b. **Performance of GNSS w.r.t UTC(k):** Compare the weighted Refsys data for each GNSS system.
c. **Multipath observation**: Perform CV and AV with same frequencies (Ex: L1C & L1P)

Use cases of CGGTTS Analyser and execution steps (1)

Effect of base line and method of time transfer : {short base line < 60 km, long base line > 1000 km}

Perform CV & AV between short and long base line stations to observe the following

a. Why AV is more suitable for long base lines
b. CV or AV which is more suitable for short base line time transfer
c. Check if Iono-free combination (L3P) is more noisy than single frequency (L1C) CV method in case of short base line

Effect of GNSS frequency on time transfer between two receiver stations:

a. Higher frequency has better performance : Perform CV/AV with L1C (1575.42 MHz) and then with L5C(1176 MHz)
b. Why Ionosphere free combination has better performance than single frequency time transfer : Perform CV/AV with single frequency (Ex. L1C/L1P/E1/B1i) and then with Iono-free combination (Ex. L3P/L3E/L3Q/L3B) to see the difference

Receiver calibration

a. Offset in AV/CV plots of the receivers connected to common clock indicates the calibration offset between the receivers

TIME TRANSFER THROUGH GNSS PSEUDORANGE MEASUREMENTS

This course aims at providing knowledge and processing capacity to obtain time transfer through GNSS...

VIEW

Thank you

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