Complete Relativistic Modelling of the GIOVE-B clock parameters and its impact on POD, track-track ambiguity resolution and precise timing

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Introduction

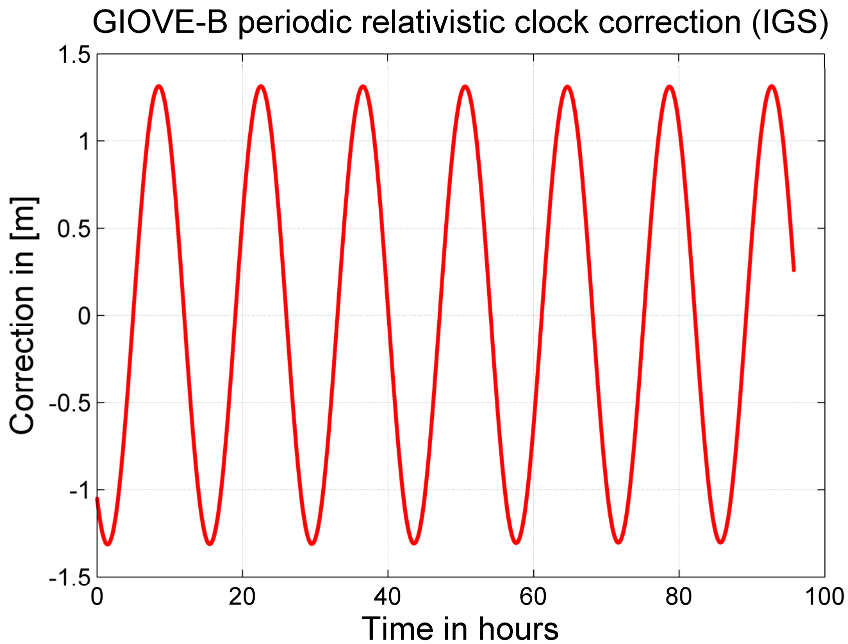
- Complete Relativistic Modelling of GIOVE-B Clock
- Track-to-Track Phase Clock Ambiguity Resolution

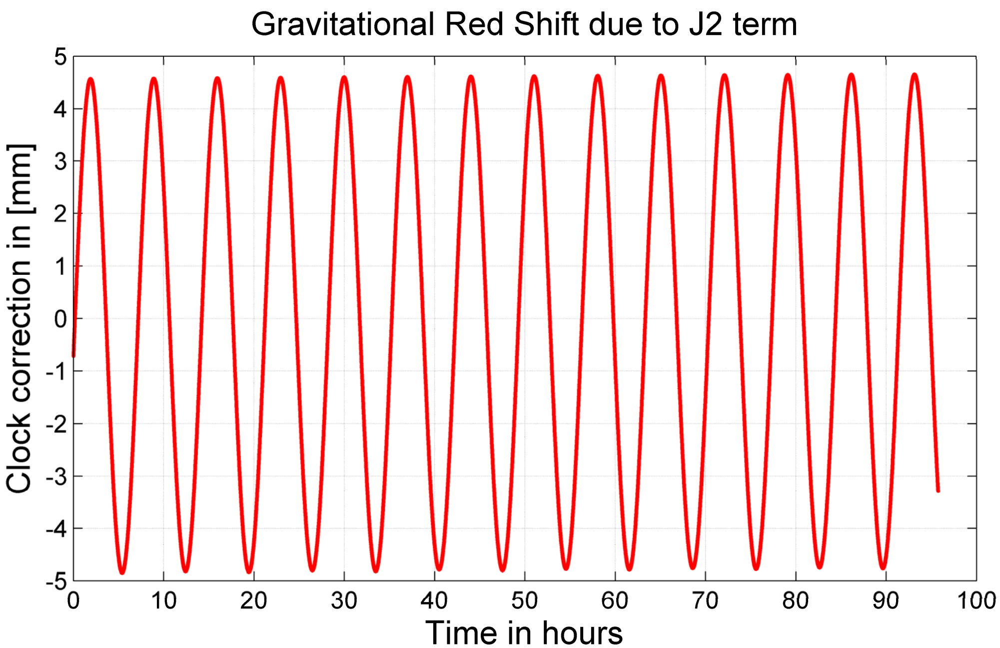
Periodic Relativistic Clock Correction
GIOVE-B Clock

Periodic relativistic IGS correction (eccentricity of the orbit):

$$\Delta t^{per} = -\frac{2}{c^2}\sqrt{a \cdot GM} \cdot e \cdot \sin E$$

$$\Delta t^{per} = -2\vec{r} \cdot \vec{v} \,/\, c^2$$





GIOVE-B: e≈0.0018

GIOVE-IOV/FOC: e< 0.001 (requirement: e=0)

Relativistic Clock Correction

Time Transformations

Relativistic clock time transformation:

Satellite

$$\frac{dT_{sv}}{dt} = 1 - \left[V(x,y,z) - W_0 + \Delta V(x,y,z) + v^2/2 \right] / c^2$$

Ground (Equator, TT)

Central gravity term

J_2

In addition:

Motion of the satellite and station in baricentric frame (TCB terms)

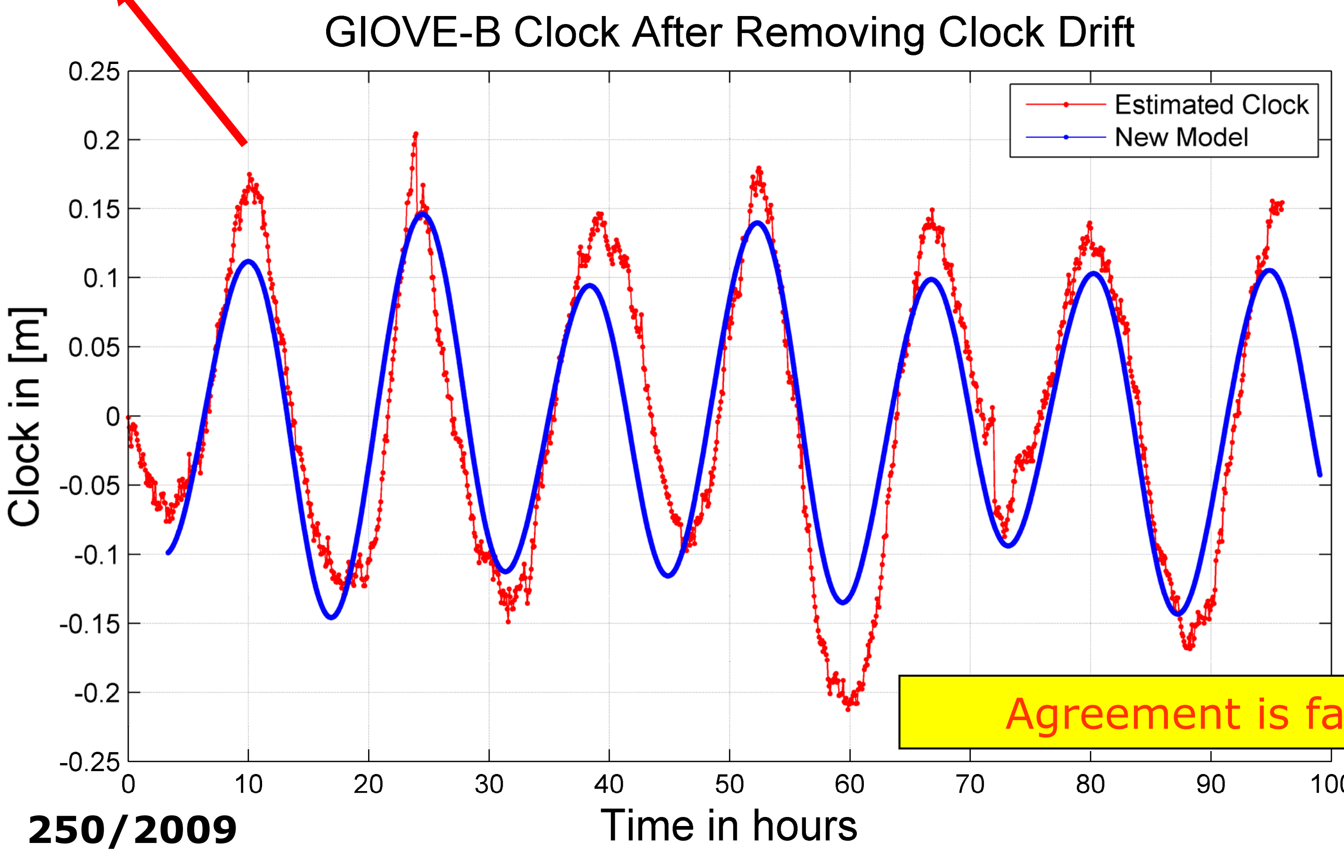
Lunisolar potential (Sun and Moon)

$$\begin{aligned} TCB - TCG &= c^{-2}\left[\int_{t_0}^{t}\left(\frac{v_E^2}{2} + w_{0ext}(\mathbf{x}_E)\right)dt + v_E^i r_E^i\right] \\ &\quad - c^{-4}\left[\int_{t_0}^{t}\left(-\frac{1}{8}v_E^4 - \frac{3}{2}v_E^2 w_{0ext}(\mathbf{x}_E) + 4 v_E^i w_{ext}^i(\mathbf{x}_E) + \frac{1}{2}w_{0ext}^2(\mathbf{x}_E)\right)dt \right. \\ &\quad \left. - \left(3 w_{0ext}(\mathbf{x}_E) + \frac{v_E^2}{2}\right) v_E^i r_E^i\right], \end{aligned}$$

GIOVE-B Passive H-Maser - Performance

GIOVE-B Clock Estimation

Estimated GIOVE-B clock shows peak-to-peak error of 30-40 cm (1 ns) over orbit period.



Agreement is fantastic!

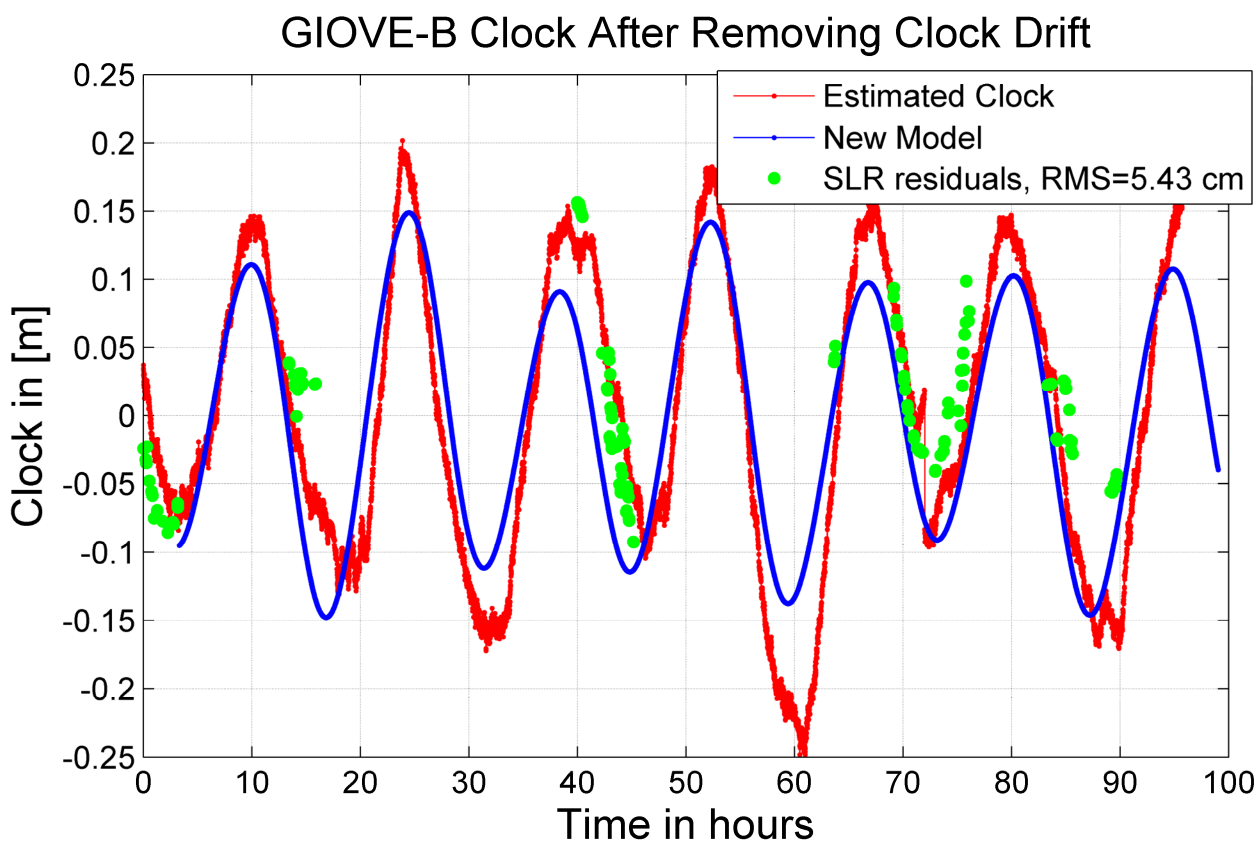
250/2009

GIOVE-B clock parameter estimated every 5-min using standard IGS relativity model (23 stations GESS+CONGO)

GIOVE-B Passive H-Maser - Performance

SLR Validation

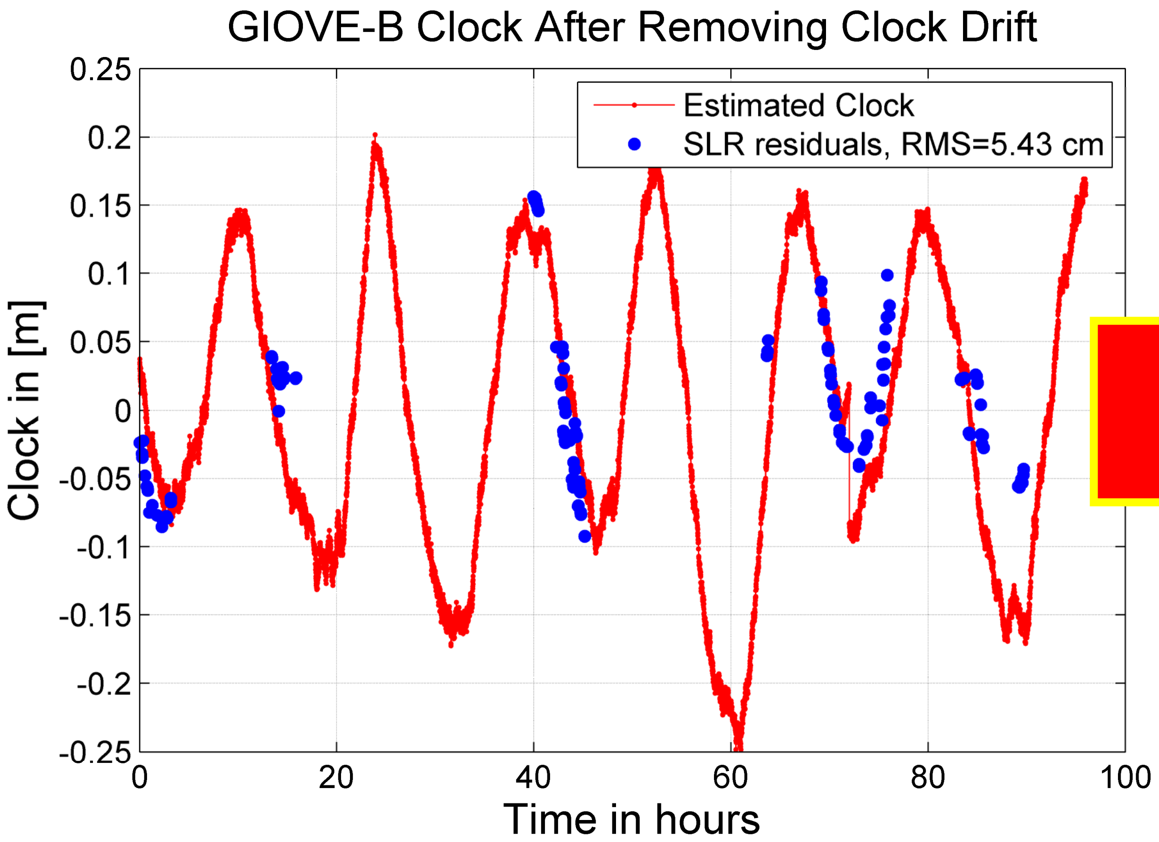
SLR Residuals and Estimated Clock Parameters (30 s)



Agreement with SLR is fantastic!

GIOVE-B Clock vs. SLR

SLR Residuals and Estimated GIOVE-B Clock Parameters (30 s)

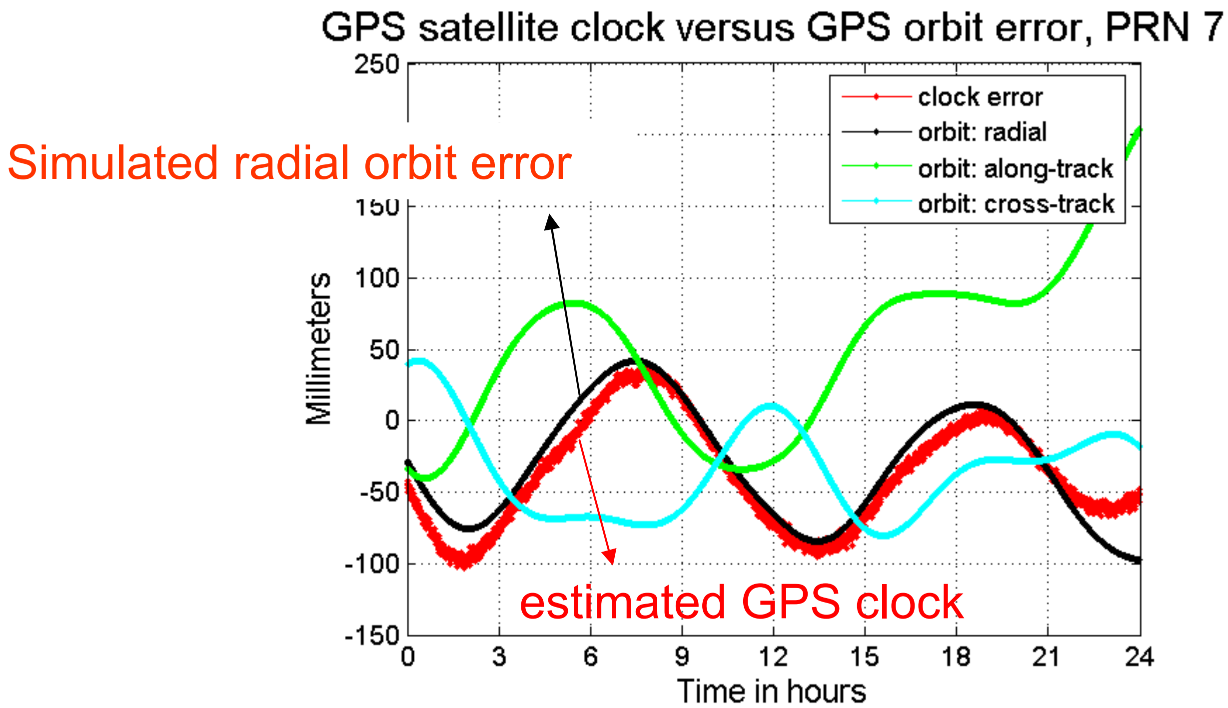


GIOVE-B clock maps the radial orbit error!!!

Agreement GIOVE-B clock and SLR is fantastic **(a few cm)!!!**

GPS Radial Orbit Error and Clock

Simulation

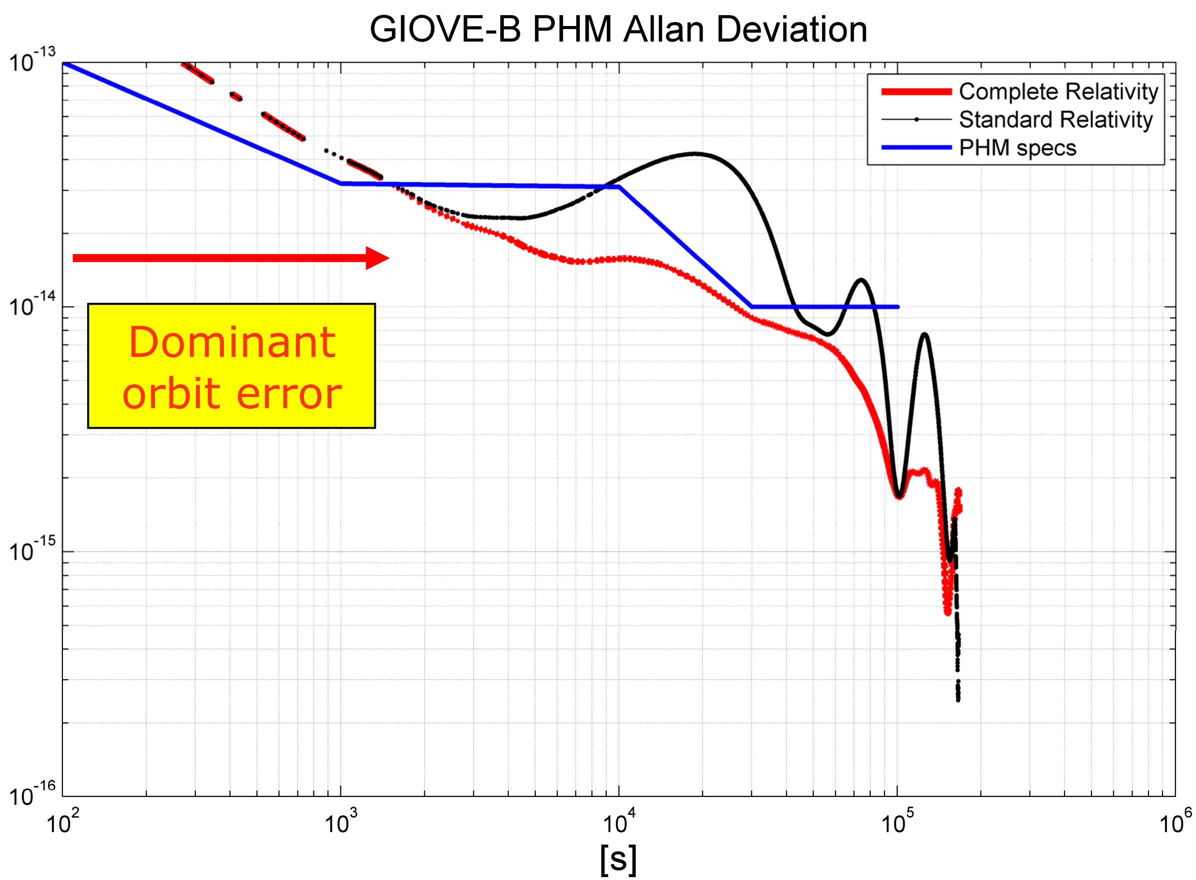


Estimated clock nicely measures simulated radial orbit error

GIOVE-B Clock Characterisation

Passive H-Maser - Frequency Stability

Overlapping ADEV – sampling 30 s

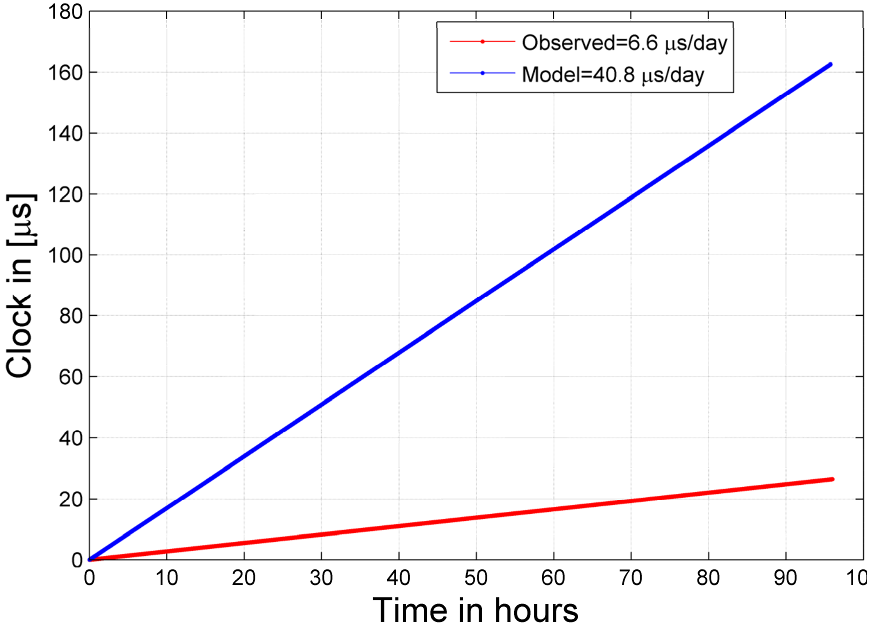


Clock stability is fantastic!

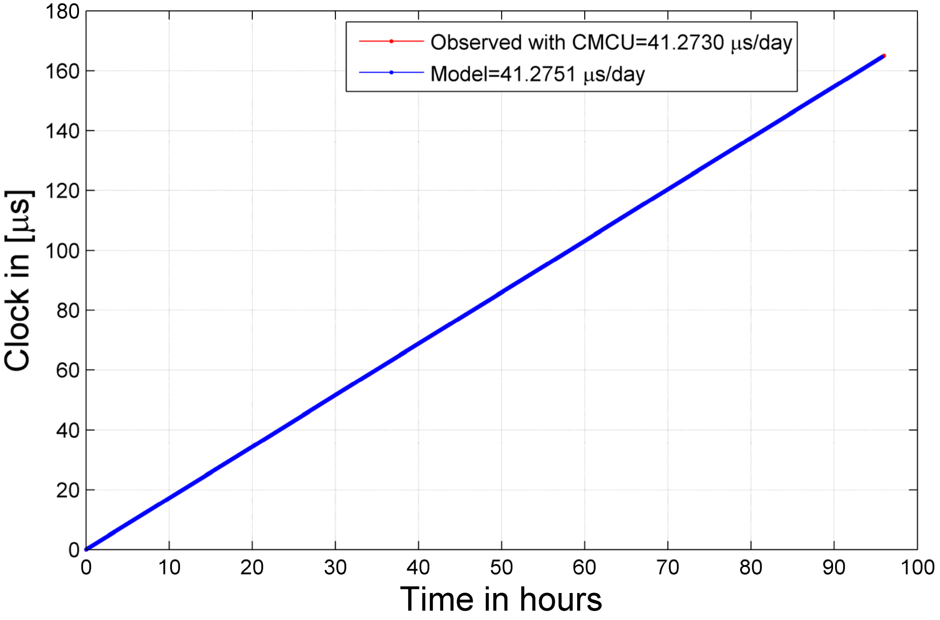
GIOVE-B Clock Drift

Observed vs. Modelled

Observed GIOVE-B Clock Drift



Observed GIOVE-B Clock Drift after applying CMCU freq. offset



GIOVE-B clock drift still needs to be corrected by one order of magnitude of the entire effect!

Test of General Relativity: 161 ppm
Comparable to GP-A (slightly better)!

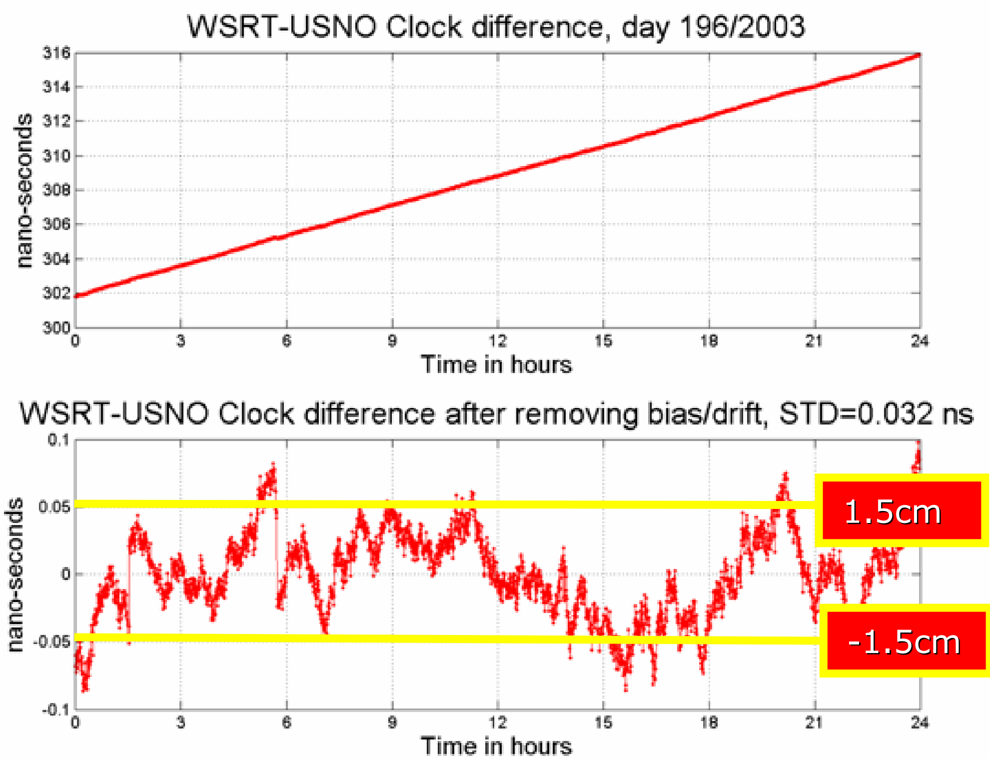
Total effect: Special + General Relativity: 51 ppm

Direct Phase Clock Ambiguity Resolution

EFTF 2006 and EGU 2007

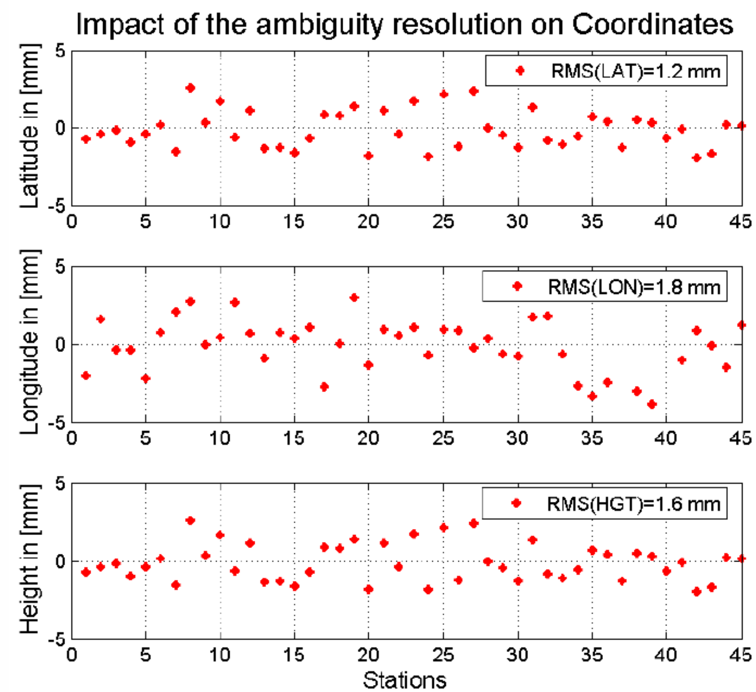
esa

Clock comparison using Phase Clocks



Only phase clocks estimated. Troposphere (TZD), station coord., EOPs, etc., fixed to IGS

PPP ambiguity resolution for the global network



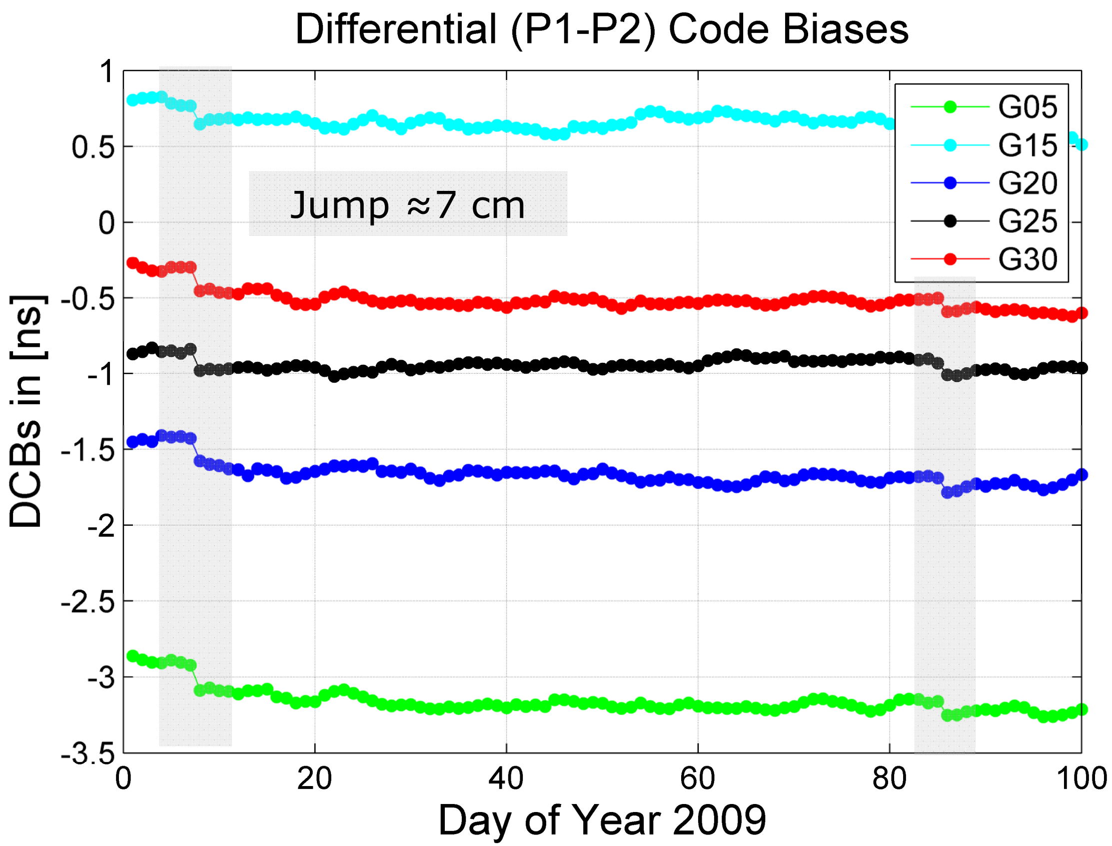
Poor performance in fixing (≈20%)
due to low number of fixed MW ambiguities

Solution:

1) CNES: estimate additional wide-lane biases (per day)
2) ESOC: network solution (GFZ, JPL)
3) ESOC: form Track-to-Track ambiguities

Differential Code Biases

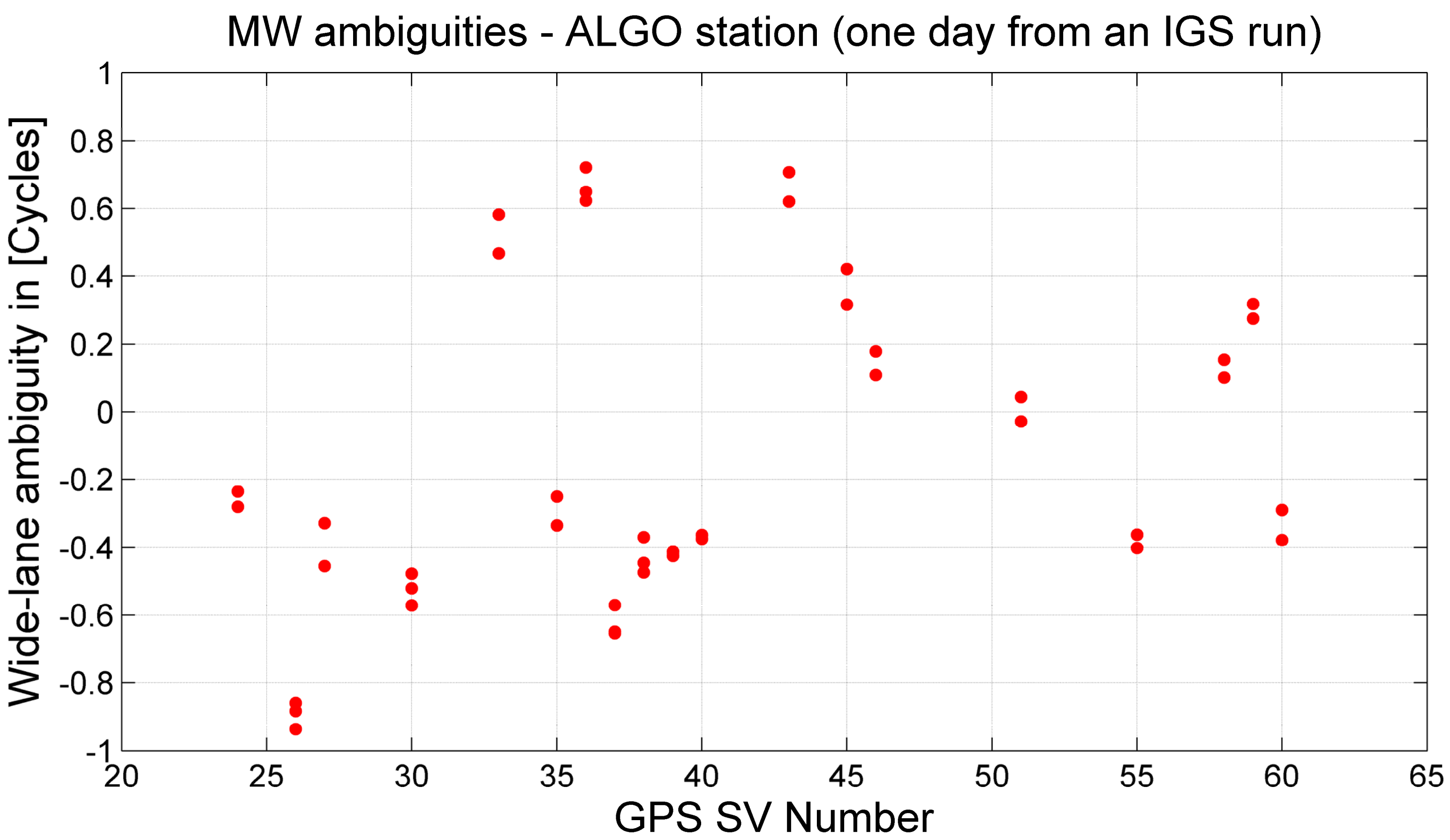
P1-P2



DCB Datum (=TEC datum): **Zero-mean over SV/Rec. DCBs**
– impossible to fix un-differenced wide-lane ambiguities

MW Ambiguities

Un-differenced



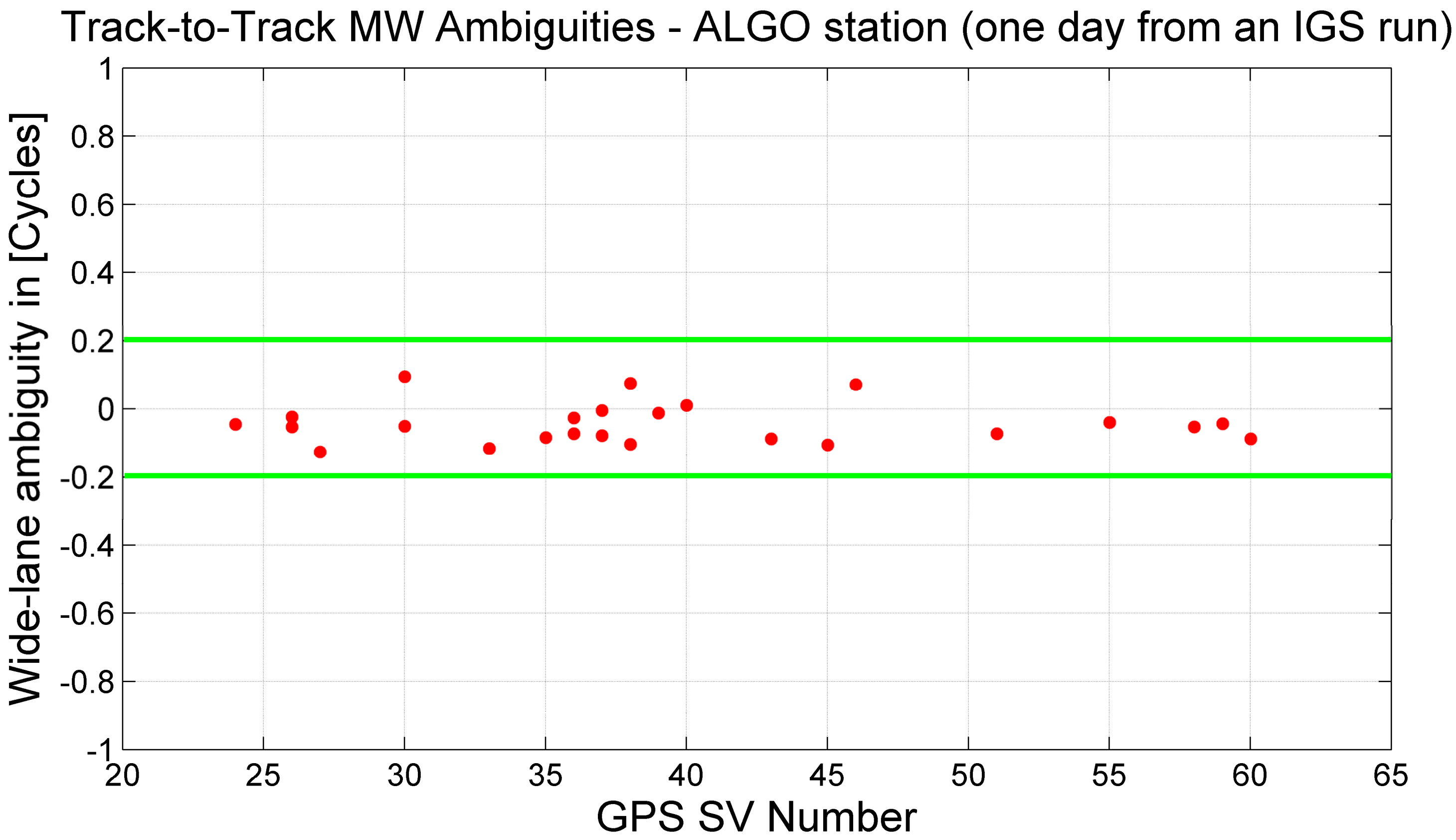
Only SMAL PERCENTAGE of wide-lane ambiguities can be fixed!

DCB-definition (mean over all satellites/stations) prevents AR!

Track-to-Track MW Ambiguities

Un-differenced

$$\lambda_W N_W^i := \lambda_W N_W^1 + \lambda_W \sum_{k=2}^{i} \Delta N_W^{i-1}$$



All track-to-track wide-lane ambiguities can be fixed!

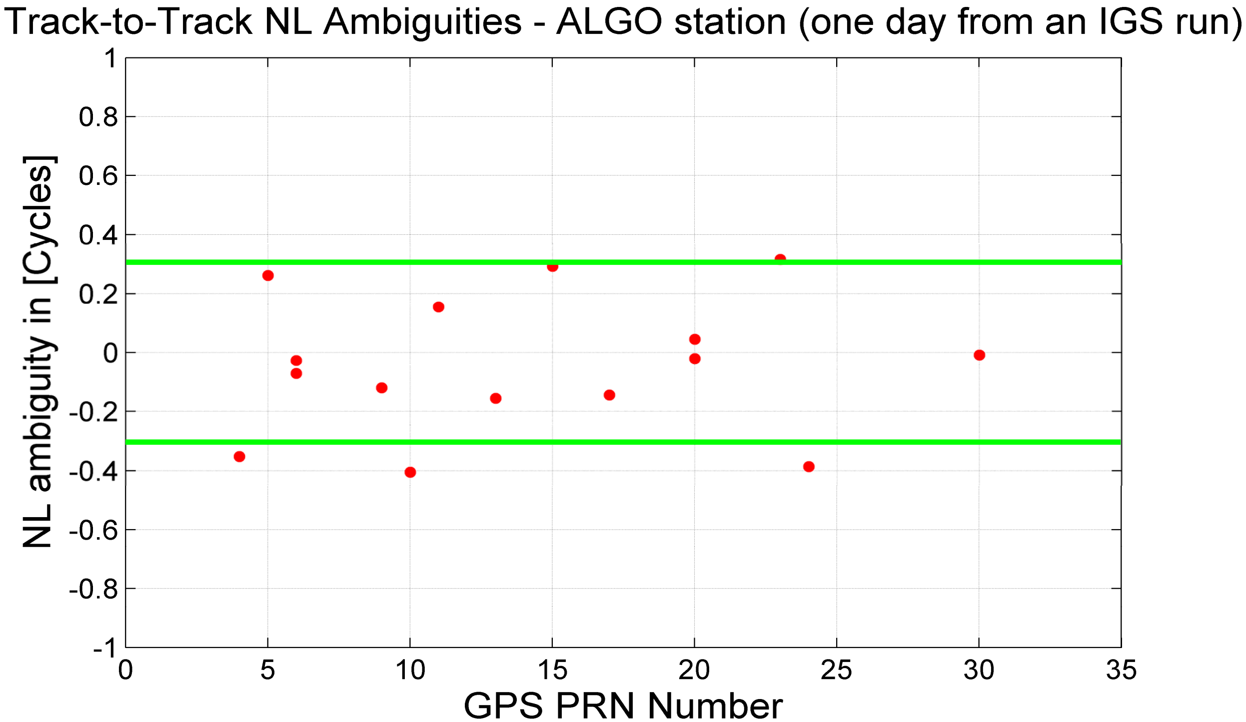
Narrow-Lane Track-to-track Ambiguities

Un-differenced

Steps:

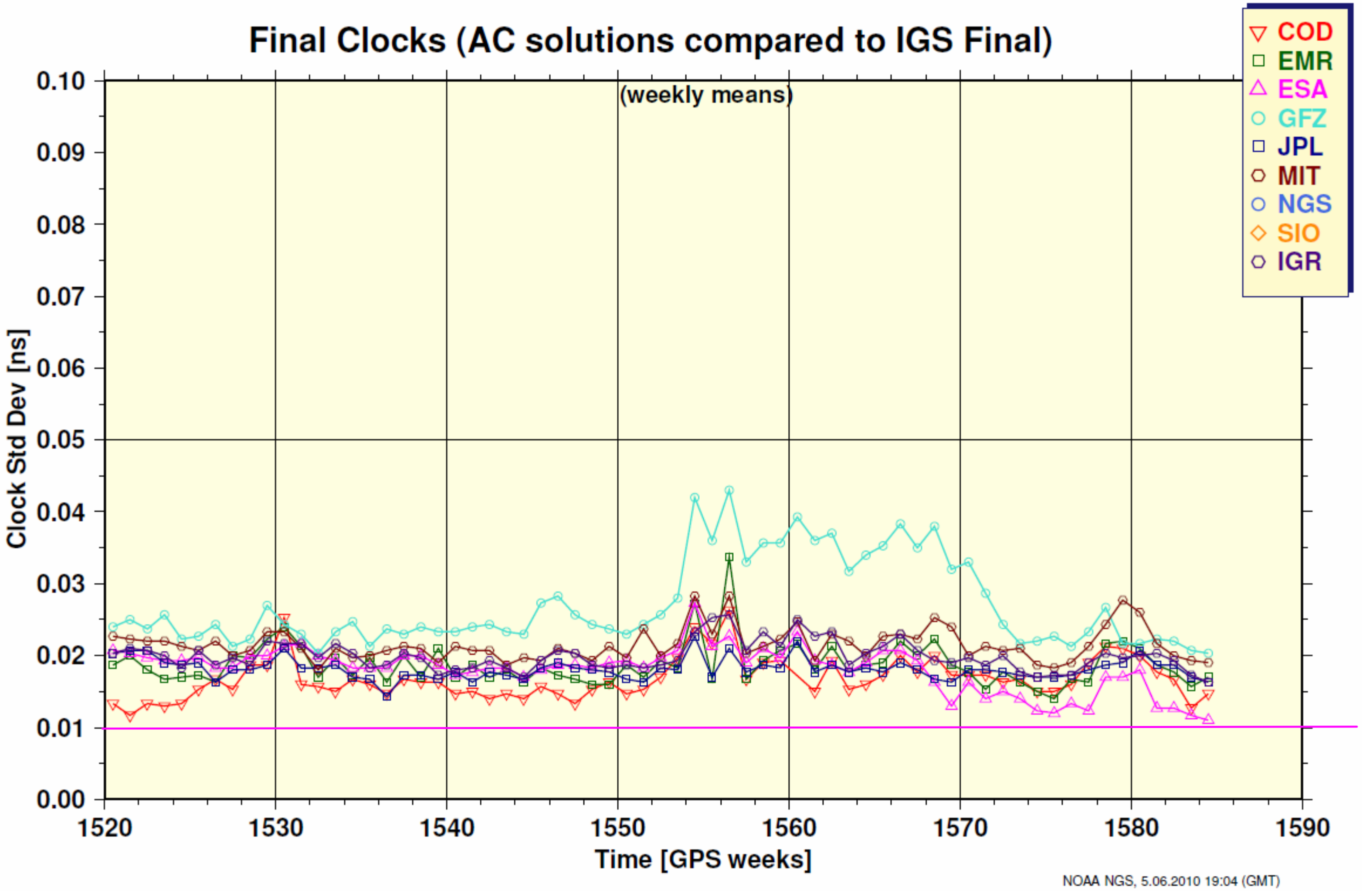
1. **Solution: DD solution with Ambiguity resolution (orbit)**
2. **Estimation of phase clocks (orbit fixed)**
3. **Track-to-track ambiguity resolution**
4. **Carrier-phase Range**

Phase clocks to bridge the gap between tracks!!!!



IGS Clocks vs. H-Maser Performance

Comparison



3 mm

$$\sigma\left(\delta_{clk}(\tau)\right) = \text{ADEV}(\tau) \cdot \tau \cdot c$$

$$\text{ADEV}(\tau) = \text{ADEV}(1\ s) / \sqrt{\tau}$$

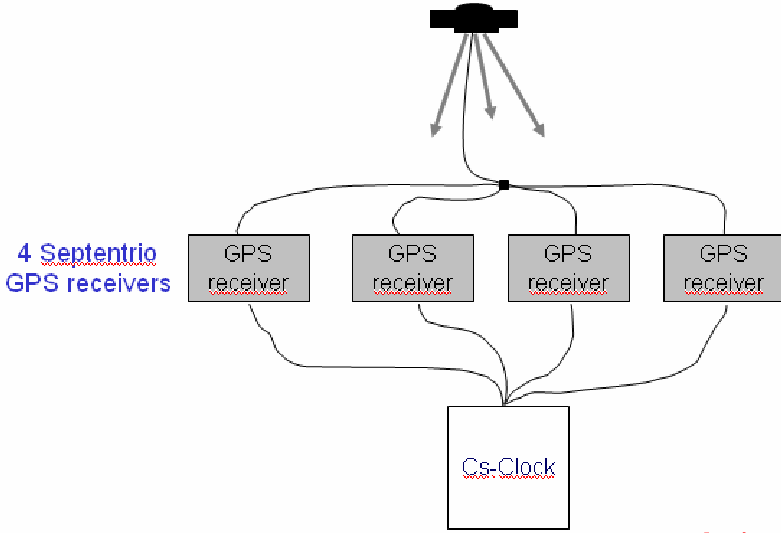
$\text{ADEV}(\tau = 1\ s)$	$\sigma(\tau = 0.5\ h)$	$\sigma(\tau = 1\ h)$	$\sigma(\tau = 6\ h)$	$\sigma(\tau = 12\ h)$
1×10^{-12} (GALILEO PHM)	13 mm	18 mm	44 mm	62 mm
1×10^{-13} (ground H-maser)	1.3 mm	1.8 mm	4.4 mm	6.2 mm
1×10^{-15} (optical clock)	0.013 mm	0.018 mm	0.044 mm	0.062 mm

Clock stability is always is better compared to the clock accuracy in this table!

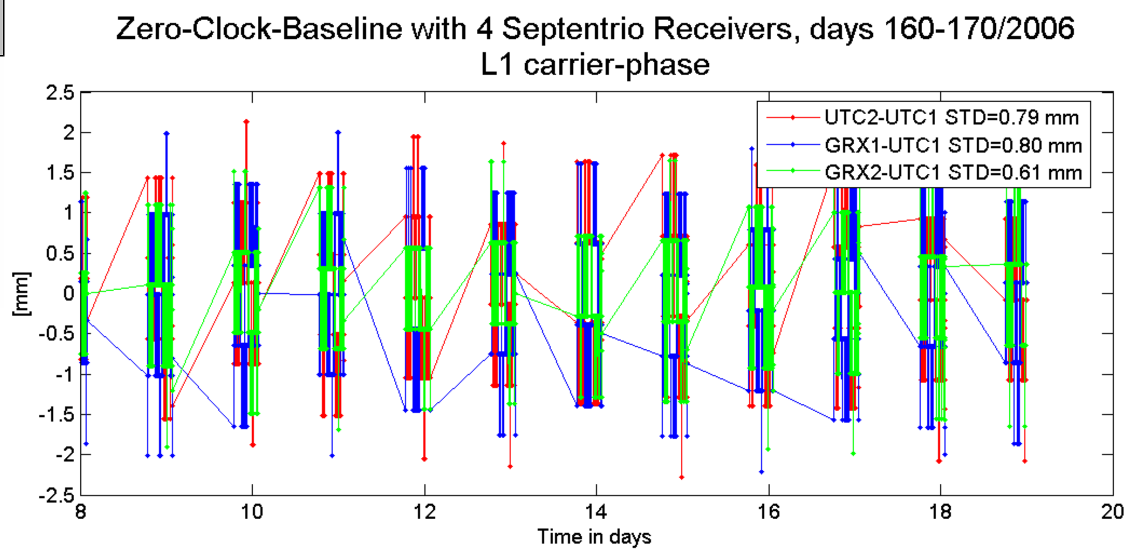
Conclusions

- Excellent GIOVE-B Clock Stability!
- For the first time GNSS clock used to map the radial orbit error!
- GIOVE-B clock drift agrees with the GP-A test of general relativity (slightly better)
- Track-to-track MW ambiguities can be fixed!
- Track-to-track NL ambiguities can be fixed!!! Clock stability or good a priori estimated phase clocks or IGS clocks to guarantee correct fixes.
- Track-to-Track Phase Clock Ambiguity Resolution demonstrated!

Receiver Delays in Clock Parameters



L1



Different clock
for L1 and L2 phase
STD up to 15 mm

L2