

測地VLBI技術による 高精度周波数比較

VLBI MEASUREMENTS FOR FREQUENCY TRANSFER

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Content

✓ Introduction

» *Previous study*

- *Intercomparison : VLBI (IVS) vs. GPS (IGS)*
 - Wettzell - Onsala
- *How stable are current VLBI systems?*
 - Kashima34m – Kashima11m
 - Kashima11m – Koganei11m

✓ Intercomparison between VLBI and other techniques

» *Can the VLBI measure the right time difference?*

- Kashima34m - Kashima11m
 - Artificial change by Line Stretcher & Trombone

✓ Conclusions



Introduction

✓ Development of frequency standard

- Atomic fountains



NICT-CsF1
..... developing

2×10^{-15}
@a few days

- Optical clocks



NICT
optical clocks
..... developing

$10^{-17} \sim$
@a few hours

Background

✓ Time and frequency transfer technique

- » GPS Carrier Phase

2×10^{-15} @1day

- » TWSTFT

$2-4 \times 10^{-15}$ @1day

- » *long averaging period*

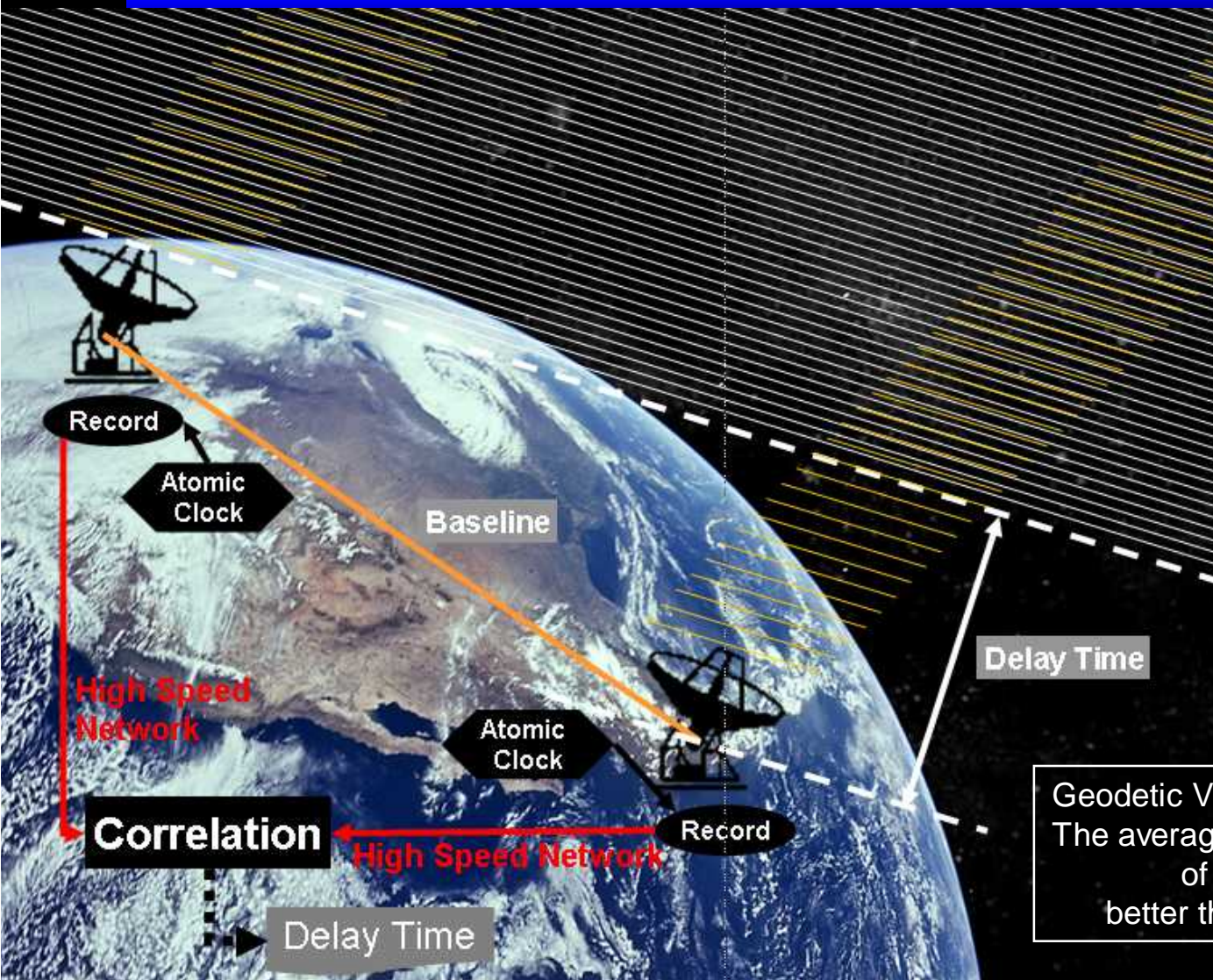
- » *insufficient accuracy*

➤ **improvements of highly precise time and frequency transfer techniques are strongly desired**

VLBI

VLBI

Very Long Baseline Interferometry



measure the arrival time delays between multiple station

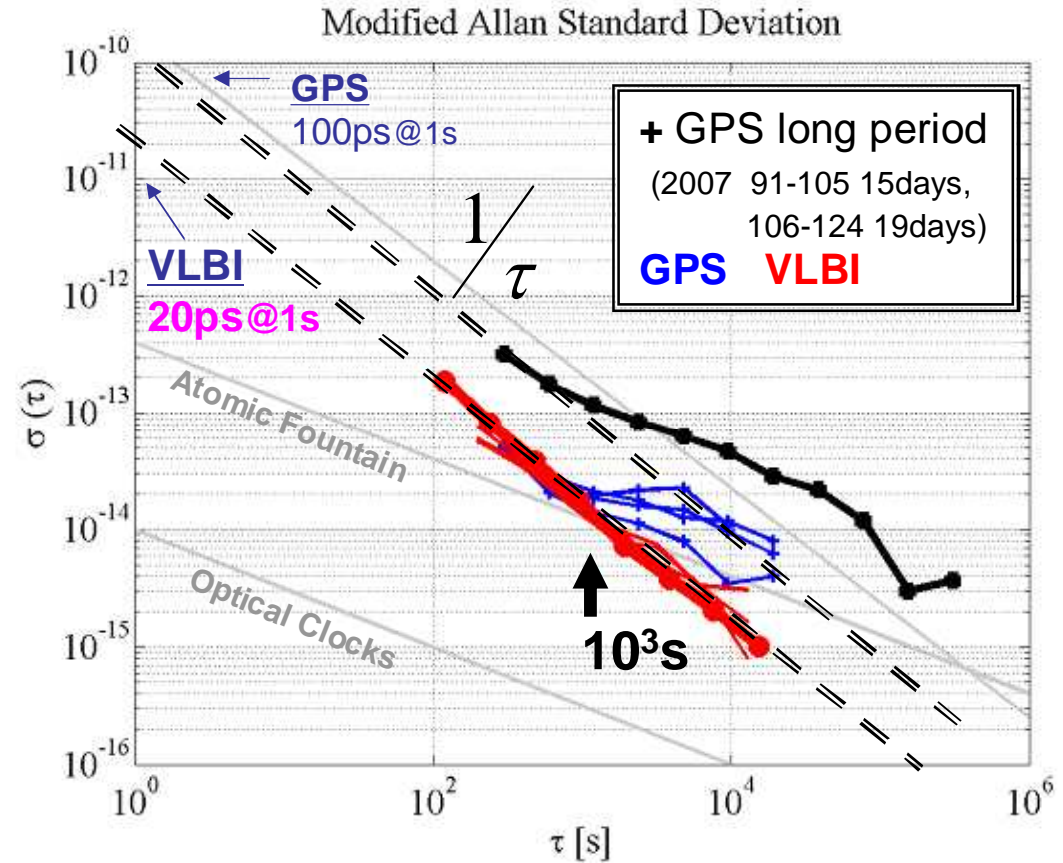
Geodetic VLBI experiment by IVS
The averaging formal error of the clock offset : 20 ps better than other current techniques

Previous study

Intercomparison: VLBI vs. GPS

1. Wettzell-Onsala

- VLBI vs. GPS CP
- IVS and IGS data



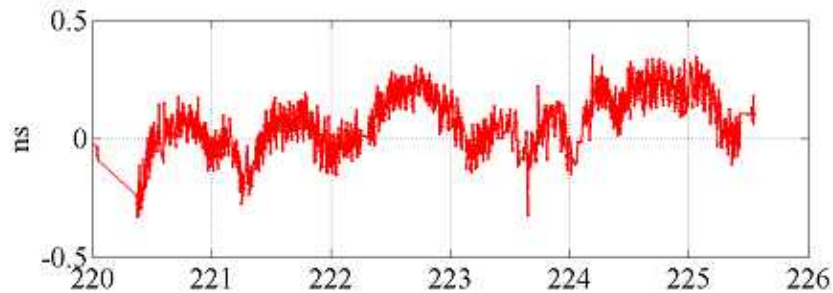
- ✓ VLBI is more stable than GPS
- ✓ surpassing the stability of atomic fountain at 10^3 s
- ✓ VLBI stability : follows a $1/\tau$ law very closely
- ✓ 2×10^{-11} (20ps) @ 1s

at each site
VLBI and GPS
are shown
The geodetic VLBI technique has the potential for precise frequency transfer

Previous study

How stable are current VLBI systems?

Kashima34m-Kashima11m

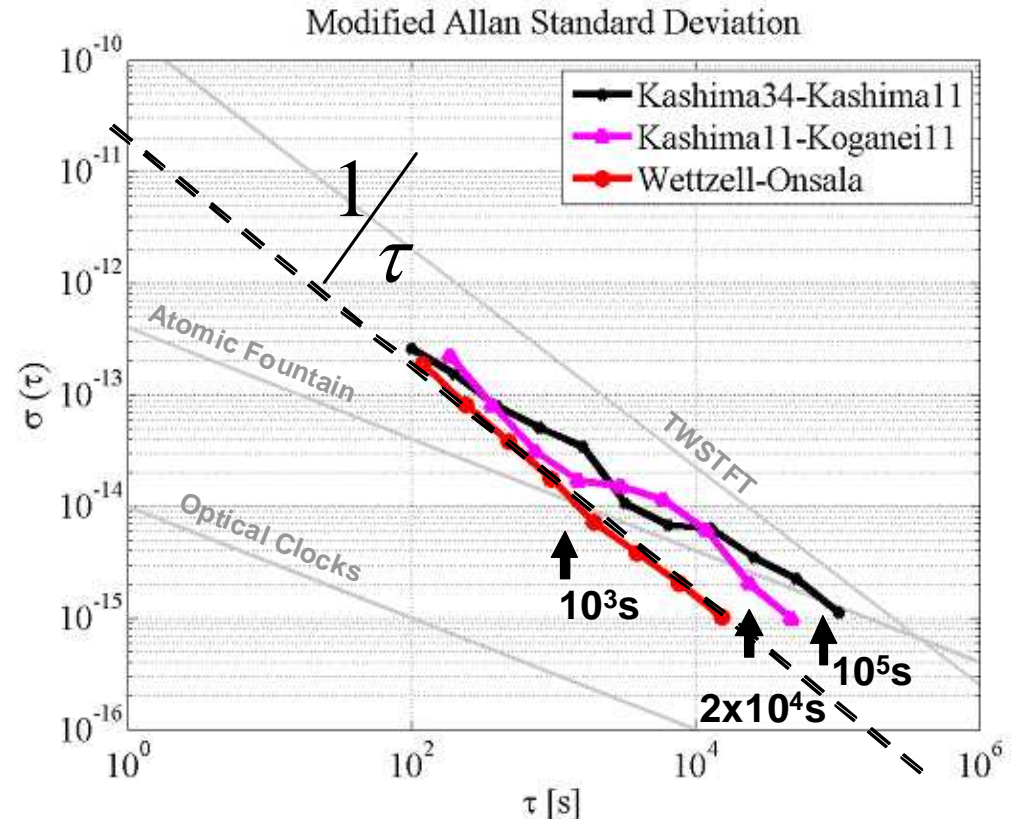


in summer

Kashima11m – Koganei11m



after removing linear trend



How stable are current VLBI systems?

surpassing the stability of atomic fountain at 2×10^4 , 10^5 s

unstable than international baseline (Wettzell-Onsala)

influence of temperature change

Measures to reduce the influence of the temperature change are necessary.

What 's Next ?

- ✓ The geodetic VLBI technique has the potential for precise frequency transfer
 - » VLBI is more stable than GPS
 - » surpassing the stability of atomic fountain at 10^3 s (Wettzell-Onsala)
 - » 2×10^4 , 10^5 s (Kashima11-Koganei, Kashima34-Kashima11)

- ✓ *Improve the station environment*

- » *for Geodesy for T&F transfer*

- ✓ *Intercomparison*

- » *MARBLE*

- » *International*

- » *other techniques : GPS, DMTD, TWSTFT, TEC(ETS-8)*

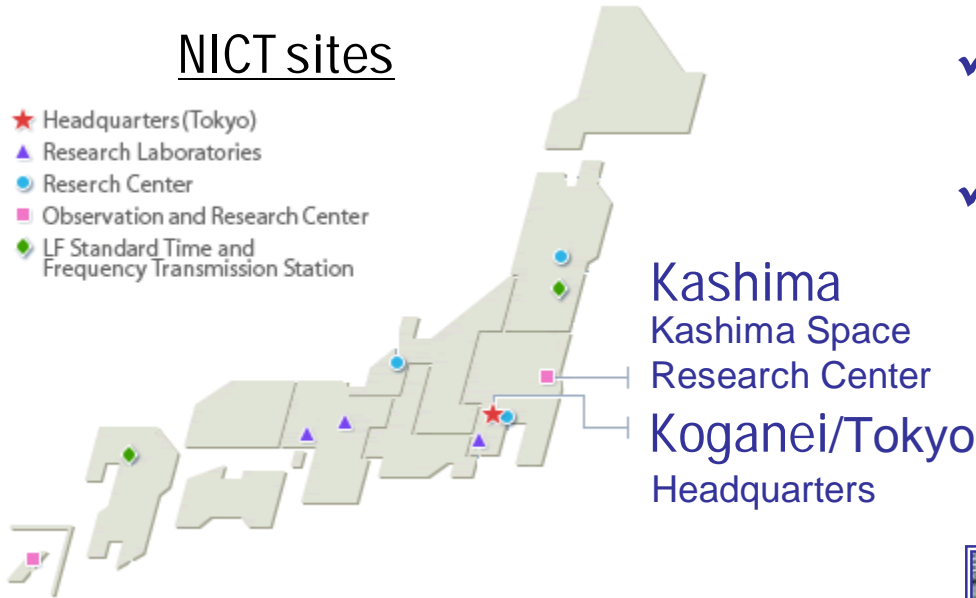
- ✓ *Calibrate instrumental delay*



Intercomparison: VLBI vs. other techniques

NICT sites

- ★ Headquarters (Tokyo)
- ▲ Research Laboratories
- Research Center
- Observation and Research Center
- ◆ LF Standard Time and Frequency Transmission Station



Kashima
Kashima Space
Research Center
Koganei/Tokyo
Headquarters

- ✓ Kashima34m – Kashima11m
239m
- ✓ Kashima11m – Koganei11m
109km

Kashima

VLBI
MARBLE
GPS

H-maser, DMTD



Koganei

GPS: kgni



VLBI
Koganei11m

VLBI
GPS
TWSTFT
TEC (ETS-8)



VLBI
Kashima11m

GPS : ksmv

GPS : ks34

VLBI
Kashima34m

Can the VLBI measure the right time difference?

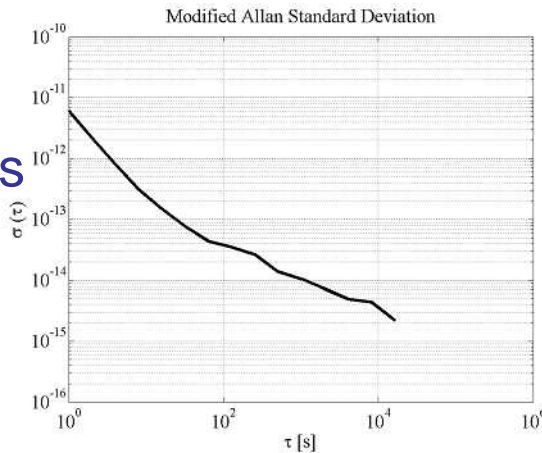
✓ Kashima34m – Kashima11m

» Artificial time difference change

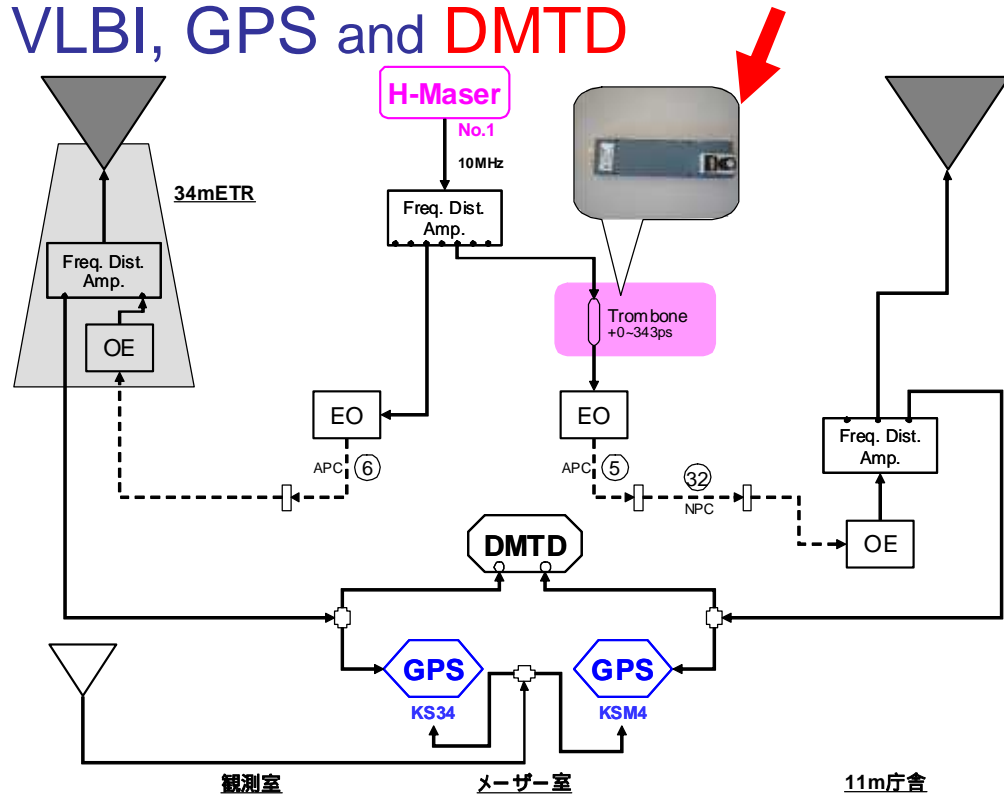
▪ using Line Stretcher & Trombone

» Intercomparison between VLBI, GPS and **DMTD**

DMTD
 6×10^{-12} @ 1s
 (6ps)



Trombone



Differences with the normal observation

✓ Normal Geodetic VLBI

- » Observation
 - multiple sources
 - antenna slew time
 - different scan time
 - 24 hours
- » Data Analysis
 - estimate
clock parameter
atmospheric delay
station coordinates

✓ This study

- » Observation
 - **one source** : 3C84
 - no antenna slew time
 - same scan time
 - a few hours
- » Data Analysis
 - estimate only
clock parameter
 - atmospheric delay :
short baseline, one source
 - station coordinates :
fixed to a-priori coordinates

Data analysis

✓ VLBI

- » CALC/SOLVE
- » single baseline
- » S/X ionosphere-free linear combination
 - clock offset / 30sec



- » Time Defference
clock offset / 30sec

✓ GPS

- » NR Canada's PPP
 - IGS Final Orbit & Clock(30s)
- » Precise Point Positioning
 - satellite clock interpolation
 - clock offset / 30sec

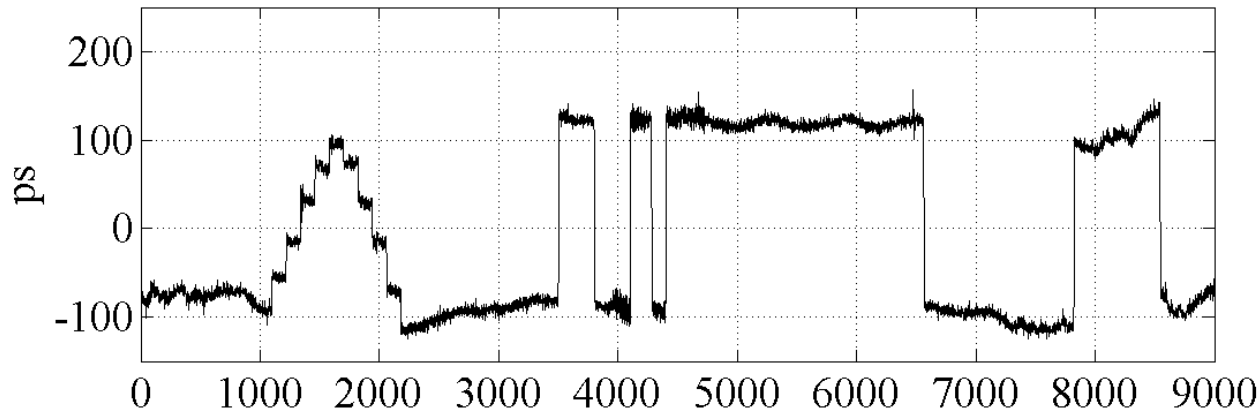


- » Time Defference
clock offset A – clock offset B
/ 30sec

vs. DMTD Time Difference / 1sec

DMTD

Time Difference DMTD



5 6
4 7
3 8
2 9
1 10

12 14 16 18
11 13 15 17

0 Max

50×メモリ



DMTD

1	37.9
2	39.7
3	46.9
4	38.8
5	26.7
6	-22.5
7	-45.0
8	-43.3
9	-55.1
10	-43.7
11	207.9
12	-210.1
13	214.2
14	-215.3
15	216.8
16	-210.6
17	203.8
18	-212.3

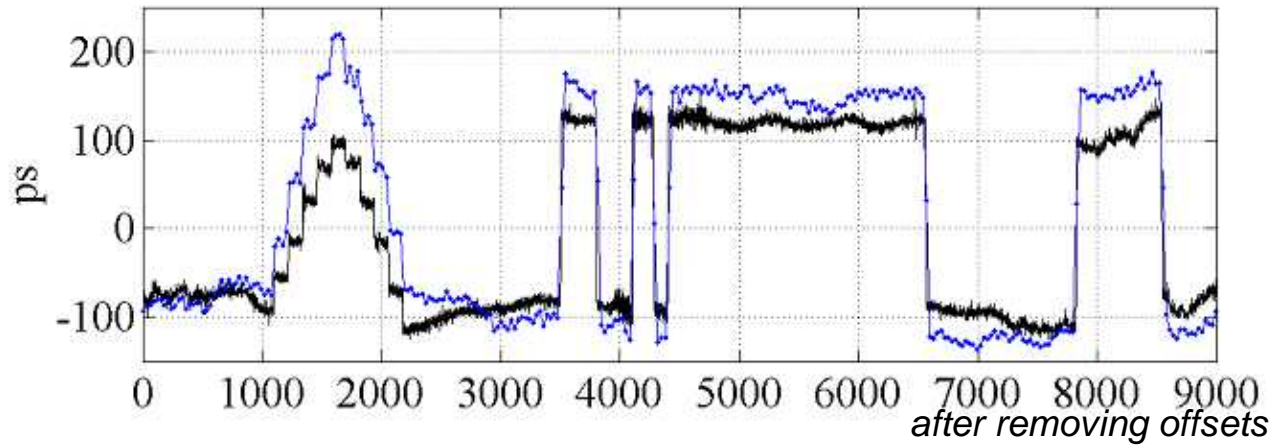
42 ps

211 ps

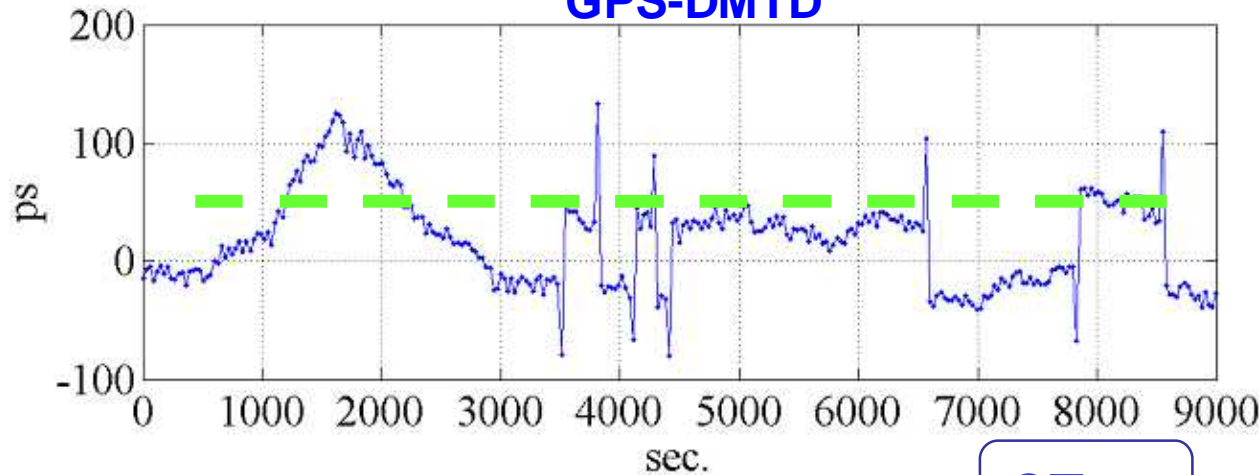
GPS vs. DMTD

Time Difference

DMTD GPS



GPS-DMTD



DMTD GPS GPS-DMTD

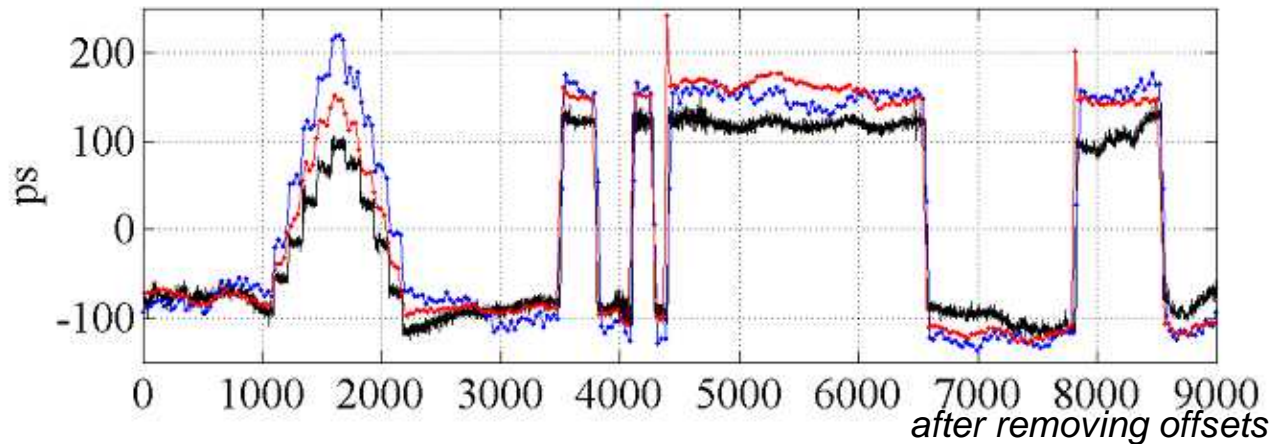
1	37.9	61.7	23.8
2	39.7	66.3	26.7
3	46.9	62.1	15.2
4	38.8	54.6	15.8
5	26.7	44.3	17.7
6	-22.5	-43.7	21.2
7	-45	18 ps	8.0
8	-43.5	54.0	10.7
9	-55.1	-72.0	16.9
10	-43.7	-65.3	21.6
11	207.9	268.0	60.1
12	-210.1	-263.0	52.9
13	214.2	273.0	58.8
14	-215	62 ps	67.7
15	216	60.6	60.6
16	-210.6	-274.3	63.7
17	203.8	269.3	65.6
18	-212.3	-279.0	66.7

37 ps

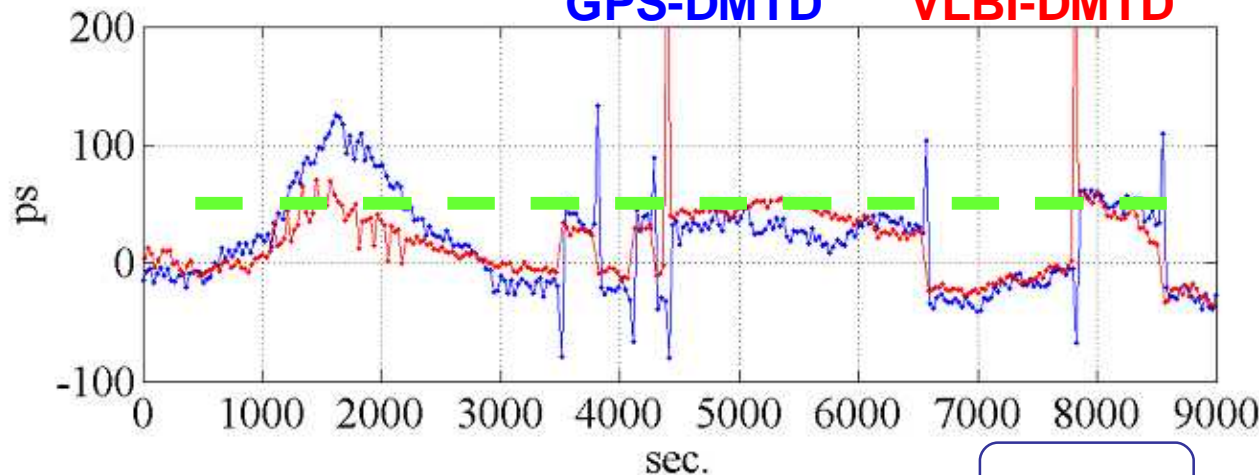
VLBI vs. GPS and DMTD

Time Difference

DMTD GPS VLBI



GPS-DMTD VLBI-DMTD



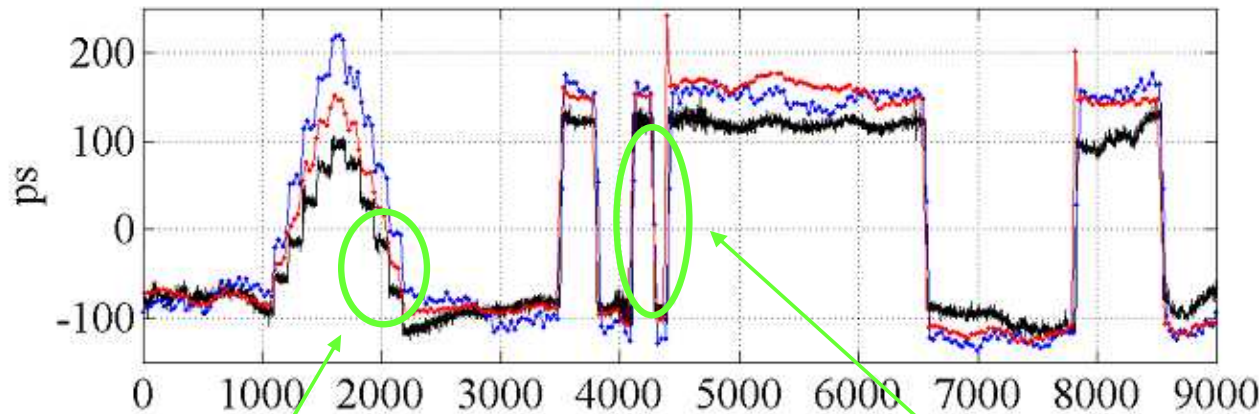
23 ps

DMTD VLBI VLBI-DMTD

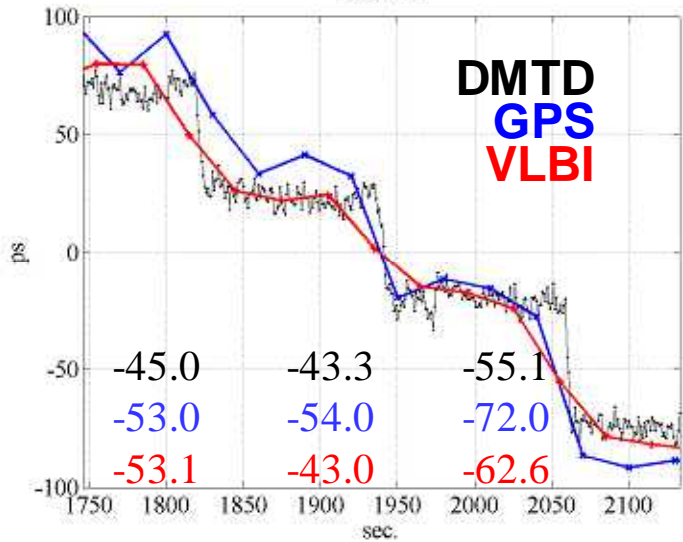
1	37.9	48.3	10.4
2	39.7	48.2	8.5
3	46.9	60.8	13.9
4	38.8	48.5	9.7
5	26.7	27.3	0.6
6	-22.5	-30.2	7.7
7	-45.1	8 ps	8.2
8	-43.5	-43.0	0.3
9	-55.1	-62.6	7.5
10	-43.7	-54.5	10.7
11	207.9	243.8	35.8
12	-210.1	-244.0	33.9
13	214.2	256.6	42.4
14	-215.1	42 ps	36.0
15	216.1	256.6	45.9
16	-210.6	-258.5	47.9
17	203.8	259.0	55.3
18	-212.3	-254.6	42.3

VLBI vs. GPS and DMTD

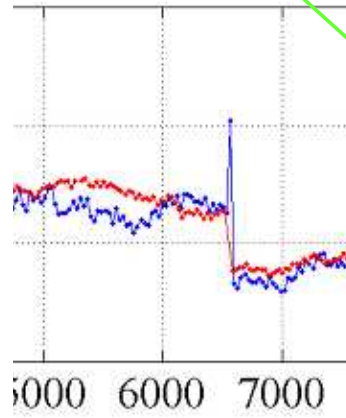
Time Difference DMTD GPS VLBI



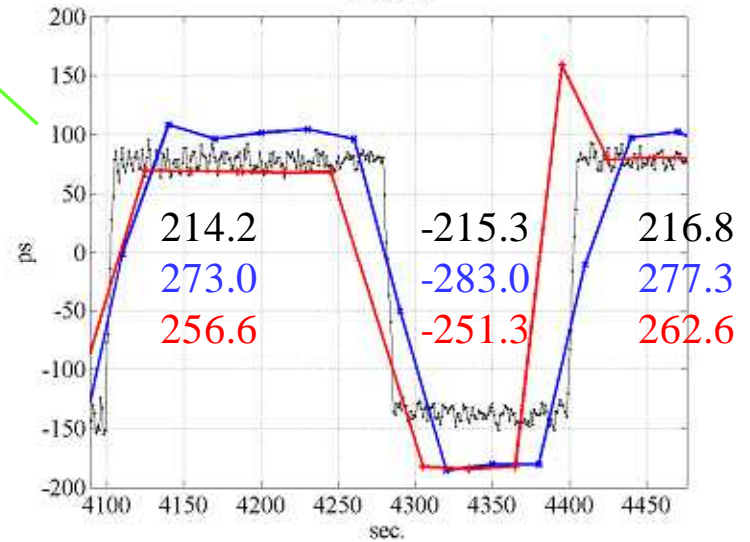
Point 8



DMTD VLBI-I



Point 14



Conclusions

- ✓ Can the VLBI measure right time difference?
 - » VLBI vs. GPS CP and DMTD
 - » Artificial change
 - VLBI vs. DMTD: 8ps@40ps, 42ps@200ps
good agreement
 - GPS vs. DMTD: 18ps@40ps, 62ps@200ps

» The geodetic VLBI technique can measure the right time difference.

Acknowledgements

IVS and IGS

for the high quality products

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for VLBI and GPS analysis software

Thank you very much for your attention.