Report from NIST

Bijunath R. Patla

Time and Frequency Division – NIST, Boulder
bijunath.patla@nist.gov

CGSIC, 2022

Report from NIST

National Institute of Standards and Technology
U.S. Department of Commerce

GNSS operations/Time transfer

- New NIST GNSS receiver
- Calibrations
- Subscription-based NIST time service

Scientific research and data analysis

- Exploring fundamental physics using atomic clocks: universality of gravitational redshift, relativistic geodesy

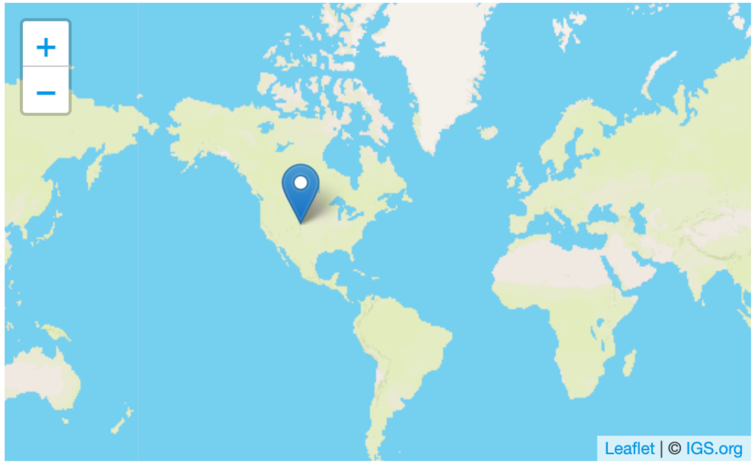
- Topics on more resilient GNSS

June 2022: NIST primary receiver and antenna upgrades

igs.org/imaps/station.php?id=NIST00USA

Overview

Map | Photos



Country/Region	Boulder, United States of America (the)
Latitude, Longitude	39.995, -105.263
Elevation	1648.353 m

Station Information - NIST00USA

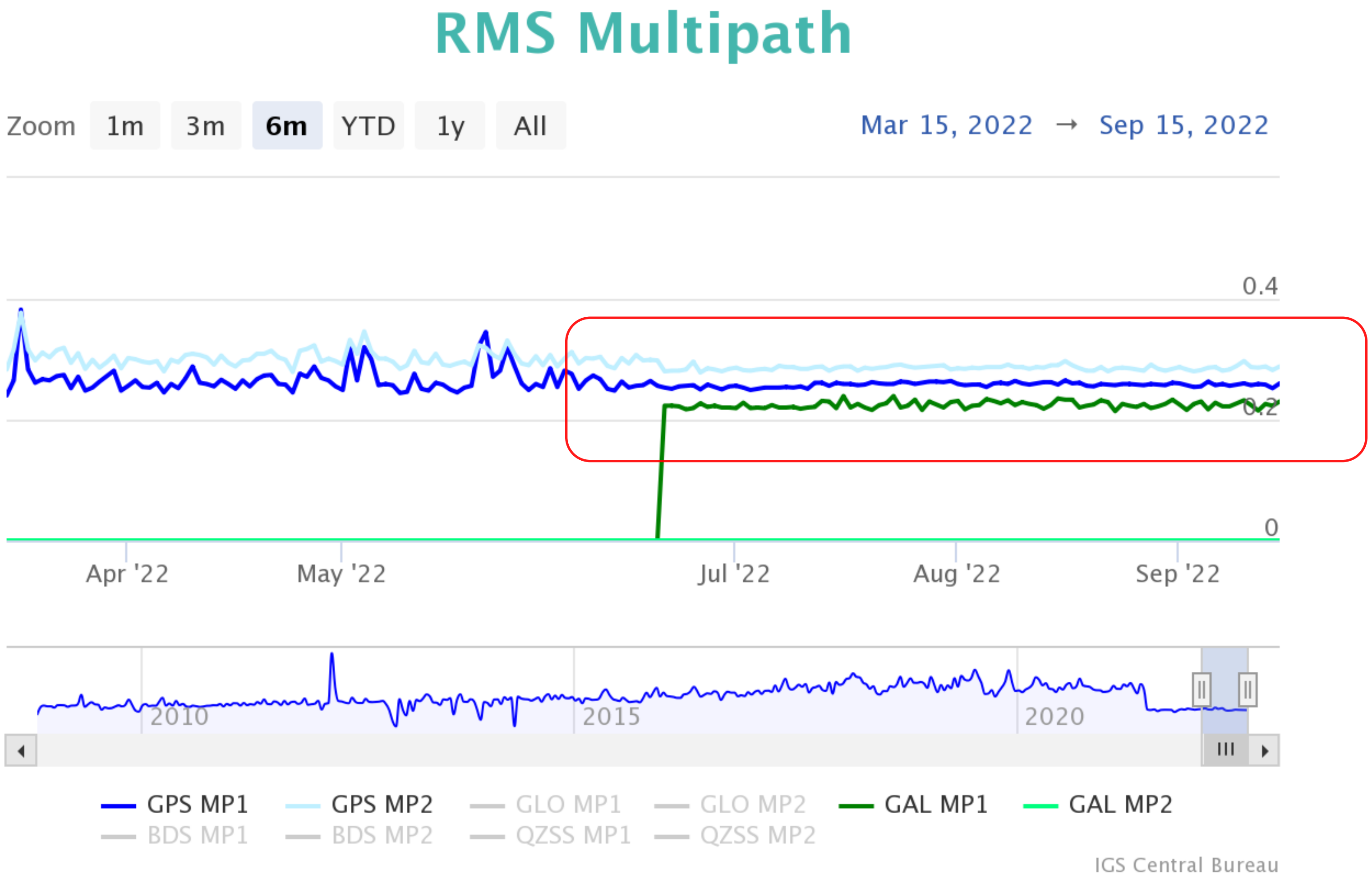
Receiver - Firmware	SEPT POLARX5TR - 5.4.0
Antenna - Radome	NOV750.R4 - NONE
Antenna Calibration	ROBOT
Clock	EXTERNAL H-MASER
Last RINEX Data - Primary Data Center	2022-09-15 (v3) - JPL
Constellation - RINEX	GPS+GLO+GAL+BDS+QZSS+SBAS
Constellation - RealTime	
DOMES Number	49507M002
Nearby Tide Gauge	N/A
Station Log	nist00usa_20220615.log

Analysis Center Usage

	Final	Rapid	Ultra
COD	2022-09-02	2022-09-16	
EMR		2022-09-16	
GFZ	2022-09-09		
JPL	2022-09-02		
MIT	2022-09-02		
NGS	2022-04-30		
SIO	2022-09-02		2022-09-16
USN		2022-06-18	

- June 15, 2022: Results of CAL_ID 1001-2020 implemented
- Internal delays 28.2 ns and 26.3 ns for GPS P1 and P2
- Ref. delay: 93.0 ns

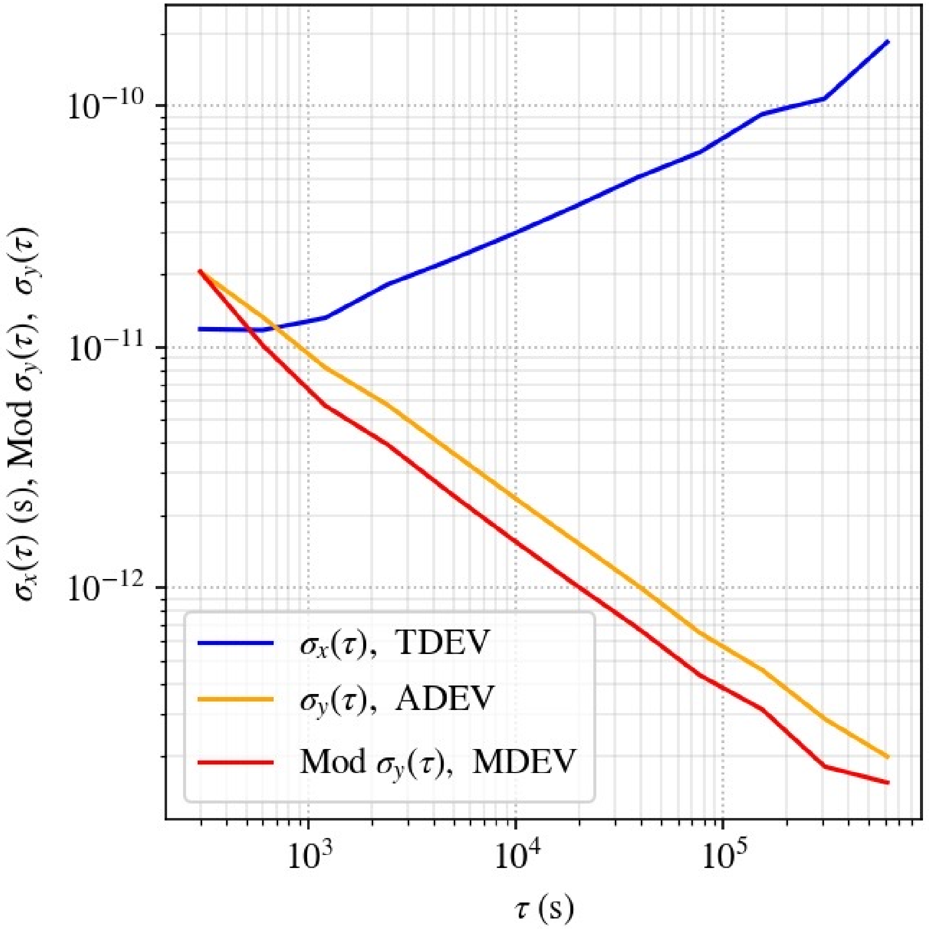
June 2022: NIST primary receiver and antenna upgrades

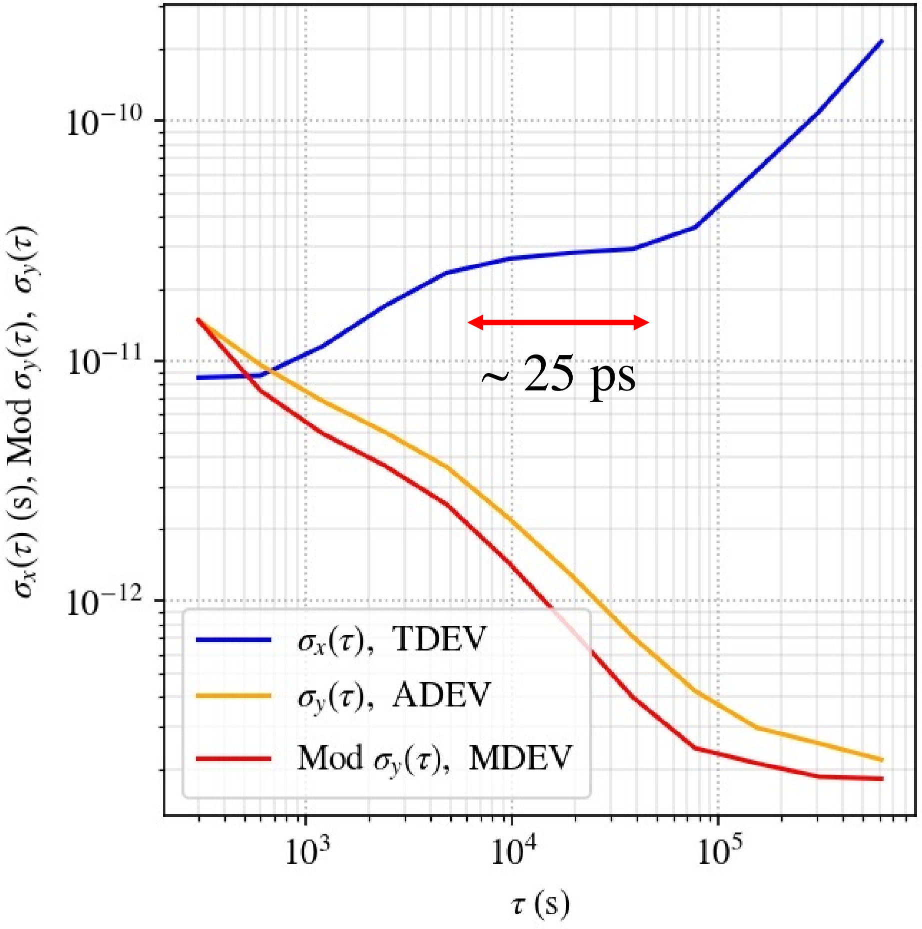


Multipath < 0.30 cm

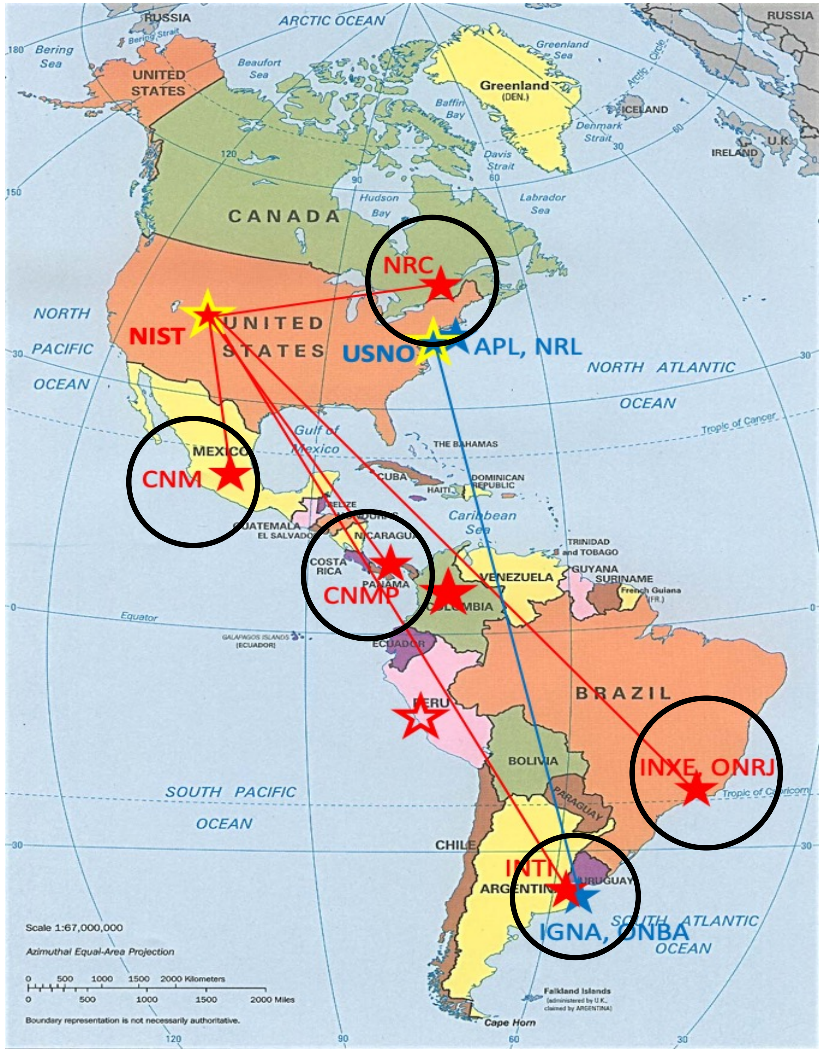
Time Transfer with GPS carrier phase : NIST-PTB

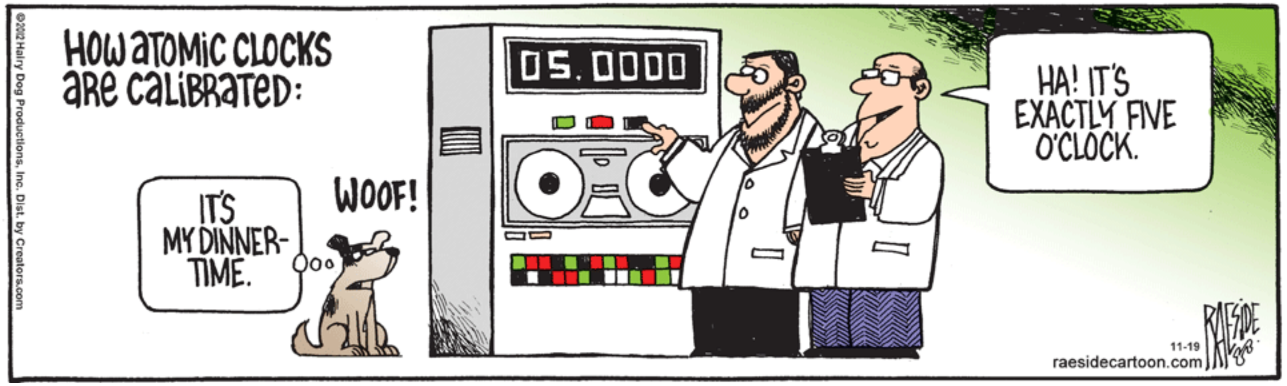
Link stability before and after (two month intervals)





Calibrations update: Group 2 (G2)

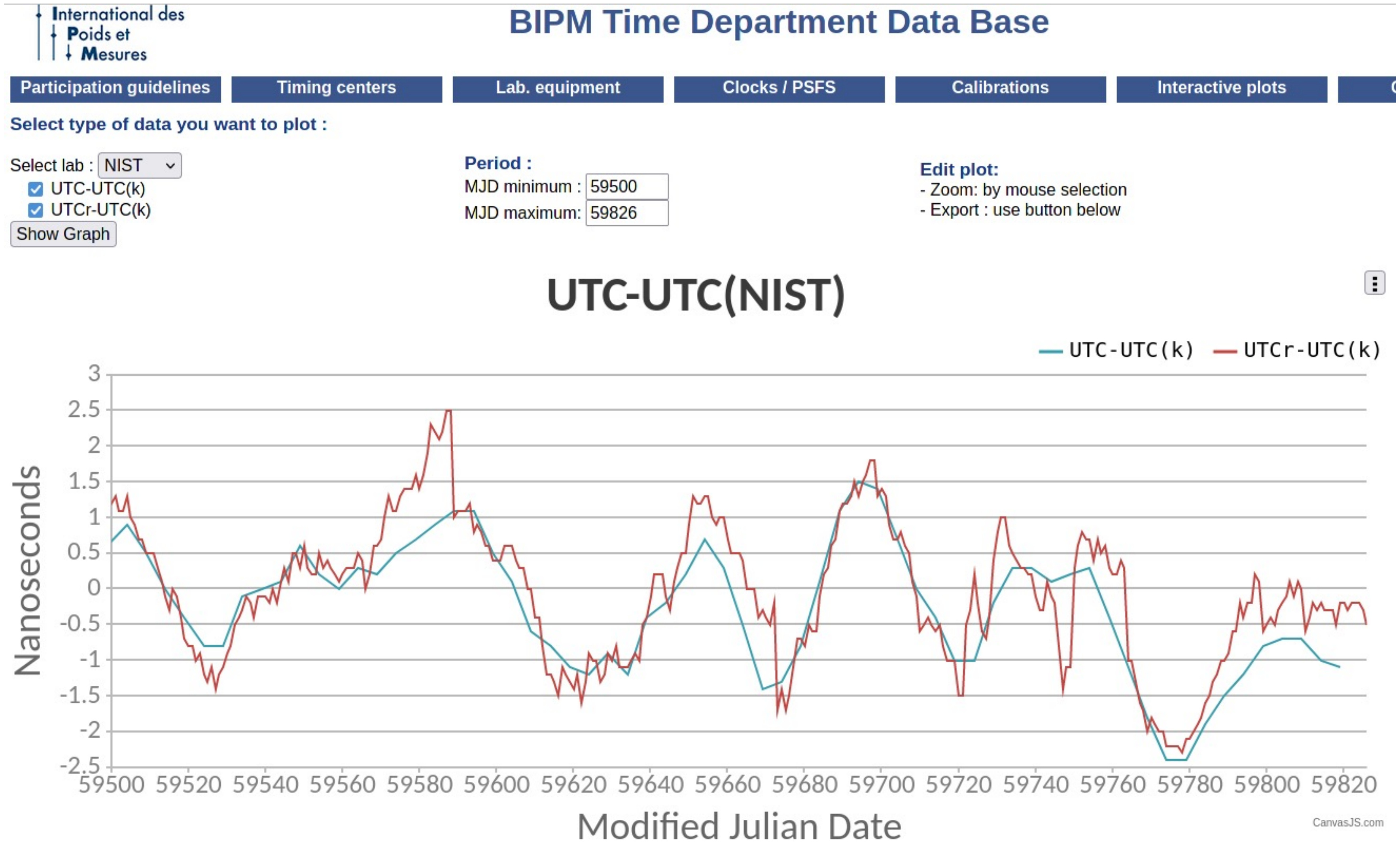




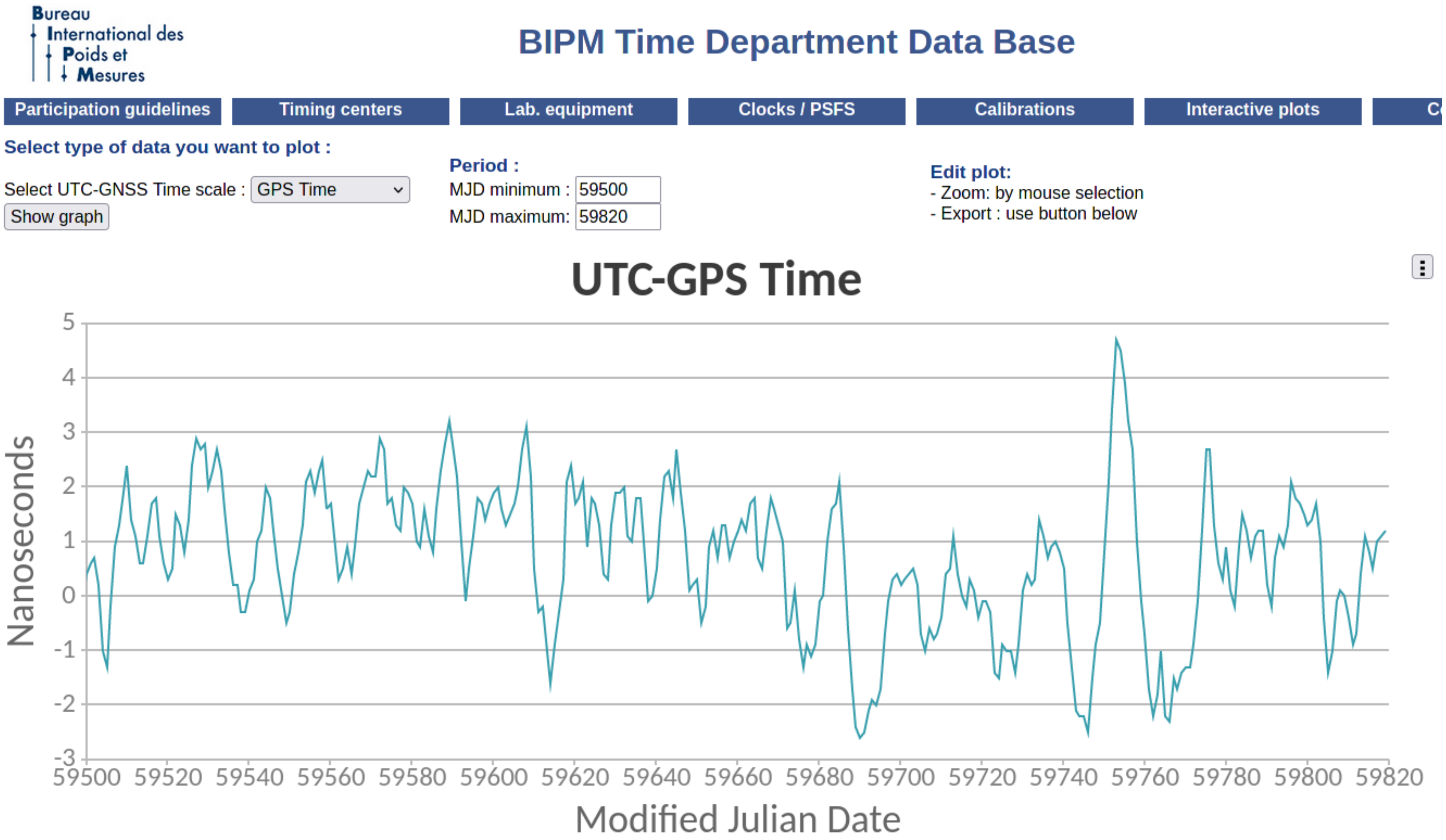
○ Completed

- ✦ NRC : Ottawa, Canada / Cal_Id:1019-2017
- ✦ CNM : Queretaro, Mexico / Cal_Id:1011-2017
- ✦ CNMP : Panama / Cal_Id: 1011-2017
- ✦ INXE,ONRJ: Brazil / Cal_Id: 1012 -2020
- ✦ AGGO,INTI,ONBA: Argentina / Cal_Id: 1014 -2021

Performance: UTC(NIST)



Performance: UTC(NIST)



NIST Time Services

shop.nist.gov/ccrz__ProductList?categoryId=a0lt00000013aE2AAI&cclcl=en_US

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PM/AM Noise

Time/Frequency Measurement Analysis

GNSS independent

TIME AND FREQUENCY

Time over Satellite Special Test

SKU: 78500S

Provide a signal traceable to UTC(NIST) through a two-way link via geo-stationary satellite.

Unit of Measure: Each

TIME AND FREQUENCY

Time Measurement and Analysis Service (TMAS) Bundle

SKU: 76101D

This is a subscription service, purchased in 1, 2, or 3 year increments. Please fill out the Order Request Form and email to the contacts listed under the Contacts tab.

Unit of Measure: Each
Click product to see pricing options.

TIME AND FREQUENCY

Time over Fiber Special Test (Boulder)

SKU: 78110S

Provide a signal traceable to UTC(NIST) from NIST Boulder through a third-party optical fiber to a customer's outside user facility.

Unit of Measure: Each

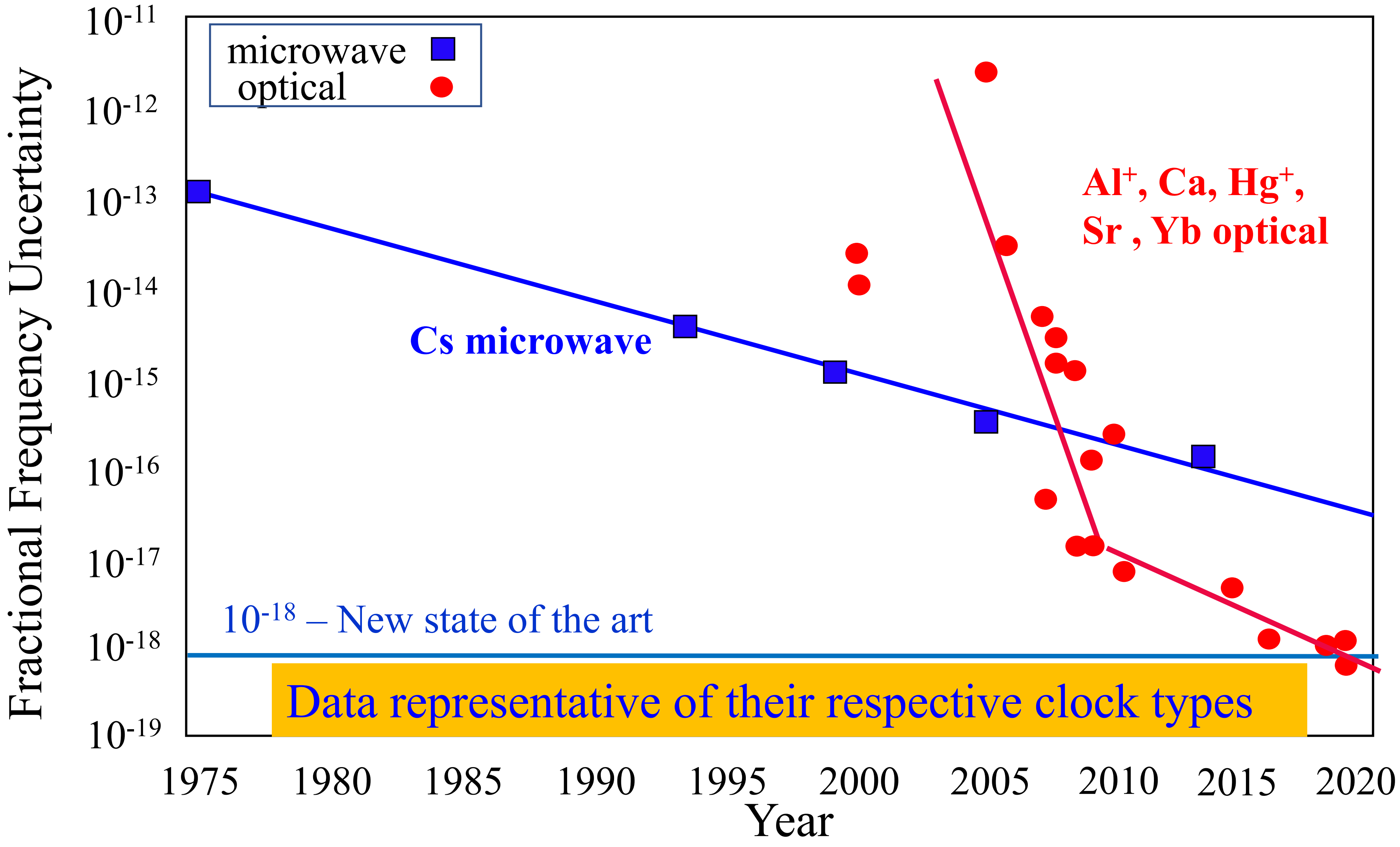
TIME AND FREQUENCY

Time over Fiber Special Test

SKU: 78100S

Provide a signal traceable to UTC(NIST) from NIST Gaithersburg through a third-party optical fiber to a customer's outside user facility.

A brief history of clocks at NIST [slide credit: Chris Oates]



Testing universality of gravitational redshift (UGR)

UGR $\longrightarrow$ Gravity affects the rate of clocks

Fractional frequency shift, $$\frac{\Delta f}{f} = (1+\epsilon)\frac{\Delta\Phi}{c^2}$$

$\Delta\Phi \rightarrow$ gravitational potential difference w.r.t. geoid

$c \rightarrow$ speed of light in vacuum

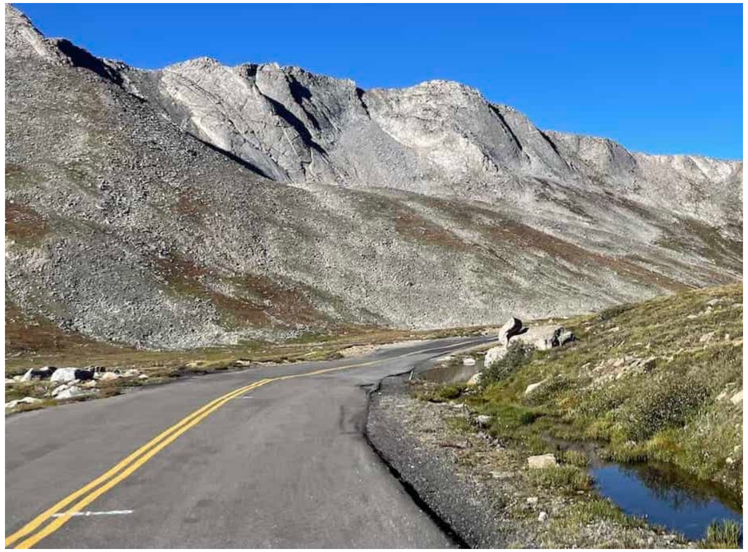
Einstein's general relativity: $\epsilon = 0$

Clocks on Mount Evans, CO / Elevation 14,265ft ?


NEWS COVID-19 SCPMC CALENDAR SCHEDULE ABO

Colorado Springs man becomes fourth person to push a peanut up Pikes Peak with his nose

By Abigail Beckman · Jul. 15, 2022, 11:59 am



Comparing with Gravity Probe A (GPA) [Vessot , R.F.C. et al. 1980, PRL]

	GPA,1976	Clock on Mt Evans, 202?
Height difference (km)	10,000	2.75
Experiment duration (hr)	~ 1	~ 10
Oscillator uncertainty, $\delta\left(\frac{\Delta f}{f}\right)$	10^{-14}	10^{-18}
ϵ (theory)	25 parts per million	6 parts per million
ϵ (measured)	~125 parts per million	~12 parts per million?

Clocks, geoid, geodesy… [in collaboration with Prof. Neil Ashby, CU Boulder]

Gravitational considerations as clocks get better

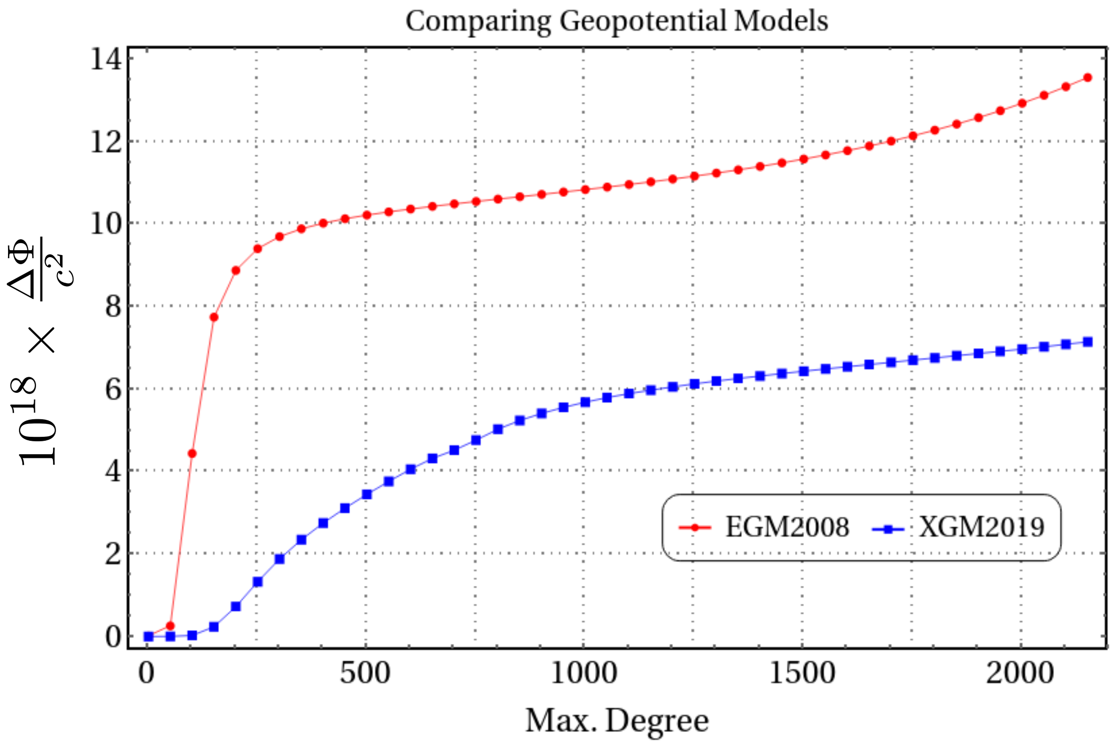
Geoid: Equipotential surface coinciding with the mean sea level

- What is the acceptable precision/uncertainty on the definition of the geoid?
- What is the effect of rising (not very predictable) sea level ?
- Local (short baseline) clock comparisons depend on mapping area under few tens of sq-km with gravimeters, spirit levelling
- Fractional frequency uncertainty for locations around NIST (2017) ~ 10^{-19}
- All measurements assign an uncertainty of *zero* for pivot (NGS marker) with respect to the geoid

Clocks, geoid, geodesy… [in collaboration with Prof. Neil Ashby, CU Boulder]

Consider the NGS marker Q407 at NIST:

The equivalent fractional frequency due to uncertainty on Q407 with respect to the geoid using the latest geopotential model $\sim 7 \times 10^{-18}$



In order to compare distant clocks, one may have to first use very precise clocks for accurately determining the geoid (chronometric levelling).

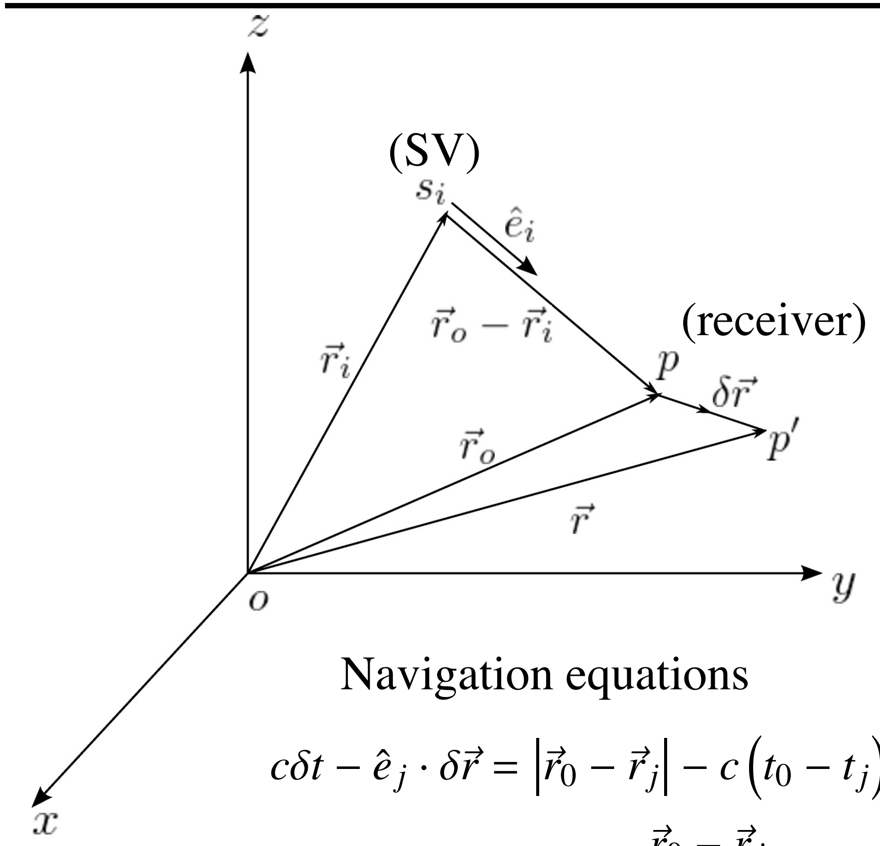
Redefinition Options: 3 Possibilities

[slide credit: Elizabeth Donley]

1. Define based on the frequency of a transition in one atom. Other atomic transitions would be "secondary representations"
   + Already done with cesium
   + Easy to describe and understand
   – The "best atom" could be different in a few years
   – Based on the chosen atom, labs might have to build a new standard once a decision is made
2. Define a standard based on the weighted average of several transitions
   + Could include many atoms whose weights adapt over time based on performance
   + Would reduce risk to labs since all standards could be used
   – Complex and hard to explain in simple terms
3. Define frequency by fixing the value of another fundamental constant, for example, the Rydberg constant
   + Would be consistent with the other definitions of the SI units
   – Would degrade the accuracy of the definition (uncertainty in R_∞ is 2×10^{-12})

Resilient GNSS timing by including doppler data: spoofing

[in collaboration with Prof. Neil Ashby, CU Boulder]



Navigation equations

$$c\delta t - \hat{e}_j \cdot \delta\vec{r} = \left|\vec{r}_0 - \vec{r}_j\right| - c\left(t_0 - t_j\right), \quad \text{where}$$

$$\hat{e}_j = \frac{\vec{r}_0 - \vec{r}_j}{\left|\vec{r}_0 - \vec{r}_j\right|}.$$

Doppler data

Navigation equations with doppler terms

$$\left(\frac{\left(\vec{v}_0 - \vec{v}_j\right) - \hat{e}_j \cdot \left(\vec{v}_0 - \vec{v}_j\right)\hat{e}_j}{\left|\vec{r}_0 - \vec{r}_j\right|}\right) \cdot \delta\vec{r} + \hat{e}_j \cdot \delta\vec{v} = c\left(\frac{\Delta f}{f}\right)_j - \left(\vec{v}_0 - \vec{v}_j\right) \cdot \hat{e}_j$$

Resilient GNSS timing by including doppler data: spoofing

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Pros:

- Can be used to detect excursions using single point solutions
- Can validate excursions in the orbital parameters as determined from the navigation message
- Method can be applied to all constellations

Cons:

- Expensive (computing power)
- Not all receivers provide doppler information

Would be very useful if navigation messages are made available to the user by a trusted source that is independent of the receiver.

Acknowledgement

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Chris Oates
Jeff Sherman

Contact information:

NIST time and frequency division chief: Elizabeth Donley (elizabeth.donley@nist.gov)

NIST time services: Mike Lombardi (michael.lombardi@nist.gov)

Optical frequency standards: Chris Oates (chris.oates@nist.gov)

NIST timescale: Jeff Sherman (jeff.sherman@nist.gov)

Discussion topic

Would users benefit from a real-time GPS navigation message made available on a secure website?

Any strong objections?

Suggestions? Use cases?