

VLBI and GNSS frequency link stabilities during CONT campaigns

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Outline

- Motivation
- CONT08 results
- CONT11 results (preliminary)
- Conclusions
- Outlook for VLBI2010

Motivation

- National Metrological Institutes (NMI) realize UTC(k)
- Operate ensembles of frequency standards such as cesium clocks, cesium fountains, hydrogen masers, etc.
- Are recommended to realize UTC ± 100 ns
- Most laboratories do this much better, SP aims as ± 5 ns
- Need to repeatedly compare time information with other international NMIs
- Use various redundant methods, e.g. two-way satellite time and frequency transfer (TWSTFT), GNSS (common view, all-in-view), optical fibre,...
- Can VLBI be an interesting alternative?

Some previous work

Author	main result
Clark <i>et al.</i> (1977)	clock synchronization using VLBI, ns level
Hurd <i>et al.</i> (1978)	1e-13 link stability, 1e-14 possible
Spencer <i>et al.</i> (1981)	5 ns in time, rate uncertainty 1.3e-14
Johnston <i>et al.</i> (1983)	MARK III calibration, sub-nanoseconds
Ward (1984)	clock synchronization using VLBI
Yoshino <i>et al.</i> (1984)	short baseline (SBI) calibration, precision < 1 ns
Hama <i>et al.</i> (1989)	zero baseline calibration (ZBI) with ns accuracy
Takiguchi <i>et al.</i> (2007, 2008)	frequency link uncertainty < 1e-15 @ 1 day
Rieck <i>et al.</i> (2010)	frequency link uncertainty 1.2e-15 @ 1 day

- 1970ies and 1980ies some interest in VLBI
- since 1990ies more GPS
- interest in VLBI again in 2000ies

This study

- CONT08 and CONT11 sessions
- 15 days of continuous VLBI data
- Involving stations with IVS and IGS equipment
- Several stations have same clock for VLBI and GPS
- VLBI data analysis with CALC/SOLVE
 - Standard solution
 - 20 min clock estimates, constraints $5e-14$
- GPS data analysis with NRCAN-PPP
 - IGS final orbits
 - Kalman filter clock estimates every 60 s

Post-processing analysis

- VLBI
 - Removal of day-boundary jumps
 - Estimation of Allan deviation (ADev) on baselines
- GPS
 - Forming of baselines (differencing) and estimation of ADev
- VLBI versus GPS
 - Differencing VLBI and GPS solutions on common baselines
 - Trend difference and RMS calculation

CONT08



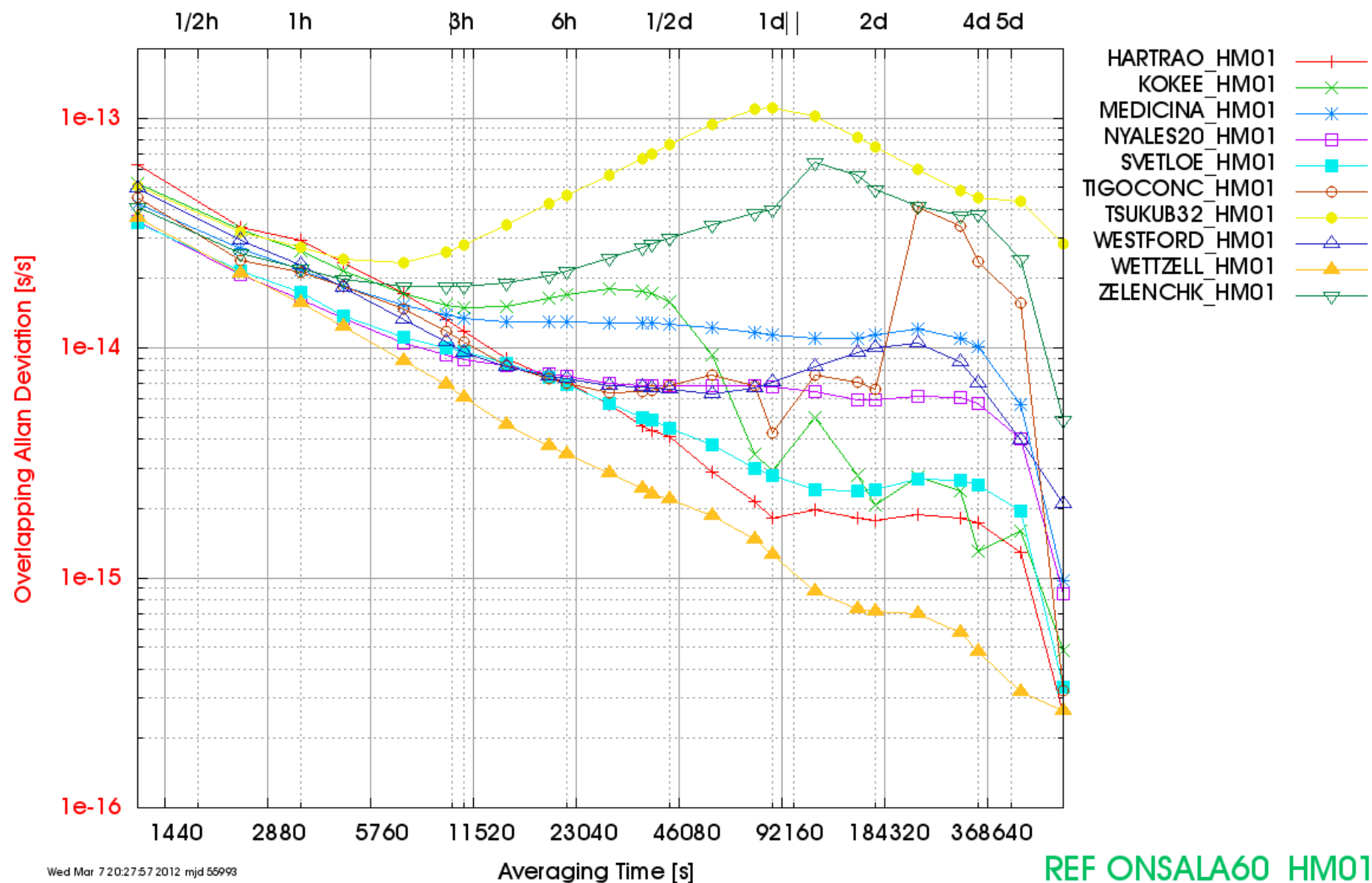
CONT08

- 2008, August 12-26
- 11 VLBI stations
- All of them operate also GNSS stations (IGS)
- 7 out of 11 stations share common clock for VLBI system and GNSS receivers

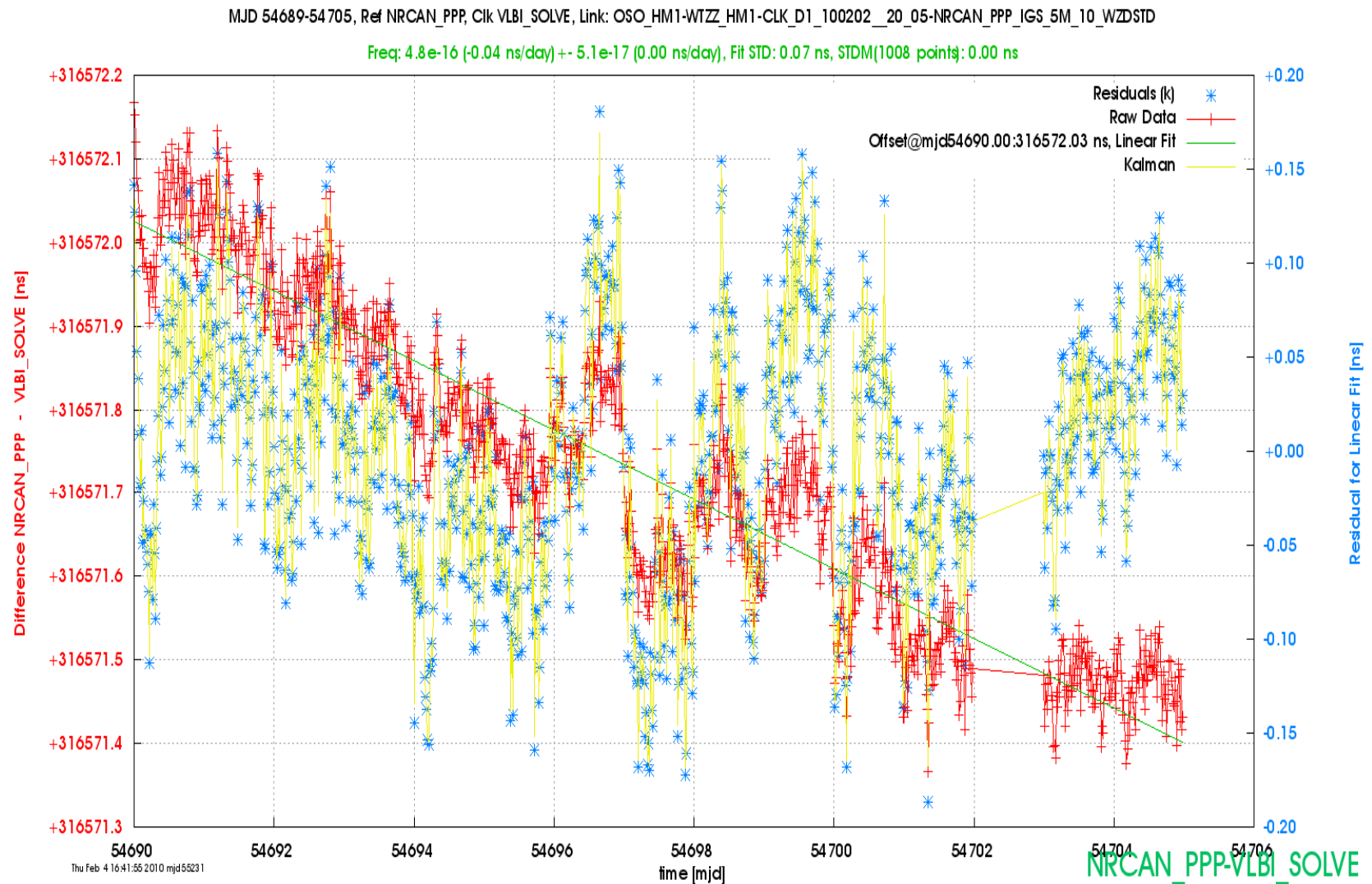
CONT08 equipment

IVS	IGS	H-maser	Common clock?
HARTRAO	HRAO	EFOS C	YES ☺
KOKEE	KOKB	Sigma Tau	YES ☺
MEDICINA	MEDI	EFOS 4	YES ☺
NYALES20	NYAL, NYA1	APL No2	YES ☺
ONSALA60	ONSA	CH1-75A	YES ☺
SVETLOE	SVTL	IEM CHI-80	NO
TIGOCONC	CONT	EFOS 24	YES ☺
TSUKUB32	TSKB, TSK2	Anritsu RH401A	NO
WESTFORD	WES2	APL No3/No4	NO
WETTZELL	WTZR, WTZS, WTZZ	EFOS 18	YES ☺
ZELENCHK	ZECK	CH1-80	NO

CONT08 Frequency Link InStabilities



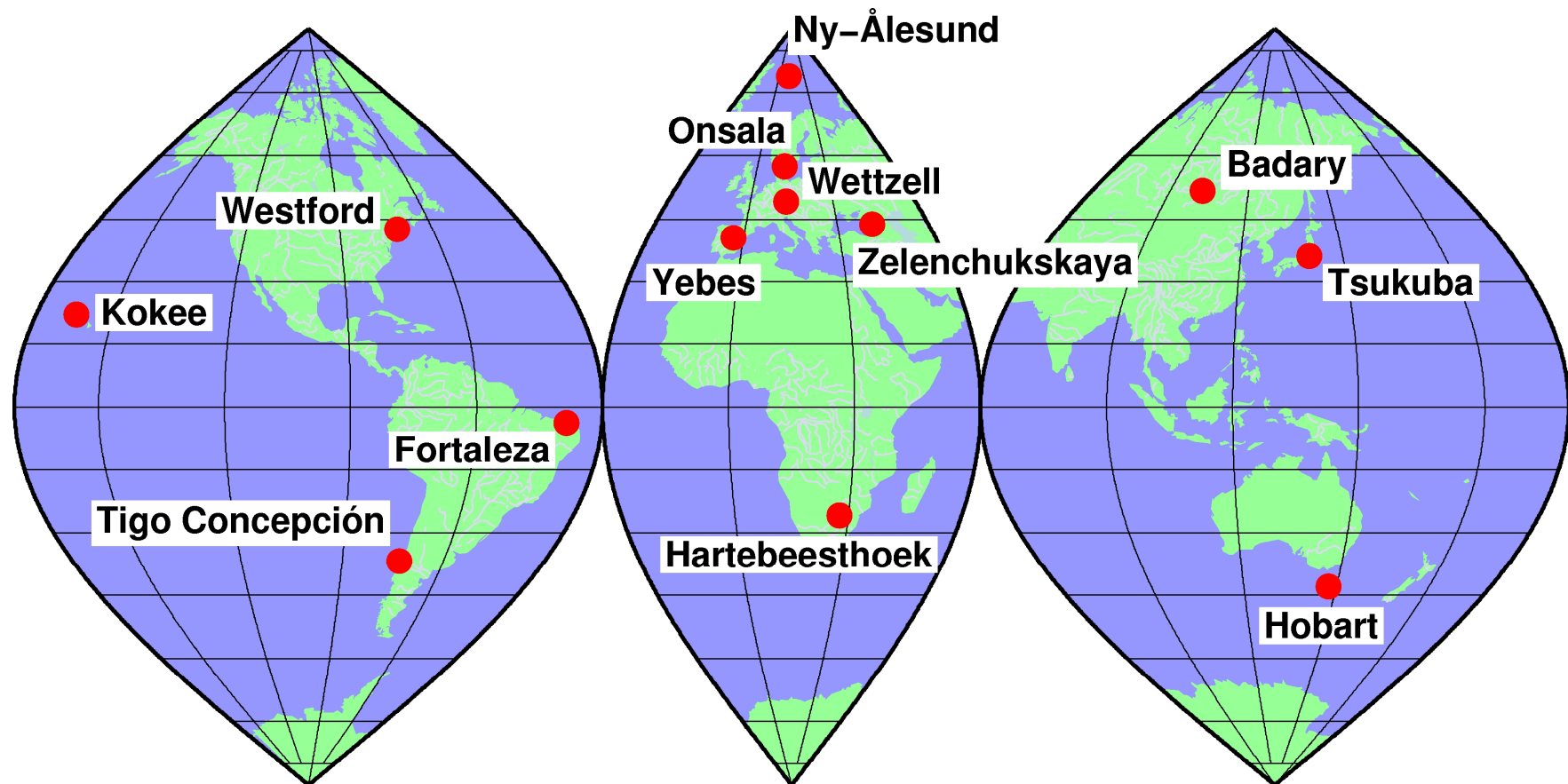
Best case: Onsala-Wettzell



CONT08 results

	VLBI	GPS	GPS-VLBI	
	ADev @ 1 day	ADev @ 1 day	Δ trend	RMS
HARTRAO	1.9e-15	8.5e-16	3.8e-17	260 ps
KOKEE	3.0e-15	3.2e-15	7.4e-17	210 ps
MEDICINA	1.2e-14	1.2e-14	1.2e-15	340 ps
NYALES20	6.8e-15	6.5e-15	-4.5e-16	110 ps
ONSALA60	reference	reference	---	---
SVETLOE	2.8e-12	1.1e-12	No common clock	---
TIGOCONC	4.3e-15	6.1e-9	No common clock	---
TSUKUB32	1.2e-13	6.5e-14	No common clock	---
WESTFORD	7.1e-15	8.4e-14	No common clock	---
WETTZELL	1.2e-15	6.2e-16	4.8e-16	70 ps
ZELENCHK	4.0e-14	4.1e-10	No common clock	---

CONT11



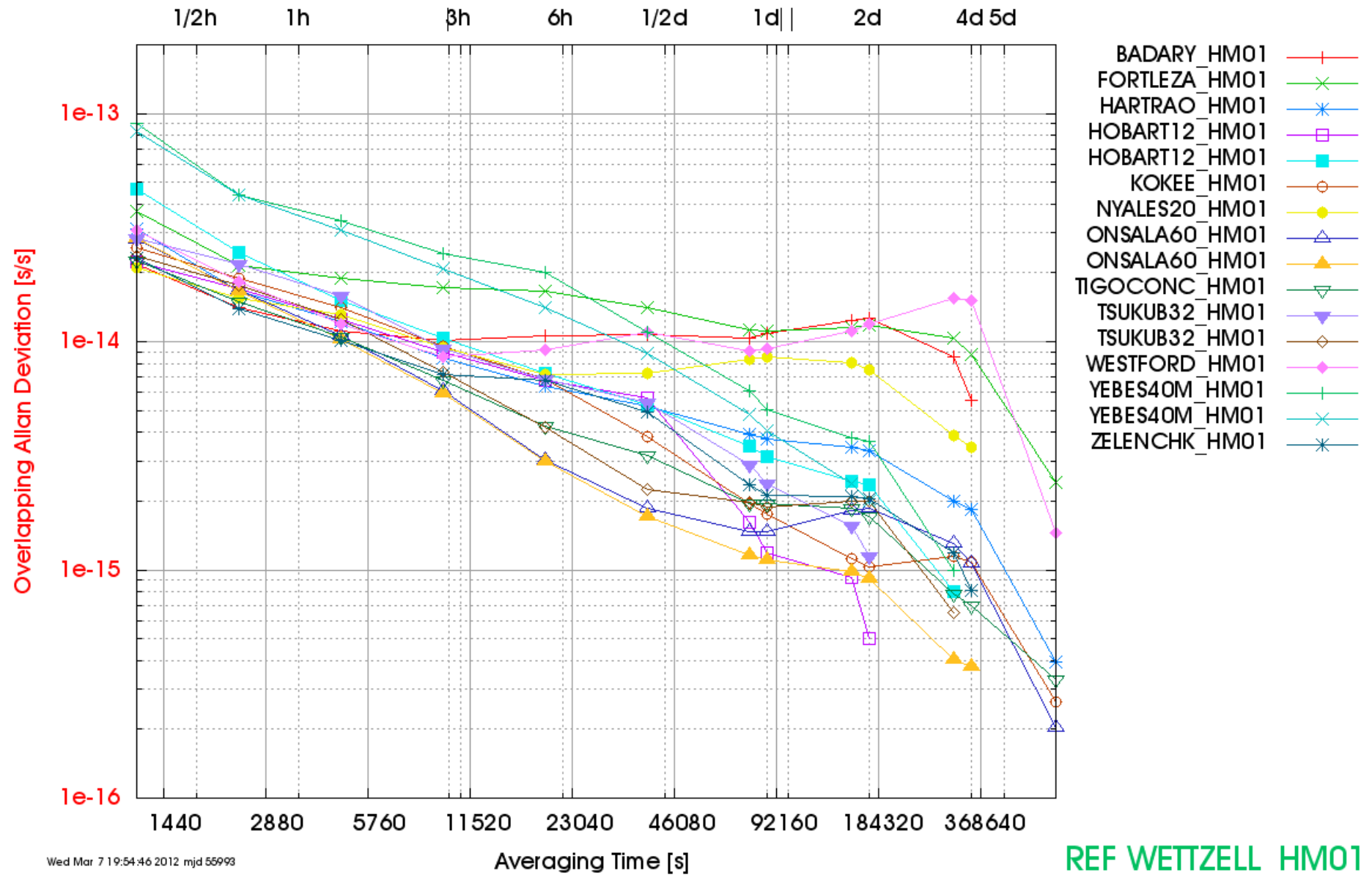
CONT11

- 2011, September 15-29
- 13 VLBI stations
- All of them operate also GNSS stations (IGS)
- 11 out of 13 stations share common clock for VLBI system and GNSS receivers

CONT11 equipment

IVS	IGS	H-maser	Common clock?
BADARY	BADG	CH1-80M	NO
FORTLEZA	BRFT	Sigma Tau	YES ☺
HARTRAO	HRAO	EFOS-C 28	YES ☺
HOBART12	HOB2	VCH-1005A	YES ☺
KOKEE	KOKB	Sigma Tau	YES ☺
NYALES20	NAYL, NYA1		YES ☺
ONSALA60	ONSA	CH1-75A	YES ☺
TIGOCONC	CONZ	EFOS-20	YES ☺
TSUKUB32	TSKB, TSK2	Anritsu SA0D05A	YES ☺
WESTFORD	WES2	APL No4	YES ☺
WETTZELL	WTZR, WTZS, WTZZ	EFOS 18	YES ☺
YEBES40	YEBE	EFOS iMaser S/N 66	YES ☺
ZELENCHK	ZECK	VCH-1003A, CH1-80M	NO

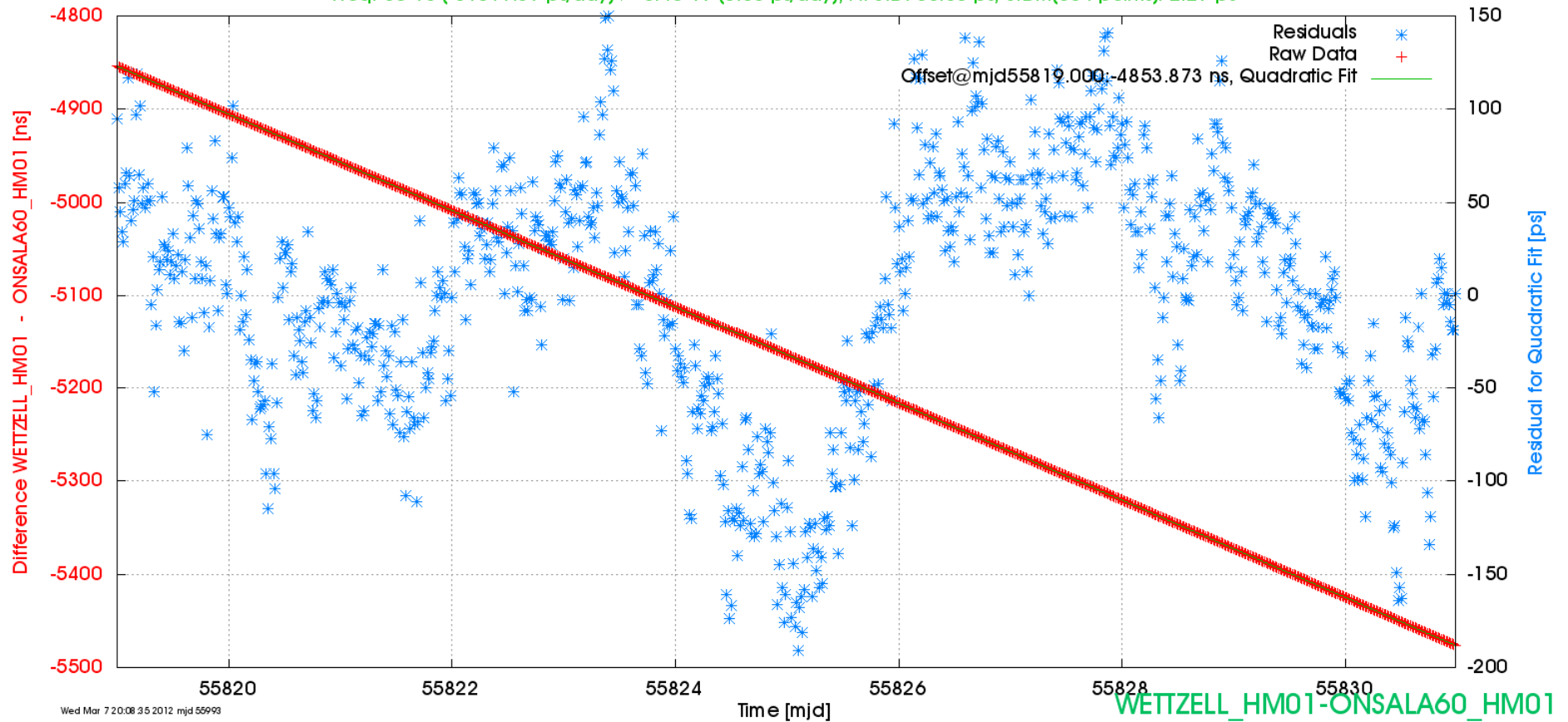
CONT1 1 Frequency Link InStabilities



Best case: Onsala-Wettzell

MJD 55819-55830, Ref WETTZELL_HM01, Clk ONSALA60_HM01, Link: VLBI_RAW_CLK_C11_WETTREF_D1_20_05_120301

Freq: 6e-13 (-51511.39 ps/day) +- 6.4e-17 (5.56 ps/day), Fit STD: 66.66 ps, STD(864 points): 2.27 ps

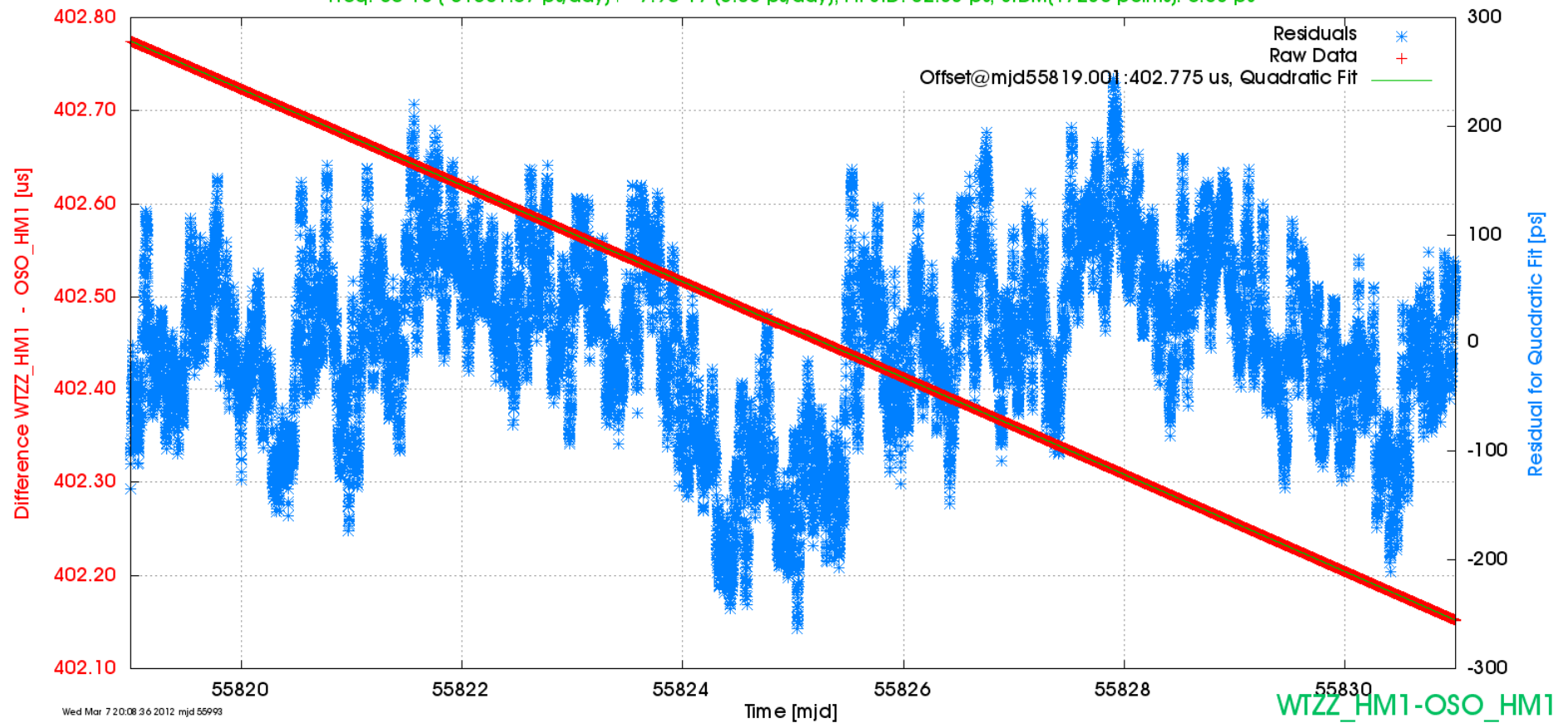


From VLBI

Best case: Onsala-Wettzell

MJD 55819-55830, Ref WTZZ_HM1, Clk OSO_HM1, Link: IGS-WTZZ_GPS9-NRCAN_PPP_IGS_30S_10_WZDSTD-OSO_GPS7-RDC

Freq: $6\text{e-}13$ (-51561.07 ps/day) + $-7.9\text{e-}17$ (6.86 ps/day), Fit STD: 82.33 ps, STD(17236 points): 0.63 ps

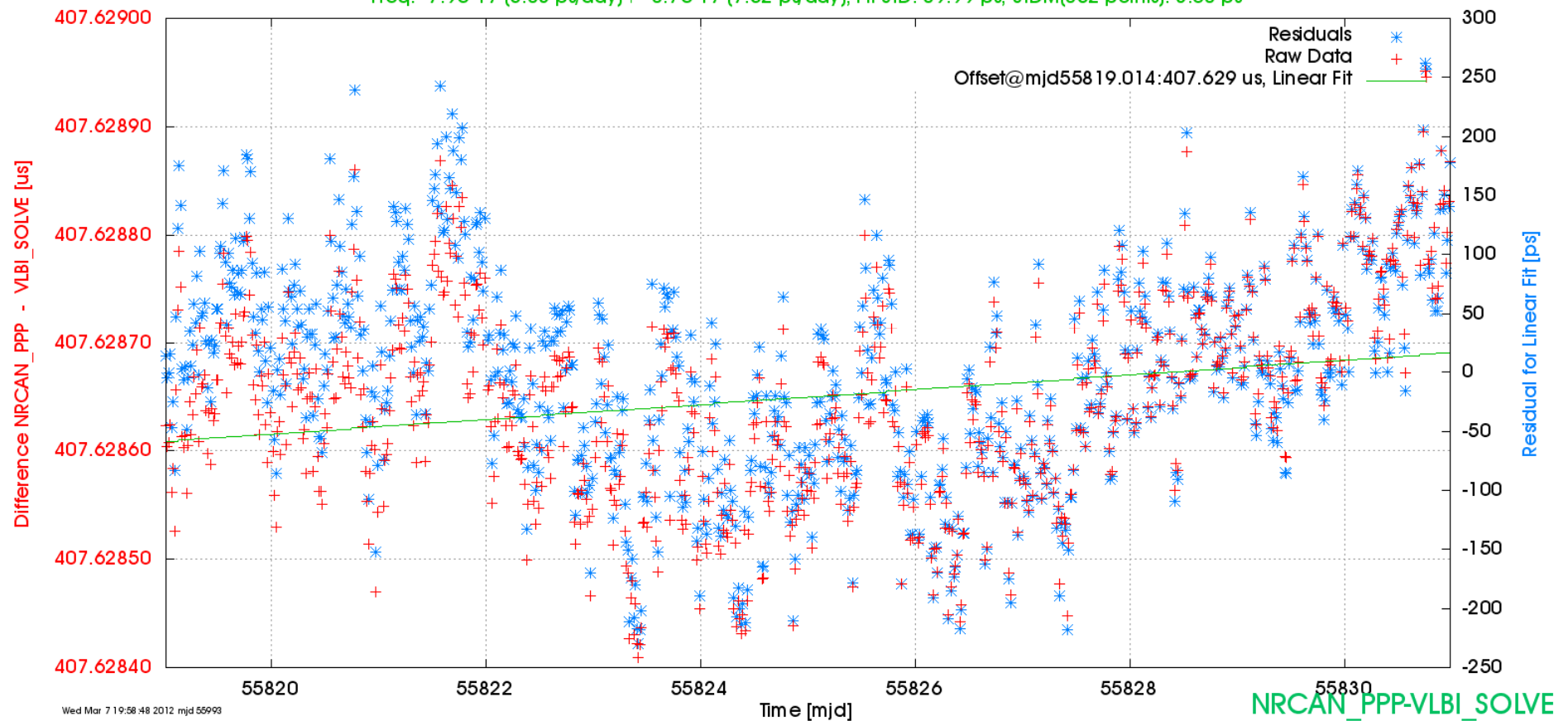


From GPS

Best case: Onsala-Wettzell

MJD 55819-55830, Ref NRCAN_PPP, Clk VLBI_SOLVE, Link: WTZZ_HM1-OSO_HM1-NRCAN_PPP_IGS_30S_10_WZDSTD-VLBI_RAW_CLK_C11_WETTREF_D1_20_05_120301

Freq: $-7.9\text{e-}17$ (6.83 ps/day) + $-8.7\text{e-}17$ (7.52 ps/day), Fit STD: 89.99 ps, STD(M852 points): 3.08 ps



CONT11 results

	VLBI	GPS	GPS-VLBI	
	ADev @ 1 day	ADev @ 1 day	Δ trend	RMS
BADARY	1.1e-14	1-8e-15	No common clock	---
FORTLEZA	1.1e-14	5.1e-14	$-2.4\text{e-}13 \pm 8.0\text{e-}15$	4.6 ns
HARTRAO	3.7e-15	3.6e-15	$-6.0\text{e-}16 \pm 8.7\text{e-}17$	112 ps
HOBART12	1.2e-15	3.3e-15	$5.9\text{e-}13 \pm 6.6\text{e-}16$	339 ps
KOKEE	1.8e-15	1.8e-15	$-1.1\text{e-}15 \pm 1.1\text{e-}16$	143 ps
NYALES20	8.6e-15	1.3e-14	$-3.8\text{e-}16 \pm 5.2\text{e-}16$	628 ps
ONSALA60	1.1e-15	1.2e-15	$-7.9\text{e-}17 \pm 8.7\text{e-}17$	90 ps
TIGOCONC	1.9e-15	1.7e-15	$7.2\text{e-}16 \pm 1.1\text{e-}16$	134 ps
TSUKUB32	1.9e-15	2.6e-15	$7.4\text{e-}16 \pm 2.2\text{e-}16$	153 ps
WESTFORD	9.3e-15	9.1e-15	$1.1\text{e-}16 \pm 1.1\text{e-}16$	142 ps
WETTZELL	reference	reference	---	---
YEBES40	4.1e-15	4.1e-15	$1.0\text{e-}15 \pm 4.2\text{e-}16$	291 ps
ZELENCHK	2.1e-15	2.3e-15	No common clock	---

Conclusions

- VLBI can provide frequency transfer on the same level of accuracy as GPS methods
- Consistent results for CONT08 and CONT11
- Onsala-Wettzell baseline gives best results
- CONT11:
 - Allan Deviation $1.1\text{e-}15$ / $1.2\text{e-}15$ for VLBI / GPS
 - insignificant trend in the difference
- VLBI proves again to be an important independent method for frequency transfer

Outlook for VLBI2010

- Wettzell
 - Twin-telescope in 24/7 operation
 - Time laboratory with Cesium clocks and H-masers
 - Time and frequency from PTB Braunschweig
- Onsala
 - Hopefully twin-telescope in 24/7 operation
 - Time laboratory with Cesium clock and H-masers
 - Time and frequency from SP Borås
- Continuous time and frequency transfer between Germany and Sweden via VLBI might be possible
- Principle can be extended to intercontinental time and frequency transfer