GNSS
Time Transfer

Pascale Defraigne
Royal Observatory of Belgium

OUTLINE

- Principle
- Instrumental point of view
- Calibration issue
- Recommendations

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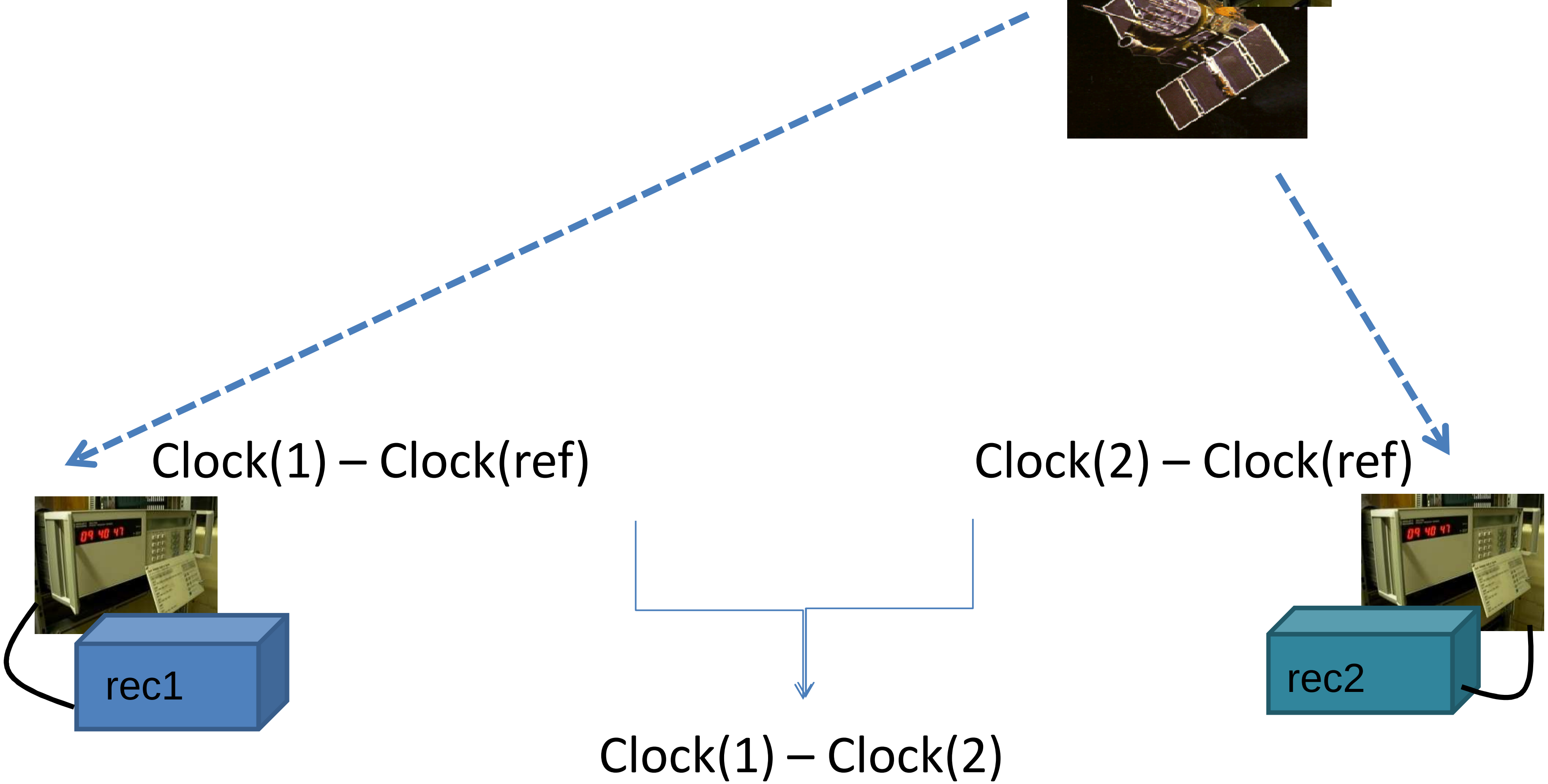
GNSS Time Transfer

Compare two remote clocks
to a same reference

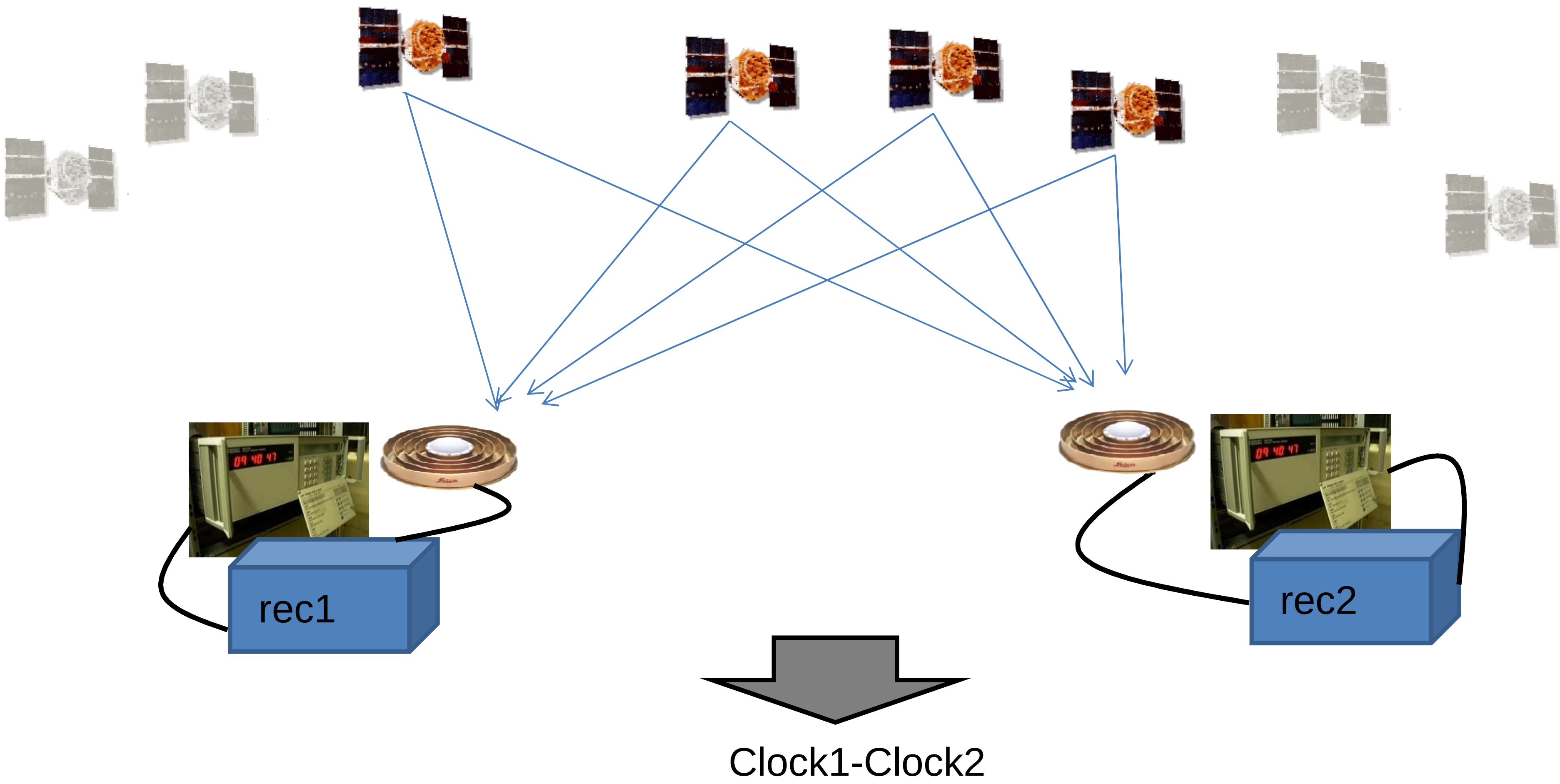


GNSS Time transfer

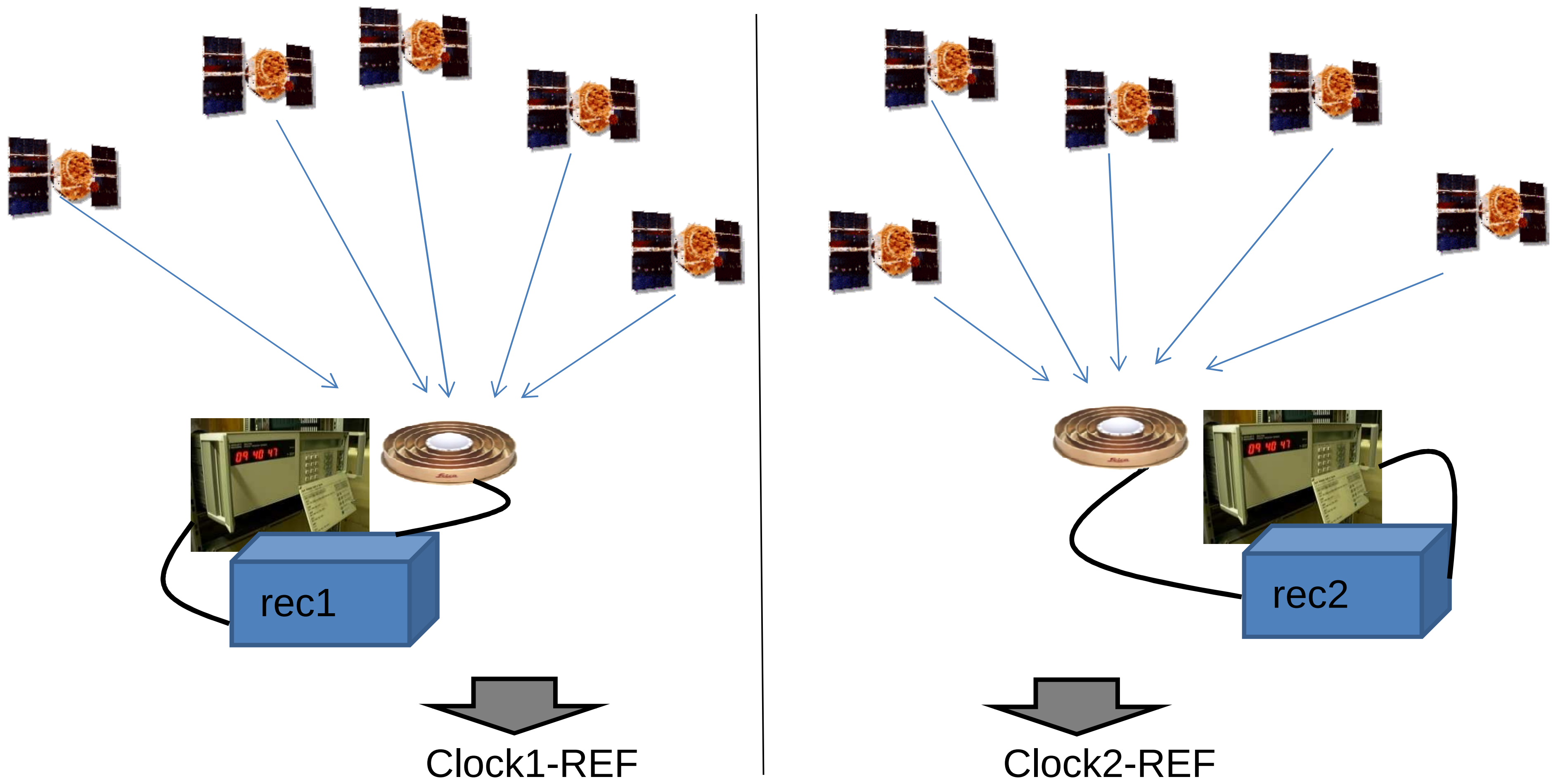
What can be this common reference :

- GPS time
- IGS time (IGS = International GNSS Service)
- Satellite clock (in common view)
- Glonass time
- Galileo time
- ……

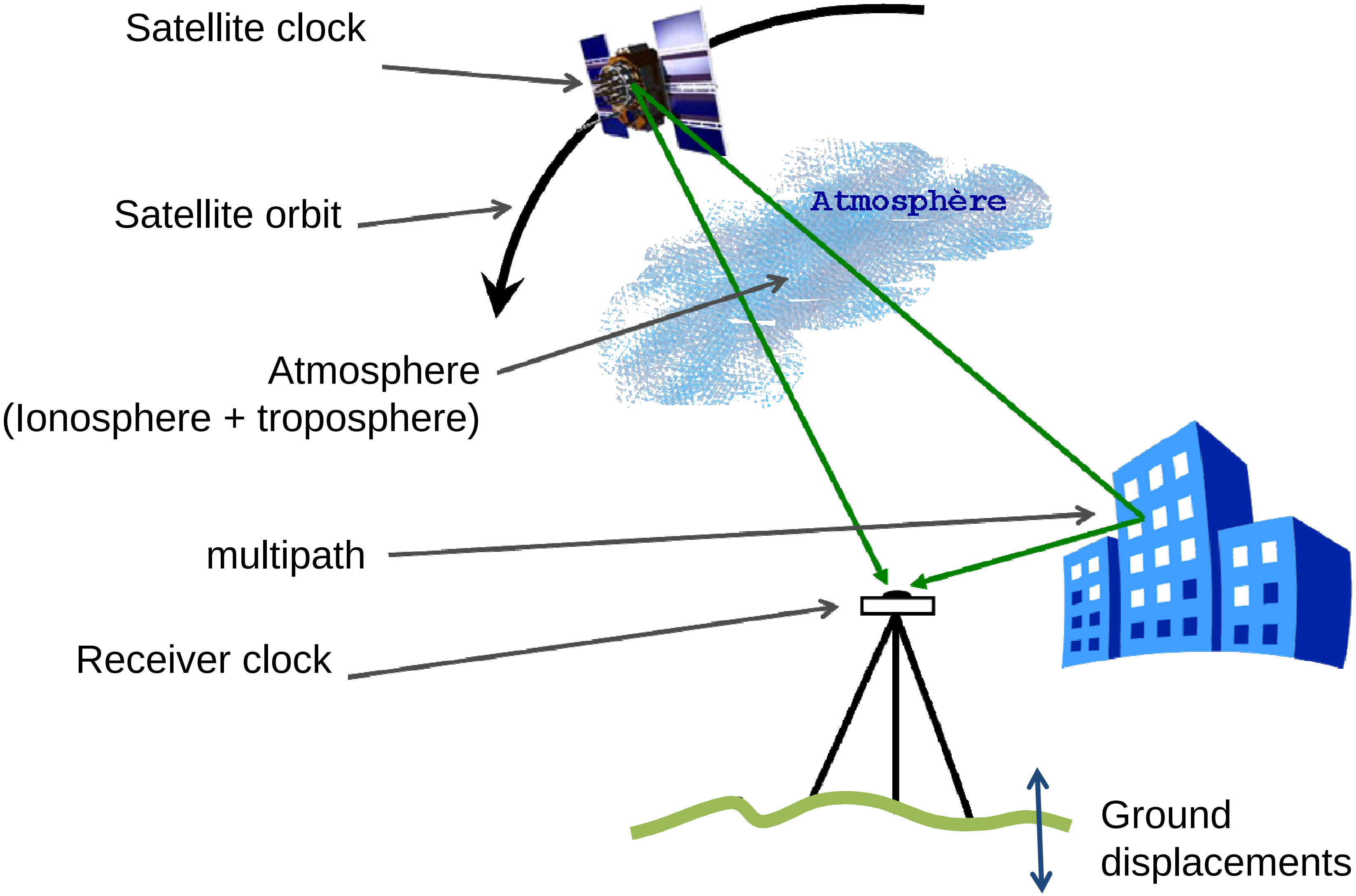
Common view



All in View (also PPP)



Observation modeling



Observation equations

Pseudorange :

To be determined

$$P_{1,2}^{sat} = \| \mathbf{x}_{sat} - \mathbf{x}_{rec} \| - c\left[\boxed{(t_{rec} - ref)} - (t_{sat} - ref)\right]$$

$$+ I_{1,2} + Tr + \delta_{1,2} + \varepsilon_{1,2}$$

iono

tropo

Hardware delays

Satellite position

To be determined

$$P_{1,2}^{sat} = \| \mathbf{x}_{sat} - \mathbf{x}_{rec} \| - c\left[\boxed{(t_{rec} - ref)} - (t_{sat} - ref) \right]$$
$$+ I_{1,2} + Tr + \delta_{1,2} + \varepsilon_{1,2}$$

From NAVIGATION message

Or

from precise IGS orbits

Receiver position

To be determined

$$P_{1,2}^{sat} = \| \mathbf{x}_{sat} - \mathbf{x}_{rec} \| - c\left[\boxed{(t_{rec} - ref)} - (t_{sat} - ref)\right]$$

$$+ I_{1,2} + Tr + \delta_{1,2} + \varepsilon_{1,2}$$

Fixed

Or

determined in PPP, i.e. using code and carrier phase data

Satellite clock

To be determined

$$P_{1,2}^{sat} = \| \mathbf{x}_{sat} - \mathbf{x}_{rec} \| - c\left[\boxed{(t_{rec} - ref)} - (t_{sat} - ref) \right]$$
$$+ I_{1,2} + Tr + \delta_{1,2} + \varepsilon_{1,2}$$

From NAVIGATION message

or

from precise IGS clock products

Ionosphère

To be determined

$$P_{1,2}^{sat} = \| \mathbf{x}_{sat} - \mathbf{x}_{rec} \| - c\left[\boxed{(t_{rec} - ref)} - (t_{sat} - ref)\right] + I_{1,2} + Tr + \delta_{1,2} + \varepsilon_{1,2}$$

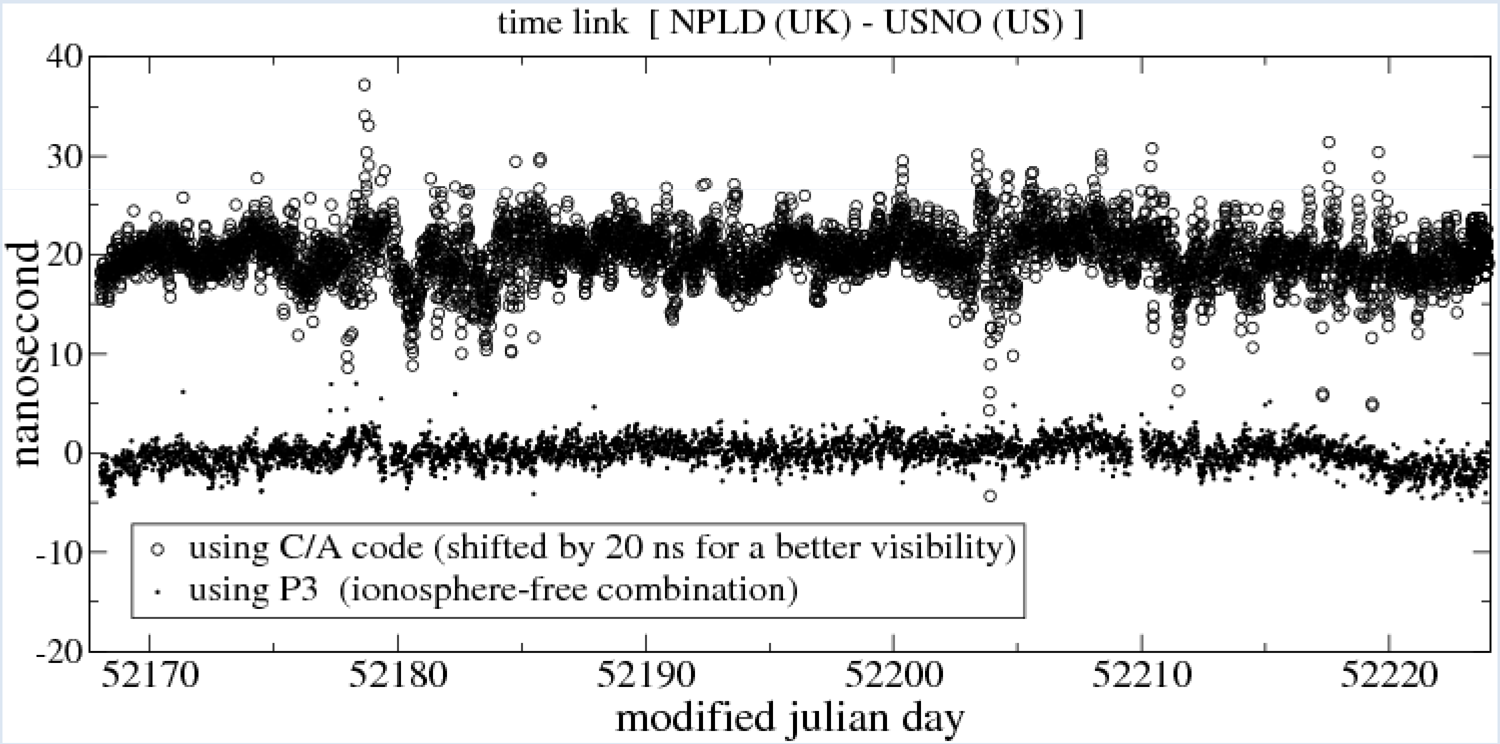
From Klobuchar model (using parameters given in the NAVIGATION message)

or

Removed using the **ionosphere-free combination P3**

P3 removes 99.9% of the ionosphere delays
While models like Klobuchar, only 60%.

CGGTTS results



Tropospheric delay

To be determined

$$P_3^{sat} = \| \mathbf{x}_{sat} - \mathbf{x}_{rec} \| - c\left[\boxed{(t_{rec} - ref)} - (t_{sat} - ref)\right] + Tr + \delta_3 + \varepsilon_3$$

Hydrostatic part :
modeled

Wet part :
Must be determined from the observations but only in PPP (small : < 1 ns)

Hardware delay

To be determined

$$P_3^{sat} = \| \mathbf{x}_{sat} - \mathbf{x}_{rec} \| - c\left[\boxed{(t_{rec} - ref)} - (t_{sat} - ref)\right] + Tr + \delta_3 + \varepsilon_3$$

To be determined by calibration

GNSS code data analysis and CGGTTS Format

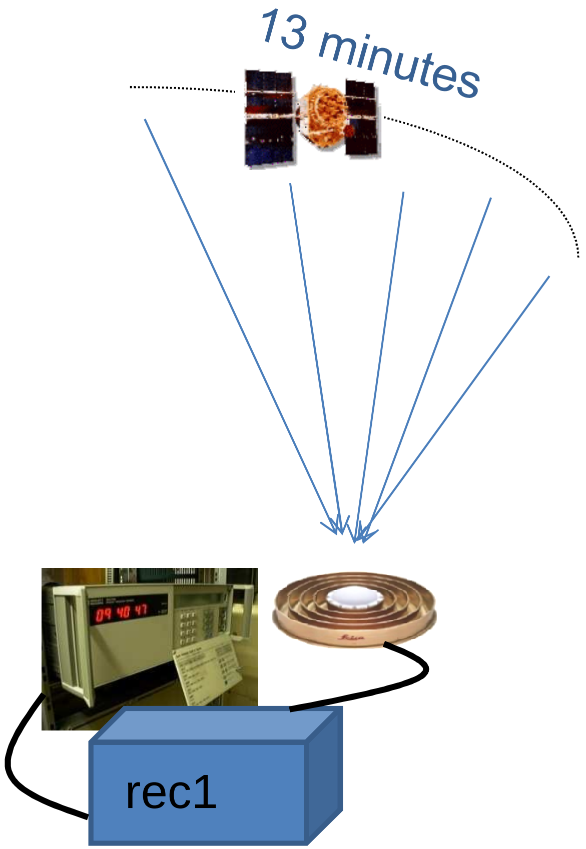
Common
GPS
GLONASS
Time
Transfer
Standard

Results for
(t_{rec} – REF) from GNSS code measurements

Using satellite positions and clocks from the navigation message

Using broadcasted satellite orbits and clocks :

1. For each point: Correction for geometric distance,
   troposphere
   relativistic effect,
   hardware delays
   ionosphere (if not P3)



2. Linear fit : UTC(lab) - Tsat (value at mid-point)

3. For each point: Correction for satellite clock

4. Linear fit : UTC(lab) – TGPS (value at mid-point)

CGGTTS FILE

CGGTTS GPS/GLONASS DATA FORMAT VERSION = 02
REV DATE = 2002-07-01
RCVR = Z-XII3T R2CGGTTS v4.0
CH = 12 (GPS)
IMS = Z-XII3T
LAB = ORB
X = +4027896.26 m (GPS)
Y = +307045.98 m (GPS)
Z = +4919478.21 m (GPS)
FRAME = ITRF
COMMENTS = NO COMMENTS
INT DLY = 303.5 ns (GPS P1), 312.8 ns (GPS P2)
CAB DLY = 333.8 ns (GPS)
REF DLY = 50.6 ns
REF = HORB
CKSUM = 22

UTC(lab) - Tsat

UTC(lab) - REF

PRN	CL	MJD	STTIME	TRKL	ELV	AZTH	REFSV	SRSV	REFGPS	SRGPS	DSG	IOE	MDTR	SMDT	MDIO	SMDI	MSIO	SMSI	ISG				
			hhmmss	s	.1dg	.1dg	.1ns	.1ps/s	.1ns	.1ps/s	.1ns	.1ns		.1ps/s	.1ns	.1ps/s	.1ns	.1ps/s	.1ns				
2	FF	53734	000200	780	426	2415	+234362	-18	125	-9	27	140	118	+11	42	-4	42	-4	17	0	0	L3P	AA
4	FF	53734	000200	780	275	2018	-1015499	-76	156	+48	75	208	173	+41	44	-21	44	-21	57	0	0	L3P	13
27	FF	53734	000200	780	687	1429	-293114	+25	147	+41	23	45	86	-3	23	-32	23	-32	16	0	0	L3P	D0
8	FF	53734	000200	780	429	1868	+517006	+30	120	+16	32	140	118	-18	44	-42	44	-42	22	0	0	L3P	E5
13	FF	53734	000200	780	486	696	-319349	-34	132	-12	23	201	107	+12	32	+16	32	16	18	0	0	L3P	DB
10	FF	53734	000200	780	353	3019	-762212	+57	142	+64	44	202	138	-24	30	-56	30	-56	33	0	0	L3P	F6
16	FF	53734	000200	780	78	247	-196937	-122	121	-108	134	231	567	+209	23	+68	23	68	104	0	0	L3P	3D
23	FF	53734	000200	780	143	766	-1568279	+1	140	-16	76	167	322	+134	44	+19	44	19	56	0	0	L3P	9
2	FF	53734	001800	780	375	2339	+234348	-30	120	-21	34	140	131	+17	50	+24	50	24	25	0	0	L3P	CD
4	FF	53734	001800	780	207	1993	-1015610	-185	164	-61	75	208	226	+72	47	+29	47	29	56	0	0	L3P	27
27	FF	53734	001800	780	719	1229	-293116	+2	159	+18	22	45	84	-1	9	-13	9	-13	15	0	0	L3P	A5
8	FF	53734	001800	780	507	1861	+516997	+15	98	+1	22	140	103	-12	36	-11	36	-11	16	0	0	L3P	CF
13	FF	53734	001800	780	419	737	-319359	-5	143	+17	28	201	120	+16	26	-4	26	-4	23	0	0	L3P	BD

« Geodetic » Time and Frequency Transfer

i.e. code + carrier phase data

Precise Point Positioning
(PPP)

-Needs precise satellite clocks/orbits like the ones delivered by the IGS
-No advantage of using precise carrier phases if broadcast orbits and clocks are used.

Observation equations

Codes :

$$P_3^{sat} = \| \mathbf{x}_{sat} - \mathbf{x}_{rec} \| - c\left[\boxed{(t_{rec} - ref)} - (t_{sat} - ref)\right] + Tr + \delta_3 + \varepsilon_3$$

Carrier Phases :

$$L_3^{sat} = \| \mathbf{x}_{sat} - \mathbf{x}_{rec} \| - c\left[\boxed{(t_{rec} - ref)} - (t_{sat} - ref)\right] + Tr + \lambda_3 N_3 + \varepsilon'_3$$

Working with GPS codes and phases

Called « geodetic time transfer »

Code Wavelength :

P code : 29.3 m, C/A code : 293 m

Carrier wavelength: 19 cm (L1) and 24 cm (L2)

→Carrier phase measurements about 100 times more precise than codes measurements

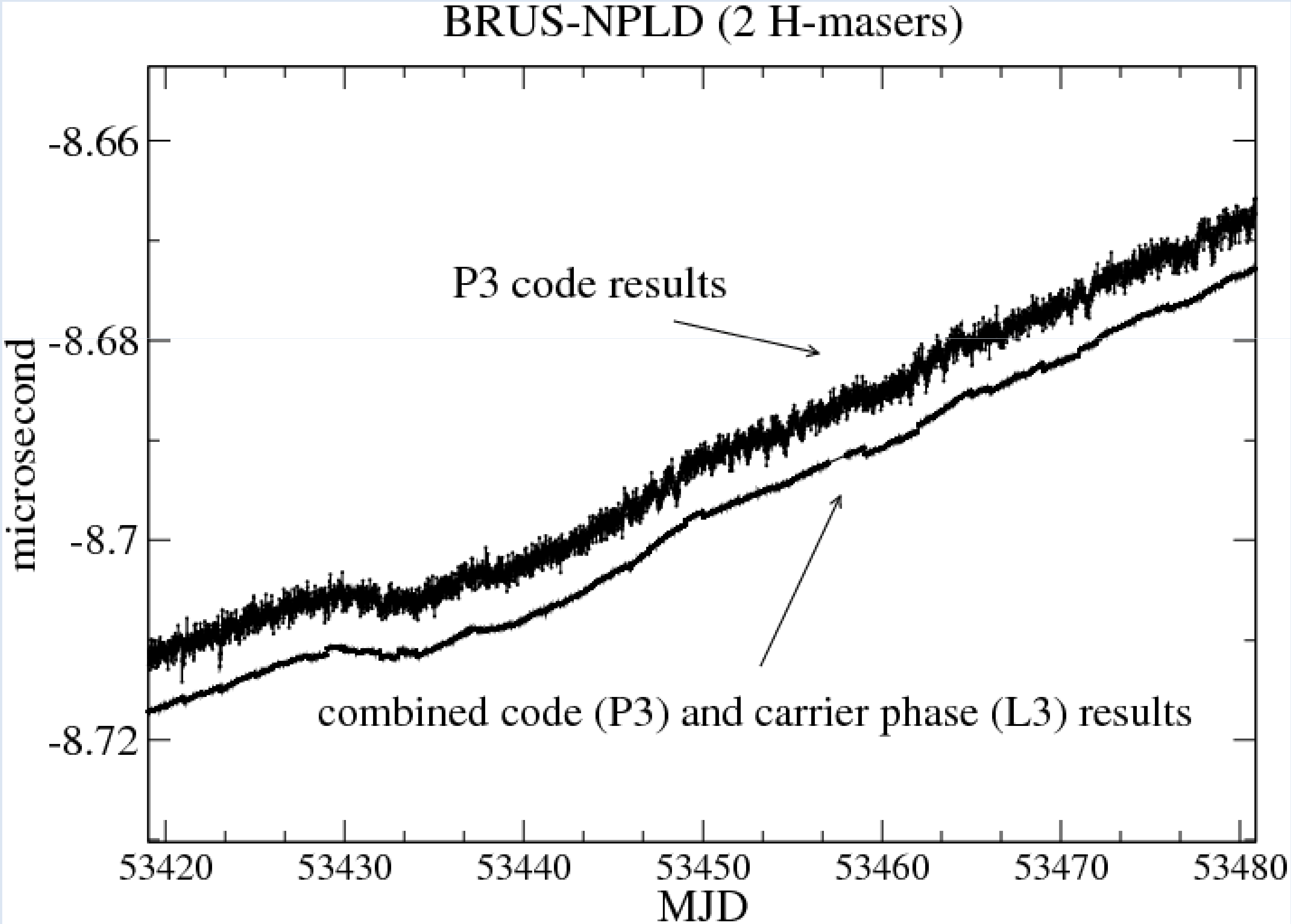
BUT carrier phases ambiguous

→ only usable for frequency transfer, no time

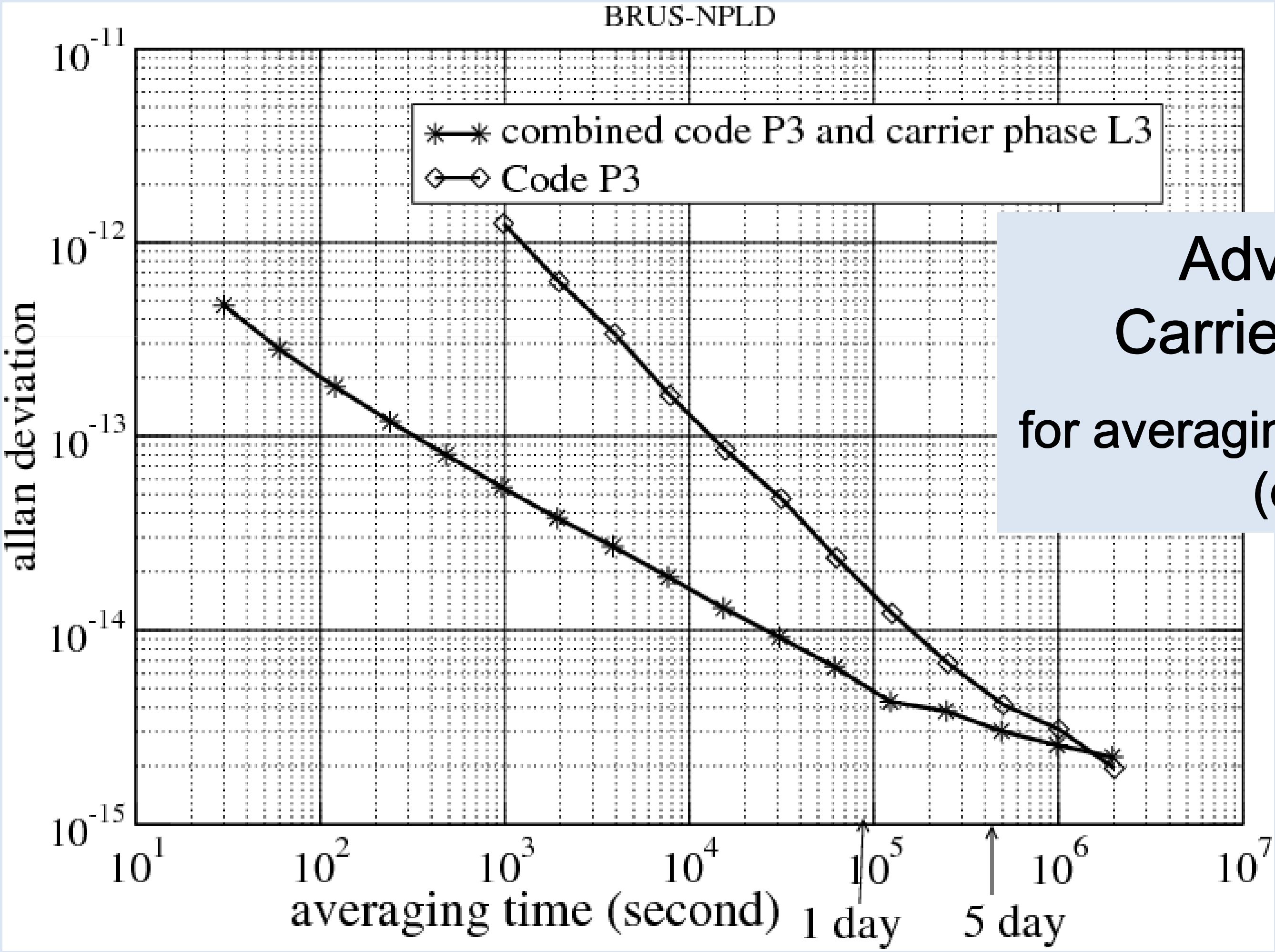
→ need code data for time transfer

Carrier phase data will give the shape of the clock solution
Code data will give the numerical value of the clock solution.

ionosphere-free
P code vs carrier phase



ionosphere-free
P code vs carrier phase

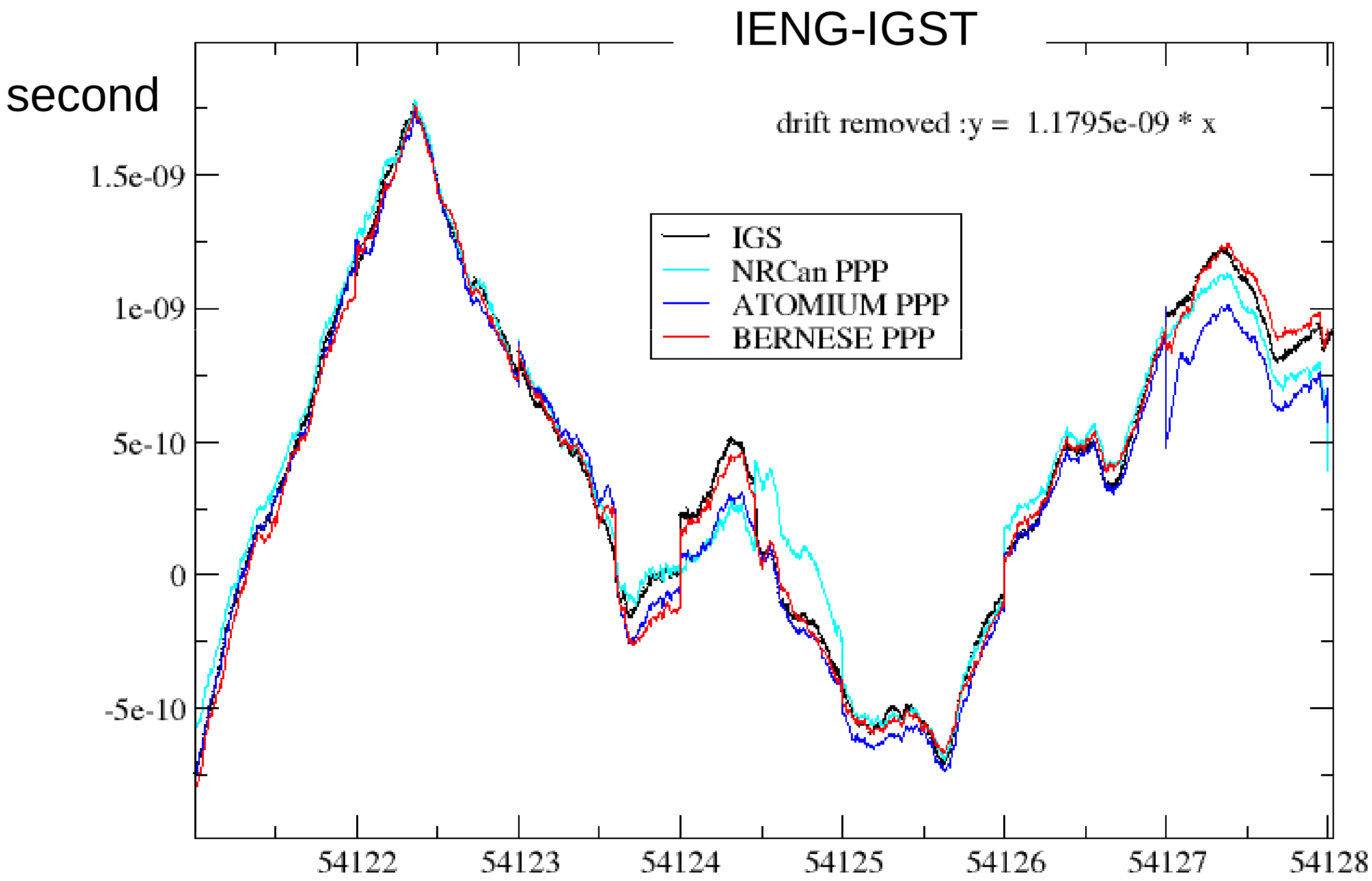


Advantage of Carrier Phases:

for averaging times < 5 (or 10) days;

Available PPP tools

Bernese, NRCan, Atomium, Gipsy, ….



Just as an example

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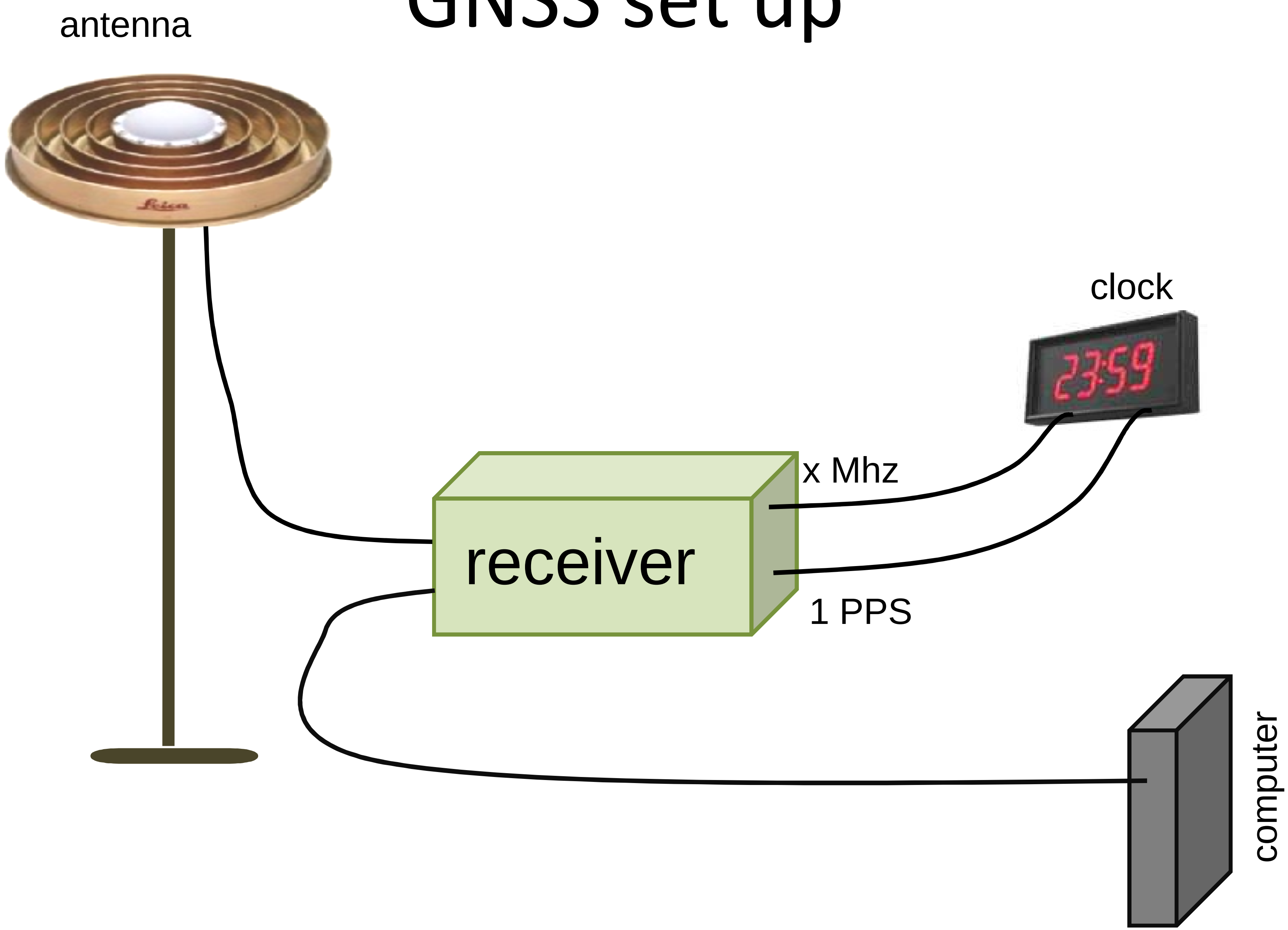
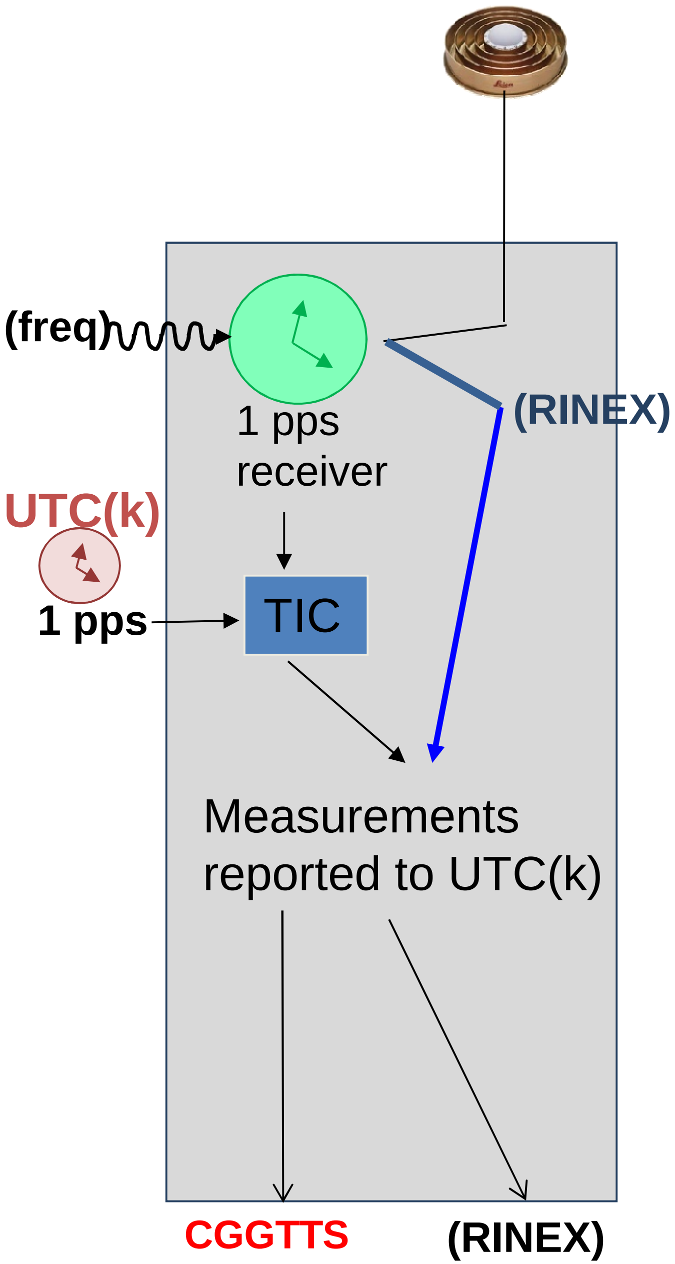
GNSS set up



Receiver

Time receivers (possibly Geodetic)



Advantage:

- calibration procedure is easy, as long as the 1PPS is the reference for calibrations and the trigger level of the receiver is known.

-Proper operation as a time receiver is simpler, in general.

- CGGTTS files directly available

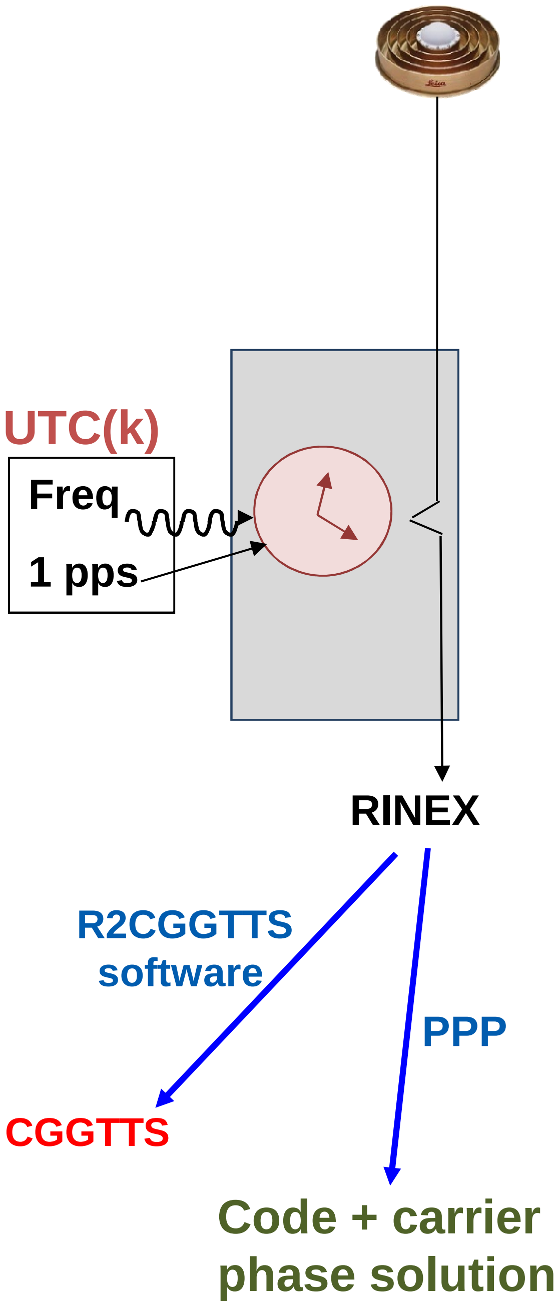
Drawback:

-Not all are dual-frequency (→ no P3, e.g. TTS2)

-Not all are code + carrier phase (→ no PPP)

- If RINEX data reported to UTC(k): may be affected by the TIC measurement
⇒phase noise is larger (e.g. GTR50) or even data affected more generally (e.g. TTS3) .

-If RINEX data reported to the internal reference: calibration procedure more complicate



Geodetic receivers (possibly Time)

using the clock signal as internal reference

Advantage :
No additional noise from a TIC

Drawback :
Calibration issue : need additional measurements to get UTC(k), following the definition of the internal reference from the combination of external 1 PPS and frequency.

Not all provide the CGGTTS, but these can be created from RINEX

(Ashtech Z12T, Septentrio, Javad, Novatel)

R2CGGTTS :

Software developed at the Royal Observatory of Belgium

Goal : Generate CGGTTS files from RINEX files

Input files : RINEX obs files
RINEX nav files
parameter file (position, receiver and cable delays)

Output file : CGGTTS

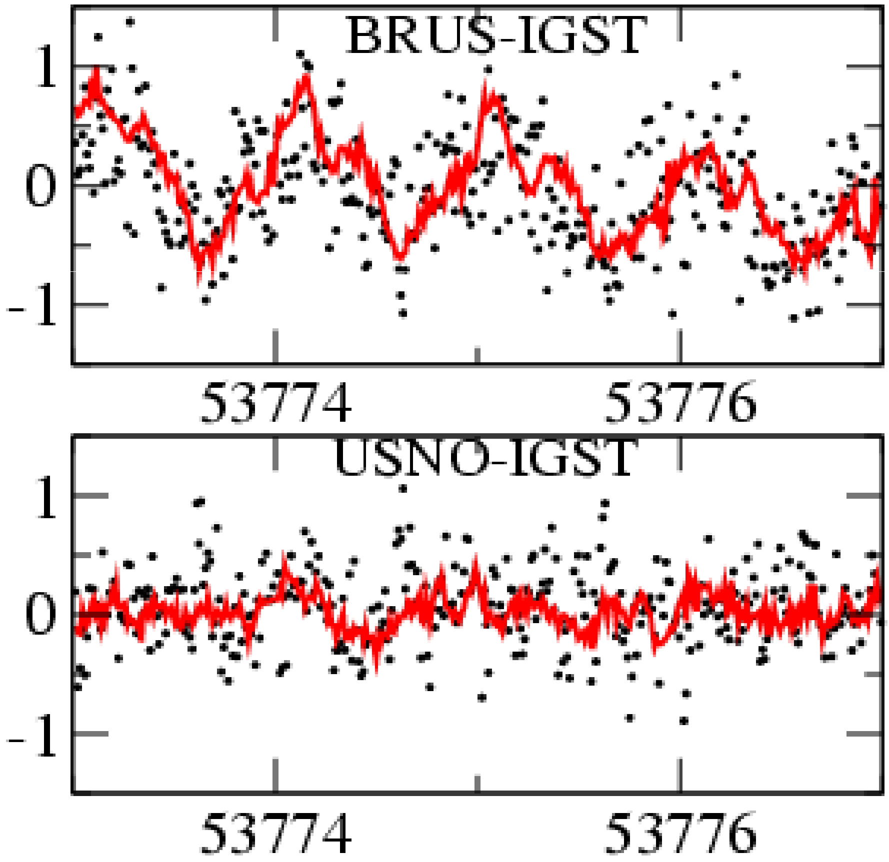
Present version 5.0 : allows for GPS and possibly GLONASS

Available on the BIPM ftp: tai.bipm.org, user: labotai,
password: dataTAI, remote directory: /soft/r2cggtts

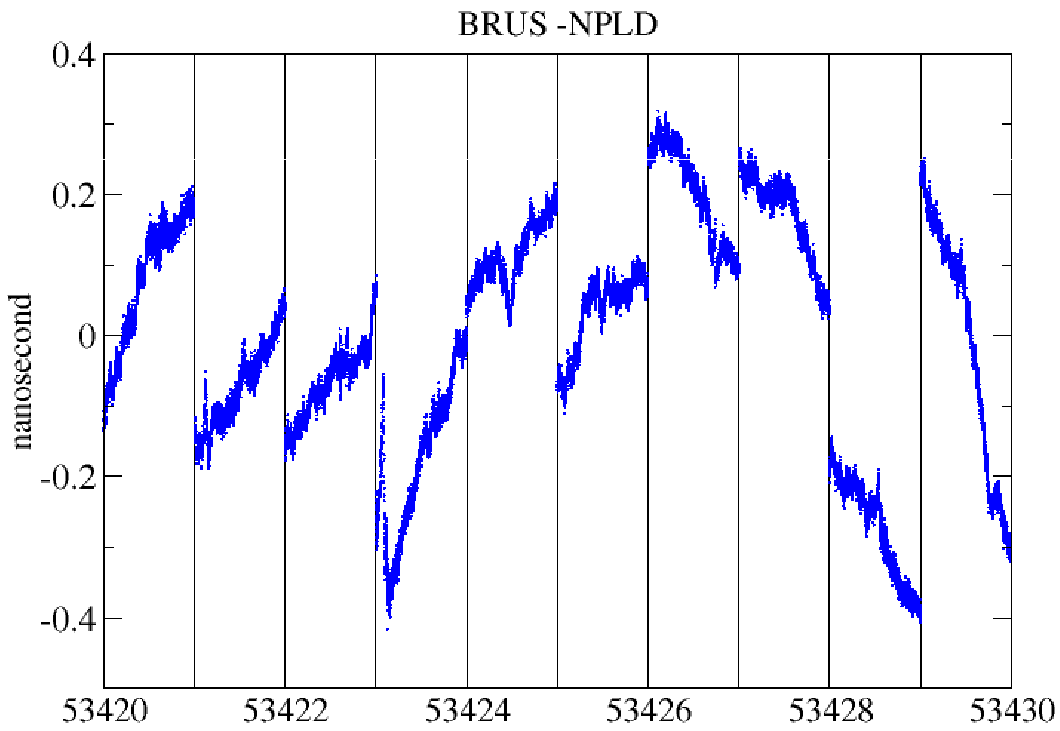
Antenna

Choose an antenna which reduces multipath

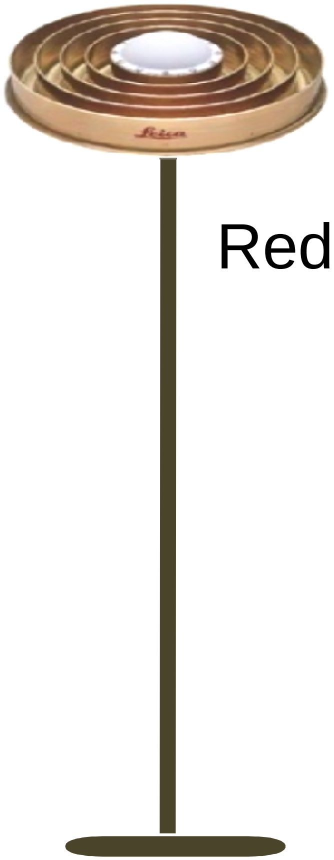
CGGTTS influenced by multipath



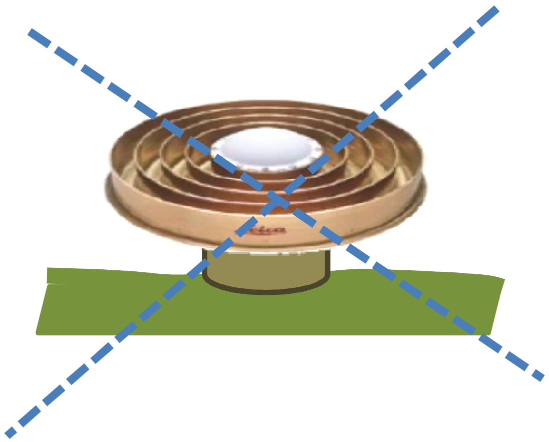
Influence of multipath on PPP solution: day-boundary discontinuities



Ideal setup

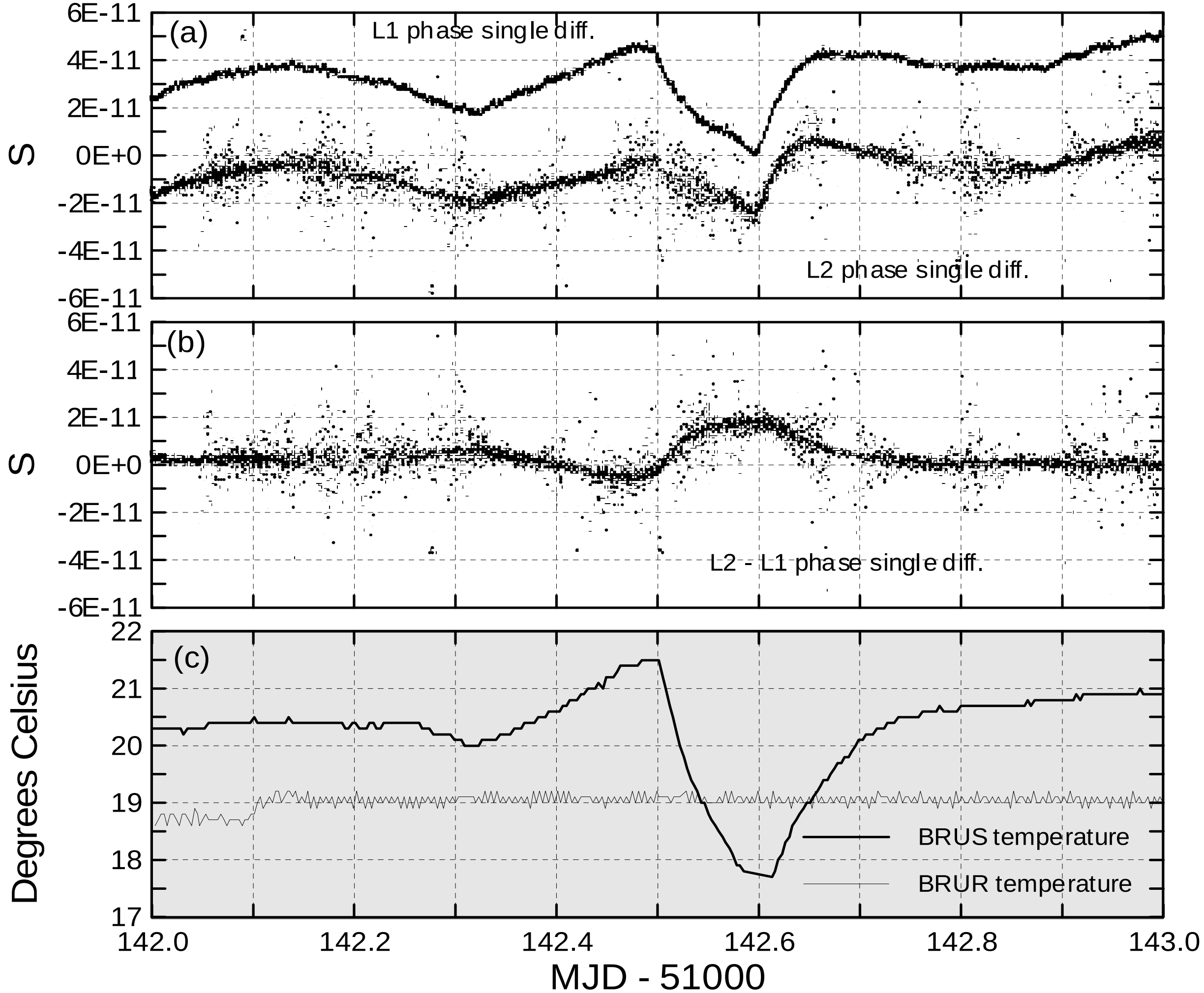


Reduces near-field effects



Temperature influences

Influence of temperature variations on the carrier phase measurements



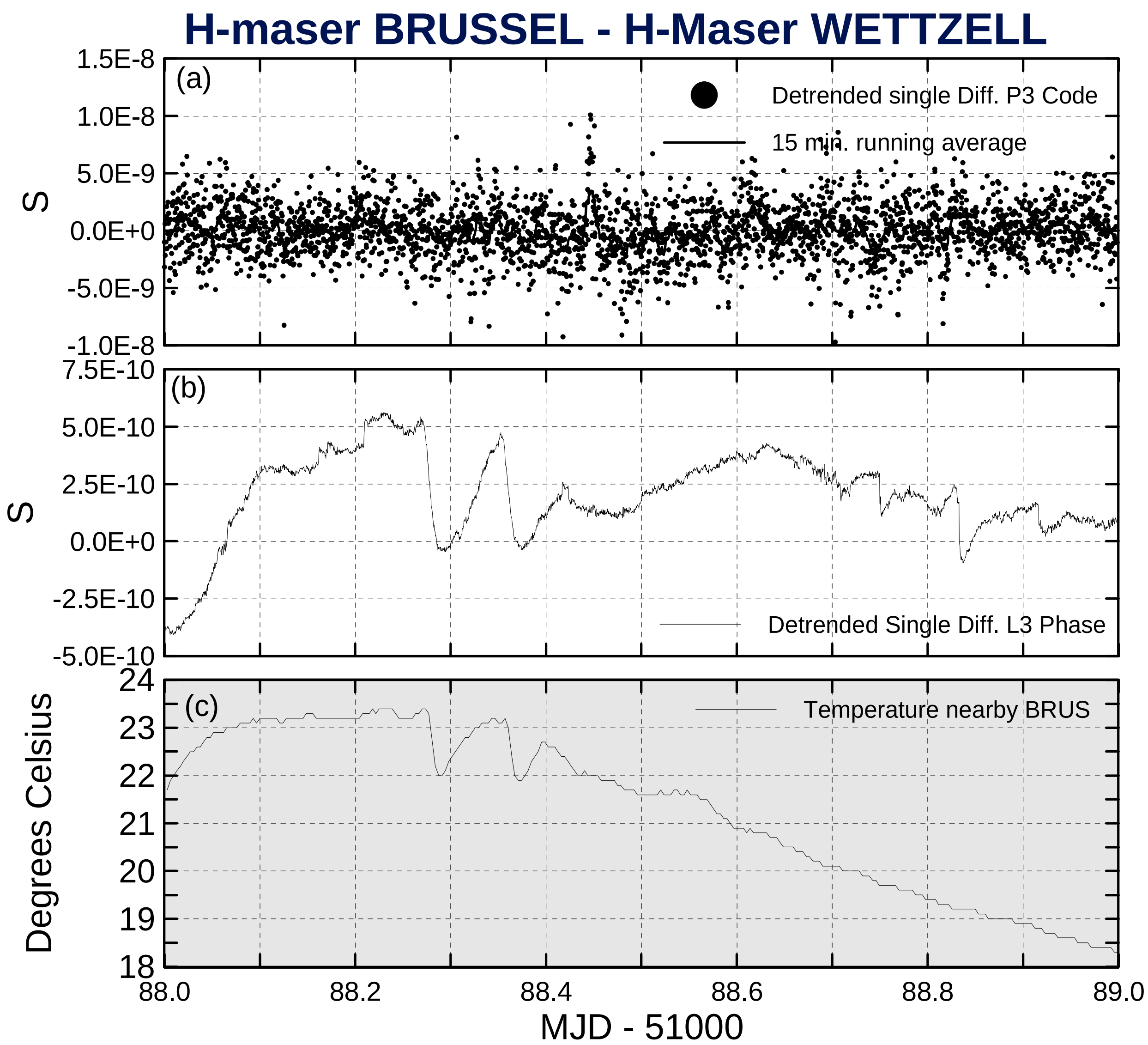
Receivers:

SNR-12RM

L1: 40 ps/℃

L2: 30 PS/℃

0.5 ns/℃ cause = amplificateur



Temperature sensitivity

Indoor : Amplifier : 0.5 ns/°C

Receiver : up to 100 ps/°C (large differences between receivers)

Solution : temperature stabilized with 0.1°C

Outdoor :

antenna : code : expected up to 2 ns /day

carrier phase : 0.2 to 2 ps/°C (diurnal) or to 10 ps/°C (long term)

example : 20 °C diurnal $\rightarrow$ max 40 ps

30 °C long term $\rightarrow$ max 300 ps

Cable :

Choose cable with low sensitivity to temperature variations,

e.g. Andrew company : about 0.02ps/m/°C

example : 30 m , 20 °C $\rightarrow$ 3 ps

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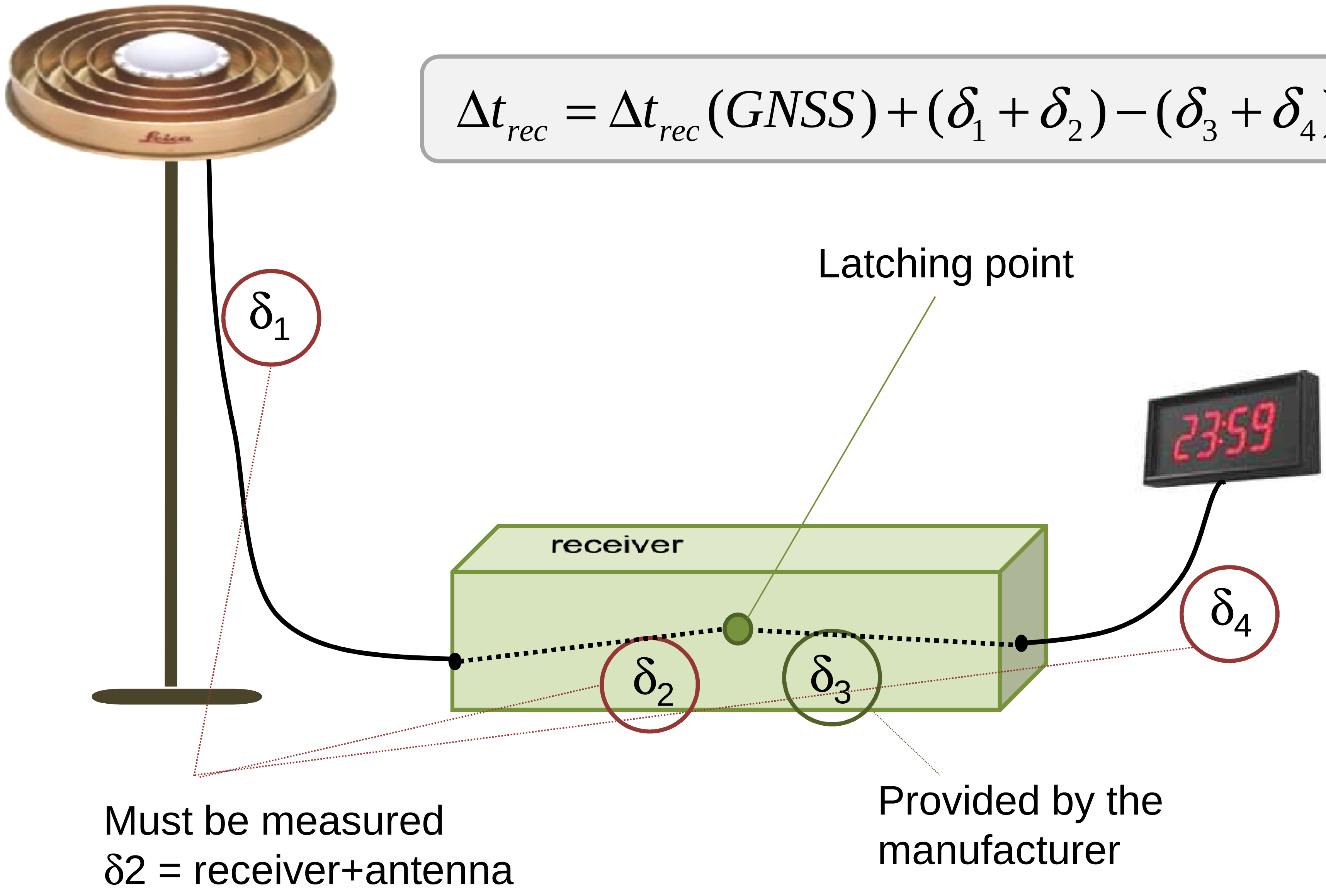
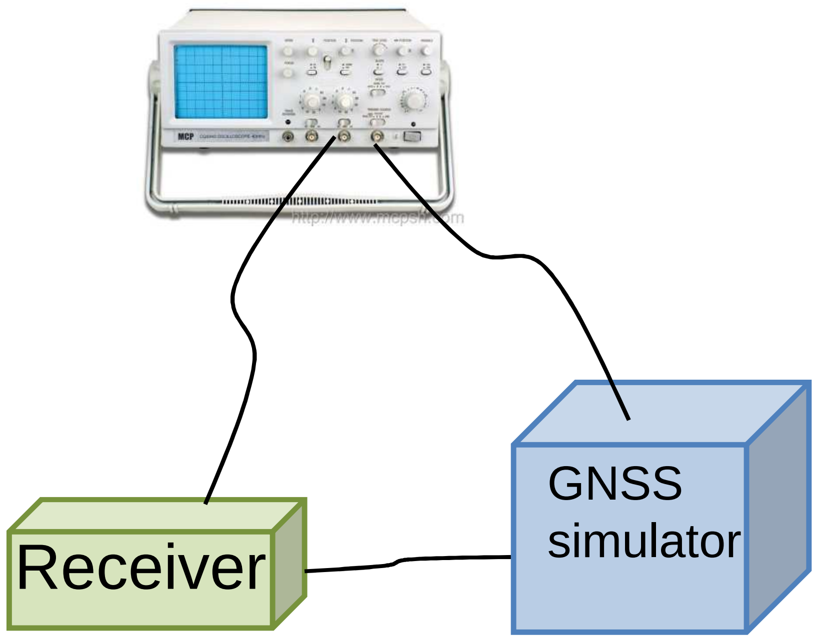
Calibration issue

$$\Delta t_{rec} = \Delta t_{rec}(GNSS) + (\delta_1 + \delta_2) - (\delta_3 + \delta_4)$$



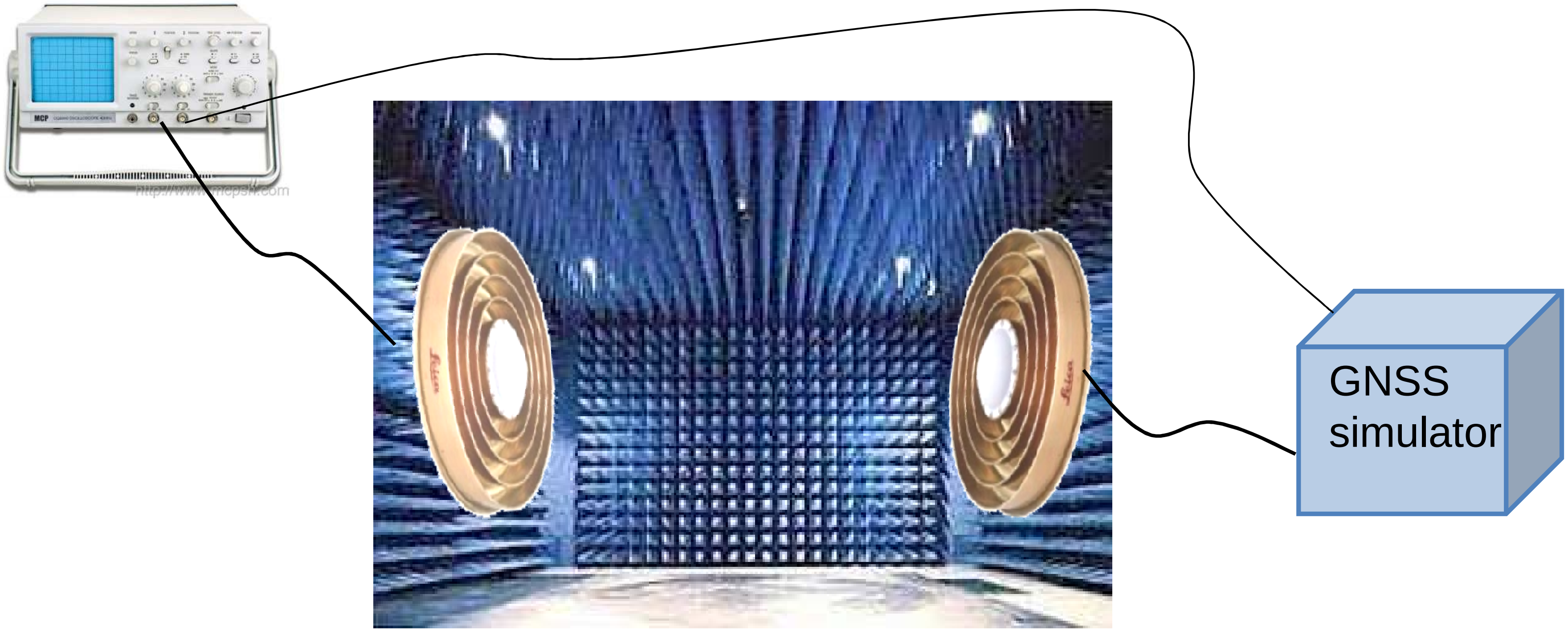
Absolute Calibration

1. Absolute calibration of one receiver
   Using GNSS signal simulator
   Precision about 1 ns (Proia et al., 2011)



Absolute Calibration

1. Absolute calibration of antenna
   Using GNSS signal simulator
   Precision about 1 ns (Proia et al., 2011)

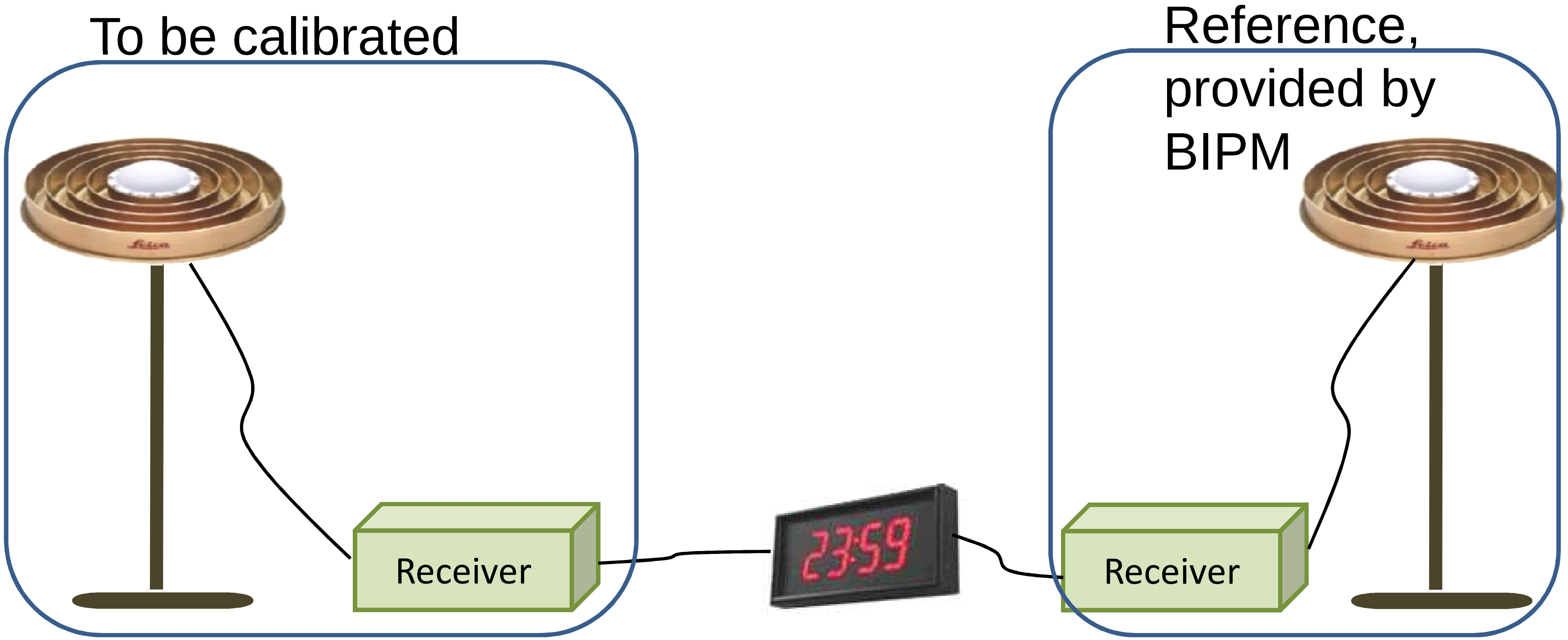


Relative Calibration :

Relative calibration of the chain receiver + antenna

P_1(Ref)-P_1(Rec)-cable delays

P_2(Ref)-P_2(Rec)-cable delays



OUTLINE

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Some recommendations

- Temperature stabilization in the laboratory
- Use dual-frequency receivers (→P3) and also measuring the carrier phases (→PPP)
- Choose an antenna setup which reduces multipath
- Use antenna cable with low temperature sensitivity
- Contact BIPM/RMO to conduct regular calibration