Bureau International des Poids et Mesures

Relation between GNSS system times and UTC

W. Lewandowski

Radiocommunication development in light of WRC-12 decision

St. Petersburg, 6-8 JUNE 2012

Bureau International des Poids et Mesures

Outline of presentation

- **A historical note**
  - **Time scales**
  - **Navigation on seas**
- **Global Navigation Satellite Systems – GNSS**
- **Relation between UTC and GNSS time scales**
  - **GPS time**
  - **Glonass time**
  - **Galileo system time**
  - **GPS/Galileo Time/Offset (GGTO)**
  - **BeiDou system time**

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Unification of time

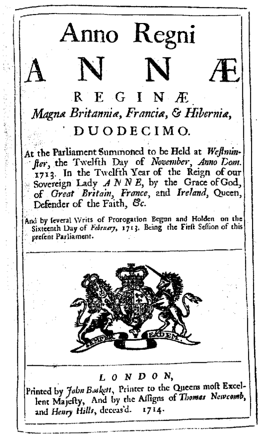
- **1884 - Adoption of a prime meridian Greenwich and of an associated time - universal time, based on the rotation of the Earth.**
- **1948 - *International Astronomical Union* recommends the use of Universal Time (UT).**
- **1968 - *13th General Conference of Weights and Measures* adopted a definition of SI second, based on a caesium transition, and opened the way toward the formal definition of International Atomic Time (TAI).**
- **1971 - *International Astronomical Union, International Telecommunications Union, General Conference of Weights and Measures* recommend the use of Coordinated Universal Time (UTC) based on TAI. Introduction of leap seconds.**
- **2000 - Use of leap seconds under revision**

If you want to know where you are, get an accurate clock.

Accurately

knowing where we are on Earth

has been worth a big investment.



Anno Regni

A N N Æ

R E G I N Æ

Magnæ Britanniæ, Franciæ, & Hiberniæ,

DUODECIMO.

At the Parliament Summoned to be Held at *Westmin-ster*, the Twelfth Day of *November*, *Anno Dom.* 1713. In the Twelfth Year of the Reign of our Sovereign Lady *ANNE*, by the Grace of God, of *Great Britain*, *France*, and *Ireland*, Queen, Defender of the Faith, &c.

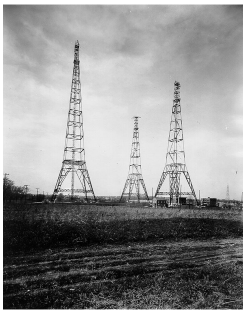
And by several Writs of Prorogation Begun and Holden on the Sixteenth Day of *February*, 1713. Being the First Session of this present Parliament.

SEMPER EADEM.

LONDON,

Printed by *John Baskett*, Printer to the Queens most Excellent Majesty, And by the Assigns of *Thomas Newcomb*, and *Henry Hills*, deceas'd. 1714.

Longitude Act of 1714



U. S. Navy radio towers, Arlington, Virginia, about 1914

Launch of the 50th GPS satellite, 2004

Courtesy of Smithonian Institution

John Harrison

Harrison's fourth marine timekeeper

Working model of Harrison's second marine timekeeper

Courtesy of Smithsonian Institution

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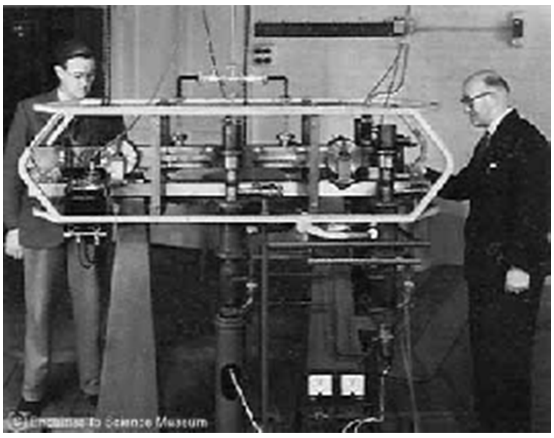
GNSS are based on atomic clocks



First atomic clock
UK, 1955

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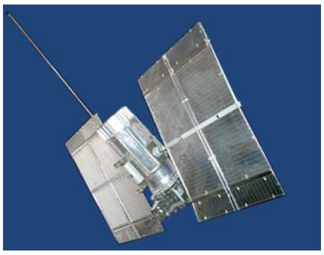
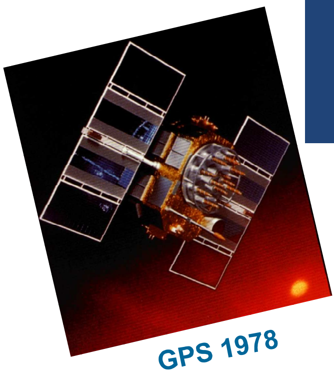
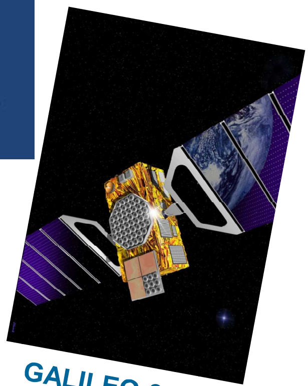
First GNSS satellites



GLONASS 1982



GPS 1978

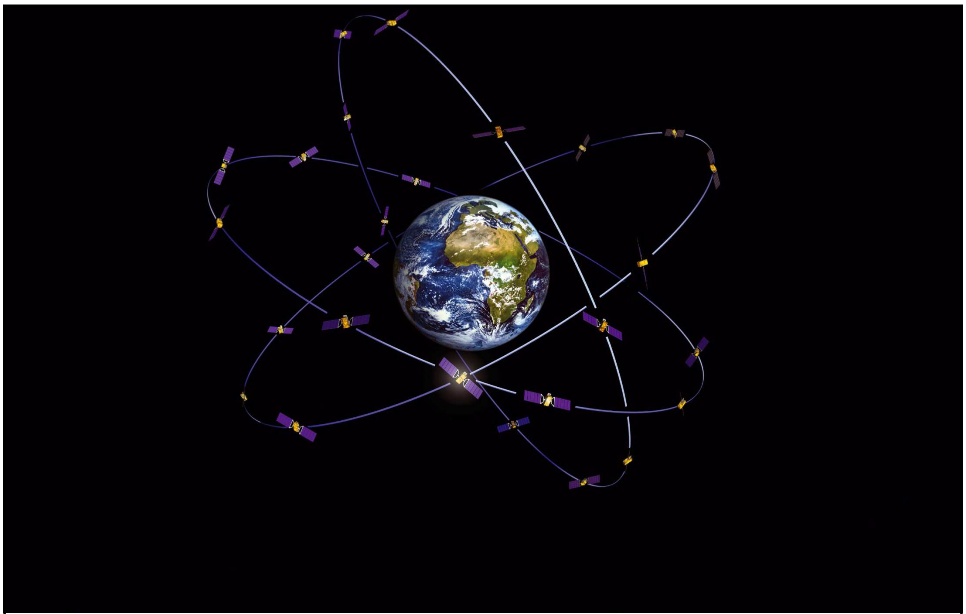


GALILEO 2011

GLONASS

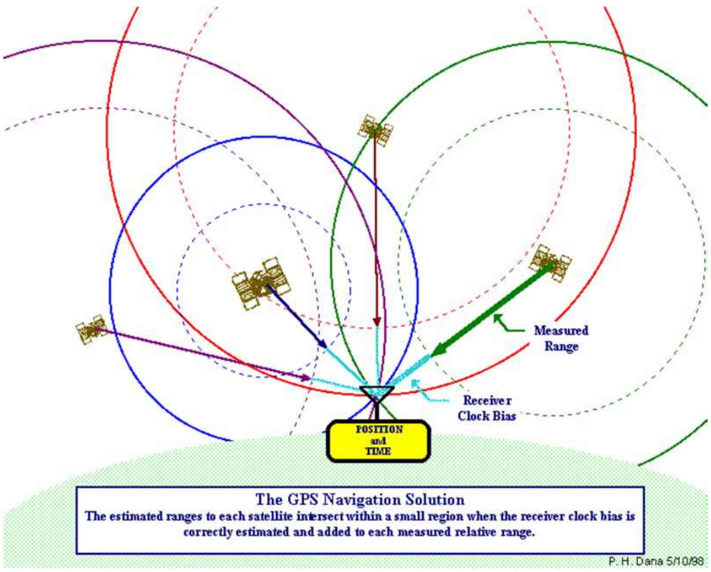
Russian Federation Global Navigation System

- **First satellite in 1982**
- **At present full 24 satellites constellation**
- **P-code, C/A –code, no signal degradation**
- **Reference frame PZ-90**
- **Dual use technology**



24 GLONASS satellites 19 100 km above Earth

Position determination by GNSS



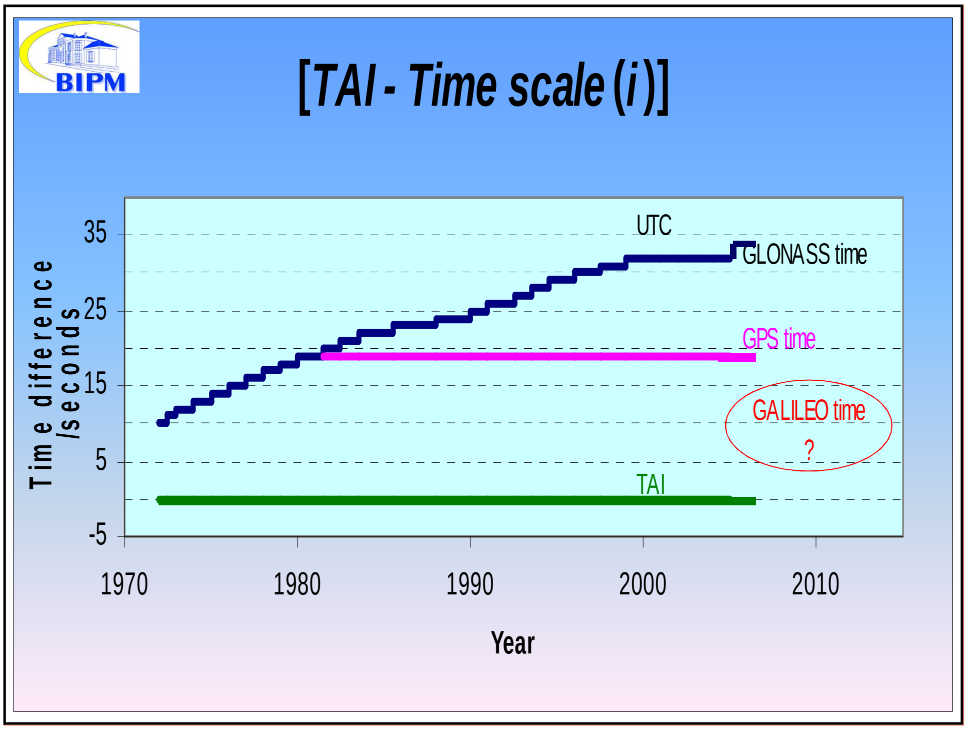
GNSS Navigation solution based on time measurement

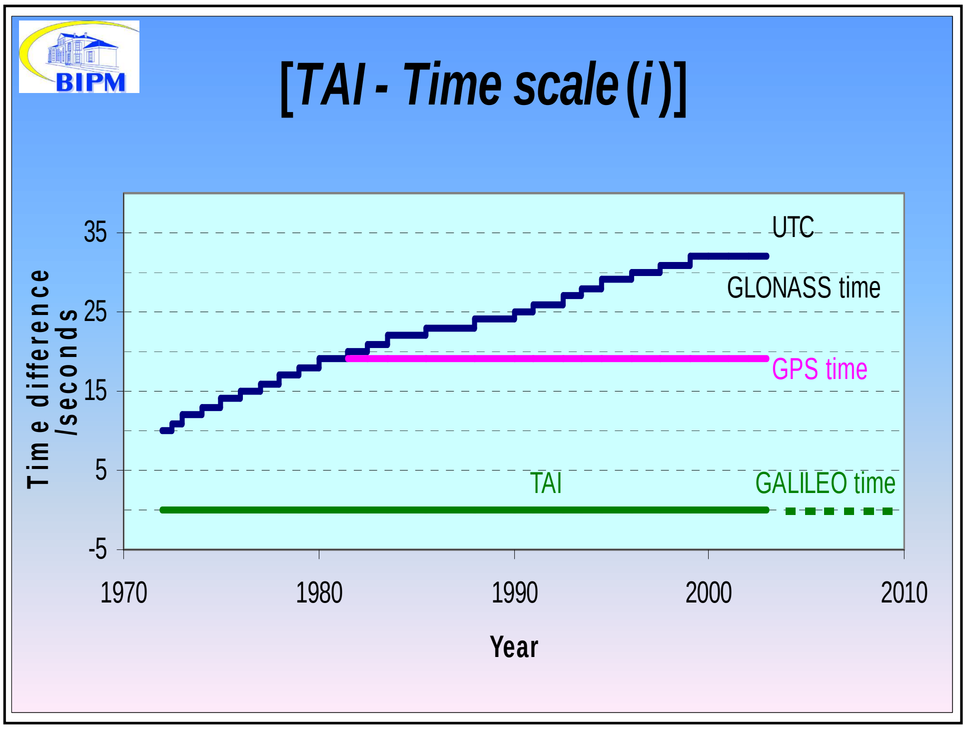
- **A common reference time scale is required**

  - ideally a common clock
- **GNSS satellites equipped with atomic clocks**
- ***For example*: GPS time is realized across GPS constellation with an uncertainty of about 10 ns**

System times

- GNSS times
  - ✓ System times (pseudo-time scales)
  - ✓ Constructed from a clock ensemble
  - ✓ Used for internal system synchronization
  - ✓ Continue (desirable)
  - ✓ Metrological quality (?)
  - ✓ Steered to a reference time scale
- GPS time
- GLONASS time
- Galileo time
- BeiDou time


BIPM
[TAI - Time scale (i)]
Time difference /seconds
35
25
15
5
-5
1970
1980
1990
2000
2010
Year
UTC
GLONASS time
GPS time
GALILEO time
?
TAI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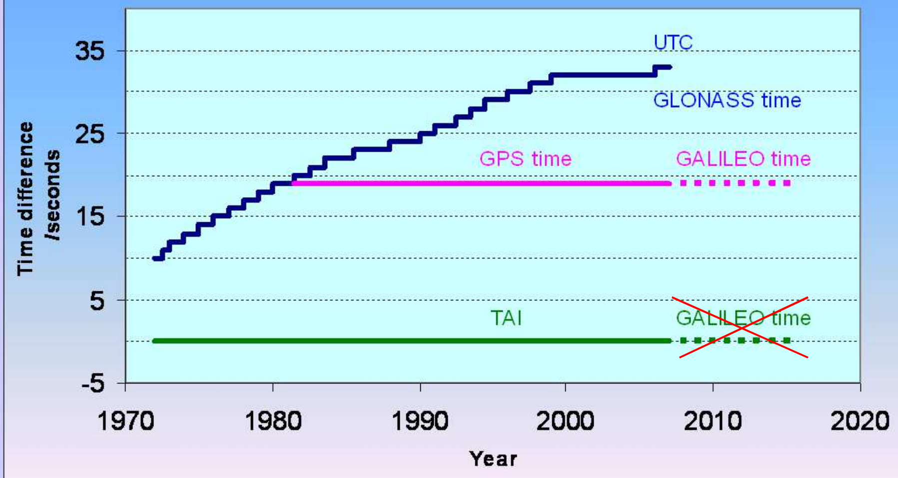
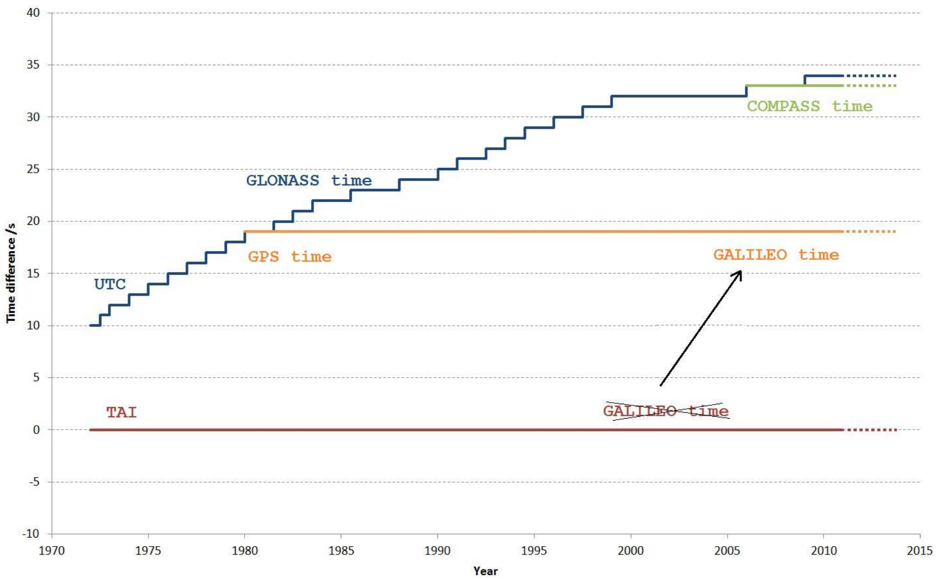
UTC
GLONASS time
GPS time
TAI
GALILEO time

[*TAI - Time scale* (*i*)]





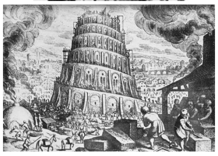
GNSS system times (cont.)

GPS time: steered to UTC(USNO) modulo 1s
- ✓ [TAI – GPS time] = 19 s + C_0
- ✓ [UTC -GPS time] = -15 s + C_0
- ✓ Tolerance is 1 µs

GLONASS time: steered to UTC(SU) with leap second
- ✓ [TAI – GLONASS time] = 34 s + C_1
- ✓ [UTC – GLONASS time] = C_1
- ✓ Tolerance is 1 ms

Galileo time: steered to a set of EU UTC(k); using GPS time seconds, GGTO
- ✓ [TAI – Galileo time] = 19 s + C_2
- ✓ [UTC -Galileo time] = -15 s + C_2
- ✓ Tolerance is 50 ns

BeiDou time: will be steered to set of Chinese UTC(k)
- ✓ [TAI –COMPASS time] = 33 s + C_3
- ✓ [UTC -COMPASS time] = -1 s + C_3
- ✓ Tolerance is 100 ns



Babel Tower

Multiple GNSS use

- **Users need:**
  - **Interoperability**
  - **Interchangability**
- **Common geodetic and time references are necessary**
- **A number of recommendations by:**
  - **ICG**
  - **CCTF**
  - **CIPM**
  - **CGPM**

International Committee on Global Navigation Satellite Systems (ICG)

ICG is meeting annually:

- last time in September 2011 in Tokyo
- next time in November 2012 in Beijing

ICG Recommendations

International Committee on Global Navigation Satellite Systems (ICG)

considering

- the international value of having many GNSS operational with a composite contribution of several tens of satellites,
- the desirability of using all systems interchangeably,
- the use by GPS of references very close to UTC and ITRF,
- the GLONASS efforts to approach UTC and ITRF,
- the Galileo design referring to UTC and ITRF,
- that other important satellite navigation systems are now being designed and developed*),

recommends

- that the reference times (modulo 1 s) of satellite navigation systems be synchronized as closely as possible to UTC,
- that the reference frames for these systems be in conformity with the ITRF,
- that these systems broadcast, in addition to their own System Time (ST):
  1. the time difference between ST and a real-time realization of UTC,
  2. a prediction of the time differences between ST and UTC.

*) Compass, IRNSS, QZSS, various SBAS, …

CCTF'2009 recommendations

- ***CCTF 3:* On the weakness of the present definition of UTC**
- ***CCTF 4:* Concerning adoption of a common terrestrial reference system by the CGPM**
- ***CCTF 5:* Alignment of Geodetic References and synchronization of Time References to international standards**

Recommendation CCTF 4 (2009) (1)

Concerning adoption of a common terrestrial reference system by the CGPM

The Consultative Committee for Time and Frequency,

considering that

- there exists at present only a few global satellite navigation systems but that new ones are being created and in the future there may be many more,
- different time and geodesy reference systems, which are in use in these navigation systems, produce additional ambiguities for users regarding interpretation of navigation and timing solutions and render systems interoperability more difficult,
- although the international terrestrial reference system ITRS is recommended by relevant scientific unions, it has not yet been adopted by an intergovernmental organization,
- such an adoption by the appropriate intergovernmental organization would lead to more user convenience regarding unification of navigation and timing solutions and systems interoperability;

Bureau International des Poids et Mesures BIPM

Recommendation CCTF 4 (2009) (2)

noting that

one of the key factors that led to the creation of the BIPM and the Metre Convention was the recommendation of the Second International Conference on Geodesy for the Measurement of Degrees in Europe held in Berlin in 1867 that a European international bureau of weights and measures be set up in order to unify European geodesy standards.

recommends that

after agreement with the relevant scientific unions, the Director of the BIPM formally discuss with the CIPM the steps so that the 24th CGPM be asked to adopt the ITRS, as defined by the IUGG and realized by the IERS and IGS, as the international standard for terrestrial reference frames used for all metrological applications.

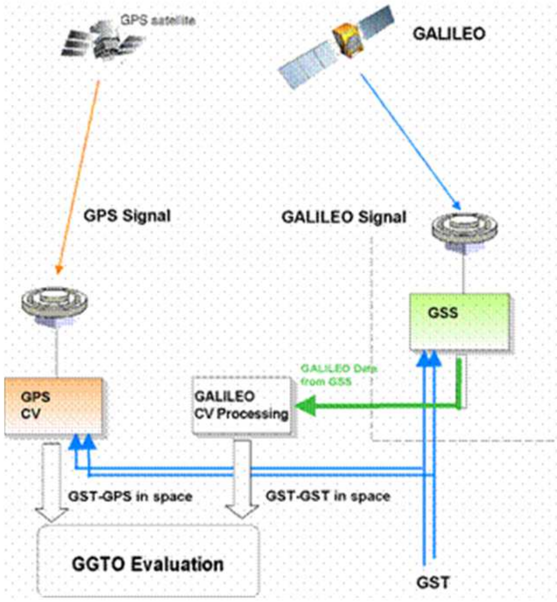
GPS/GALILEO Time Offset (GGTO)

Five different ways of the determination of GGTO:

1. **Using a GPS receiver at PTF and GST realized at PTF.**
2. **Using a single GPS/Galileo receiver.**
3. **Using two separate GPS and Galileo receivers.**
4. **Using a GPS receiver at USNO, a Galileo receiver at PTF, and TWSTFT link between USNO and PTF.**
5. **Using a GPS receiver at USNO, a Galileo receiver at PTF, and GPS P3 CV link between USNO and PTF.**

GGTO will be broadcast by GALILEO

Determination of GGTO at Galileo PTF



GGTO determined using separate GPS and Galileo receivers at PTF

Uncertainty budget

Source of uncertainty	Real-time (broadcast orbits) smoothing 24h back	Real-time (ultra-rapid predicted) smoothing 24h back
Smoothed GPS P3	3.0 ns	2.0 ns
Smoothed Galileo P3	3.0 ns	2.0 ns
GPS rec. calib.	2.5 ns	2.5 ns
Galileo rec. calib.	2.5 ns	2.5 ns
Total uncert.	5.5 ns	4.5 ns

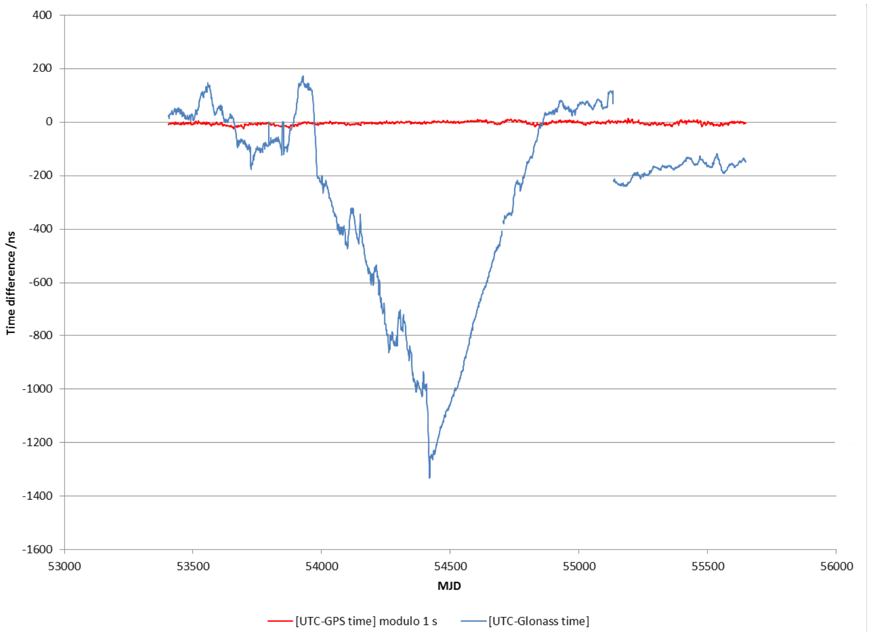
GNSS time dissemination

GNSS broadcast :

- System time
- Prediction of UTC(k) through broadcasting related correction to system time

UTC- ....

2011	GPS time +15 s /ns	**UTC(USNO) by GPS** /ns	GLONASS time /ns	**UTC(SU) by GLONASS** /ns
APR 1	-3.5	-3.4	-153.8	-307.8
APR 2	-3.0	-3.8	-156.1	-312.8
APR 3	-2.3	-2.2	-154.8	-313.4
APR 4	-4.3	-5.0	-152.0	-311.9
APR 5	-2.6	-3.8	-152.4	-313.5
APR 6	1.1	0.8	-153.9	-316.4
APR 7	0.3	-0.7	-155.2	-319.4
APR 8	-2.2	-3.5	-156.0	-322.0
APR 9	-3.3	-3.4	-154.7	-322.5
APR 10	-8.0	-8.5	-153.2	-322.7
APR 11	-10.2	-10.4	-151.6	-323.1
APR 12	-7.9	-5.9	-146.9	-320.5
APR 13	-3.7	-2.2	-146.5	-321.3
APR 14	-3.0	-2.0	-147.6	-323.8
APR 15	-2.4	-2.0	-148.4	-325.7
Stand. dev.	**1.5**	**1.6**	**6.8**	**6.8**
Uncert. uB	**10.0**	**10.0**	**500.0**	**500.0**



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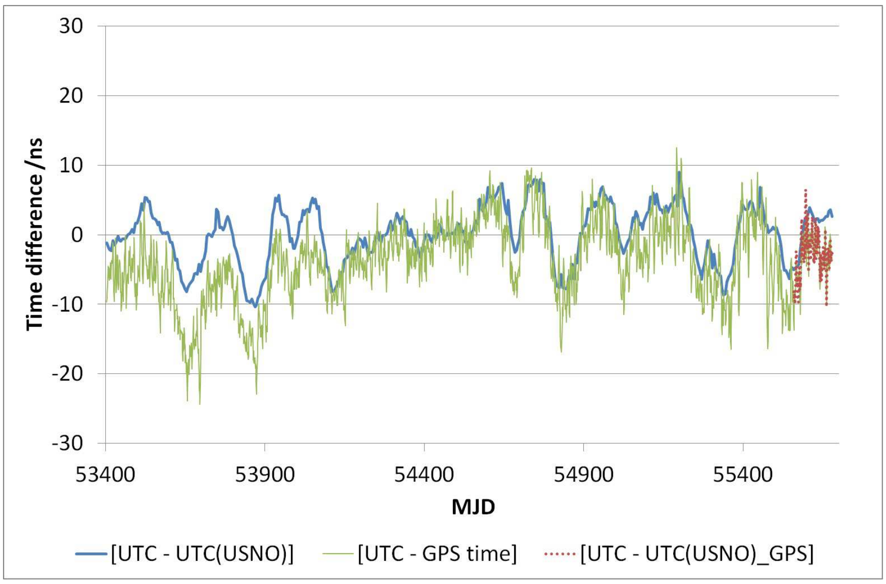

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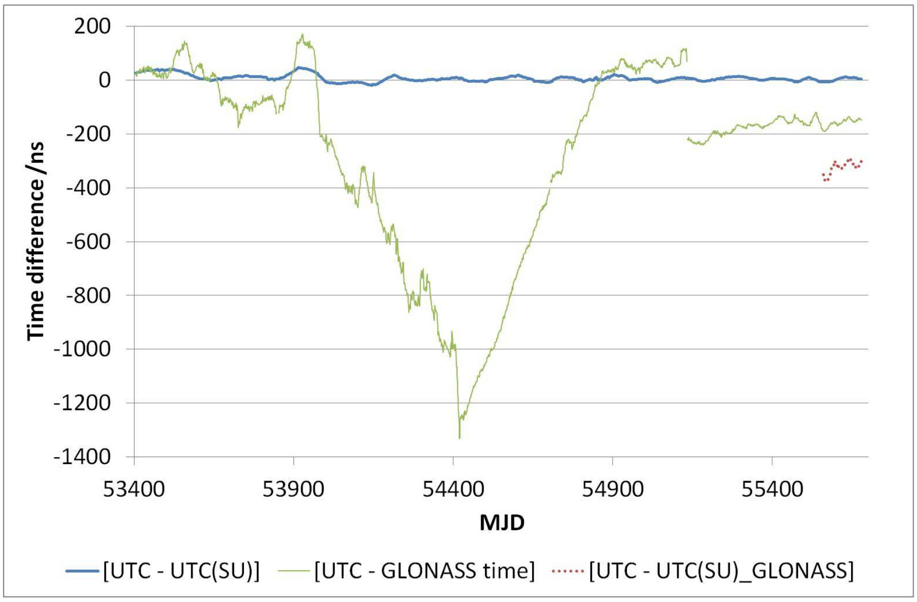
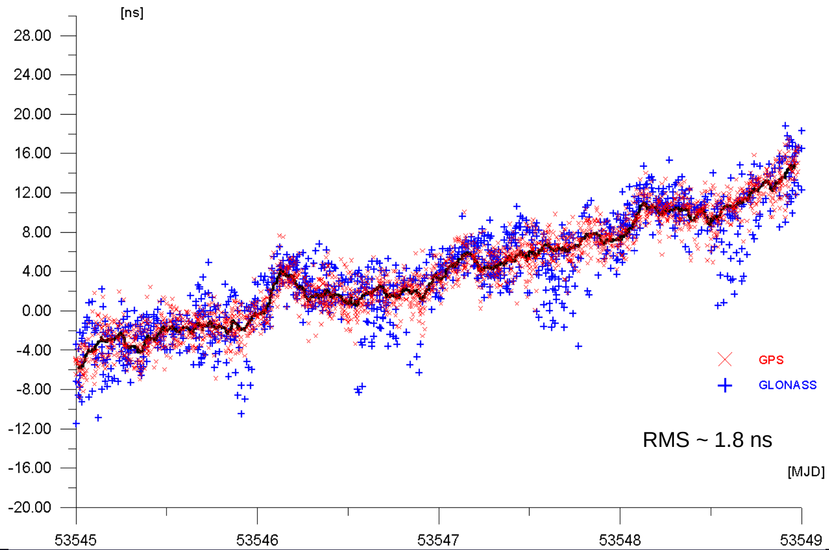
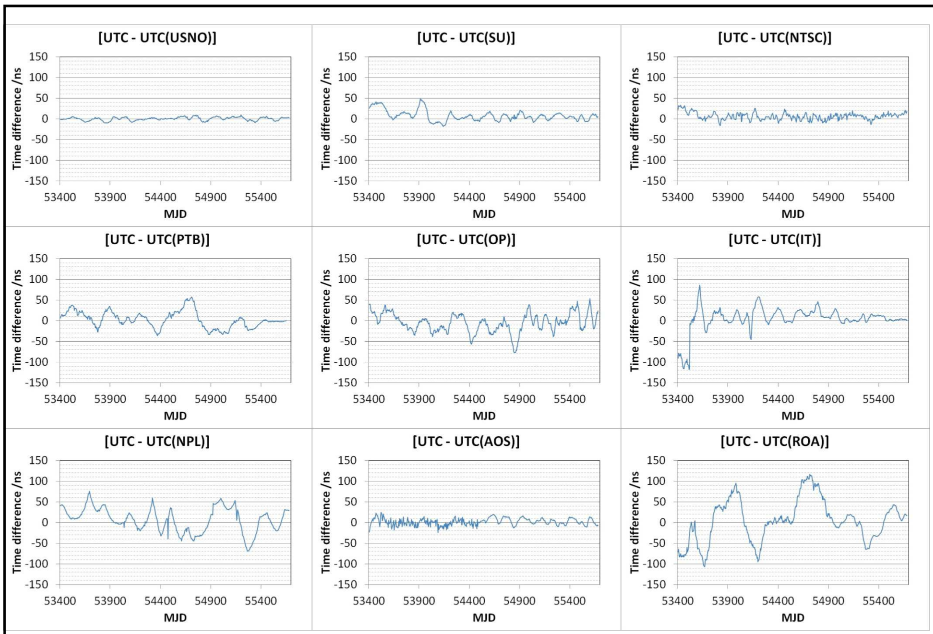


AOS/BIPM, GPS+GLONASS, P1 CODE



Accurately
knowing where we are on Earth
has been worth a big investment.



Summary (1/2)

- GNSS providers choose most often flat system times for safety of life issues, because of weakness of stepping UTC
- GNSS system times are not representations of UTC, and being broadcast they are not fulfilling requests of ITU, which is recommending only UTC to be broadcast, even if GNSS broadcast predictions of UTC(k).
- Only GLONASS system time is a representation of UTC, so rigourously fulfilling recommendations of ITU, but is experiencing major difficulties.

Summary (2/2)

- GNSS system times shall be considered as internal technical parameters used only for internal system synchronization, but this is not the case.
- Flat system times are used for a number of apllications, contributing to proliferation of alternative time scale, and creating major source of confusion.
- Within GNSS might be a confusion by using system time and UTC for dating various system functions.
- Possible errors due to leap second when using MJD datation.
- GNSS users need interoperability or even interchangability of various systems. Multiplicity of reference time scales is not helping.

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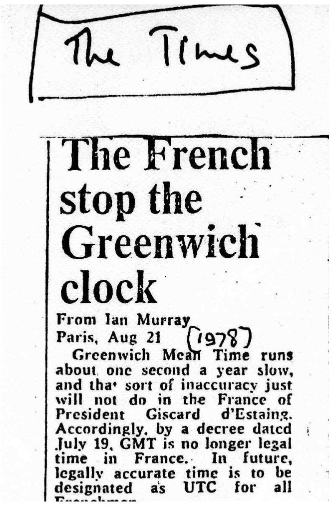
Louis Essen :

"…… In 1960s there was a suggestion that astronomical time should be used for sea navigation and domestic purposes, and atomic time for air navigation and scientific work. My experiences with time signals and standard frequency transmissions convinced me that this would cause endless confusion as well as involving duplication of equipment and I argued strongly that a method of combining all the information in one set of transmission must be found….."

Reactions against the UTC…


The Times

The French stop the Greenwich clock

From Ian Murray
Paris, Aug 21 (1978)

Greenwich Mean Time runs about one second a year slow, and that sort of inaccuracy just will not do in the France of President Giscard d'Estaing. Accordingly, by a decree dated July 19, GMT is no longer legal time in France. In future, legally accurate time is to be designated as UTC for all Frenchmen

Greenwich Mean Time runs about one second a year slow. And that sort of inaccuracy just will not do in the France of President Giscard d'Estaing.

…

The International Office of Time is not in Greenwich – it is based in the Observatory at Paris, where President Giscard d'Estaing can watch it more closely.

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BIPM

Recently a journaliste to me:

„Fittingly for an interview about time,
I managed to miscalculate the time that
I was due to call you, by one hour. I have
just realised, so I am sorry for the confusion."

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BIPM


THANK YOU!