GNSS systems calibration, cooperation with RMOs

Héctor Esteban, F. Javier Galindo
Real Instituto y Observatorio de la Armada (ROA)
San Fernando, Spain
hesteban@roa.es

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Introduction

- ROA has carried out several GPS calibrations:
  - 2008 ROA-PTB
  - 2010 IPQ *failed*
  - 2010 ROA-PTB-INRIM
  - 2011 ROA-PTB-INRIM
  - 2012 ROA-PTB-INRIM-OP-NPL

EURAMET Project 1156

The Travelling Sets

- Antennas

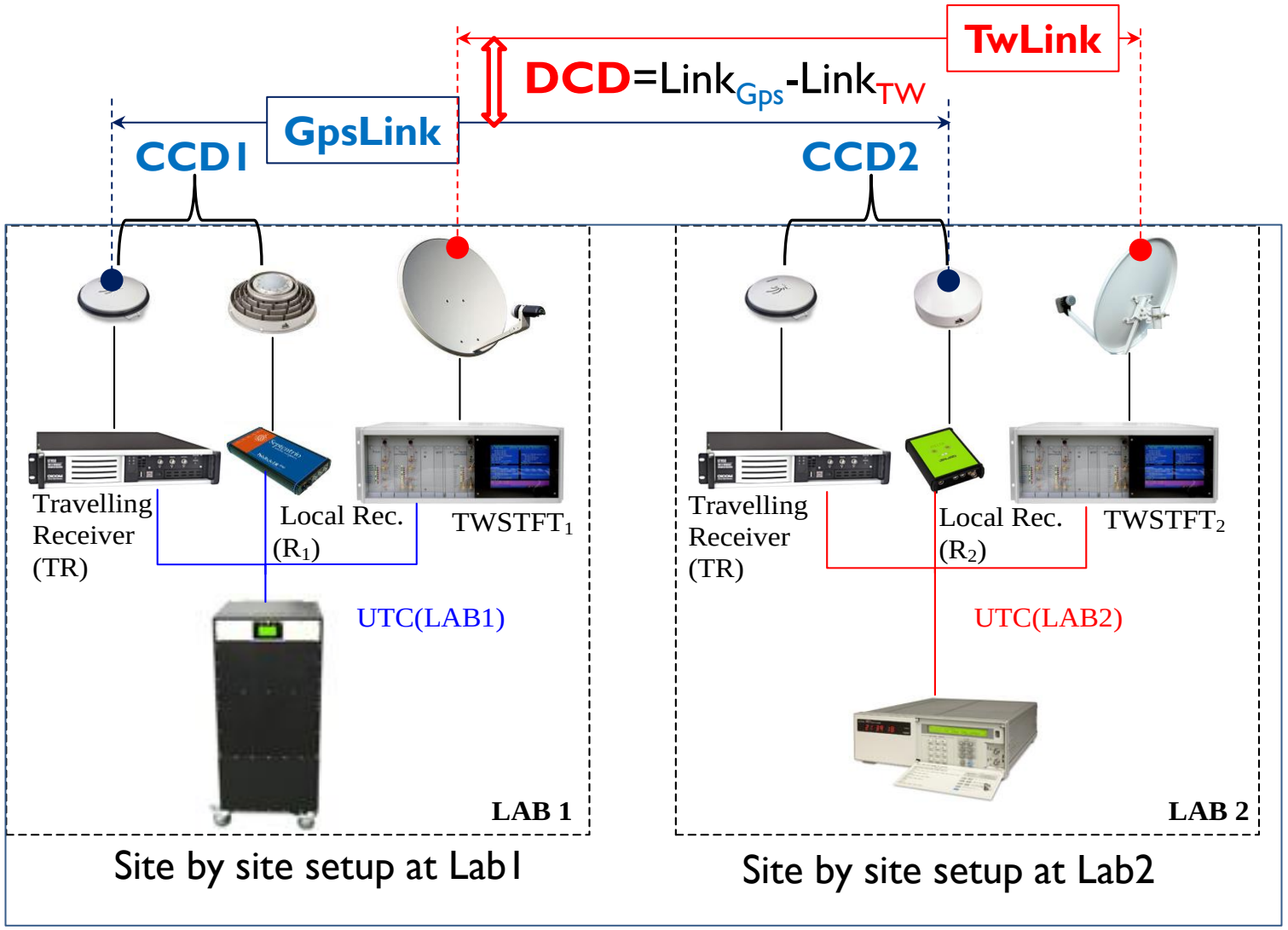
- 50 m low loss H155 antenna cables

H155 5,4 mm

RG58 5,0 mm

- Geodetic receivers

GPS/TWSTFT CCD/DCD at Lab1-Lab2



GPSPPP Link Calibration Computation

$$GpsCAL_{R1,R2} = CCD2 - CCD1$$

$$UTC(LAB1) - UTC(LAB2) = GPS(R1) - GPS(R2) - GpsCAL_{R1,R2}$$

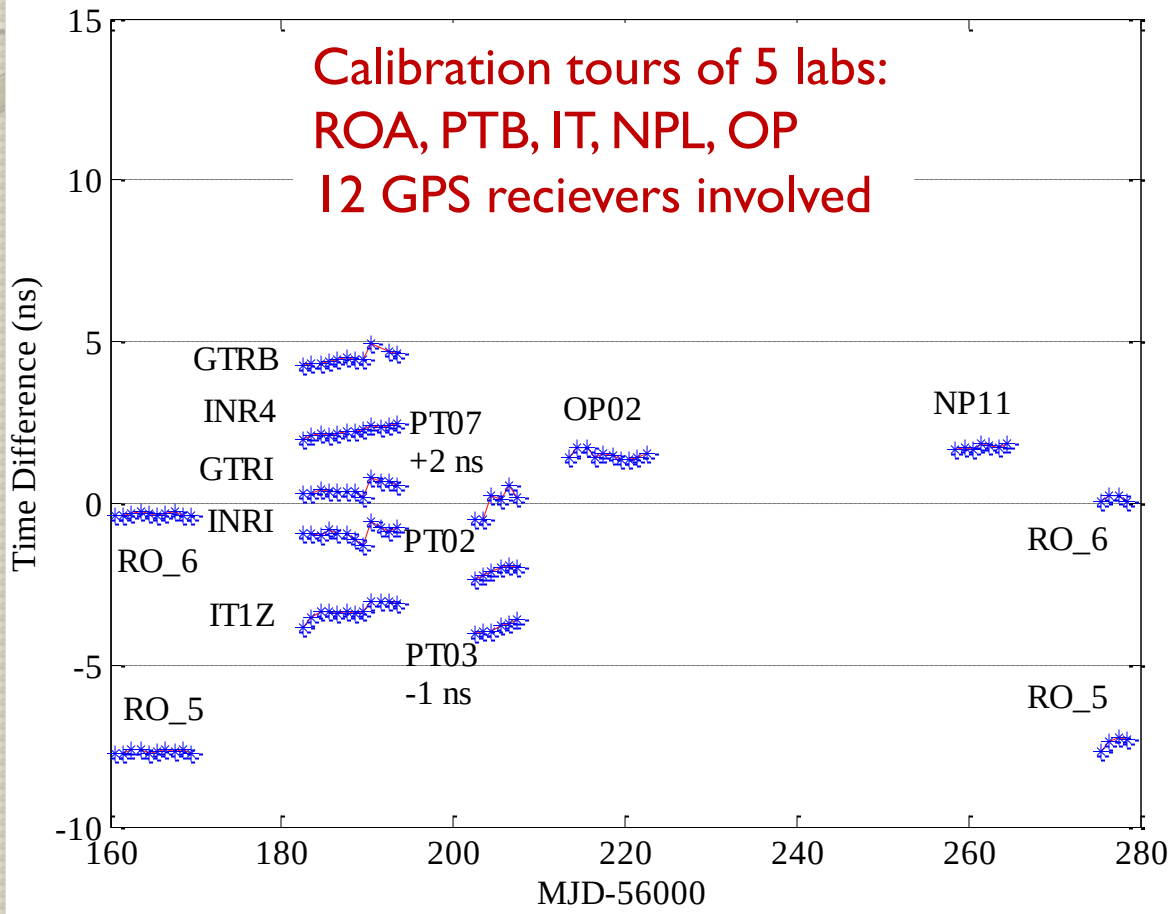
The travelling GPS calibration needs not to be calibrated
All required is its stability during the calibration tour
➔ A black box

TWSTFT Link Calibration Computation

$$\mathbf{TWCAL}_{Lab1\text{-}Lab2} = \mathbf{DCD} = [TW(LAB1) - TW(LAB2)] - [GPS(R1)\text{-}GPS(R2)\text{-}GpsCAL_{R1,R2}]$$

*The TW calibration guidelines for UTC links allows the GPS link calibration as an alternative when the TW mobile station is not applicable

The 2012 calibration campaign



GPS link calibration results

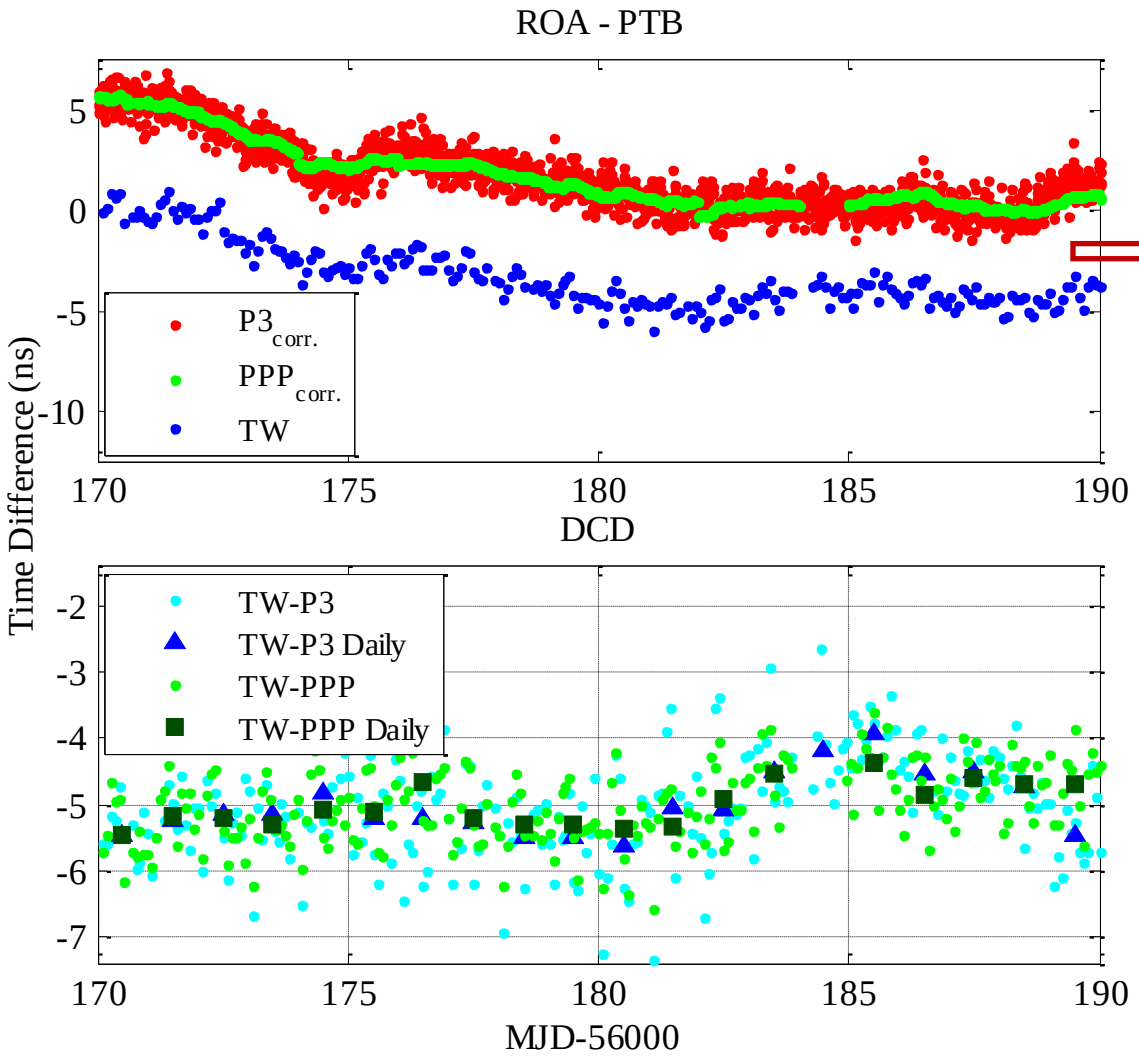
Link Lab(k)-PTB	Year	GPS LINK	CAL/ns Vs. BIPM Clb
ROA-PTB	2010	RO_6 – PTBB	**-3.01 ± 1.00**
	2011	RO_6 – PTBB	**-1.27 ± 1.34**
	2012	RO_6 – PTBB	**-1.83 ± 0.80**
INRIM-PTB	2010	IT1Z – PTBB	**-5.25 ± 0.97**
	2011	IT1Z – PTBB	**-4.47 ± 1.36**
	2012	IT1Z – PTBB	**1.39 ± 0.83**
OP-PTB	2012	OP02 – PTBB	**3.54 ± 0.82**
NPL-PTB	2012	NP11 – PTBB	**3.88 ± 0.80**

Uncertainty in a GPS link calibration

$$u_{c\,GPS} = \sqrt{u_{A,1}^2 + u_{A,2}^2 + u_{B,1}^2 + u_{B,2}^2 + u_{B,3}^2 + u_{B,4}^2 + u_{B,5}^2 + u_{B,6}^2}$$

- $u_{A,1(2)}$ **statistical uncertainty of CCD Lab 1 (Lab 2)**
- $u_{B,1(2)}$ **local uncertainty of 1PPS delay (0.2 TIC / 0.5 ns)**
- $u_{B,3}$ **instability of the receivers and antennas (0.4 ns)**
- $u_{B,4}$ **signal propagation effects (0.3 ns for P3; 0.1 for PPP)**
- $u_{B,5}$ **closure measurement (0.4 ns)**
- $u_{B,6}$ **ambiguity estimation in the PPP processing (0.3 ns)**

TWSTFT link calibration DCD



⇒ 5.1 ns

TWSTFT link calibration results

Link	Year	LINK	TWCAL /ns
ROA-PTB	2010	ROA01 – PTB01	**-4.0 ± 1.4**
	2011	ROA01– PTB01	**-4.4 ± 1.5**
	2012	ROA 01– PTB01	**-5.1 ± 0.9**
INRIM-PTB	2010	IT02 – PTB01	**-1.7 ± 1.4**
	2011	IT02 – PTB01	**-0.5 ± 1.5**
	2012	IT02 – PTB01	**-3.7 ± 0.9**
OP-PTB	2012	OP01 – PTB01	**-3.1 ± 0.9**
NPL-PTB	2012	NPL01 – PTB01	**-0.1 ± 0.9**

TWSTFT link calibration results

Link	Year	LINK	TWCAL /ns
ROA-PTB	2010	ROA01 – PTB01	**-4.0 ± 1.4**
	2011	ROA01– PTB01	**-4.4 ± 1.5**
	2012	ROA 01– PTB01	**-5.1 ± 0.9**
	2014	**TW TVF (Mob.)**	**-4.7 ± 1.0**
	2014	**BIPM (Metode)**	**-4.1 ± 1.5**

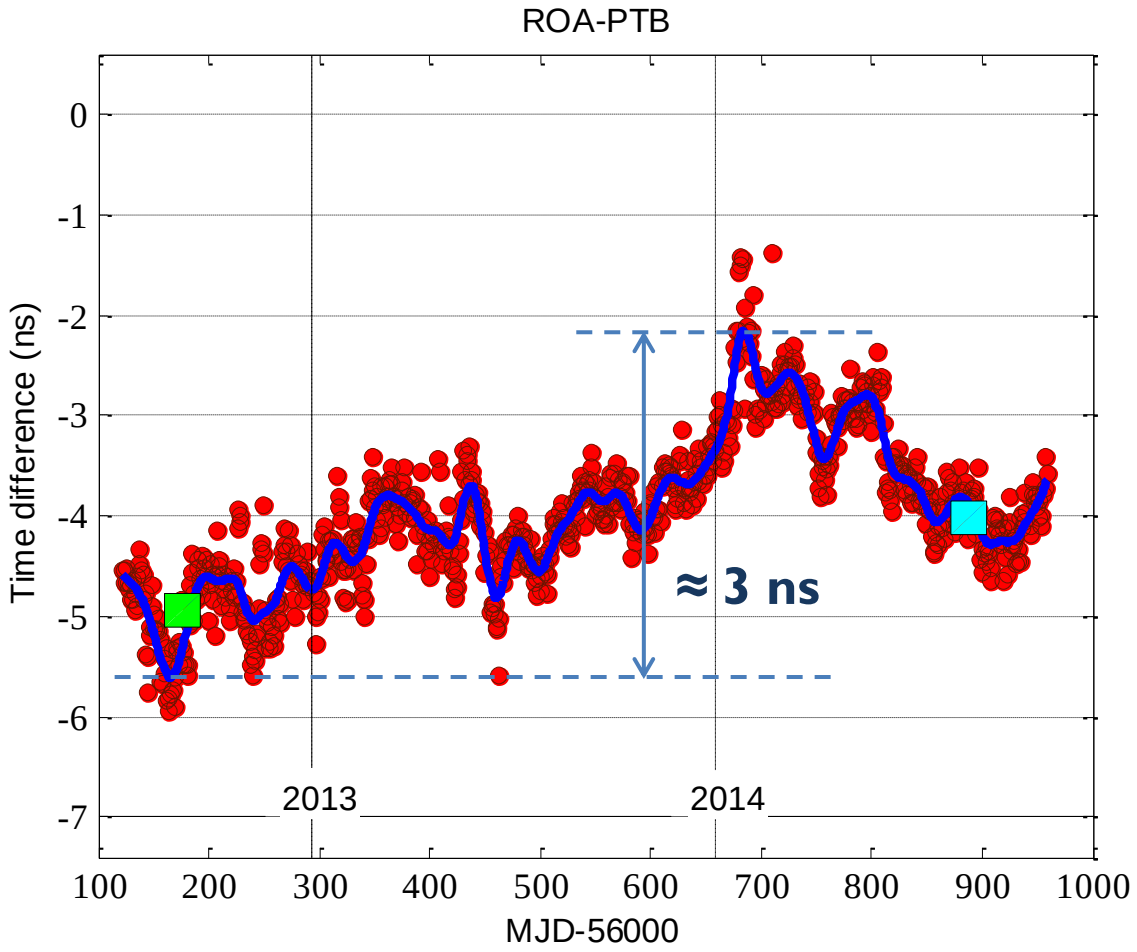
TWSTFT calibration uncertainty

$$u_{c\,TW} = \sqrt{u_{A,3}^2 + u_{B,7}^2 + u_{B,8}^2}$$

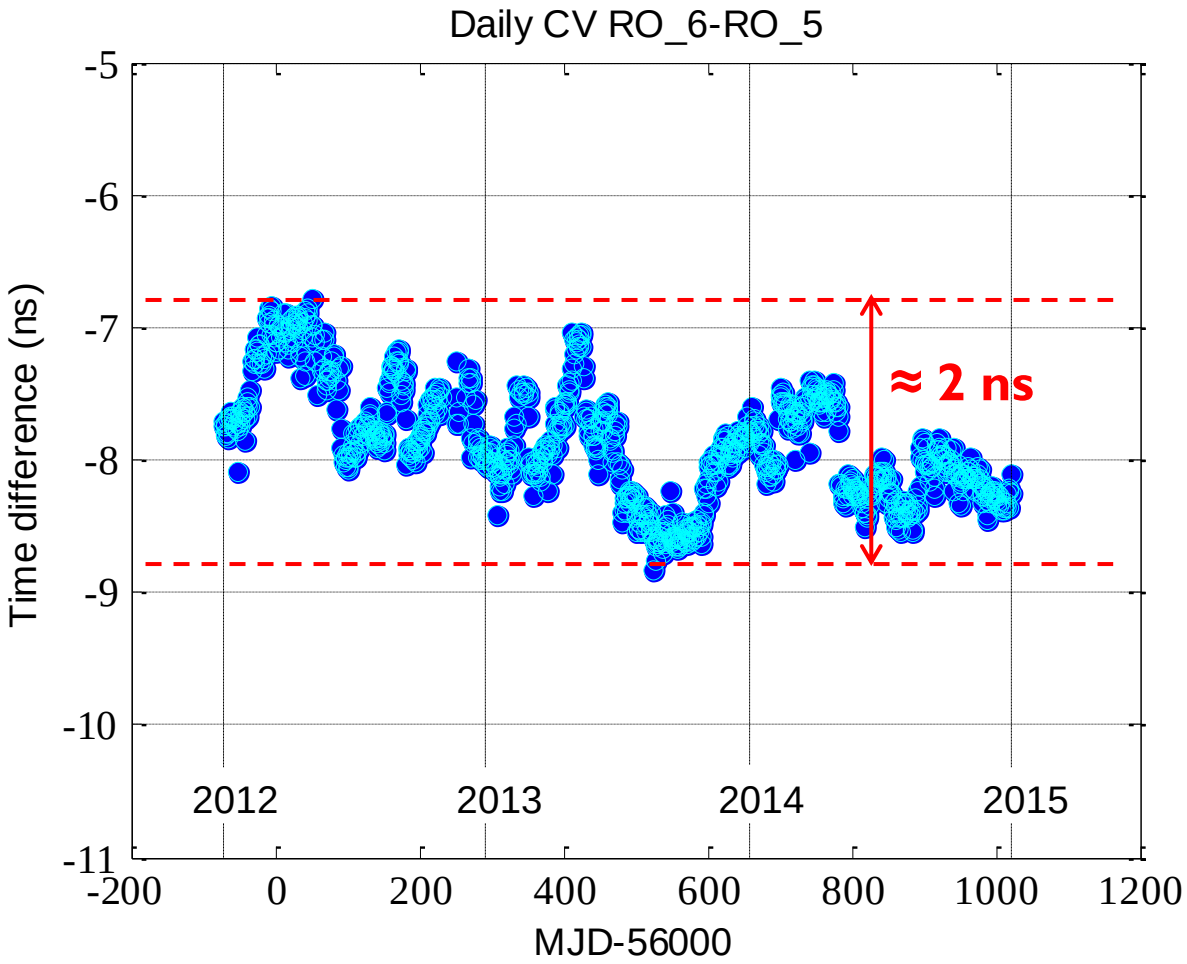
- $u_{A,3}$ **Statistical uncertainty of TWCAL values (0.4 ns)**
- $u_{B,7}$ **TW stations' instabilities (0.3 ns)**
- $u_{B,8}$ **Uncertainty of the GPS link (0.8 ns)**

$$u_{c\,TW} = \sqrt{0,4^2 + 0,3^2 + 0,8^2} \approx 0,9 \text{ ns}$$

Long-term variation TW-GPS DCD of ROA-PTB



Long-term variation GPS CCD at ROA



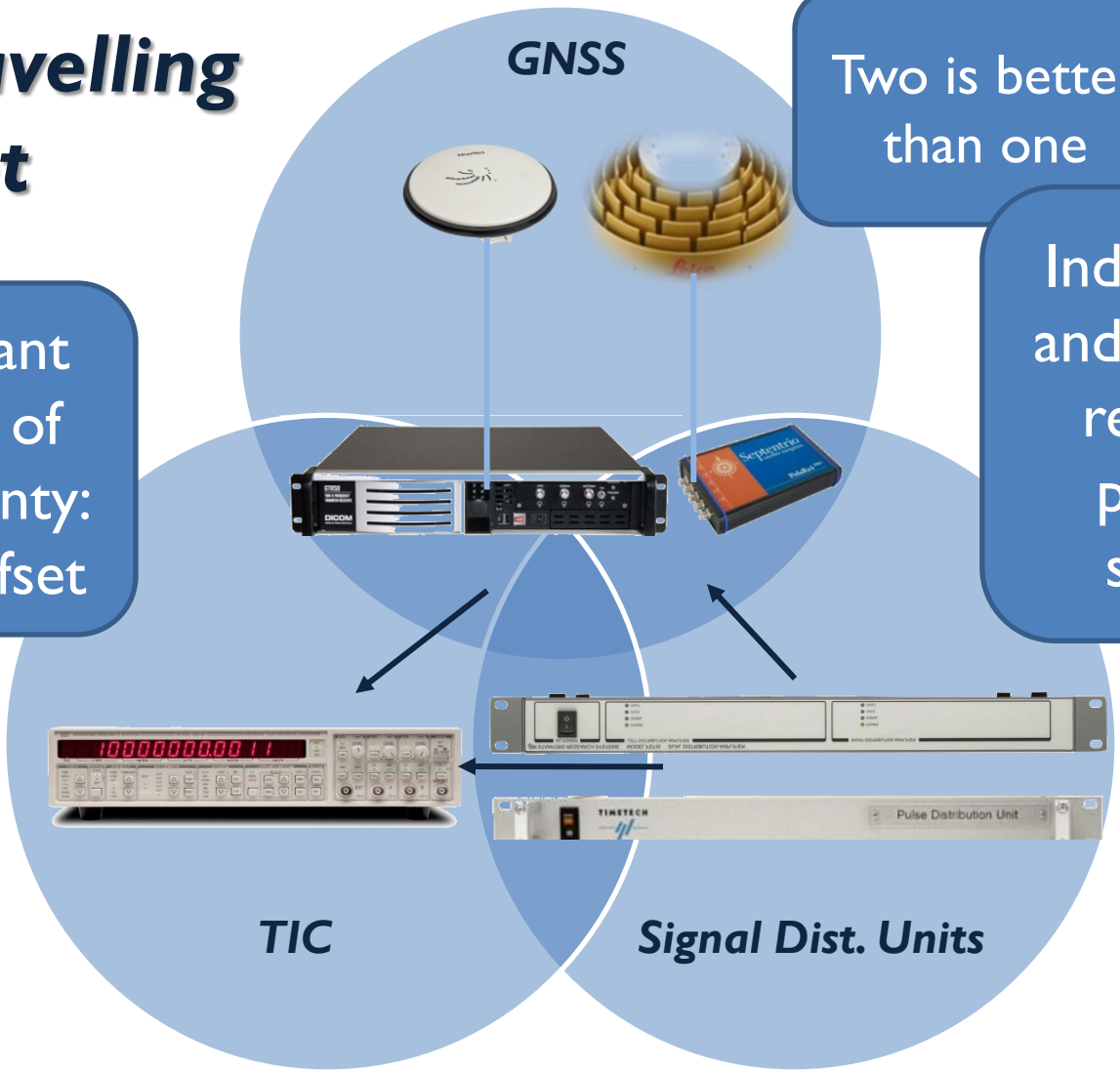
Lessons Learned

- Calibration as simple as possible, e.g. Total Delay
- Recalibrations performed in the same season.
- TR's long-term stability is not a critical issue.
- Regularly check the DCD=$Link_{GPS}$-$Link_{TW}$ series.
- To study the inconsistency, performing a TW calibration parallel by both of TW Mob +GPS Link

Thank you for your attention!

Room for improvement

- ***Travelling Set***



Two is better than one

Independent and stabilised reference pps/freq. sources

Important source of uncertainty: TIC's offset

Room for improvement: *State of the art*

BIPM GPS traveling calibrator 2-3 receiver systems

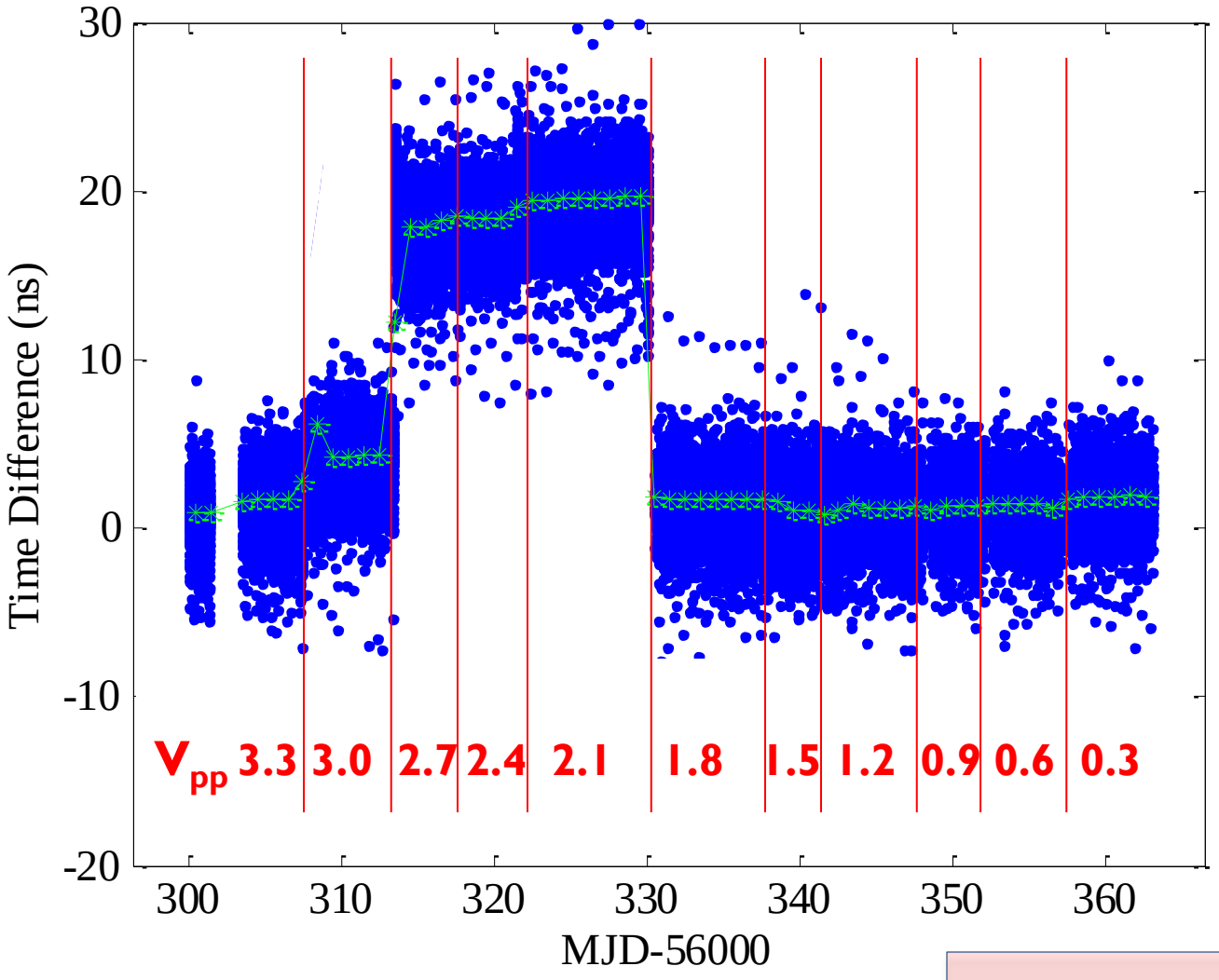
Conclusions

- Sub-nanosecond accuracy is attainable in GPS link calibration.
- The uncertainty of calibration degrades with time. Recalibration is necessary.
- The uncertainty in TW link calibration is dominated by that of the GPS.

Calibration procedure

- GPS calibrations were carried out in ***differential*** mode or ***link*** calibration
- GPS units involved in each Lab (*Ri*) were disposed in common clock (*UTC(Lab)*) and near zero baseline set-up together with TR
- Calibration value (*GPSCAL*) for a couple of receivers and Labs, is calculated by the simple difference of common clock difference (*CCD*)

CCD TR-RO_6 (10 MHz from 3,3 to 0,3 Vpp)



$0.5V_{pp}$ to $2V_{pp}$ (unloaded) (-8dBm to +4dBm in a **50Ω** load ≈ **$0.25\,V_{pp}$ to $1.00V_{pp}$**)

Period between calibrations