Timing applications for GNSS

***

IGS partnership with the BIPM

E. Felicitas Arias
Gérard Petit
Bureau International des Poids et Mesures
Time section

- BIPM general mission
- Timing activities
  - International time scales: TAI, UTC
  - clocks in TAI
  - clock comparison in TAI, GNSS role
- IGS/BIPM
  - Pilot project (1998 - 2002)
  - contribution to the improvement of TAI
  - comparison of IGS and BIPM timing results

Bureau International des Poids et Mesures

- Ensure world-wide unification of physical measurements:
  - agreement on the definition and realization of units;
  - establishment of national standards of demonstrable international equivalence;
  - international harmonization of laws and regulations related to metrology.

BIPM

International time scales (atomic)

- TAI (International Atomic Time)
  - Unit is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom (second of the SI).
  - Uniform time scale.
  - High stability in the long term (0.6×10^{-15}, ~ 40 days).
  - Accuracy conferred by using the reported measurements of the PFS. Relative departure of the duration of the TAI interval from the SI second (*d*) is 0.5×10^{-14} to 1.0×10^{-14}
    $u = 0.2 \times 10^{-14}$

International time scales (atomic)

- UTC (Coordinated Universal Time)
  - Defined to fulfil mainly the need of a time scale somehow related to the rotation of the earth.
  - Conceptually identical to TAI but suffering from 1 second time steps (TAI - UTC = 32 s today).
  - UTC is the reference time scale for world wide time coordination.
  - UTC is calculated at the BIPM in concertation with the IERS on the basis of readings of clocks in the national laboratories.
  - Local realizations of UTC named UTC(k) are broadcast by time signals.

BIPM

TAI/UTC

- Calculated in differed time on the basis of monthly blocks of data.
- Clock data provided by the participating laboratories.
- Organisation of international time links for clock comparison.
- Appropriate methods of time transfer.
- Primary frequency standard measurements.
- Algorithm to elaborate a time scale which fulfils the required characteristics: stability in the long term and frequency accuracy.

Clocks participating in TAI

- HP5071A 68%
- H masers 16%
- Other 16%

Clock weighting → stability

- independent clocks,
- relative weights,
- upper limit to clock weights,
- weight of a clock remains constant on the 30 days of the interval of computation,
- iterative process based on the previous interval to predict the clock frequencies on the following interval (random walk frequency modulation…),
- weight determination based on 12 intervals of computation (one year)
  - deweighting (annual frequency variations, long term drifts),
  - detection of abnormal behavior

Clock weights (stat.)

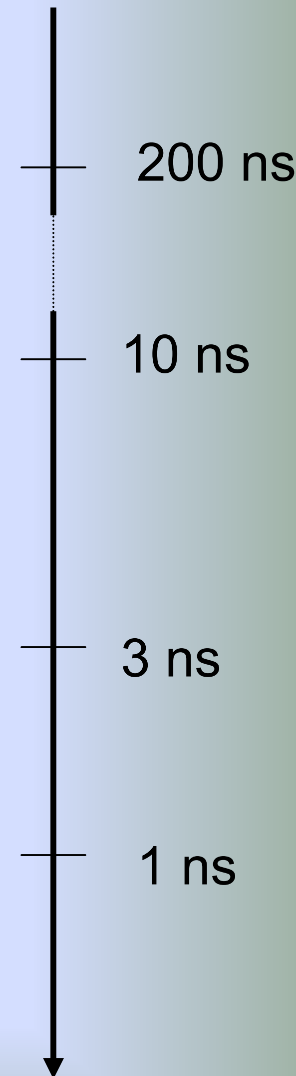
- 11% of clocks at ω_{max}
  - 14% are H-masers
  - 79% are HP5071A

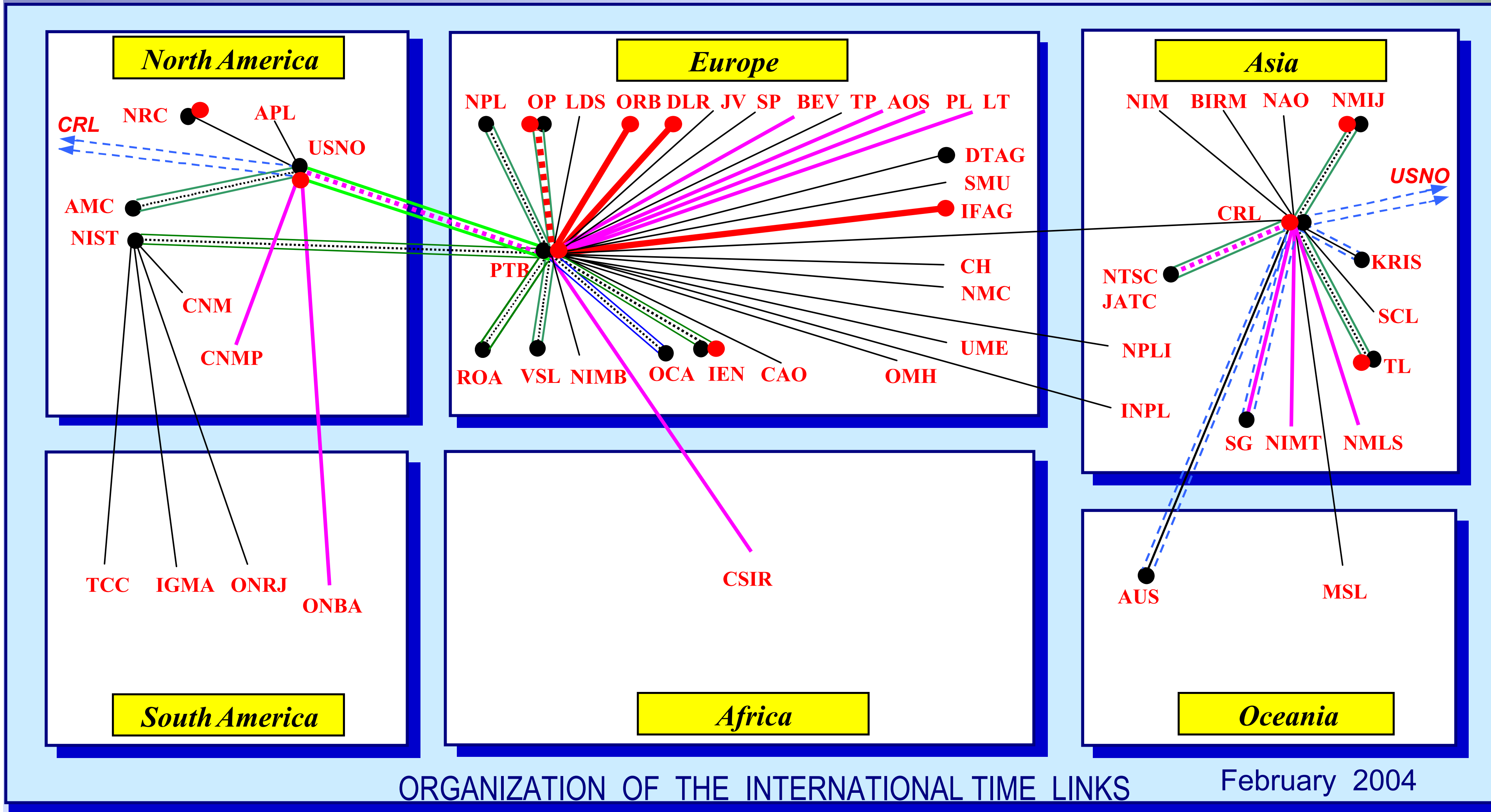
- Over the H-masers
  - 10% are at ω_{max}

- Over the HP5071A
  - 13% are at ω_{max}

Clock comparison in TAI

- Loran-C, TV links (before)
  - (several hundreds of ns uncertainty)
- GPS C/A-code single-channel common-view
  - (3-10 ns uncertainty)
- GPS C/A-code multi-channel common view
  - (ns uncertainty)
- TWSTFT
- GPSP3





ORGANIZATION OF THE INTERNATIONAL TIME LINKS

February 2004

TWSTFT
TWSTFTback-uplink
TWSTFTlink in preparation
OCA/PTBlink not used for computation of TAI
Laboratoryequippedwith TWSTFT
TWSTFT by Ku band with X band back-up
Laboratory equipped with Dual Frequency reception

GPS CV single-channel
GPS CV single-channel back-up
GPS CV link multi-channel
GPS CV multi-channel back-up
GPS CV link Dual frequency link
GPS CV dual frequency back-up
link

BIPM

IGS products in TAI

- Single-frequency GPS C/A links in TAI are corrected by using:
  - Precise IGS orbits
  - Ionospheric maps from CODE

- Schedule for (monthly) Circular T
  - standard dates are MJD ending by 4 / 9
  - deadline for data submission of month M is 5th M+1
  - process of calculation starts (hopefully) on 6th M+1
- Latency is essential for the choice of IGS products

Access to other time scales

- GPS Time
  - UTC-GPS Time, Circular T, every day at 0hUTC
- GLONASS Time (same)
- Future:
  - GALILEO Time
  - IGS Time

BIPM differential calibrations of GPS time equipment

Uncertainty 3 ns (1 σ)

- In 2001-2004 campaigns were carried out
  - West and central Europe, Asia-Pacific region, North America
- About 20 laboratories out of the 50 that participate in TAI have been calibrated in the period

BIPM

IGS/BIPM Pilot Project (1998- 2002)

- Goal: developing operational strategies to exploit geodetic GPS methods for improved time and frequency comparisons.
- IGS: dual frequency carrier-phase based geodetic techniques.
- BIPM: time and frequency transfer by single-frequency GPS C/A common views and TWSTFT.
- IGS+BIPM: global time and frequency comparisons at the sub-ns level by using GPS carrier phase and geodetic techniques.

Actions

- Hardware requirements (1-pps input in timing receivers)
- Software requirements (BIPM time transfer format CGGTTS) --> P. Defraigne
- Calibration of receivers (Ashtech Z12-T, …)
  --> G. Petit
- Integration of time laboratories into the IGS network
  --> next slide

IGS stations located at BIPM time laboratories

IGS Site	*Time Lab*	*GPS Receiver*	*Freq. Std.*	*City*
AMC2	AMC *	AOA SNR-12 ACT	H-maser	Colorado Springs, CO, USA
BOR1	AOS	AOA TurboRogue	cesium	Borowiec, Poland
BRUS	ORB	Ashtech Z-XII3T	H-maser	Brussels, Belgium
KGN0	CRL *	Ashtech Z-XII3	cesium	Koganei, Japan
MDVO	IMVP	Trimble 4000SSE	H-maser	Mendeleevo, Russia
MIZU	NAO	AOA Benchmark	cesium	Mizusawa, Japan
NPLD	NPL *	Ashtech Z-XII3T	H-maser	Teddington, UK
NRC1	NRC *	AOA SNR-12 ACT	H-maser	Ottawa, Canada
NRC2	NRC *	AOA SNR-8100 ACT	H-maser	Ottawa, Canada
OBE2	DLR	AOA SNR-8000 ACT	rubidium	Oberpfaffenhofen, Germany
OPMT	OP	Ashtech Z-XII3T	H-maser	Paris, France
PENC	SGO	Trimble 4000SSE	rubidium	Penc, Hungary
PTBB	PTB *	AOA TurboRogue	H-maser	Braunschweig, Germany
SFER	ROA *	Trimble 4000SSI	cesium	San Fernando, Spain
SPT0	SP	JPS Legacy	cesium	Boras, Sweden
TLSE	CNES	AOA TurboRogue	cesium	Toulouse, France
TWTF	TL *	Ashtech Z-XII3T	cesium	Taoyuan, Taiwan
USNO	USNO *	AOA SNR-12 ACT	H-maser	Washington, DC, USA
WTZA	IFAG	Ashtech Z-XII3T	H-maser	Wettzell, Germany
WTZR	IFAG	AOA SNR-8000 ACT	H-maser	Wettzell, Germany

- participates in two-way satellite time transfer (TWSTT) operations

Use of GPS dual-frequency P code observations in TAI

- TAI P3 pilot experiment (April 2002)
- Calibrated Ashtech Z12T receivers
- Data since mid-2002
- 7 TAI P3 links compared to other techniques in TAI
  - TWSTFT, GPS C/A SC
- Long term time stability of order 1.0 ns (1 σ)
- Start introducing TAI P3 links in TAI (July 2003)
  - DLR/PTB
  - IFAG/PTB
  - ORB/PTB

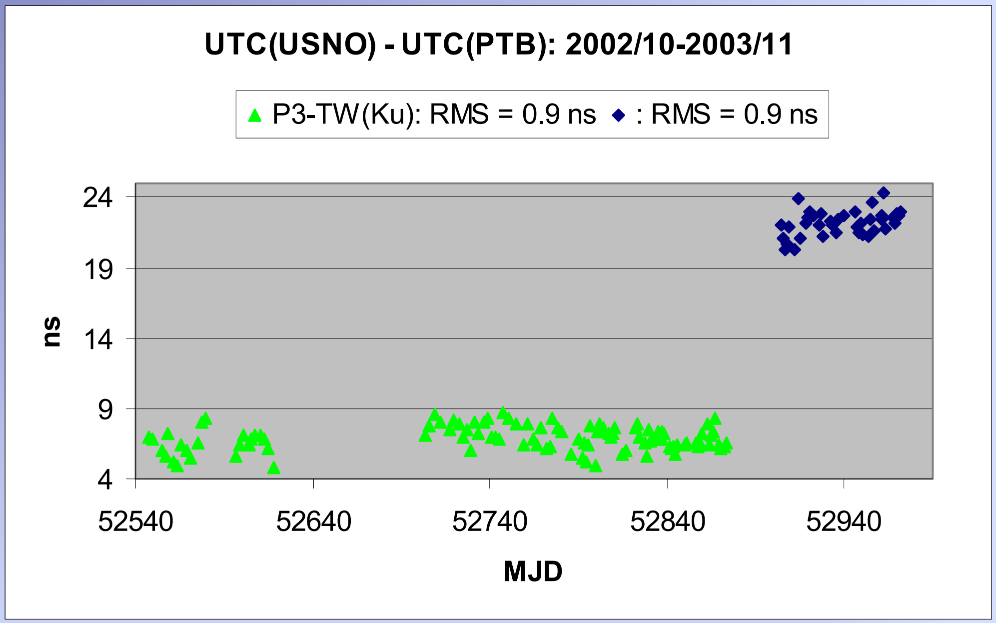
BIPM

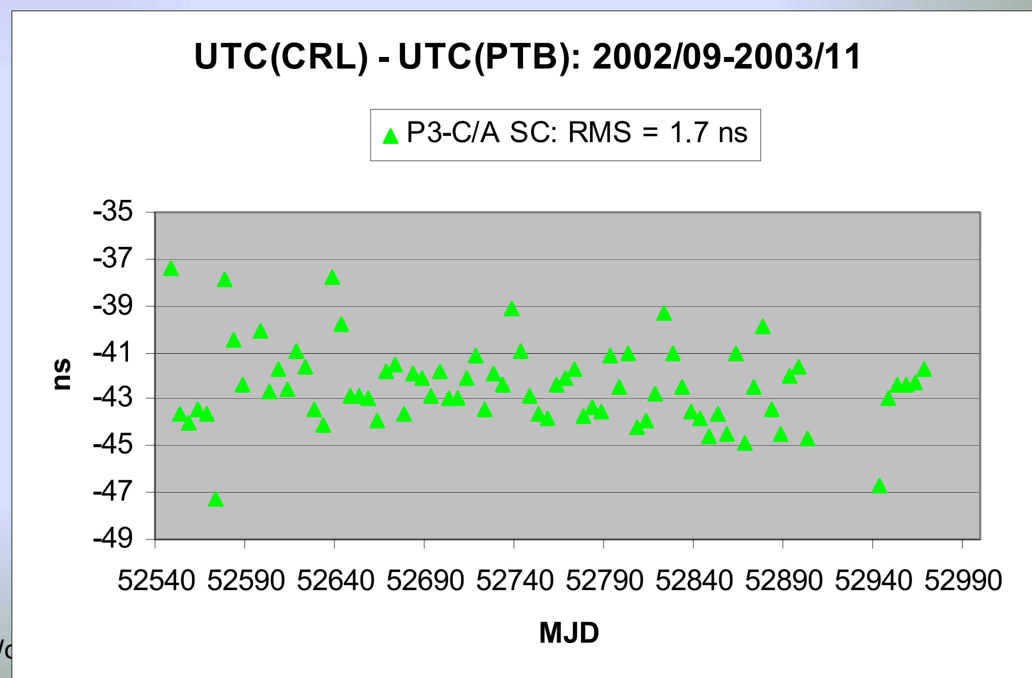
GPS P3 links

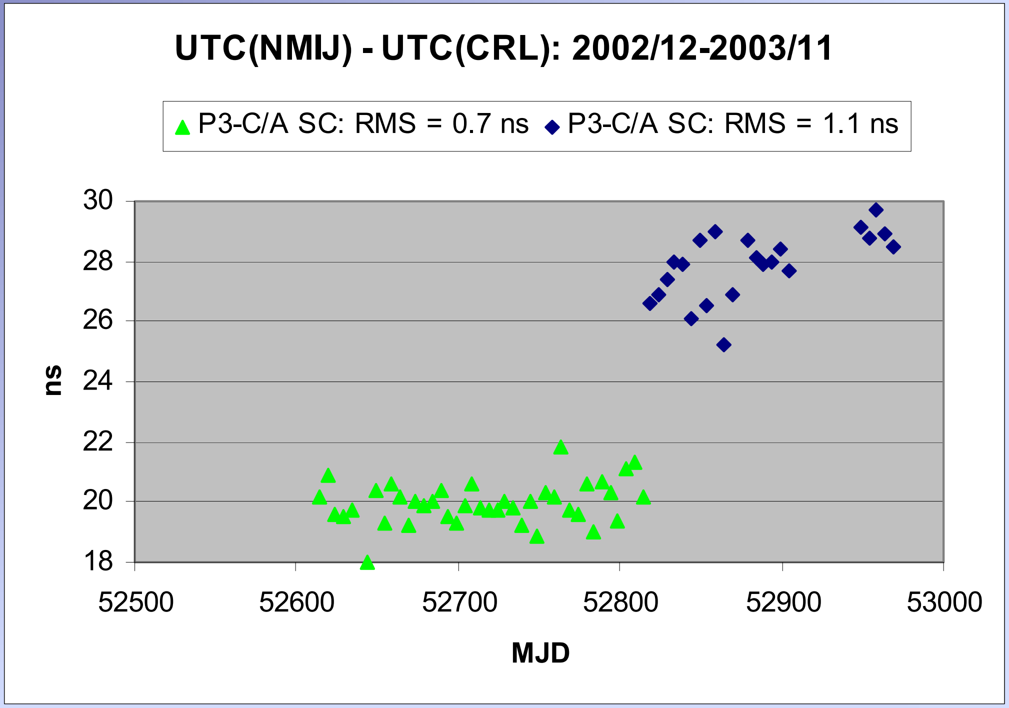
- Long term instability of GPS P3 links is of order 1.0 ns (1σ)
- Equivalent to the performance of TW links, at least twice better than GPS C/A links

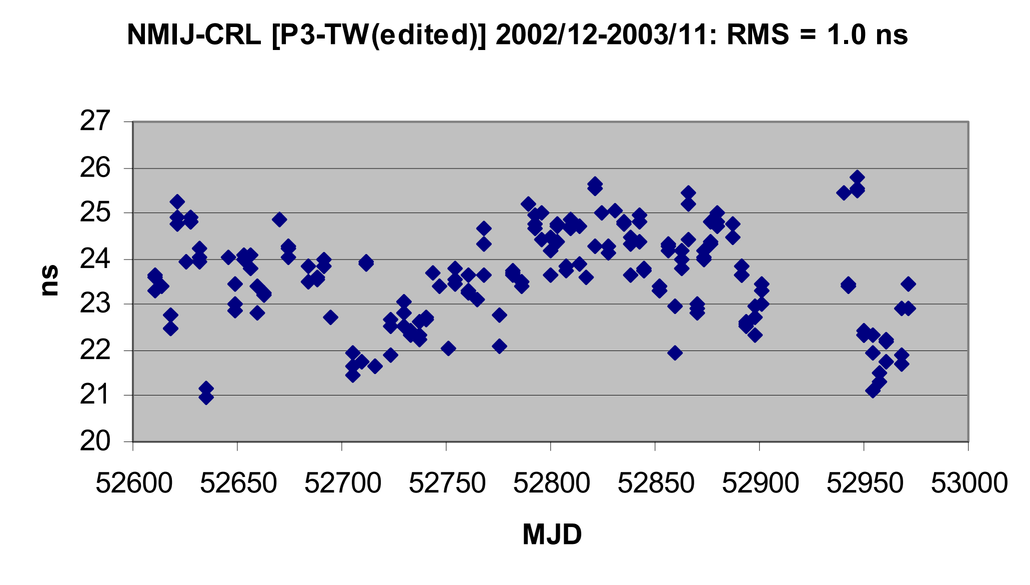
Laboratory	GPS P3 equipment	TW equipment	GPS C/A equipment
IEN	Ashtech Z12T	MITREX 2500A	3S Nav. GNSS-300T (MC)
BNM/SYRTE (OP)	Ashtech Z12T		NBS TTR5 (SC)
PTB	Ashtech Z12T	TimeTech/SATRE	AOA TTR5 (SC)
USNO	Ashtech Z12T	MITREX 2500	AOS SRC TTS-2 (MC)
NRC	Ashtech Z12T		(SC)
CRL	Ashtech Z12T	AOA/Atlantis	3S Nav. R-100 (MC) AOA TTR6 (SC)
NMIJ	Ashtech Z12T	AOA/Atlantis	AOA TTR6 (SC)
TL	Ashtech Z12T	AOA/Atlantis	AOA (SC)

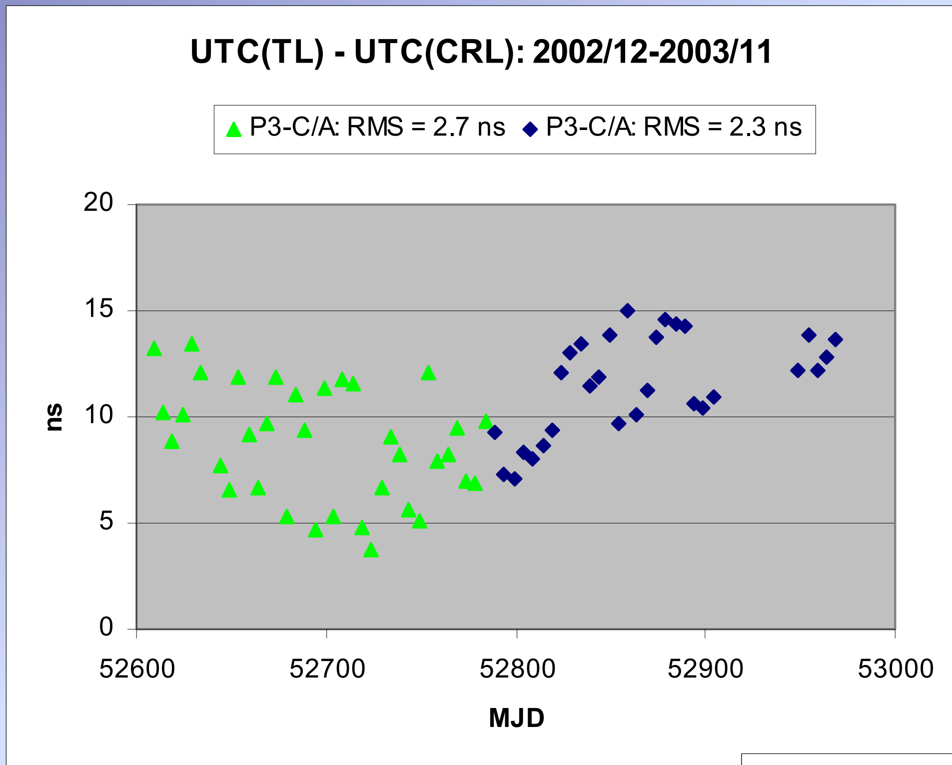
Link	Distance	Techniques
IEN-PTB	800 km	P3, TW, C/A SC
OP-PTB	700 km	P3, C/A SC
CRL-PTB	8300 km	P3, C/A SC
USNO-PTB	6300 km	P3, TW
NRC-USNO	700 km	P3, C/A SC
NMIJ-CRL	70 km	P3, TW, C/A SC
TL-CRL	2100 km	P3, TW, C/A SC

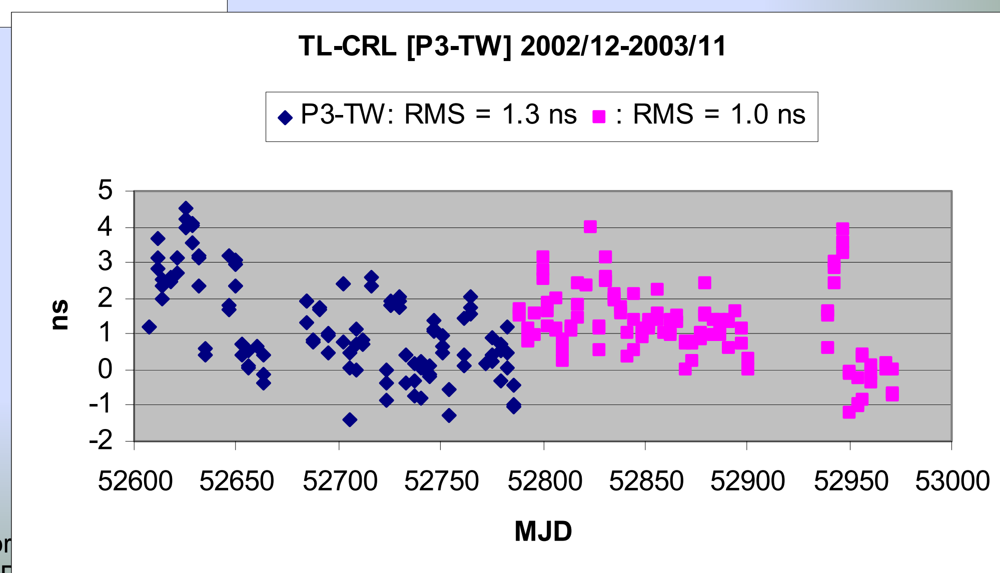

UTC(USNO) - UTC(PTB): 2002/10-2003/11
P3-TW(Ku): RMS = 0.9 ns
: RMS = 0.9 ns
ns
24
19
14
9
4
52540
52640
52740
52840
52940
MJD


UTC(CRL) - UTC(PTB): 2002/09-2003/11
P3-C/A SC: RMS = 1.7 ns
ns
-35
-37
-39
-41
-43
-45
-47
-49
52540 52590 52640 52690 52740 52790 52840 52890 52940 52990
MJD


UTC(NMIJ) - UTC(CRL): 2002/12-2003/11
P3-C/A SC: RMS = 0.7 ns
P3-C/A SC: RMS = 1.1 ns
ns
MJD
30
28
26
24
22
20
18
52500
52600
52700
52800
52900
53000


NMIJ-CRL [P3-TW(edited)] 2002/12-2003/11: RMS = 1.0 ns
ns
MJD
27
26
25
24
23
22
21
20
52600
52650
52700
52750
52800
52850
52900
52950
53000


UTC(TL) - UTC(CRL): 2002/12-2003/11
P3-C/A: RMS = 2.7 ns
P3-C/A: RMS = 2.3 ns
ns
20
15
10
5
0
52600
52700
52800
52900
53000
MJD


TL-CRL [P3-TW] 2002/12-2003/11
P3-TW: RMS = 1.3 ns
: RMS = 1.0 ns
ns
5
4
3
2
1
0
-1
-2
52600
52650
52700
52750
52800
52850
52900
52950
53000
MJD

Links to other organizations

IAU WG on RCMAM

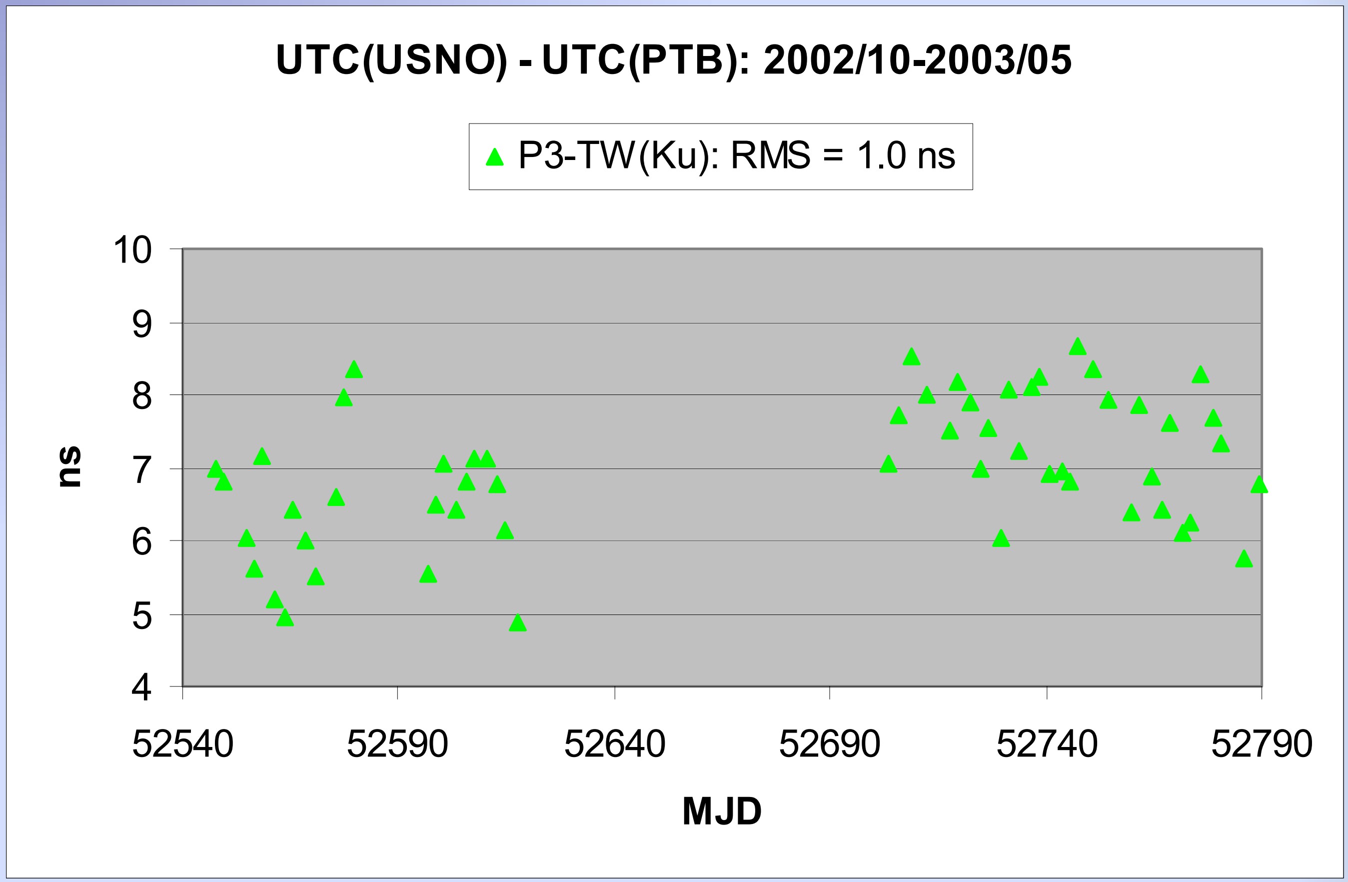
IERS Conventions Product Centre, with USNO

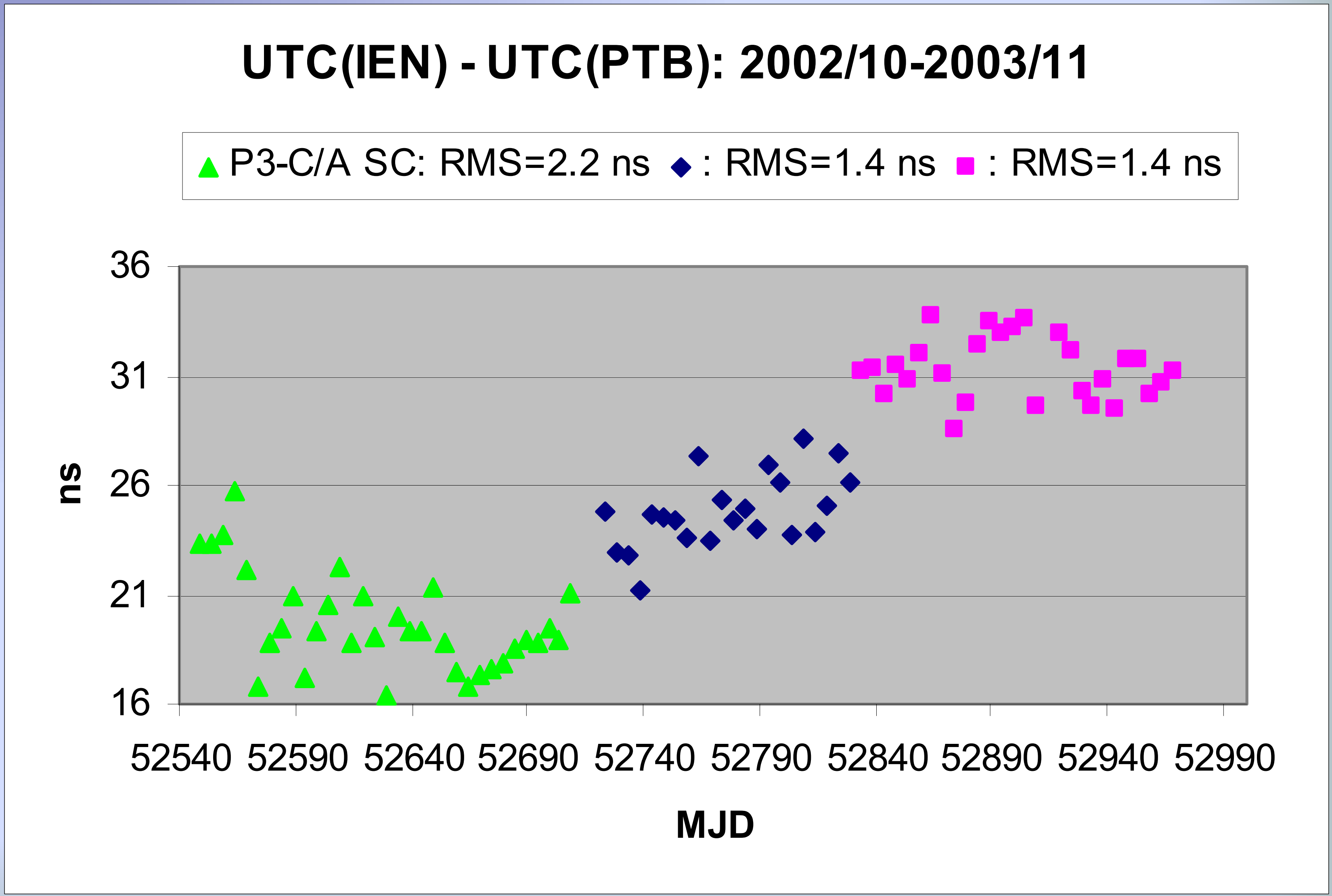
IGS WG on Clock Products

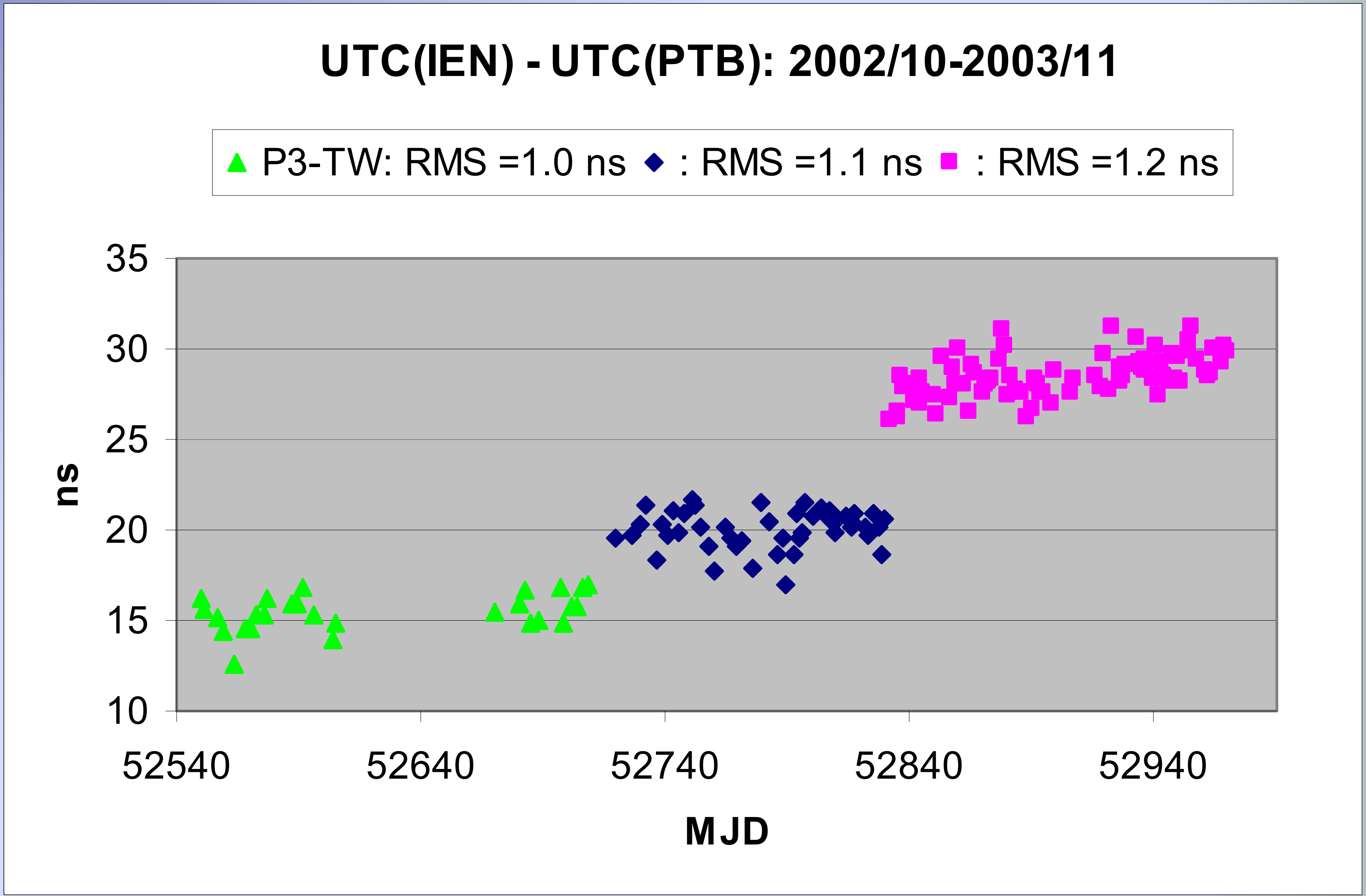
Sector member ITU-R

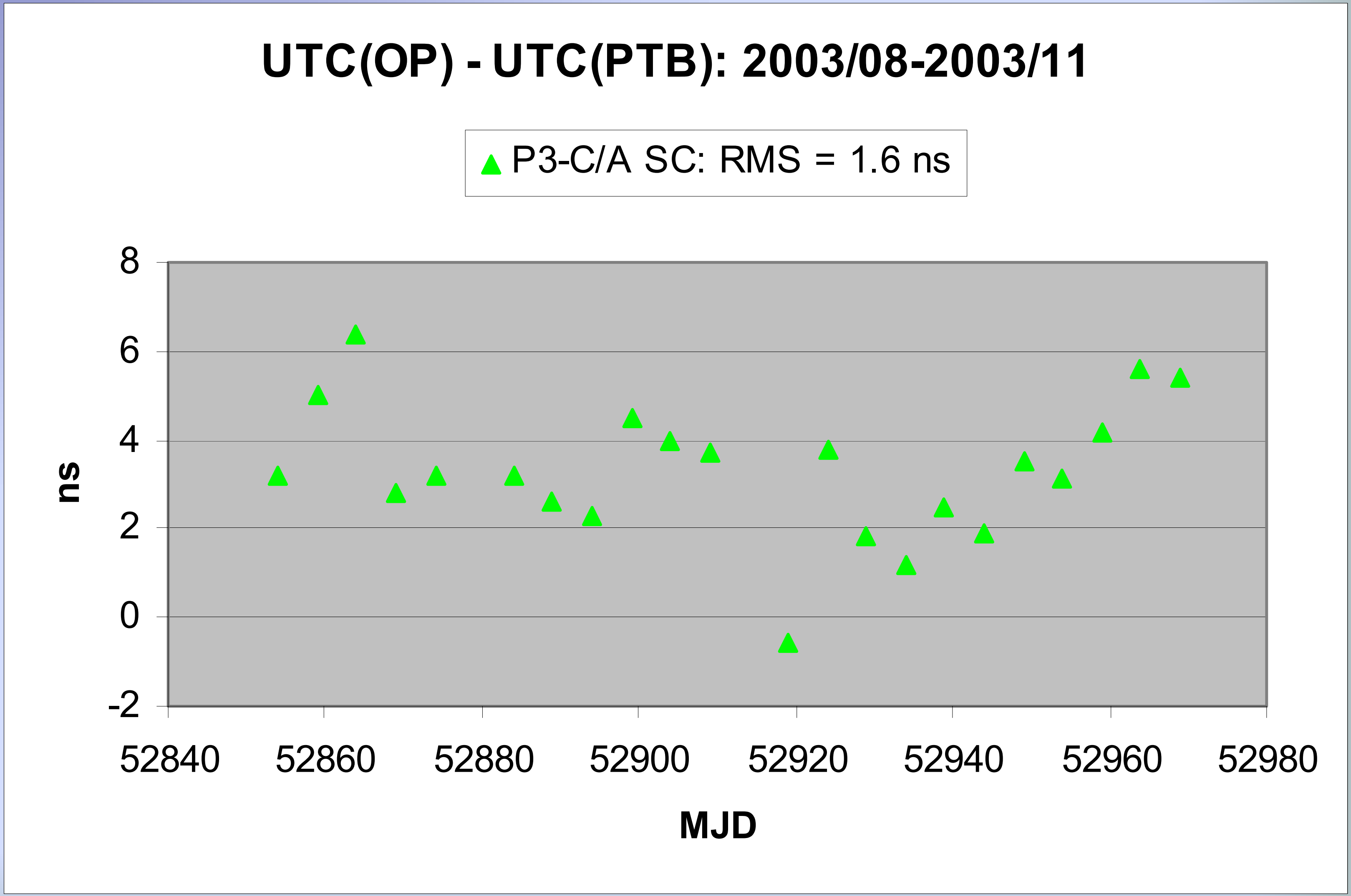
AIG - UGGI

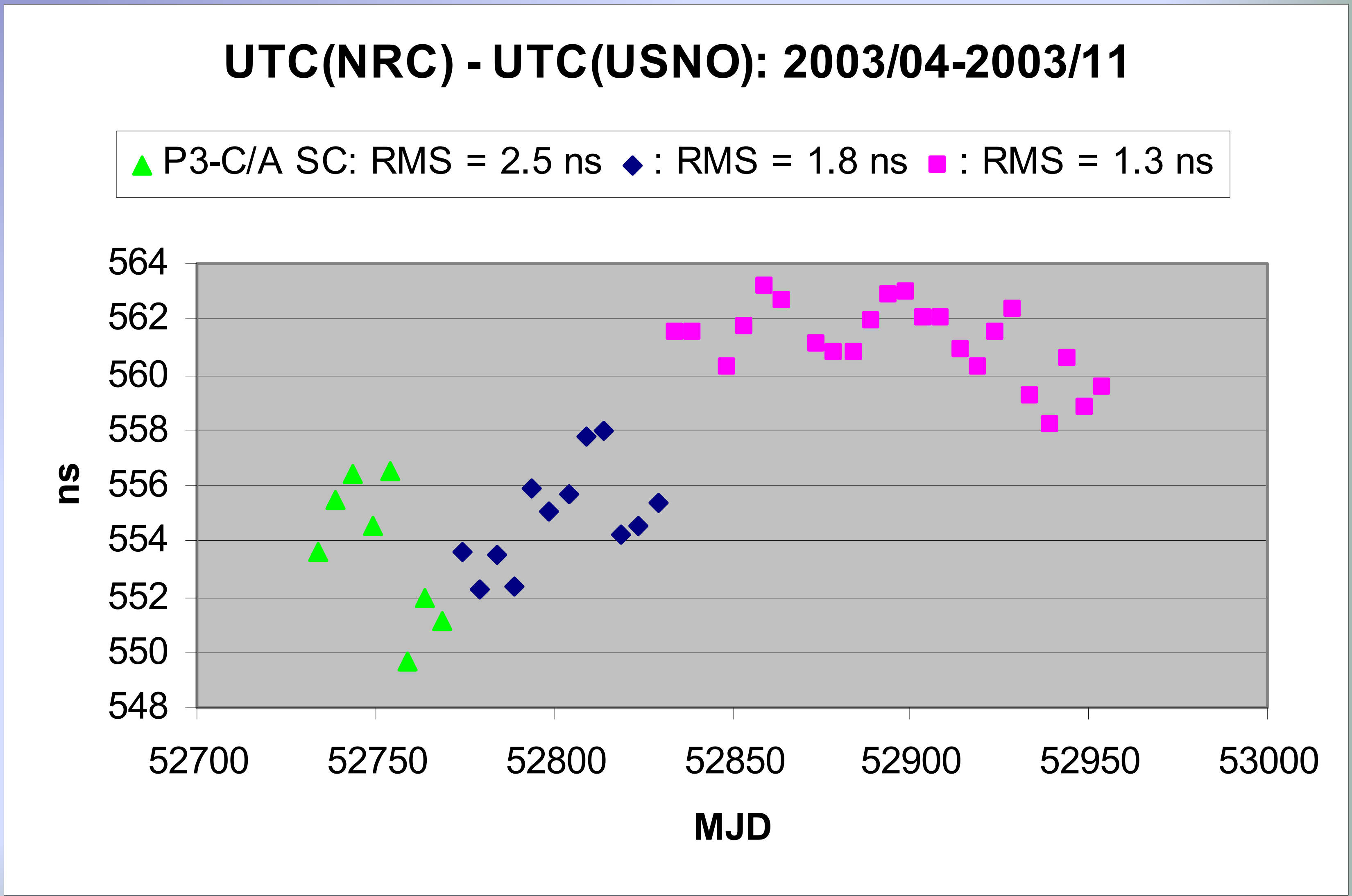
[redacted]


UTC(USNO) - UTC(PTB): 2002/10-2003/05
P3-TW(Ku): RMS = 1.0 ns
10
9
8
7
6
5
4
ns
52540
52590
52640
52690
52740
52790
MJD


UTC(IEN) - UTC(PTB): 2002/10-2003/11
P3-C/A SC: RMS=2.2 ns
: RMS=1.4 ns
: RMS=1.4 ns
36
31
26
21
16
ns
52540 52590 52640 52690 52740 52790 52840 52890 52940 52990
MJD


UTC(IEN) - UTC(PTB): 2002/10-2003/11
P3-TW: RMS =1.0 ns
: RMS =1.1 ns
: RMS =1.2 ns
35
30
25
20
15
10
ns
52540
52640
52740
52840
52940
MJD


UTC(OP) - UTC(PTB): 2003/08-2003/11
P3-C/A SC: RMS = 1.6 ns
8
6
4
2
0
-2
ns
52840
52860
52880
52900
52920
52940
52960
52980
MJD


UTC(NRC) - UTC(USNO): 2003/04-2003/11
P3-C/A SC: RMS = 2.5 ns
: RMS = 1.8 ns
: RMS = 1.3 ns
564
562
560
558
556
554
552
550
548
ns
52700
52750
52800
52850
52900
52950
53000
MJD