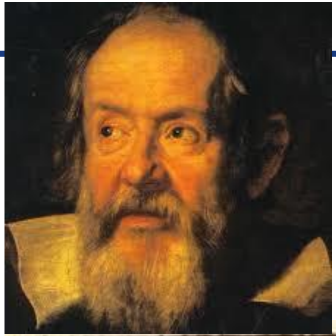
GNSS and UTC: a mutual benefit

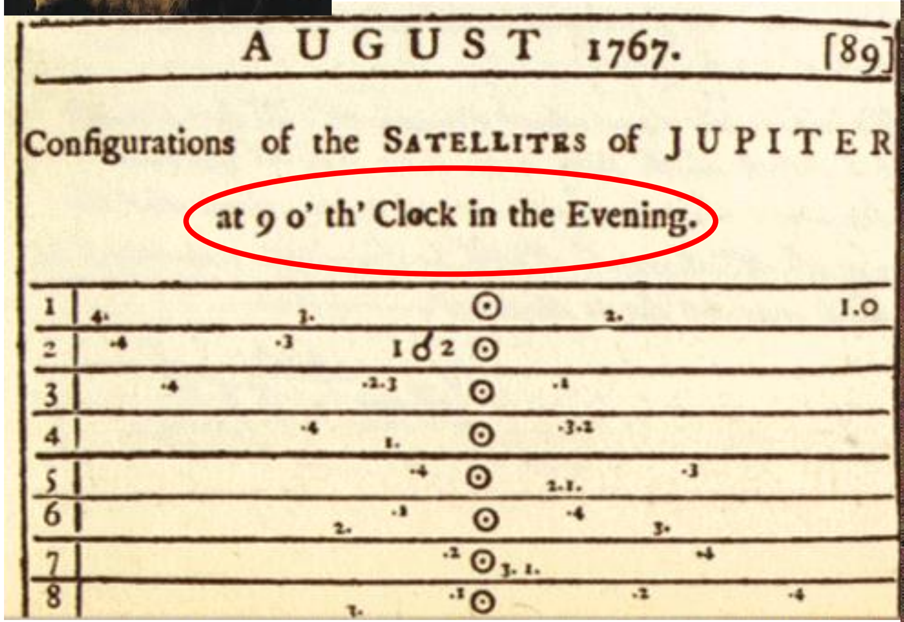
Patrizia Tavella

Director of the Time Department

Bureau
International des
Poids et
Mesures

Positioning and Timing

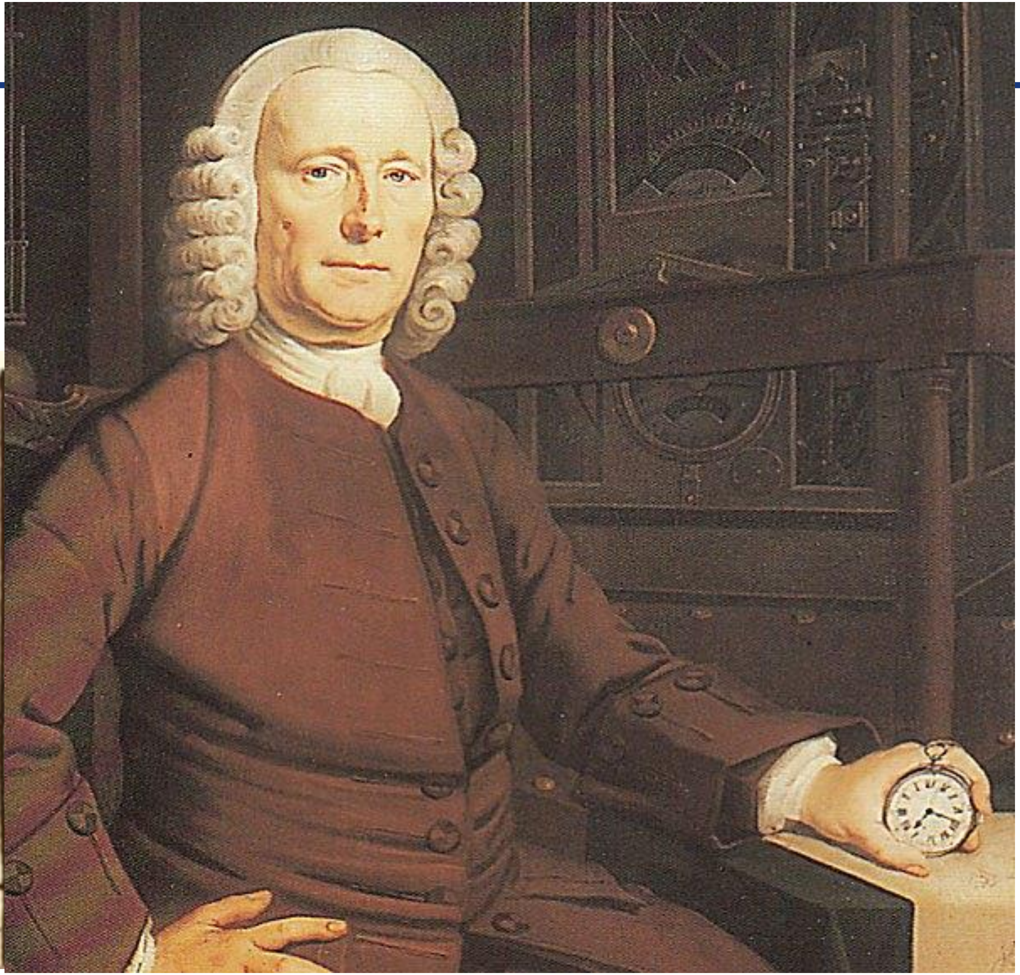




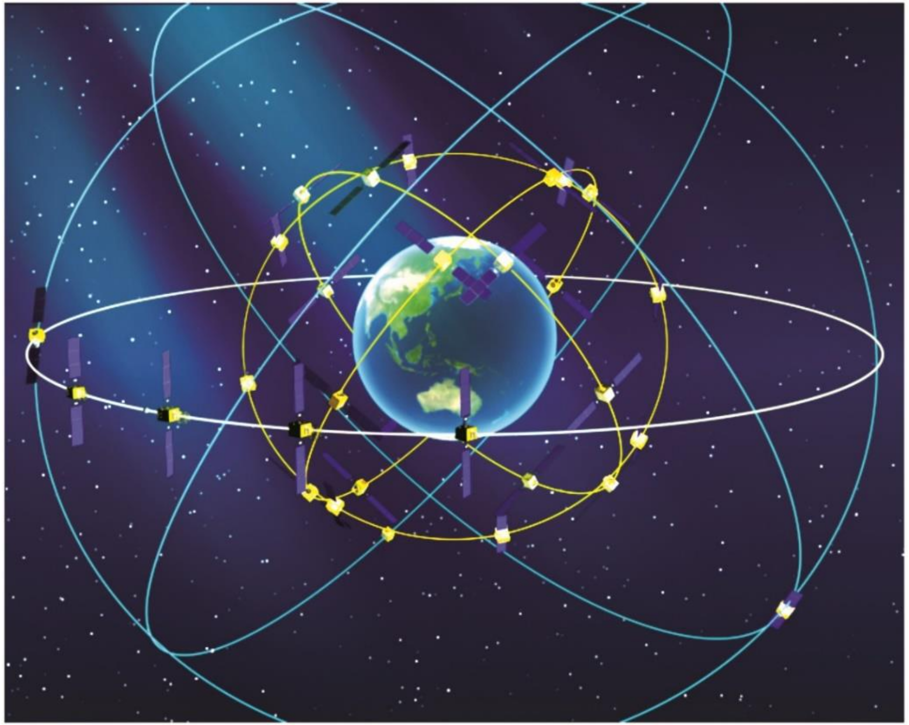
AUGUST 1767. [89]

Configurations of the SATELLITES of JUPITER

at 9 o' th' Clock in the Evening.



Navigation by "moon" observation and time measurement



Beidou.gov.cn

Measuring **a time of flight**, with atomic clocks, we estimate position

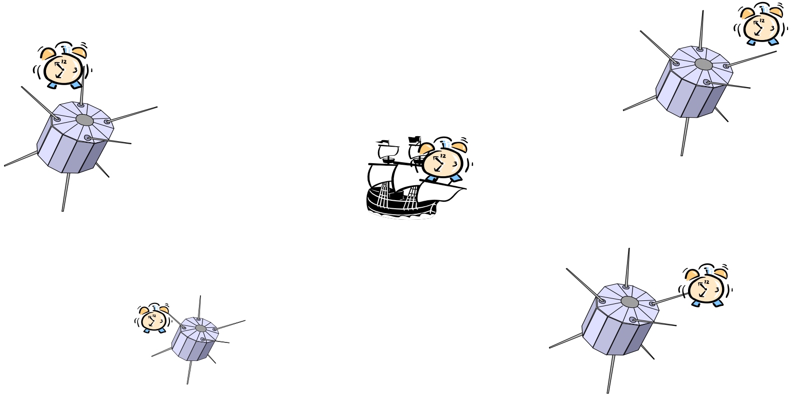
An error in time of

1 nanosecond = 10^{-9} second

correspond at least to an

error in positioning of **30 centimetres**

All the system clocks have to be highly synchronised to a reference time scale

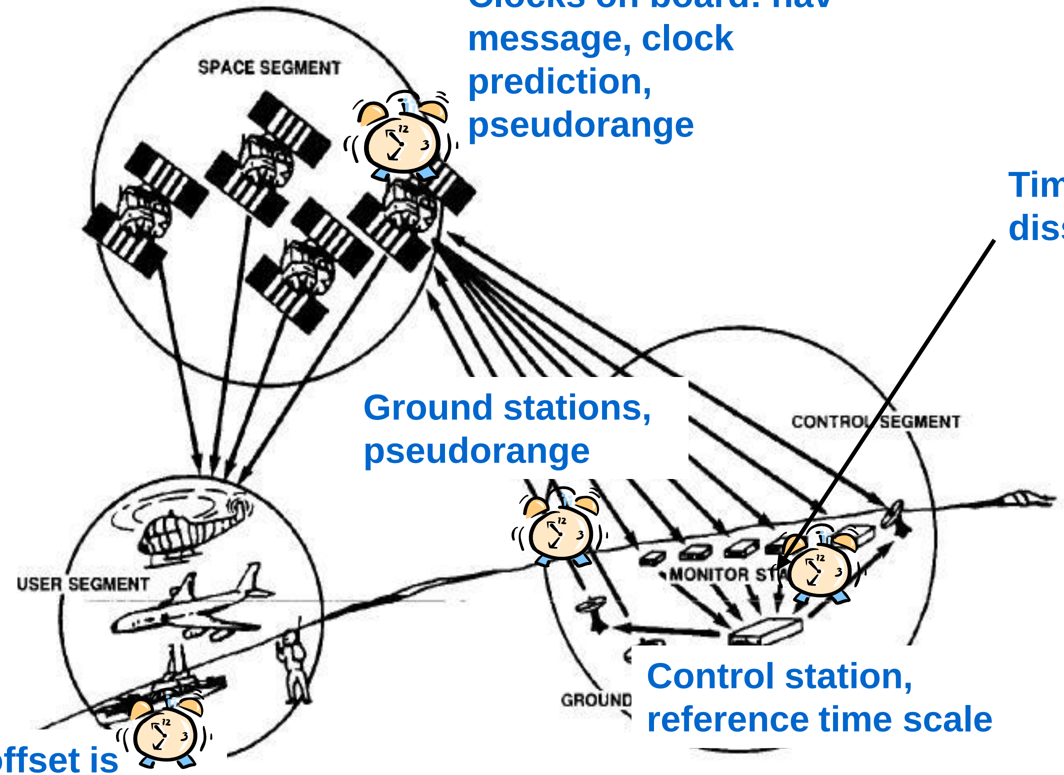


If they are also synchronised to the “international standard time UTC”, the GNSS system can offer the service of

Time dissemination

GNSS: Where are the clocks and why?

Clocks on board: nav message, clock prediction, pseudorange



Time dissemination

Ground stations, pseudorange

Universal Time Coordinated by the Bureau International des Poids et Mesures

Control station, reference time scale

The user clock offset is estimated as additional 4th unknown

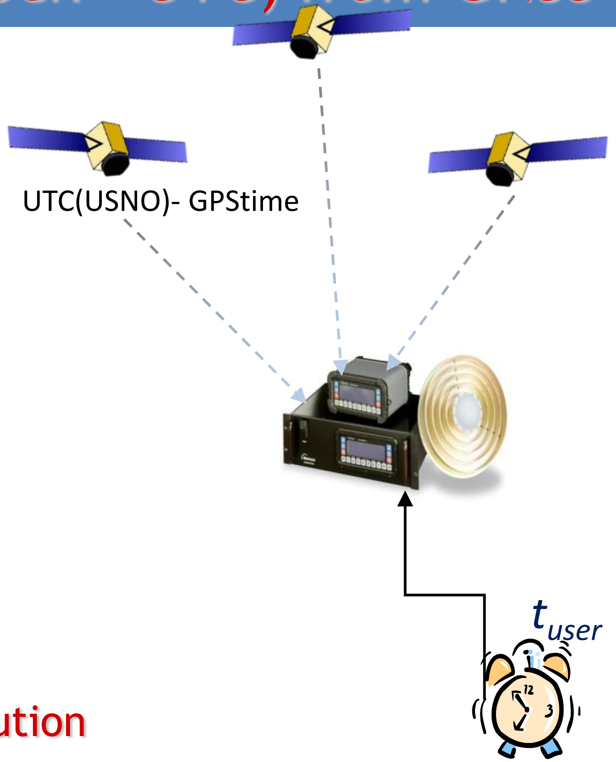
Time metrology is fundamental in navigation systems

The user can get an estimation of (local clock - UTC) from GNSS

The Navigation Message transmits a prediction of $(UTC - GNSS\ time)_{GNSS}$ as for example the predicted $(UTC(USNO) - GPStime)_{GPS}$

- GNSS receiver and its antenna
  - Timing receiver
  - Fixed (and known) location

- External Local clock reference t_{user} for receiver
  - Atomic clocks (H-maser, Cesium…)
  - Physical time scale UTC(k)



the difference Local clock – GNSS time =

= $(t_{user} - GPS\ time)$ is estimated in the navigation solution

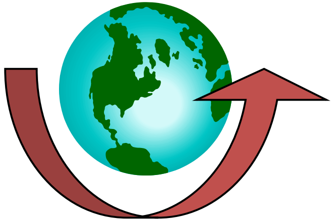
$$(t_{user} - GPS\ time) - (UTC(USNO) - GPS\ time)_{GPS} = t_{user} - UTC(USNO\ )_{GPS}$$

A navigation system is also a mean for

UTC time dissemination

What is the Universal Time Coordinated?

For centuries



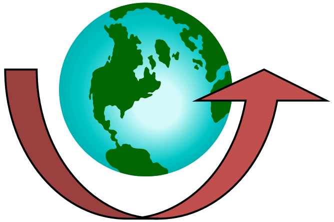
The time was given by the rotating Earth

on which we set the clock

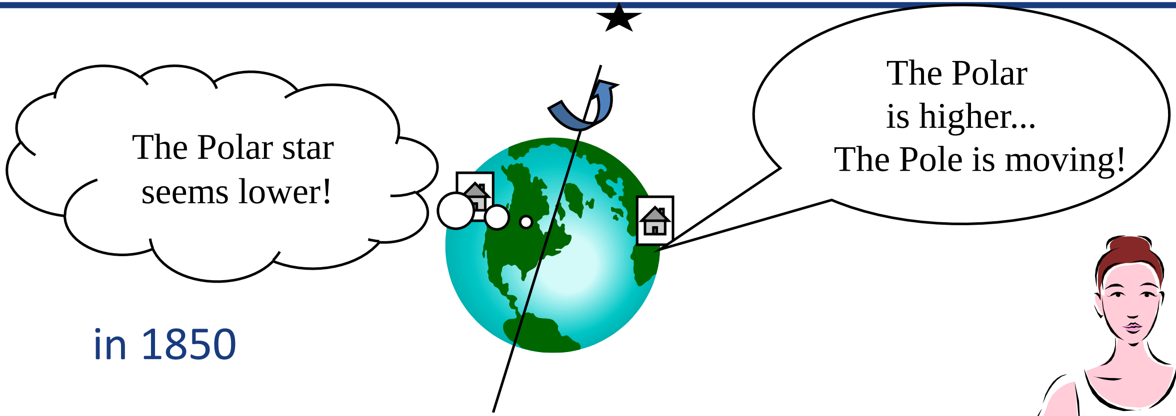
From 1967

The time is given by atomic clock

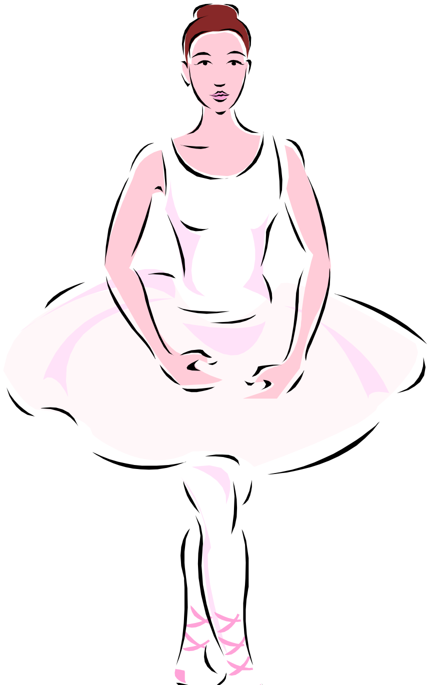
used to study Earth rotation



The rotation of the Earth is not regular



in 1850



...in summer we spin faster

- A. Scheibe, 1936 Berlin
- N. Stoyko, 1936 Paris (BIH)

with crystal clock the day was measured shorter of about 1.2 ms

Variations in the duration of the day

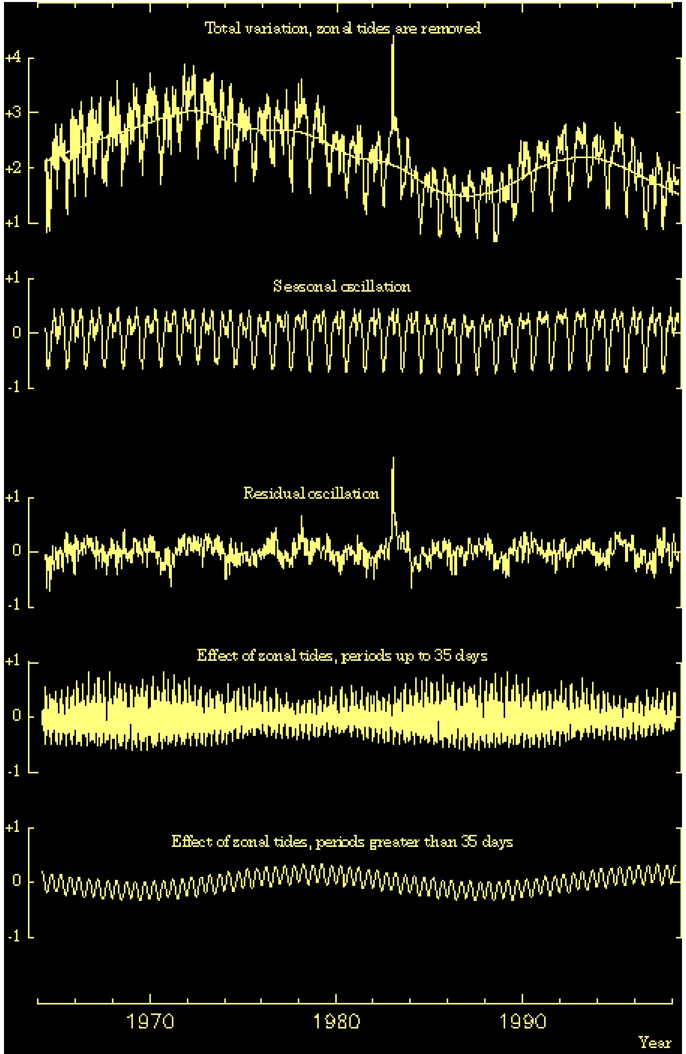
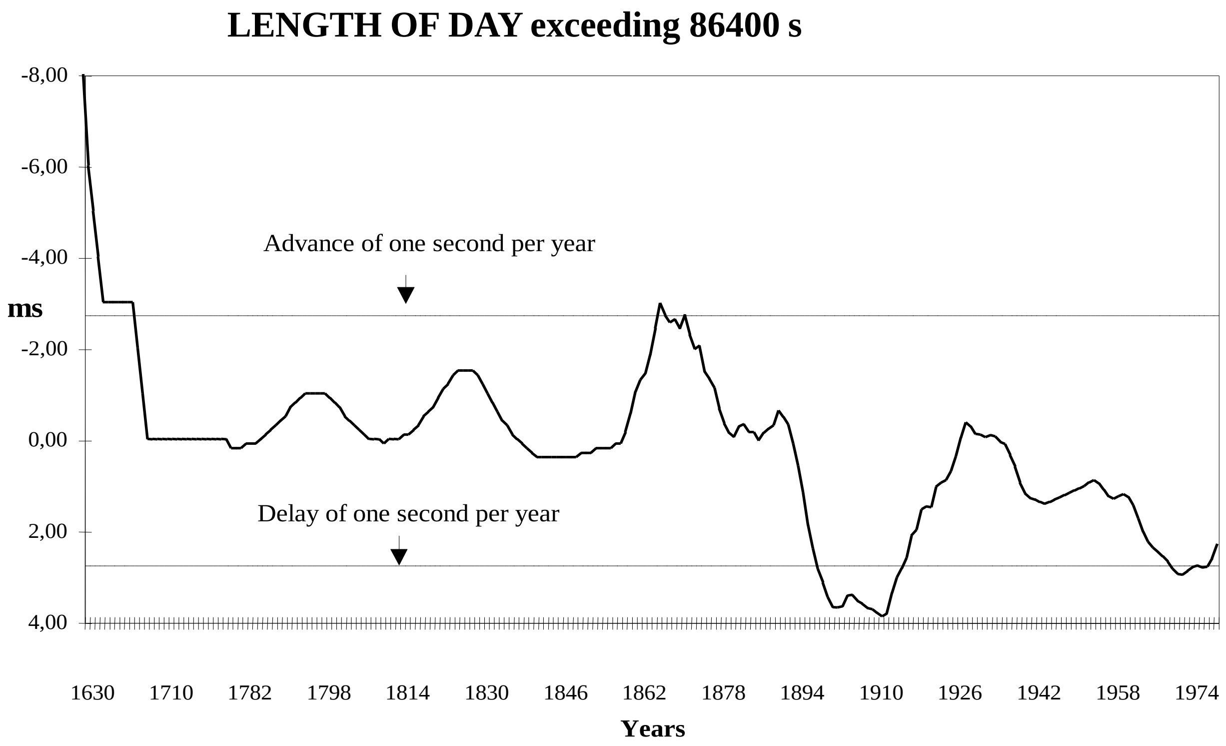


Figure II-5: Variations in the duration of the day

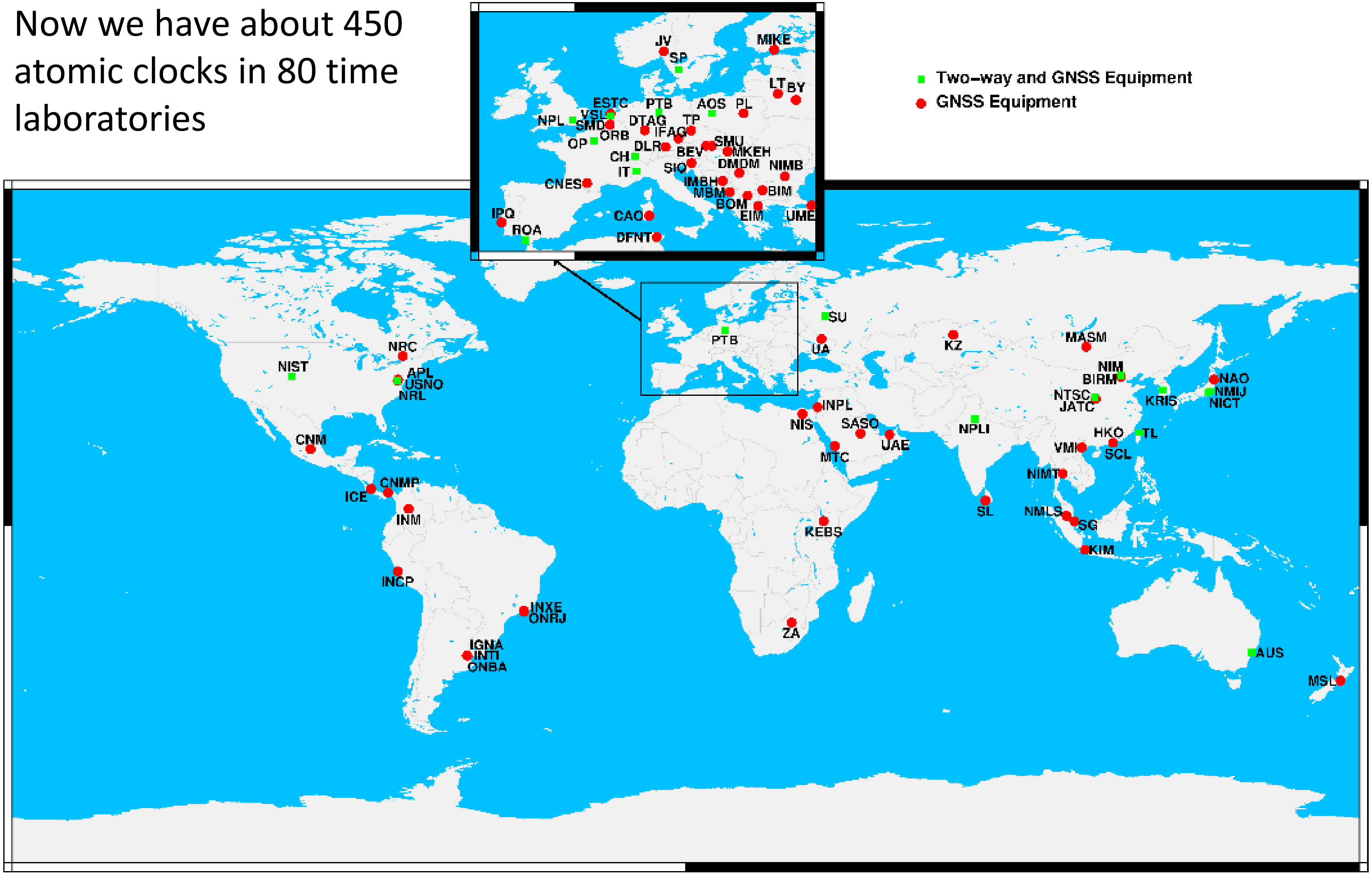
International Earth Rotation and Reference Systems Service

http://www.iers.org

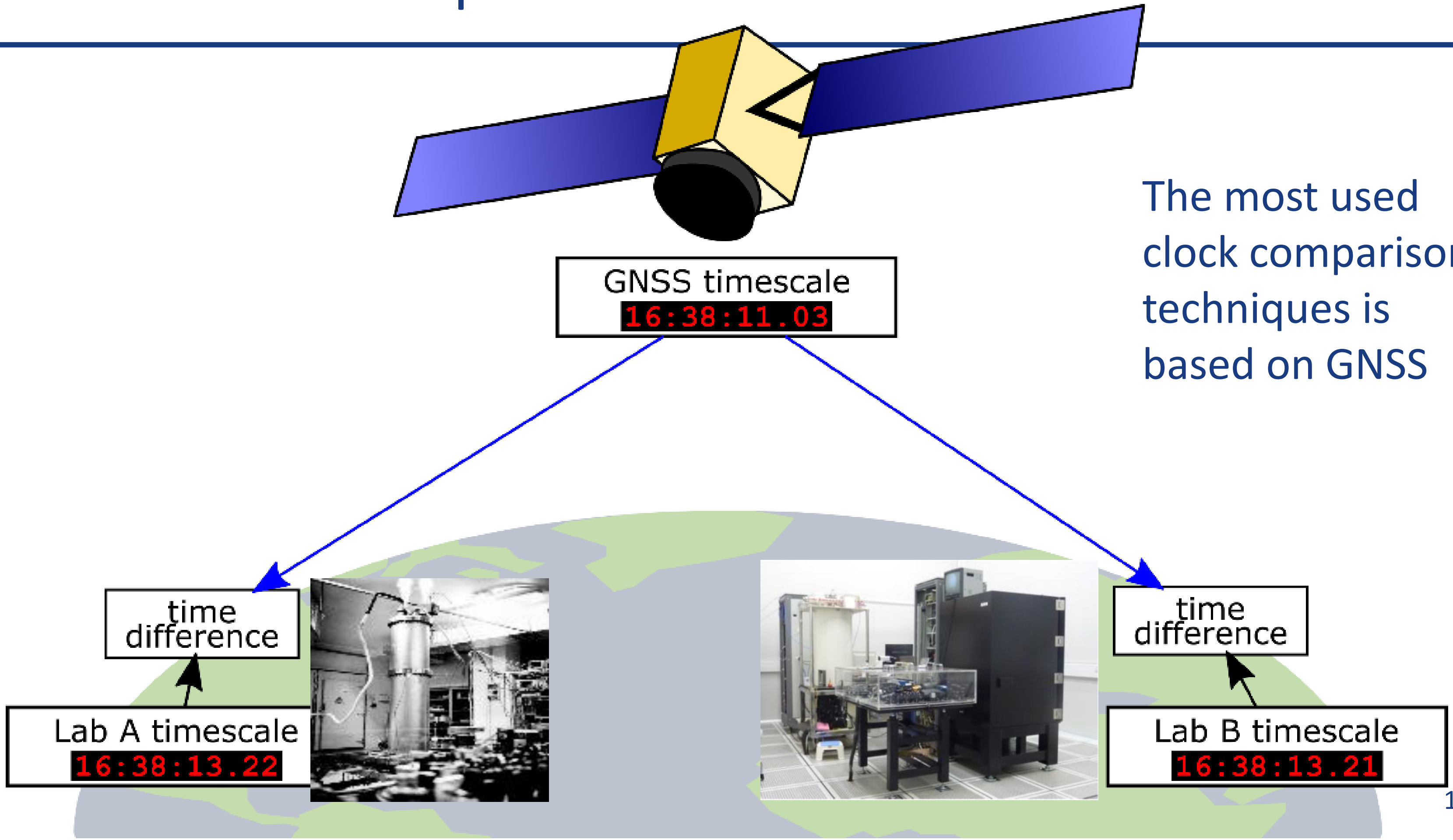
Secular slowing down: the rotational day is getting longer



Now we have about 450 atomic clocks in 80 time laboratories

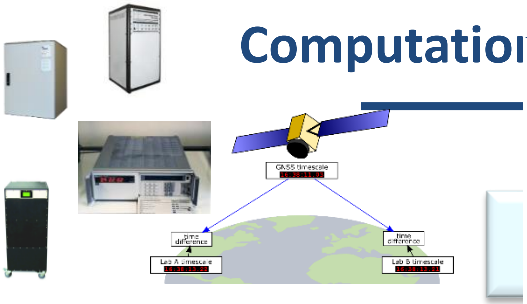


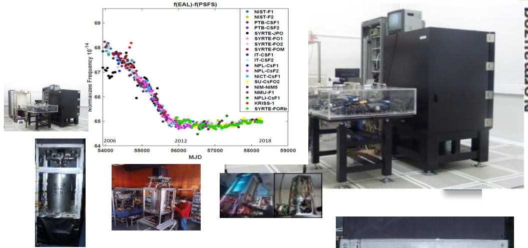
Clocks need to be compared

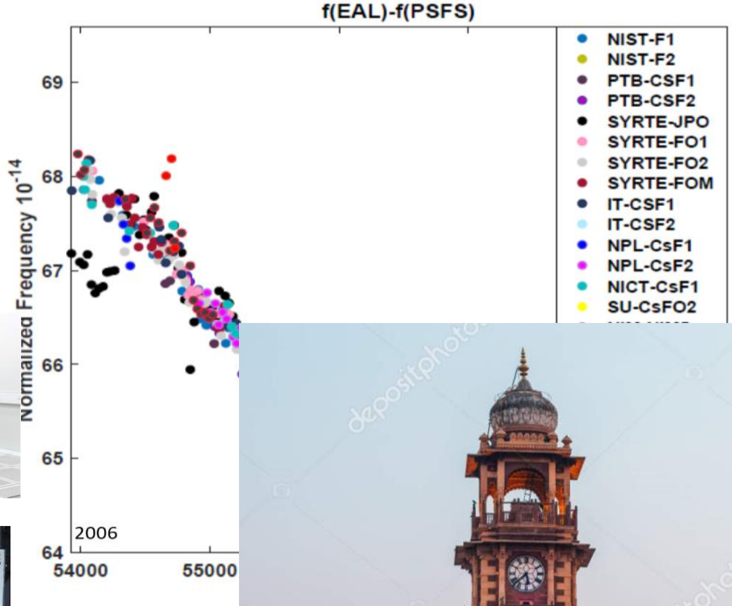


The most used clock comparison techniques is based on GNSS

Computation of UTC (monthly) at the BIPM







age EAL

ng TAI

Echelle Atomique Libre
freq stability
3×10^{-16}
@ 30-40 days

International Atomic Time
freq accuracy $\sim 10^{-16}$

Atomic time is pe… cking
is the angular po… the E…
When is it noon?

Some users need to know the relationship between the Universal Time UT1 (rotational) and the Atomic Time

Coordinated

in 1975

The Universal Coordinated Time (UTC) is a trade-off defined with the same time unit as TAI but with insertion of additional leap second to keep the agreement with the rotation of the Earth

TAI-UTC = n seconds $\qquad n = 0, \pm 1, \pm 2, \ldots$

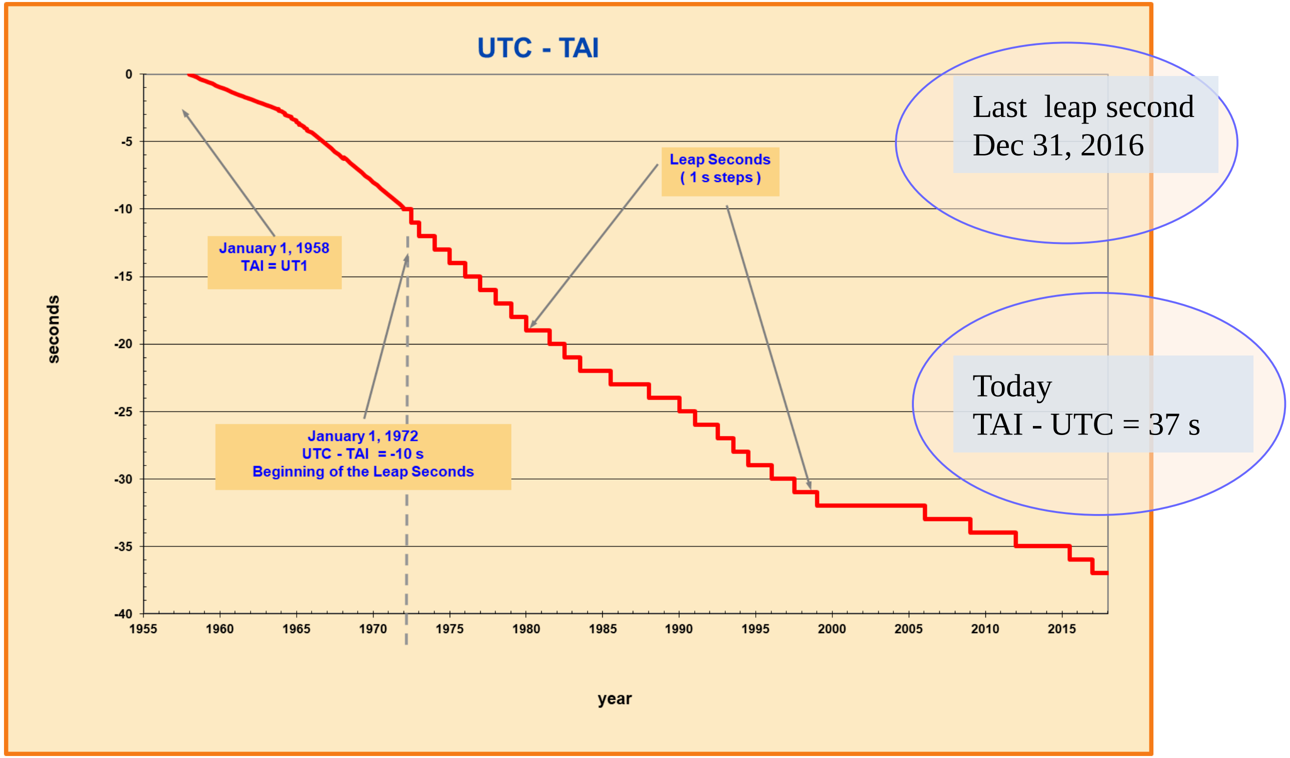
$$|UT1-UTC| < 0.9 \text{ s}$$

Universal Time UT1 is related to the angular position of the Earth

Universal Coordinated Time and leap seconds

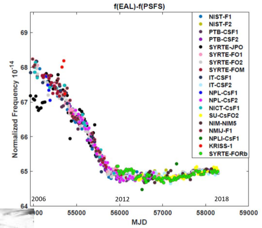
When the rotation of the Earth (UT1 time scale) reaches a one second difference with respect to atomic time TAI, one second is added to maintain the reference time scale UTC in agreement with the Earth's rotation

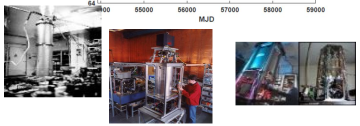
|UTC - UT1| < 1 second

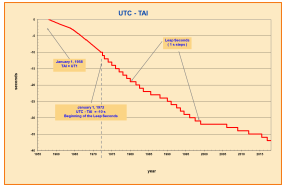


UTC = TAI + leap seconds

Computation of UTC (monthly) at the BIPM







≈ 450 atomic clocks in 80 laboratories — weighted average → **EAL**

≈ 10 primary and secondary frequency standards — frequency steering → **TAI**

Measurement of Earth's rotation (IERS) — leap seconds → **UTC**

Echelle Atomique Libre
freq stability
3 x 10^{-16}
@ 30-40 days

International Atomic Time
freq accuracy ~10^{-16}

Coordinated Universal Time

[UTC - UTC(k)] **BIPM *Circular T***

At the Bureau International des Poids et Mesures the Universal Coordinated Time is produced

Bureau International des Poids et Mesures

CIRCULAR T 376

ISSN 1143-1393

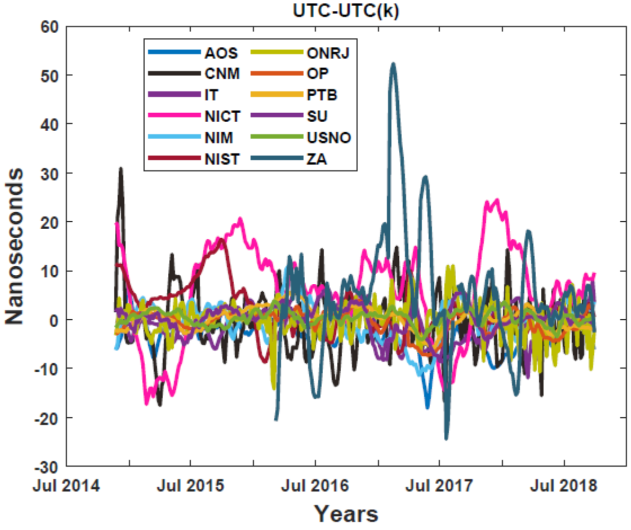
2019 MAY 10, 09h UTC

BUREAU INTERNATIONAL DES POIDS ET MESURES
THE INTERGOVERNMENTAL ORGANIZATION ESTABLISHED BY THE METRE CONVENTION
PAVILLON DE BRETEUIL F-92312 SEVRES CEDEX TEL. +33 1 45 07 70 70 tai@bipm.org

The contents of the sections of BIPM *Circular T* are fully described in the document " Explanatory supplement to BIPM Circular T " available at ftp://ftp2.bipm.org/pub/tai/publication/notes/explanatory_supplement_v0.2.pdf

1 - Difference between UTC and its local realizations UTC(k) and corresponding uncertainties. From 2017 January 1, 0h UTC, *TAI-UTC* = 37 s.

Date 2019 0h UTC			MAR 27	APR 1	APR 6	APR 11	APR 16	APR 21	APR 26	Uncertainty/ns		
		MJD	58569	58574	58579	58584	58589	58594	58599	u_A	u_B	u
Laboratory *k*					[*UTC-UTC*(*k*)]/ns							
AOS	(Borowiec)	123	-1.9	-2.2	-2.7	-2.0	-2.7	-2.4	-4.3	0.7	7.6	7.7
APL	(Laurel)	123	0.0	-0.8	0.4	1.4	3.5	6.4	3.2	0.4	11.2	11.2
AUS	(Sydney)	123	-132.5	-138.0	-140.3	-135.1	-139.9	-152.1	-155.9	0.4	6.4	6.4
BEV	(Wien)	123	3.8	-3.3	-15.0	-24.9	-35.2	-47.7	-60.1	0.4	3.1	3.2
BIM	(Sofiya)	123	-	-	-	-	-	-	-			
BIRM	(Beijing)	123	7.4	3.0	0.5	1.4	3.3	4.4	6.7	0.7	3.1	3.2
BOM	(Skopje)	123	-1819.6	-1842.1	-1860.9	-1883.4	-1905.8	-	-2029.5	1.5	8.3	8.5
BY	(Minsk)	123	1.5	1.8	1.4	0.6	0.2	0.1	0.4	1.5	12.2	12.3
CAO	(Cagliari)	123	-10613.4	-10720.3	-10825.8	-	-	-	-	1.5	20.0	20.1
CH	(Bern-Wabern)	123	-14.0	-11.7	-10.0	-8.6	-10.4	-9.3	-8.7	0.5	1.9	2.0
CNES	(Toulouse)	123	3.1	-0.7	-4.1	-6.8	-6.3	-7.1	-1.9	0.4	4.5	4.5
CNM	(Queretaro)	123	-2.2	-4.3	-0.3	8.3	5.6	3.2	-0.5	2.5	11.2	11.5
CNMP	(Panama)	123	-0.1	-11.6	-1.7	0.4	14.6	14.4	17.3	0.5	7.4	7.4
DFNT	(Tunis)	123	5117.4	5305.3	5480.9	5670.7	5883.0	6119.2	6314.1	0.7	20.0	20.0
DLR	(Oberpfaffenhofen)	123	-	626.2	627.3	637.9	648.6	665.1	674.8	0.7	3.2	3.3
DMDM	(Belgrade)	123	19.1	15.4	11.2	14.1	6.8	5.8	6.7	0.4	3.1	3.2
DTAG	(Frankfurt/M)	123	-187.9	-189.7	-184.6	-182.5	-185.8	-	-182.7	0.4	2.8	2.9
EIM	(Thessaloniki)	123	2.3	5.4	6.7	1.8	11.1	1.0	2.8	3.0	11.2	11.6
ESTC	(Noordwijk)	123	0.7	0.0	-0.3	0.1	0.3	0.2	-1.0	0.4	2.9	2.9
HKO	(Hong Kong)	123	-28.6	-26.5	-31.5	-28.5	-19.8	-19.5	-17.5	0.4	7.8	7.8
ICE	(San Jose)	123	57.5	49.4	51.3	41.2	36.7	34.1	44.6	5.0	20.0	20.6



The BIPM Circular T also informs on the GNSS transmitted UTC

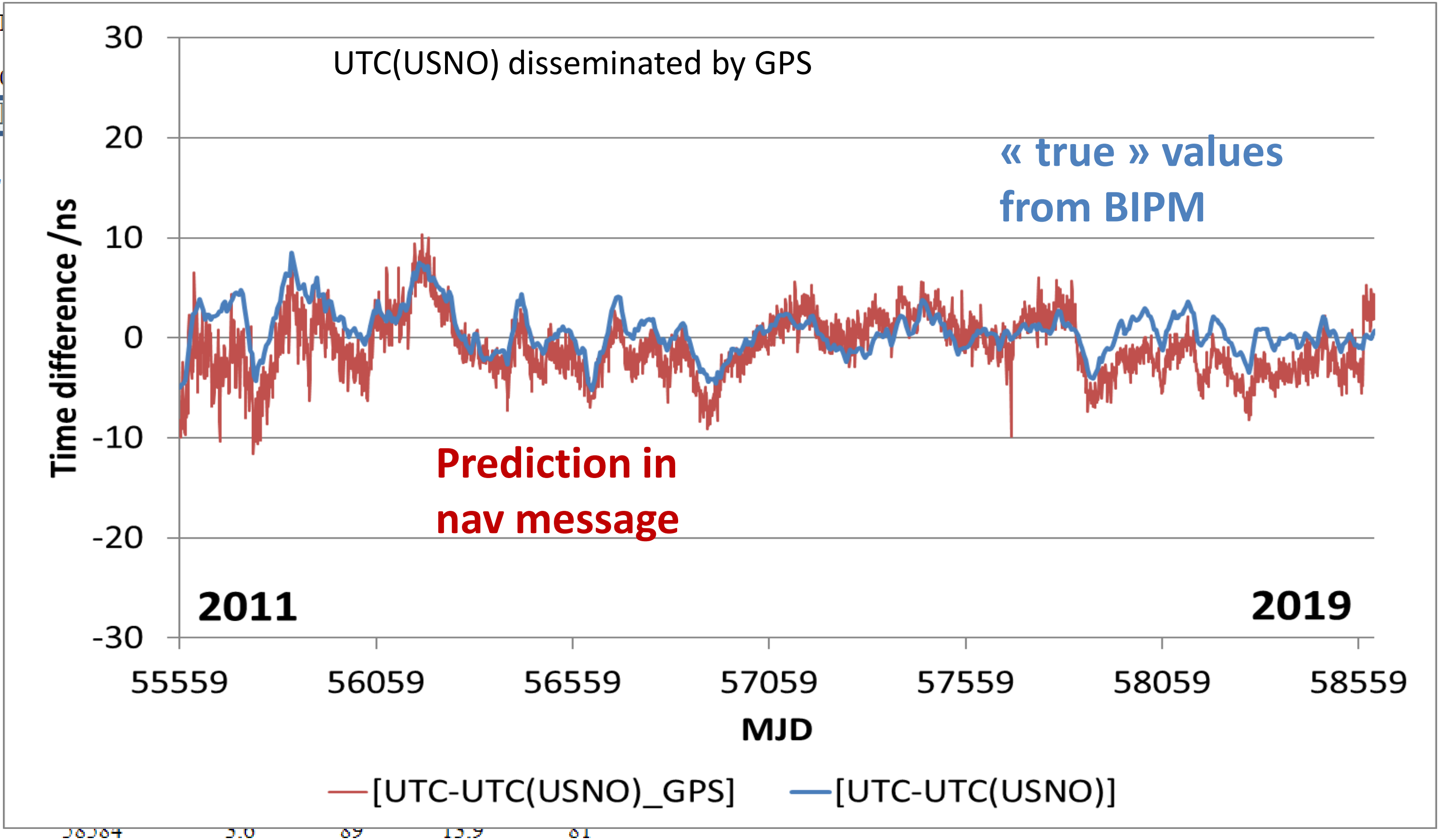
4 - Relations of UTC and T

[UTC-UTC(USNO)_GPS] = (

[UTC-UTC(SU)_GLONASS]

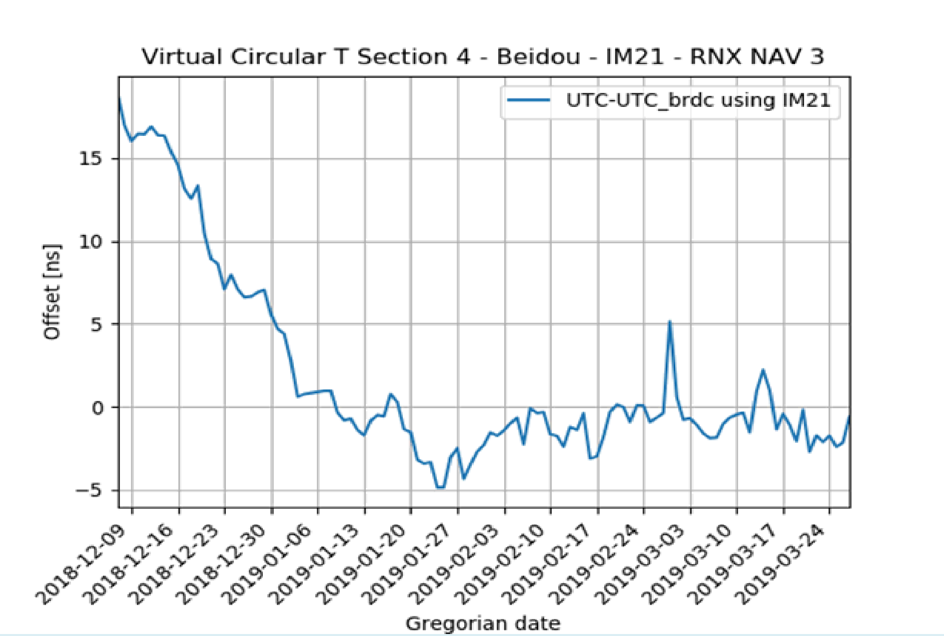
For this edition of *Circular T*,

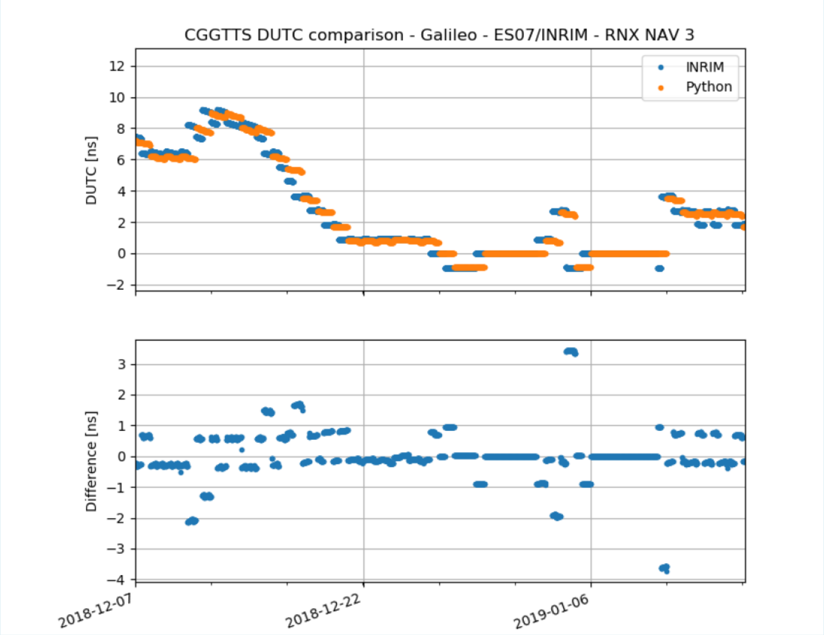
2019	0h UTC
	MAR 27
	MAR 28
	MAR 29
	MAR 30
	MAR 31
	APR 1
	APR 2
	APR 3
	APR 4
	APR 5
	APR 6
	APR 7
	APR 8
	APR 9
	APR 10
	APR 11



The BIPM Circular T also informs on UTC disseminated by GNSS

This section will soon be updated to add Beidou and Galileo time service

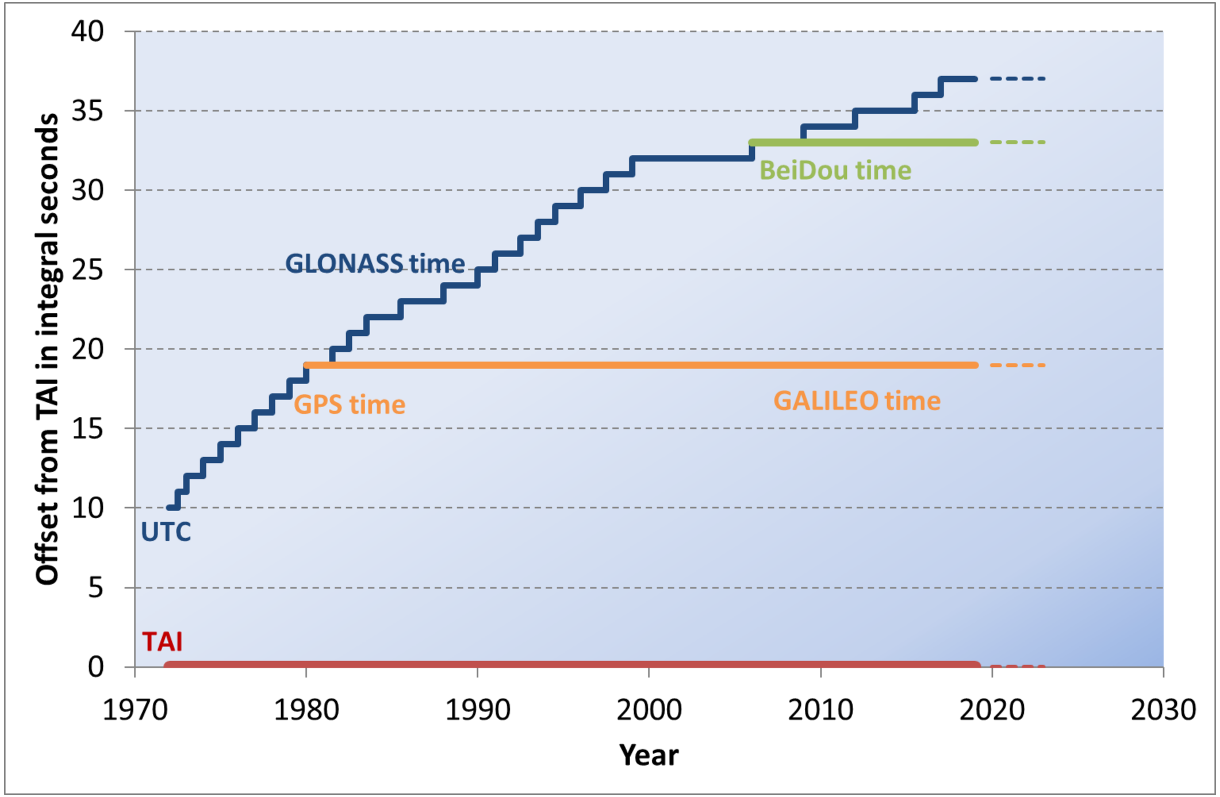




Leap seconds in Global Navigation Satellite System time scales

GNSSs prefer not to apply leap seconds (except GLONASS), their time scale is easily available all over the world inside the navigation message and these reference time scales differ from seconds

Several international organisations created working groups to discuss this topic.
It is important we evaluate all the possible issues for the next ITU World Radio Assembly in 2023

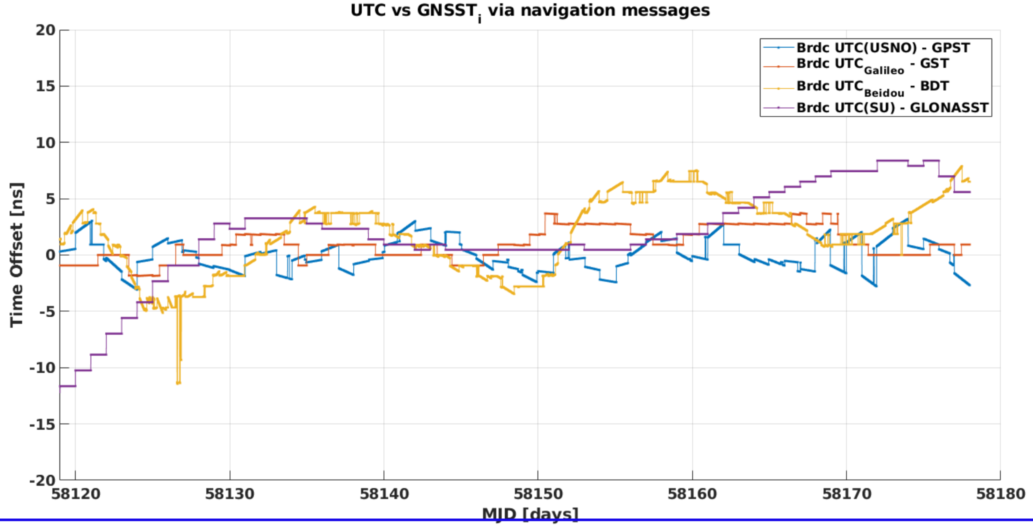


Coordinated Universal Time can help interoperability?

It was recently proposed that each constellation broadcast only one information: the time offset between its time scale and a reference common to all GNSS. Can the international time UTC serve as common reference?

Each GNSS transmits a prediction of (GNSST-UTC)

→ The broadcast predictions of (GNSST-UTC) are based on different UTC/UTC(k) time scale but in agreement within few nanoseconds



Decision CIPM/108-41

International Committee for Weights and Measures (CIPM)

The CIPM decided to support the International GNSS services (IGS) and the International GNSS Committee (ICG) in exploring the capacity of GNSS providers to ensure multi-GNSS interoperability, based on Coordinated Universal Time (UTC), with the final goal of avoiding the proliferation of international reference time scales.

https://www.bipm.org/en/committees/cipm/meeting/108(II).html

Thank you

patrizia.tavella@bipm.org