Geodynamics with an interferometric water level tilt meter

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Content

- Historical interferometric water level tiltmeters in geodynamics
- Old NSWT and EWWT tilt meter observations of the FGI in 1977 - 1996 in Lohja, southern Finland
- New water level tilt meter with modern fiber-optic and computer technique
- Geodynamic tilt observations with new NSWT in Lohja.
- Toroidal free oscillations after Chilean earthquake 27.2010
- Crustal loading tilt caused by the Baltic Sea level variations and loading influence of the Arctic Sea on Earth tide tilt wave group M2
- Conclusions

Michelson&Gale WT 1914-1919

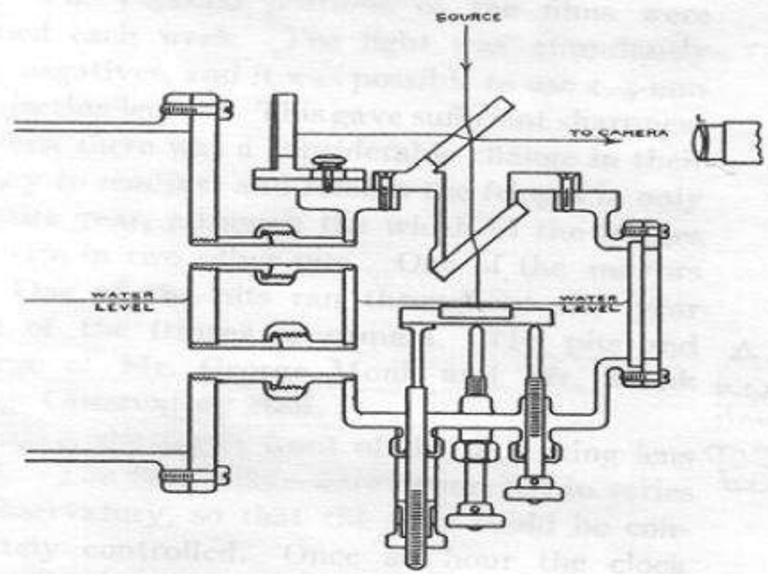
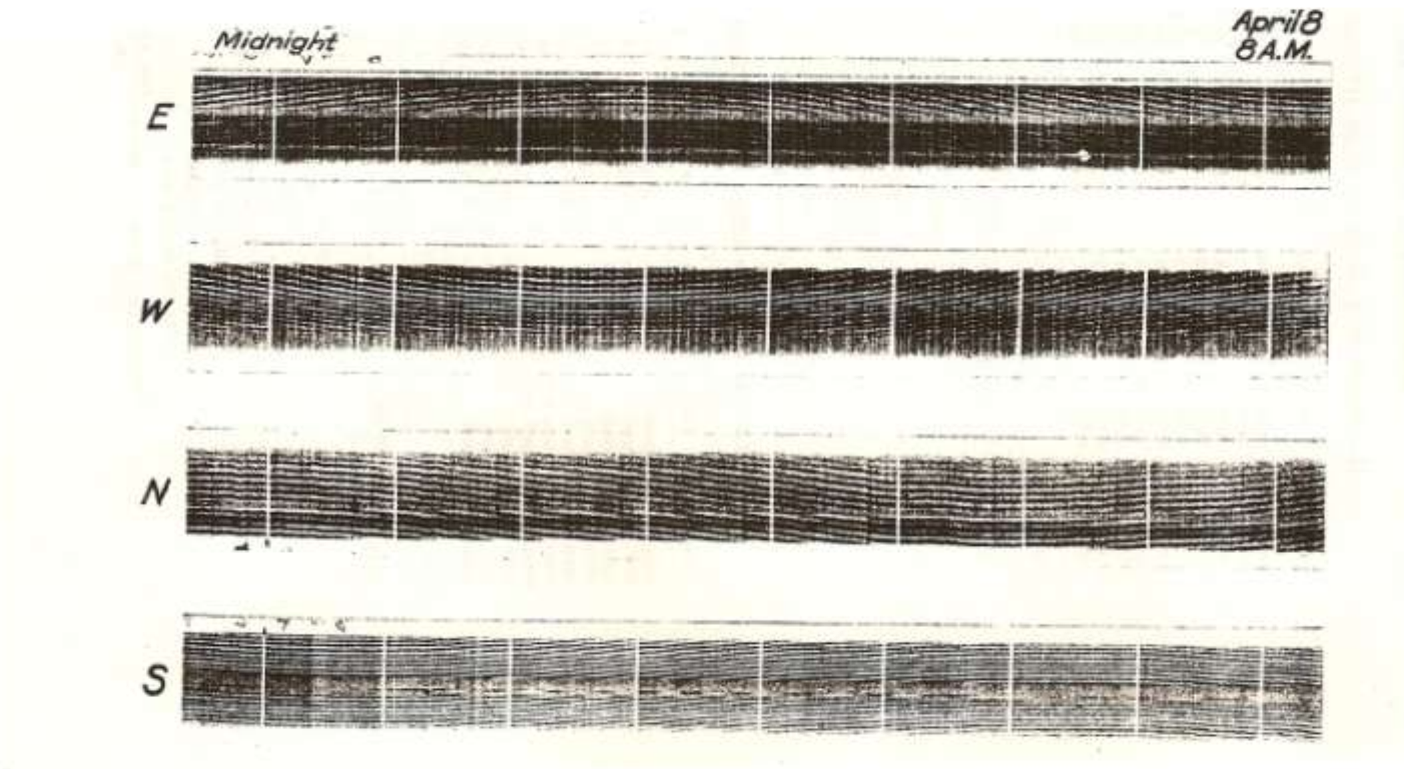


FIG. 1

Other interference arrangements are obvious which would give a displacement of a greater number of fringes, or permit the use of a shorter pipe; e.g., the fringes formed between the water surface and the lower mirror might be used, or the lower mirror might be dispensed with and use made of the fringes formed by the light reflected from the water surface and the vertical mirror. But the arrangement actually used was the most satisfactory, since the long pipes, 502 feet, were already installed.

Courtesy: Michelson & Gale, (1919)



Courtesy:Michelson& Gale, 1919

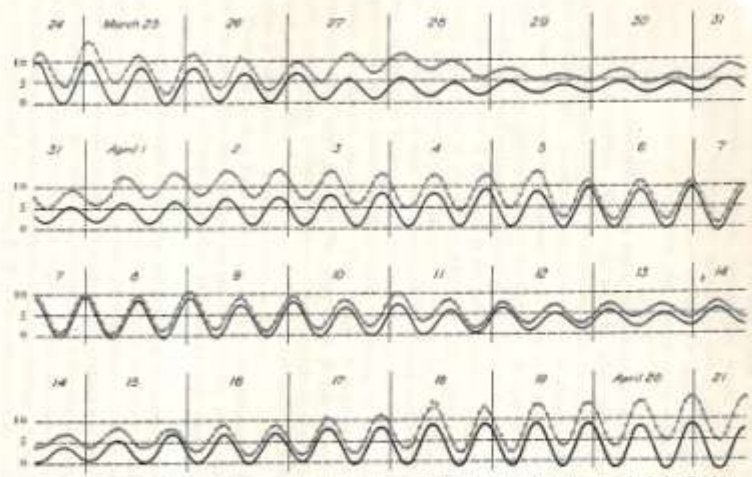


FIG. 1.—N-S tides, March 24 to April 11, 1917. Dotted curves, observed values. Full curves, 0.7 of calculated values

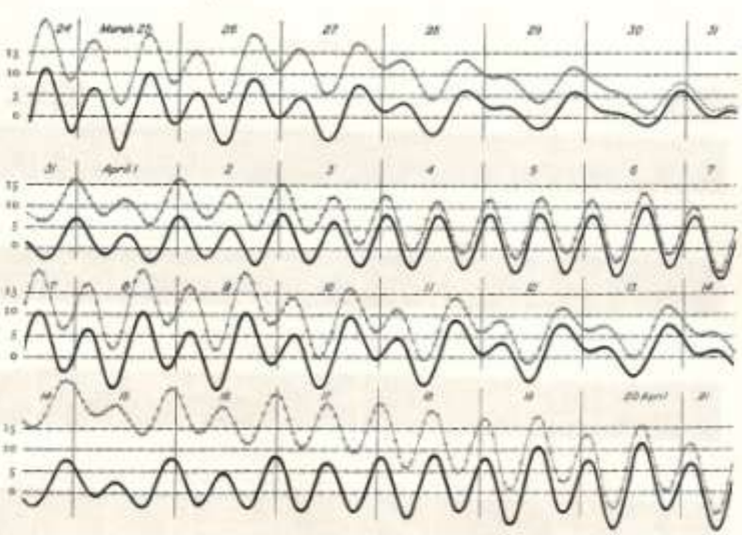
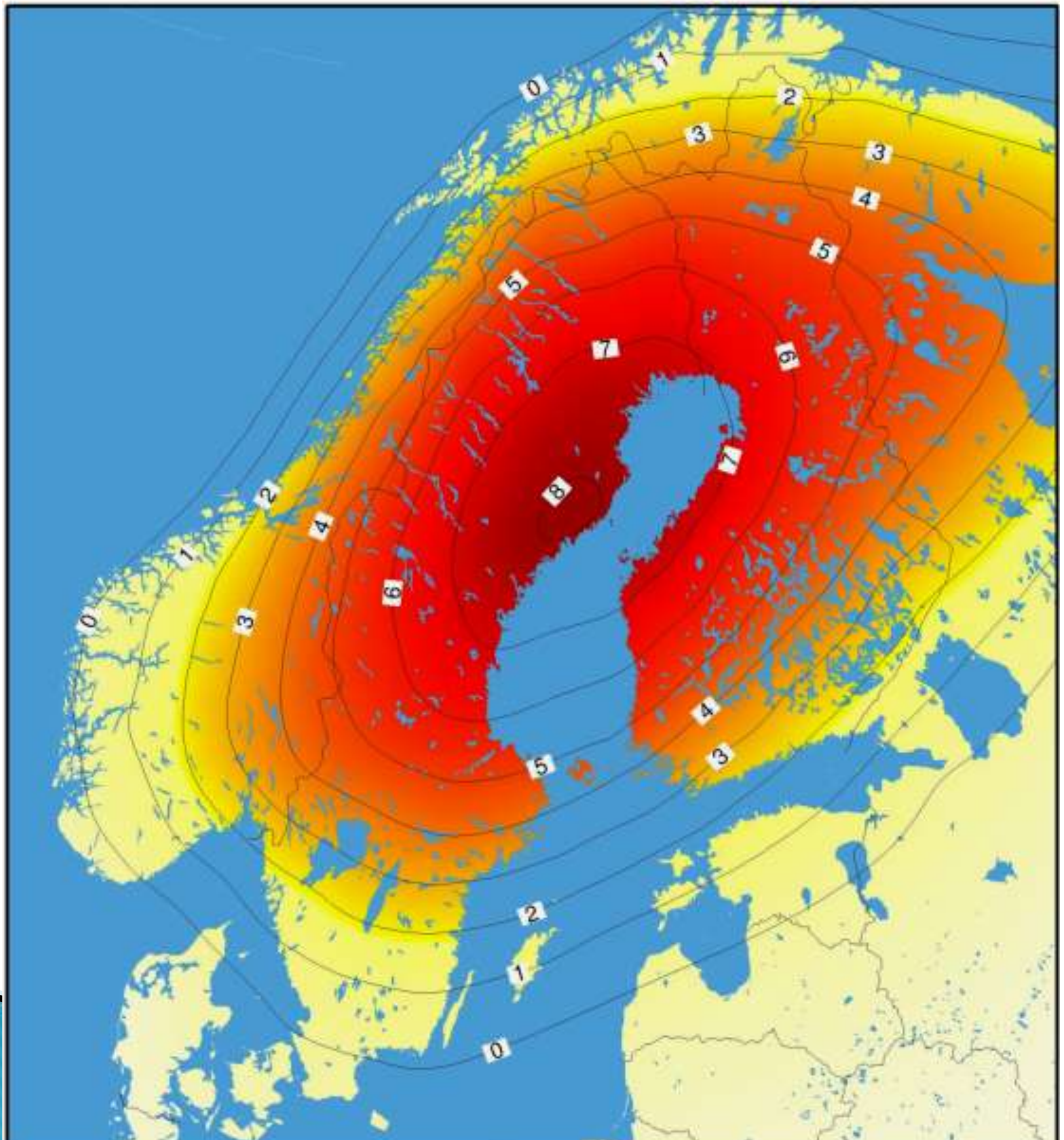


FIG. 2.—E-W tides, March 24 to April 11, 1917. Dotted curves, observed values. Full curves, 0.7 of calculated values

Courtesy:Michelson&Gale, 1919


1
0
2
3
3
4
5
5
7
6
7
8
2
4
1
6
0
3
4
5
3
2
1
0

A 1 km long tiltmeter for land uplift research – A plan by Kukkamäki, FGI in 1965

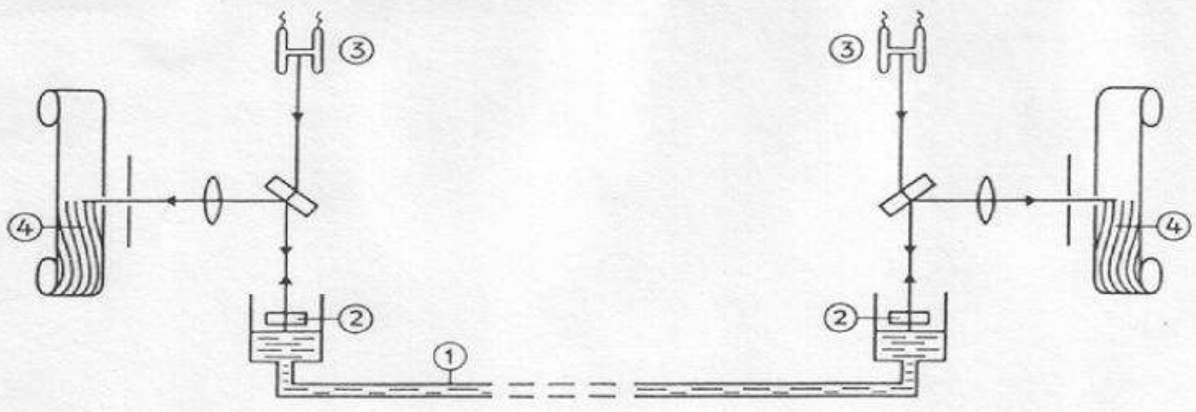


Fig. 1. Pipe level.

1. Pipe, 1000 m long
2. Fixed reference surface
3. Light source of the interferometer
4. Photographic record of interference fringes

A pipe about 1000 m long is planned to be placed in a horizontal drift situated perpendicularly to isobases. The pipe is filled with a suitable liquid, e.g. with mercury. The elevation of the liquid surface at each end is recorded with light interference by which an internal precision of one tenth of the interference fringe interval, i.e. $\pm 0.02\ \mu$ is to be obtained.

This precision, when compared with the yearly tilting of 15 μ per 1000 m would be satisfactorily high. This precision would be a real accuracy for

Courtesy: Kukkamäki, 1965

NS (62m long) & EW(177m long) water tube tilt meters in Lohja mine 1977-1996 by Kääriäinen, FGI

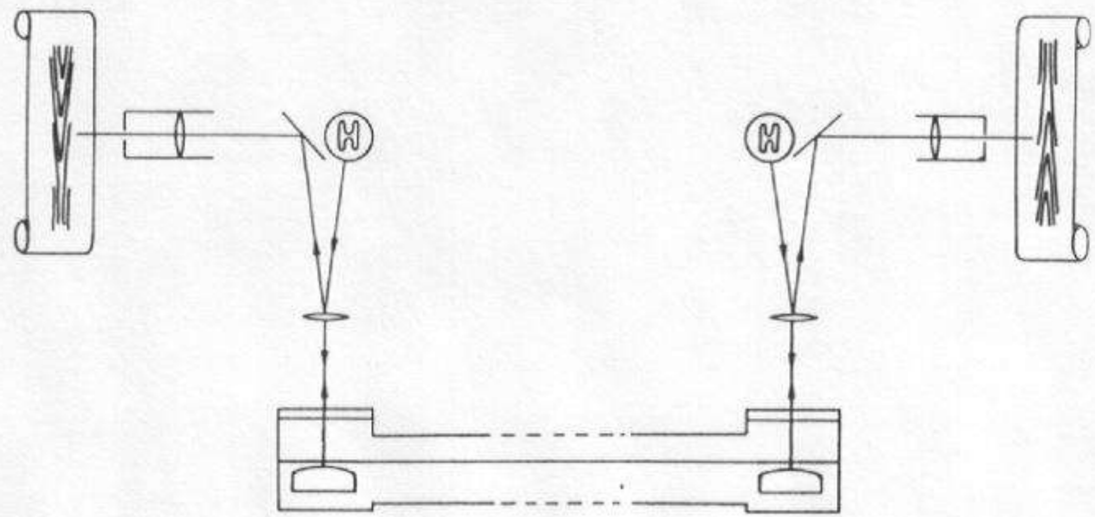


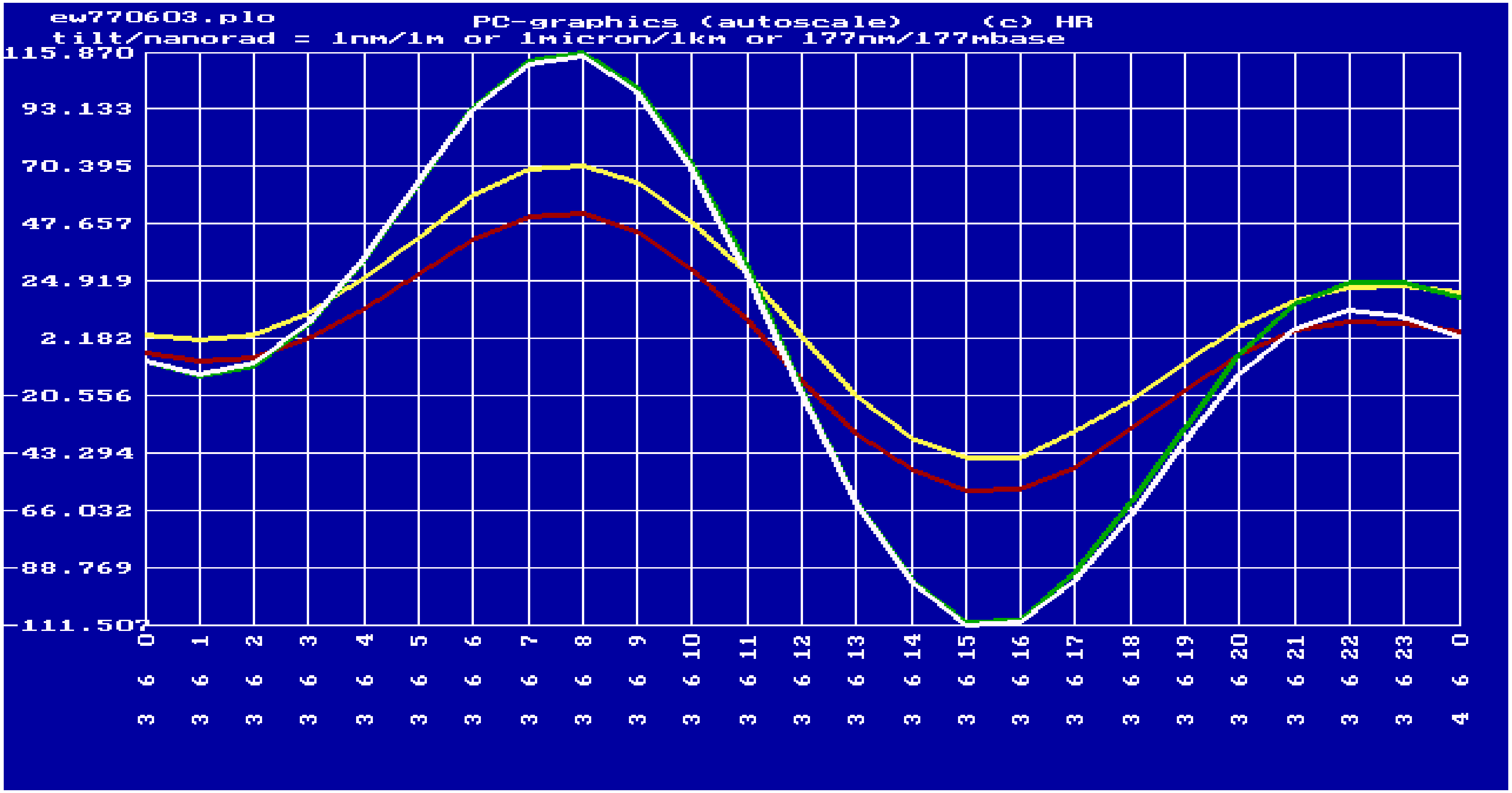
Fig. 2. The principle of the instrument .

would be satisfactorily high. This precision would be a real accuracy for

Courtesy:Kääriäinen, 1979


SWEDEN
FINLAND
Lohja NSWT
Helsinki
ESTONIA
BALTIC SEA
LATVIA
LITHUANIA

Photo:H. Ruotsalainen, FGI


ew770603.plo
PC-graphics (autoscale) (c) HR
tilt/nanorad = 1nm/1m or 1micron/1km or 177nm/177mbase
115.870
93.133
70.395
47.657
24.919
2.182
-20.556
-43.294
-66.032
-88.769
-111.507

EWWT recordings analysed with Eterna 3.3 (Wenzel, 1995)

adjusted tidal parameters :

from [cpd]	to [cpd]	wave	ampl. [mas]	ampl.fac.	stdv.	ph. lead [deg]	stdv. [deg]
0.721500	0.851182	138	0.0572	1.37066	0.54489	10.6357	22.7839
0.852096	0.857262	2Q1	0.0804	0.56144	0.18085	7.2778	18.4642
0.857571	0.870023	SIG1	0.0949	0.54918	0.15241	7.0314	15.9174
0.887327	0.894010	Q1	0.7606	0.70299	0.02398	1.1341	1.9557
0.895216	0.906315	RO1	0.1255	0.61070	0.12707	2.6861	11.9281
0.921941	0.932583	O1	3.9684	0.70227	0.00455	0.4411	0.3717
0.932583	0.940487	TAU1	0.0799	1.08348	0.34699	2.5312	18.3382
0.958086	0.968565	M1	0.3052	0.68672	0.05319	-0.2869	4.4423
0.968566	0.974188	CHI1	0.0532	0.62583	0.31049	-33.7735	28.4286
0.989049	0.994755	PI1	0.1279	0.83172	0.19968	3.9360	13.7475
0.995143	0.998028	P1	1.8668	0.70999	0.01254	-1.9379	1.0129
0.999853	1.000147	S1	0.0973	1.56456	0.76176	-126.5737	27.8548
1.001825	1.003651	K1	5.7740	0.72655	0.00414	-2.8628	0.3271
1.005329	1.005623	PSI1	0.0210	0.33704	0.52373	-28.3115	89.2665
1.007595	1.011099	FI1	0.0560	0.49472	0.27922	8.2502	32.3242
1.013689	1.034320	THE1	0.0472	0.55569	0.30626	28.3914	31.5835
1.034467	1.044800	J1	0.3013	0.67800	0.05826	-3.2356	4.9228
1.064841	1.073202	SO1	0.0579	0.78526	0.35450	-1.9257	25.8351
1.073349	1.080797	OO1	0.1645	0.67640	0.09048	0.7635	7.6679
1.080944	1.216397	V1	0.0362	0.77640	0.43654	5.3150	32.2846
1.719381	1.827343	3N2	0.0152	0.67881	0.31430	-22.3711	26.5291
1.827799	1.853920	EPS2	0.0412	0.71131	0.14223	1.5487	11.4596
1.854524	1.863634	2N2	0.1401	0.70608	0.04113	-0.0527	3.3362
1.864091	1.872142	MI2	0.1697	0.70851	0.03513	-1.5131	2.8420
1.888387	1.900529	N2	1.0417	0.69458	0.00550	-0.3031	0.4534
1.900545	1.906462	NI2	0.1919	0.67360	0.02942	1.3149	2.5020
1.923766	1.942753	M2	5.4571	0.69667	0.00105	-0.8168	0.0862
1.958233	1.966446	LMB2	0.0406	0.70281	0.14513	-7.6831	11.8283
1.966447	1.976926	L2	0.1650	0.74535	0.03069	0.4608	2.3574
1.991787	1.998287	T2	0.1260	0.59099	0.04271	3.2979	4.1411
1.999706	2.000766	S2	2.5470	0.69887	0.00260	-0.2271	0.2134
2.002591	2.002885	R2	0.0295	0.96518	0.25443	-41.4186	15.1120
2.003032	2.031288	K2	0.6810	0.68728	0.00893	-2.9251	0.7441
2.031435	2.044652	ETA2	0.0273	0.49240	0.13396	-3.0273	15.5802
2.047243	2.182843	2K2	0.0060	0.41278	0.36113	-13.3625	50.1153
2.753244	2.869714	493	0.0191	0.91138	0.17184	-9.8374	10.8073
2.892640	2.935615	M3	0.0629	0.82238	0.04983	-1.5685	3.4714
2.940178	3.081254	SO3	0.0078	0.78184	0.35594	9.4799	26.0795
3.791964	3.937897	M4	0.0021	3.07459	3.87061	-169.7102	72.1331

Courtesy: Ruotsalainen, 2005 (C)

Finnish Geodetic Institute

NSWT-recordings analysed with Eterna3.3 (Wenzel, 1995)

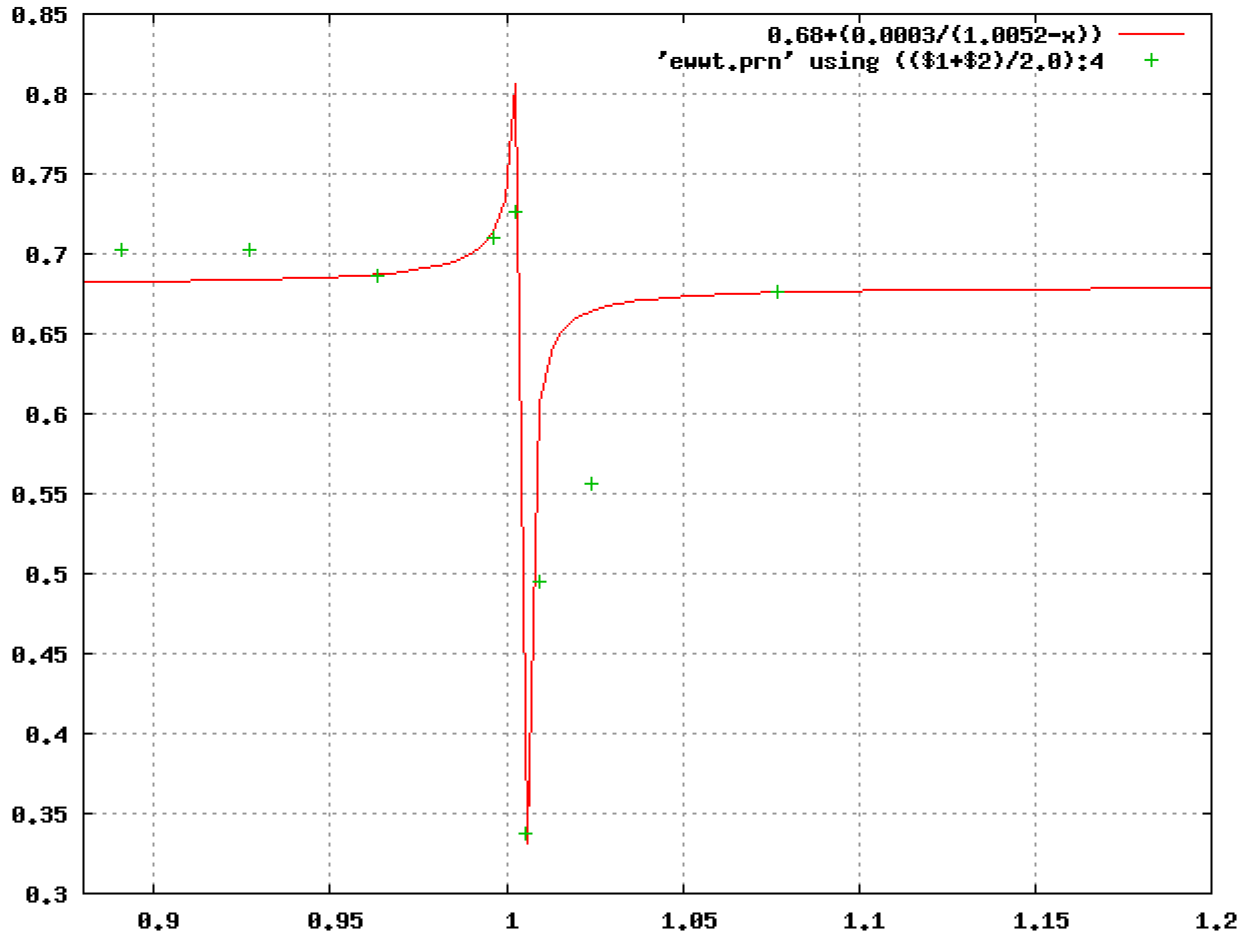
Finnish Geodetic Institute

Adjusted tidal parameters :

from [cpd]	to [cpd]	wave	ampl. [mas]	ampl.fac.	stdv.	ph. lead [deg]	stdv. [deg]
0.002428	0.003425	SA	2.7860	21.55820	0.75580	4.8689	1.8418
0.004710	0.010951	SSA	4.5598	5.60478	0.12162	51.5398	1.2575
0.025812	0.044652	MM	0.8659	0.93765	0.10133	8.7152	6.1477
0.060132	0.080797	MF	1.1464	0.65560	0.04199	2.8095	3.7034
0.096423	0.249951	MTM	0.0922	0.27538	0.21450	-80.1844	44.7297
0.721500	0.851182	138	0.0343	1.41036	3.25907	24.0543	132.2977
0.852096	0.857262	2Q1	0.0951	1.13901	1.01500	-4.9167	51.0428
0.857571	0.870023	SIG1	0.0548	0.54408	0.84477	13.5732	88.9585
0.887327	0.894010	Q1	0.4579	0.72561	0.13443	-1.9058	10.6178
0.895216	0.906315	RO1	0.0833	0.69542	0.70207	1.5820	57.9633
0.921941	0.932583	O1	2.5148	0.76295	0.02591	-1.4785	1.9463
0.932583	0.940487	TAU1	0.0307	0.71399	2.52335	59.1197	202.5765
0.958086	0.968565	M1	0.1768	0.68231	0.31800	2.8929	26.7250
0.968566	0.974188	CHI1	0.0561	1.13219	1.70969	-42.1682	86.3876
0.989049	0.994755	PI1	0.1312	1.46351	1.10599	-10.4809	43.2952
0.995143	0.998028	P1	1.2100	0.78906	0.06562	-7.2004	4.7656
0.999853	1.000147	S1	0.0289	0.79809	4.04260	84.9280	290.2278
1.001825	1.003651	K1	3.6823	0.79470	0.02026	-5.7299	1.4605
1.005329	1.005623	PSI1	0.0158	0.43636	2.68225	-145.4647	352.3107
1.007595	1.011099	FI1	0.0999	1.51310	1.55209	39.6401	58.7408
1.013689	1.034320	THE1	0.0380	0.76677	1.73124	-4.0525	129.3109
1.034467	1.044800	J1	0.1800	0.69451	0.32882	-3.5987	27.1182
1.064841	1.073202	SO1	0.0391	0.91002	1.95890	-25.1447	123.2810
1.073349	1.080797	OO1	0.1034	0.72898	0.45691	2.2679	35.9021
1.080944	1.216397	V1	0.0212	0.77909	2.24936	0.3968	165.4682
1.719381	1.827343	3N2	0.0122	0.62731	4.20675	28.4906	384.3158
1.827799	1.853920	EPS2	0.0396	0.78810	1.88617	-35.8638	137.1802
1.854524	1.863634	2N2	0.0746	0.43242	0.54204	-10.9248	71.8084
1.864091	1.872142	MI2	0.1389	0.66747	0.46639	-20.2920	40.0389
1.888387	1.900529	N2	0.7334	0.56285	0.07322	-6.9163	7.4590
1.900545	1.906462	NI2	0.1687	0.68164	0.39201	-9.2398	32.9550
1.923766	1.942753	M2	3.9361	0.57841	0.01415	-1.7387	1.4019
1.958233	1.966446	LMB2	0.0358	0.71342	1.92947	17.7563	154.9270
1.966447	1.976926	L2	0.1195	0.62105	0.44625	-9.0471	41.1837
1.991787	1.998287	T2	0.0959	0.51820	0.53139	-6.0360	58.7565
1.999706	2.000766	S2	1.9665	0.62117	0.03120	3.5951	2.8779
2.002591	2.002885	R2	0.0372	1.40775	3.02582	40.4057	123.1780
2.003032	2.031288	K2	0.5167	0.60060	0.09613	3.0589	9.1716
2.031435	2.044652	ETA2	0.0193	0.40182	1.48795	5.8089	212.1664
2.047243	2.182843	2K2	0.0081	0.64315	3.80547	26.9722	338.7919
2.753244	2.869714	493	0.0175	0.96148	5.09948	-48.6560	303.9119
2.892640	2.935615	M3	0.0540	0.81358	1.45512	-18.6712	102.4983
2.940178	3.081254	SO3	0.0112	1.29493	8.45729	-58.6584	374.0662
3.791964	3.937897	M4	0.0137	22.83434	149.00132	-113.3949	373.8013

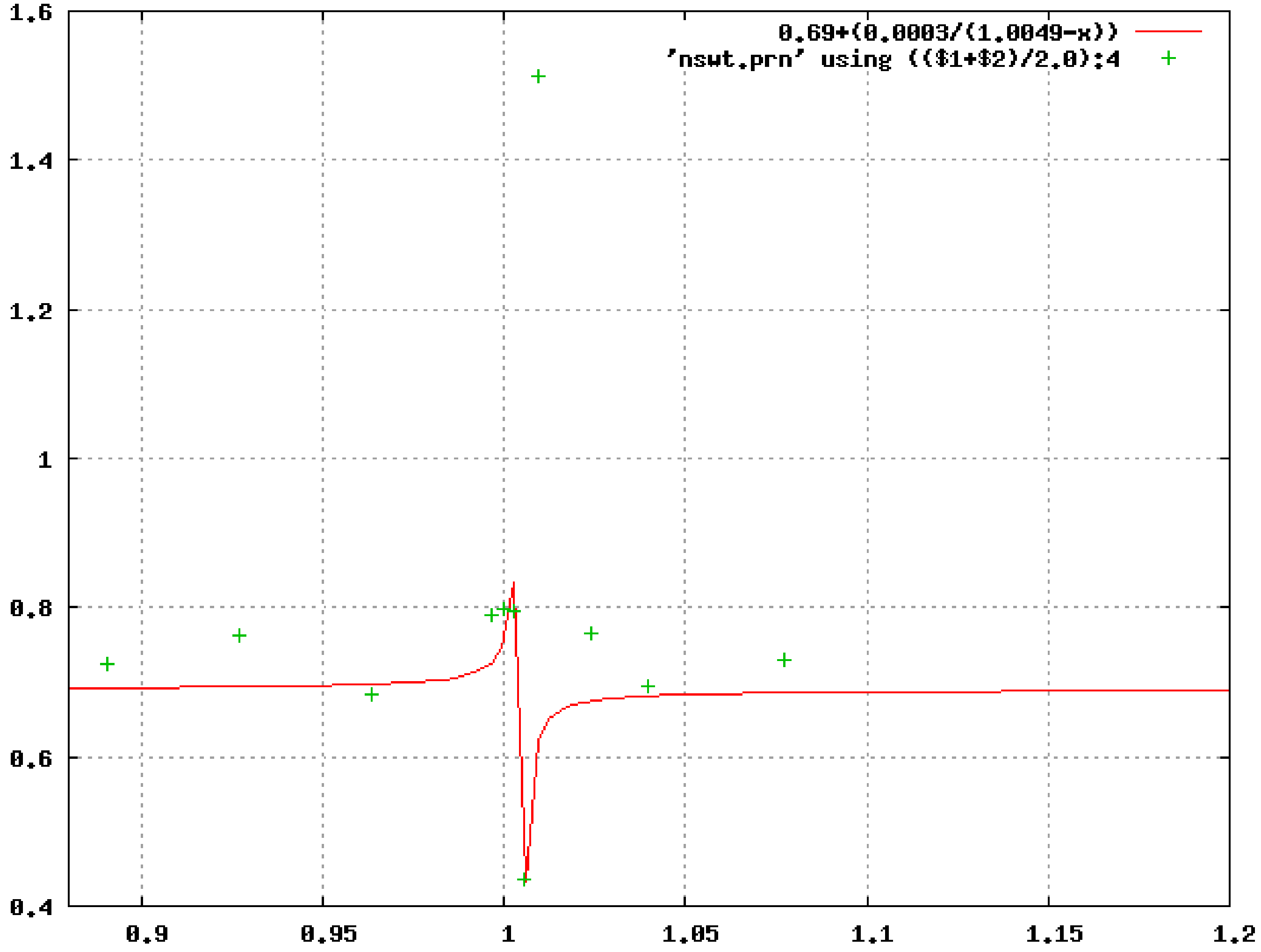
Courtesy: Ruotsalainen, 2005, FGI (C)

Recorded core resonance/tidal tilt signals recorded with EWWT in Lohja (nanoradians)



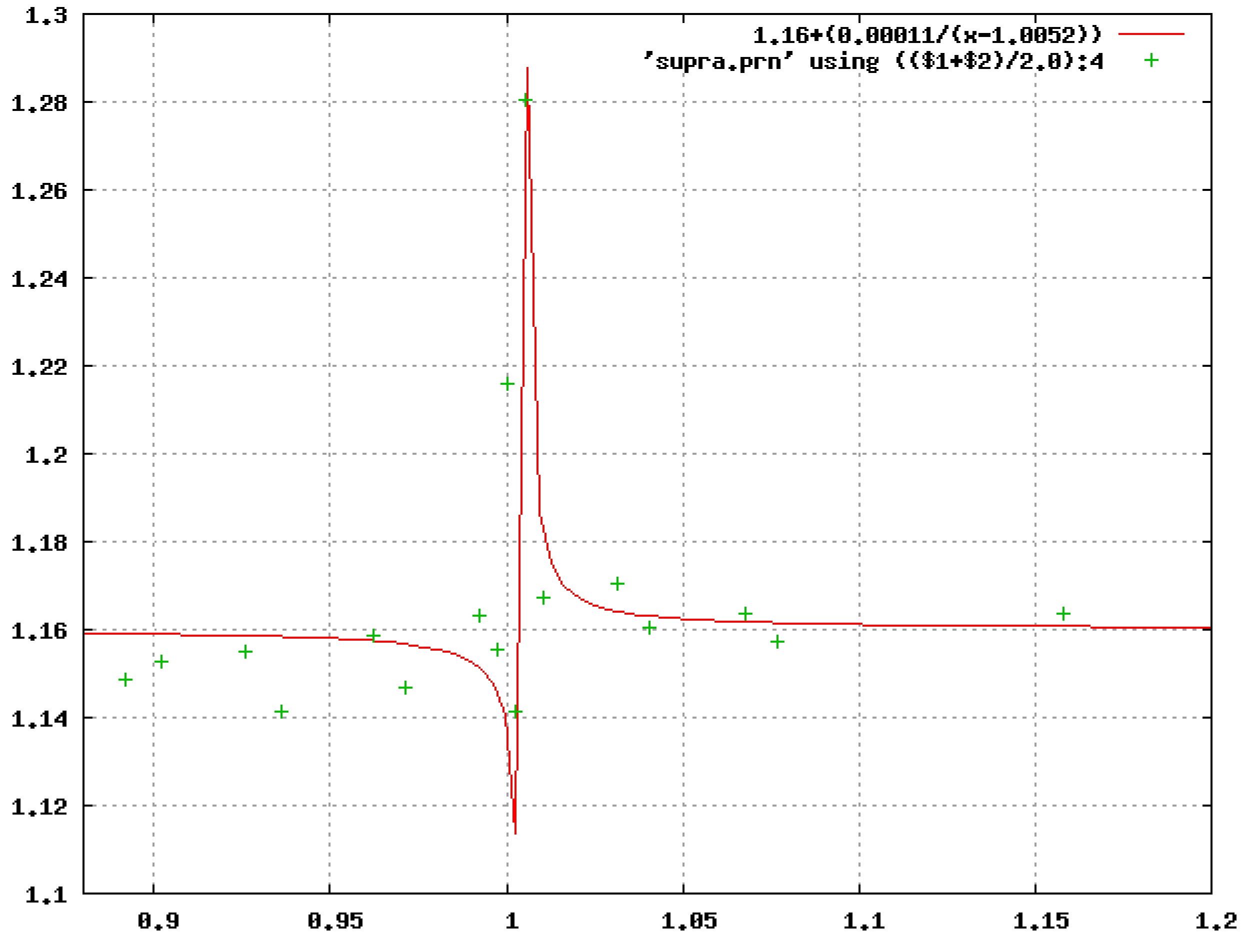
Courtesy: H.Ruotsalainen, FGI

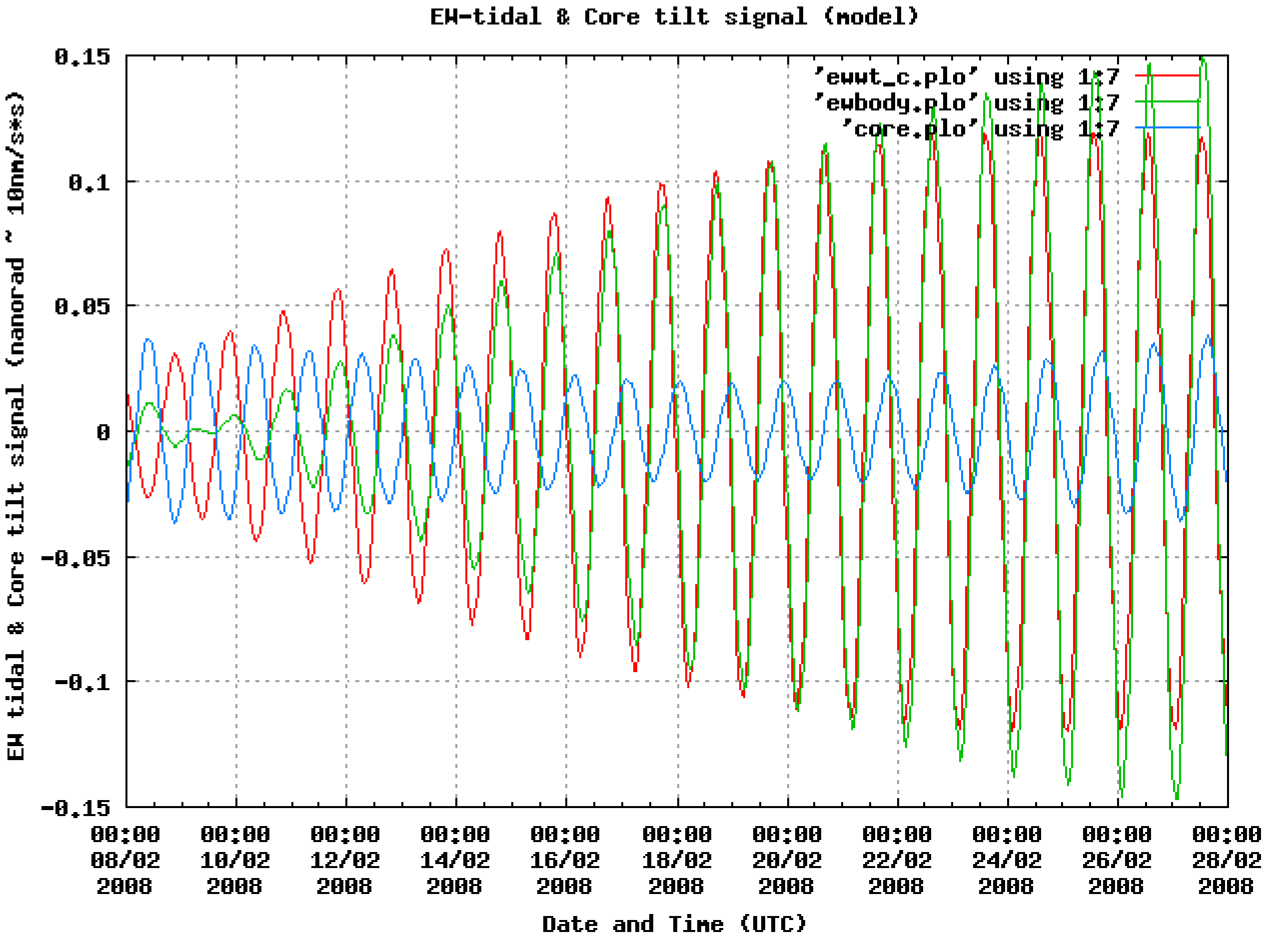
Recorded core resonance/tidal tilt signals recorded with NSWT in Lohja (nanoradians)



Courtesy: H.Ruotsalainen, FGI

Core resonance/tidal tilt signals recorded with superconducting gravimeter GWR-TT20 in Metsähovi (Virtanen, 2006)



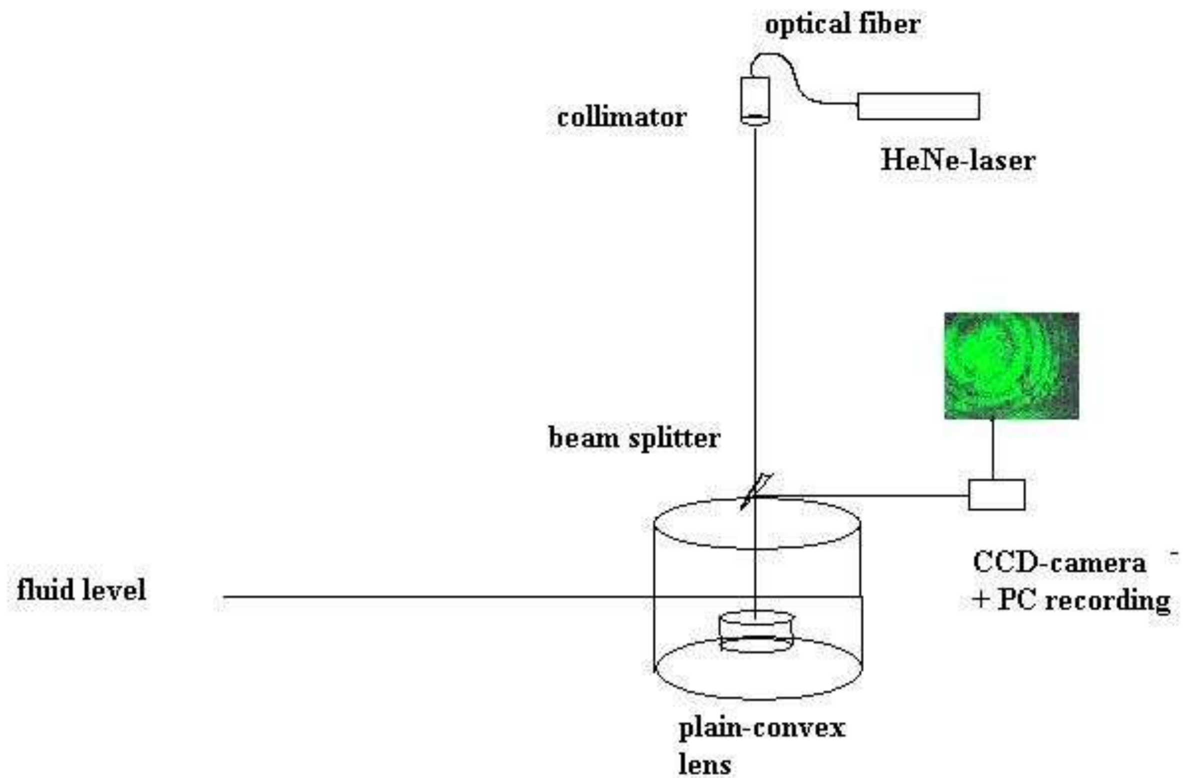


EW-tidal & Core tilt signal (model)
'ewwt_c.plo' using 1:7
'ewbody.plo' using 1:7
'core.plo' using 1:7
EW tidal & Core tilt signal (nanorad ~ 10nm/s*s)
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
00:00 08/02 2008
00:00 10/02 2008
00:00 12/02 2008
00:00 14/02 2008
00:00 16/02 2008
00:00 18/02 2008
00:00 20/02 2008
00:00 22/02 2008
00:00 24/02 2008
00:00 26/02 2008
00:00 28/02 2008
Date and Time (UTC)

Modernized water level tilt meter

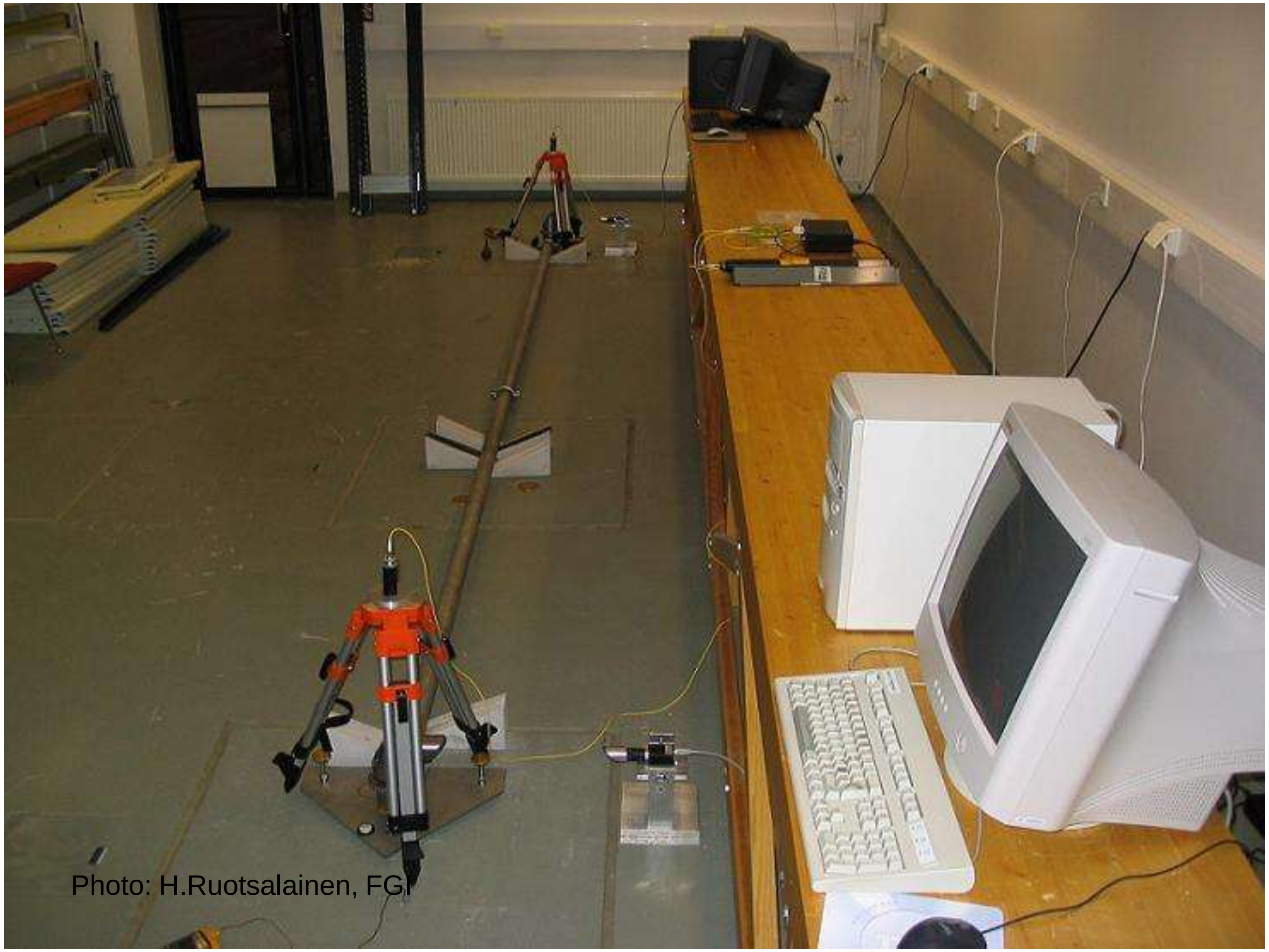
- Project third generation WT started in year 2000
- Thermal expansion modelling were carried out
- Modular stainless construction
- New end pots were built at the Helsinki University of Technology and installed on the adjustable tripods with special ball&socket type joints to the tube
- End pots plated inside by teflon to avoid water friction against walls
- Single mode fibers used between 2 mW HeNe-lasers and collimators to avoid thermal influence of laser on the level interferometer
- Fringe image recordings are carried out using Basler digital firewire cameras
- Interference phase interpretation carried out by a computer on-the-fly with 15 hz sampling rate under Linux operating system programmed by A. Pavenis (Latvia, Riga University/FGI 2002-2005)
- Estimated tilt resolution 0.1 nanoradians with this 50.4 m tube. Resolution is comparable to 1mm tilt in 10000 km base.

Fizeau-Kukkamäki level interferometer



(C) Courtesy: Hannu Ruotsalainen, FGI

Prototype wt at the FGI lab



Proto WT (2.75m) in Lohja

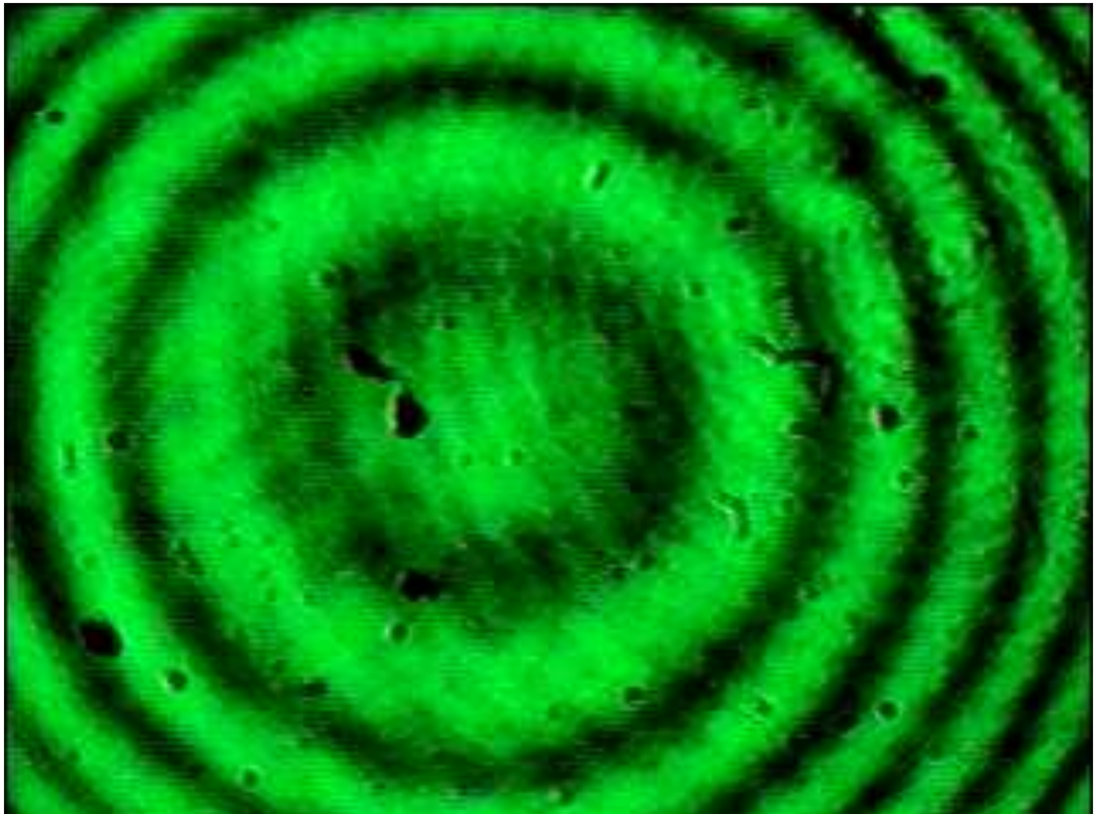
Photo: Hannu Ruotsalainen, FGI

New 50.4 m long proto NSWT in Lohja

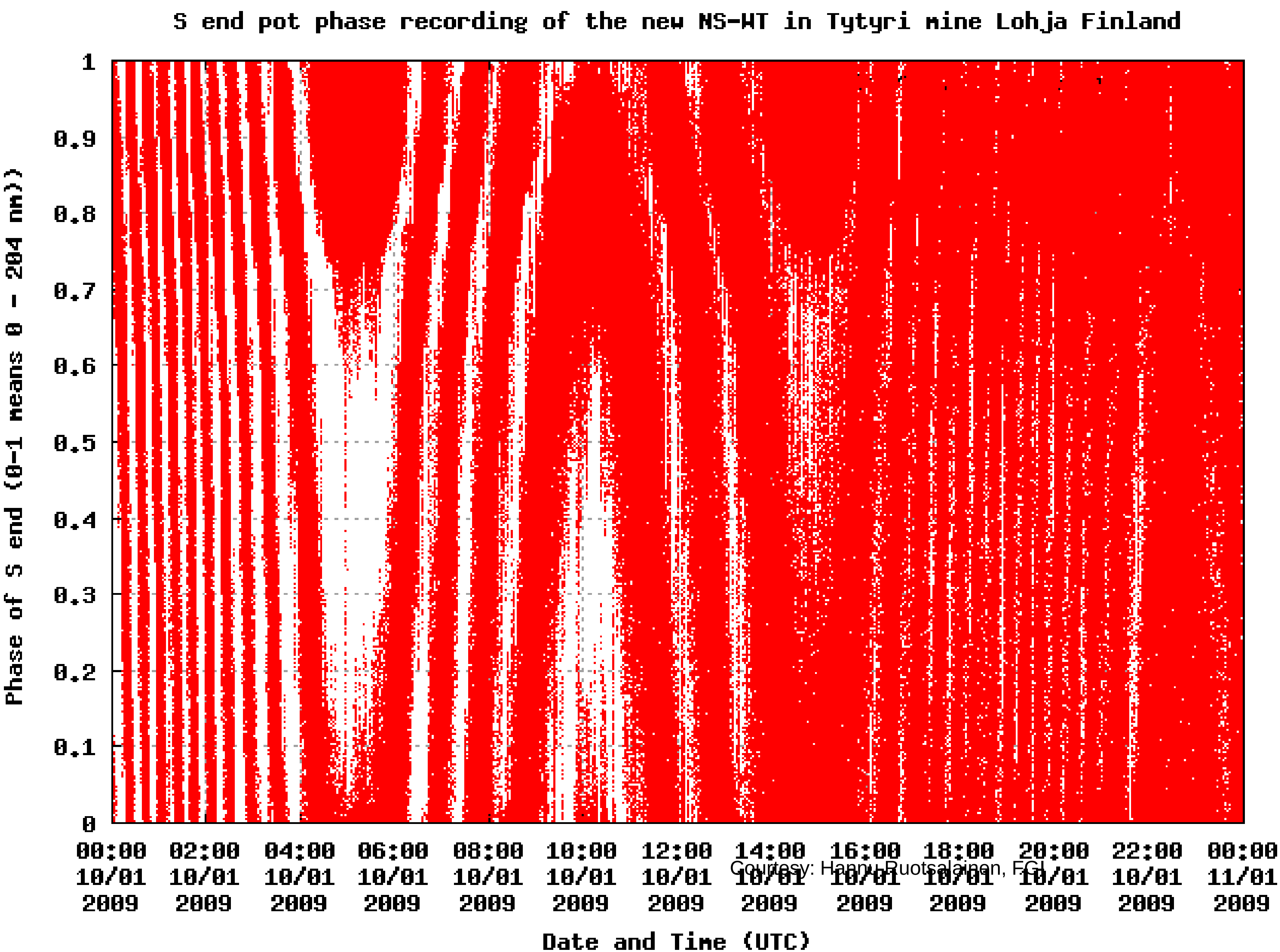

Photo: Hannu Ruotsalainen, FGI

Computers in entrance room (200 and 260 m from interferometers) recording fringes and interpreting on the fly with 15Hz sampling rate. Data is downloaded from computers on hard disks and transported to FGI for analyse e.g. monthly.

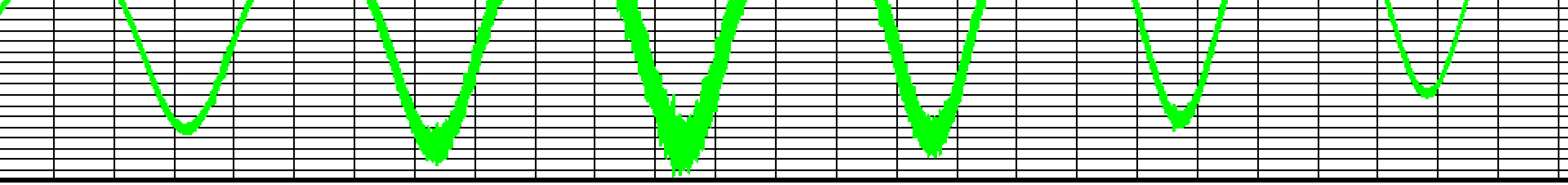
Photo: H. Ruotsalainen, FGI



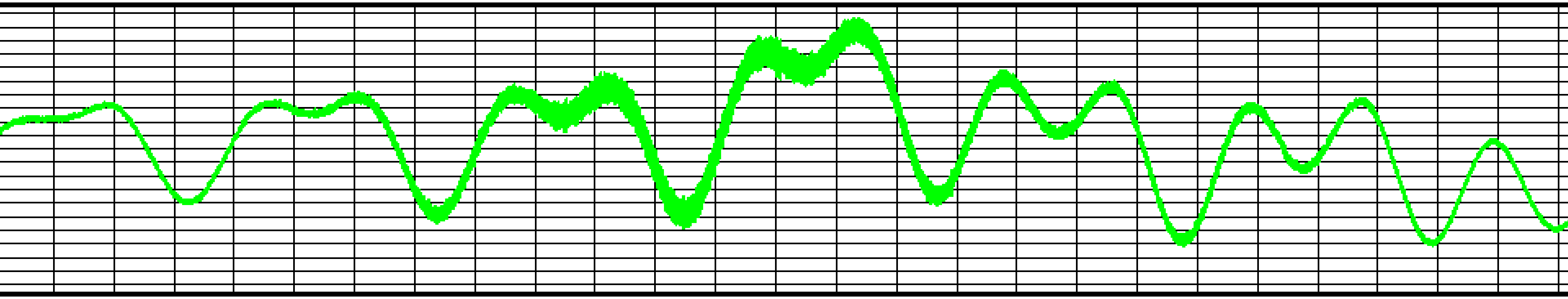
fringe26.avi



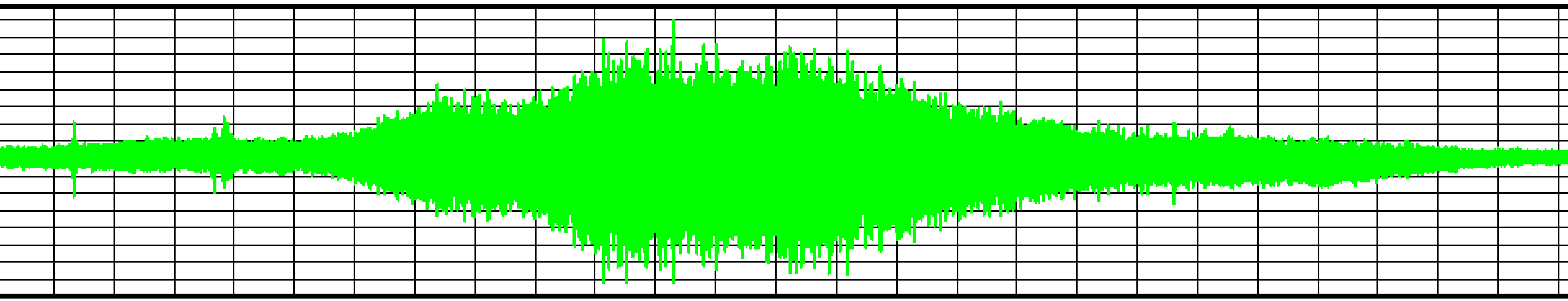
S end pot phase recording of the new NS-WT in Tytyri mine Lohja Finland
Phase of S end (0-1 means 0 - 204 nm))
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
00:00 10/01 2009
02:00 10/01 2009
04:00 10/01 2009
06:00 10/01 2009
08:00 10/01 2009
10:00 10/01 2009
12:00 10/01 2009
14:00 10/01 2009
16:00 10/01 2009
18:00 10/01 2009
20:00 10/01 2009
22:00 10/01 2009
00:00 11/01 2009
Date and Time (UTC)
Courtesy: Hannu Ruotsalainen, FGI



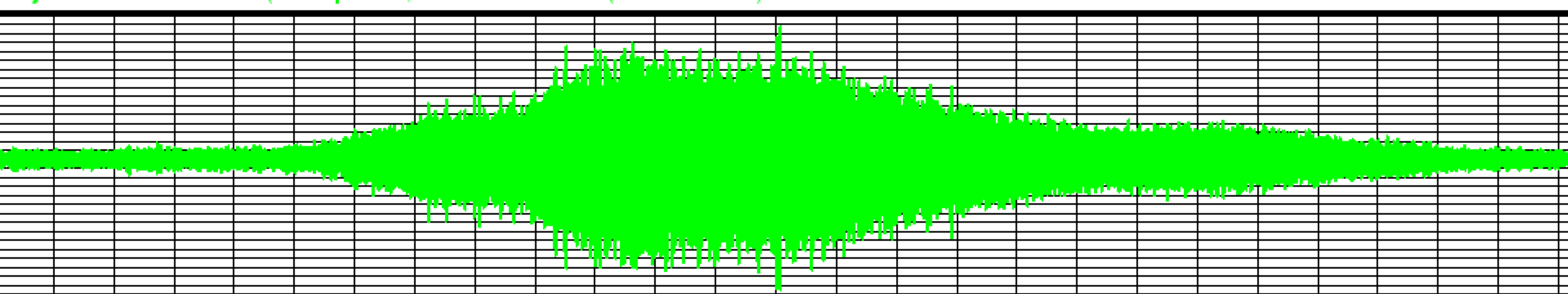
Lohja:NSWT:Crustal tilt (10x nanorad)

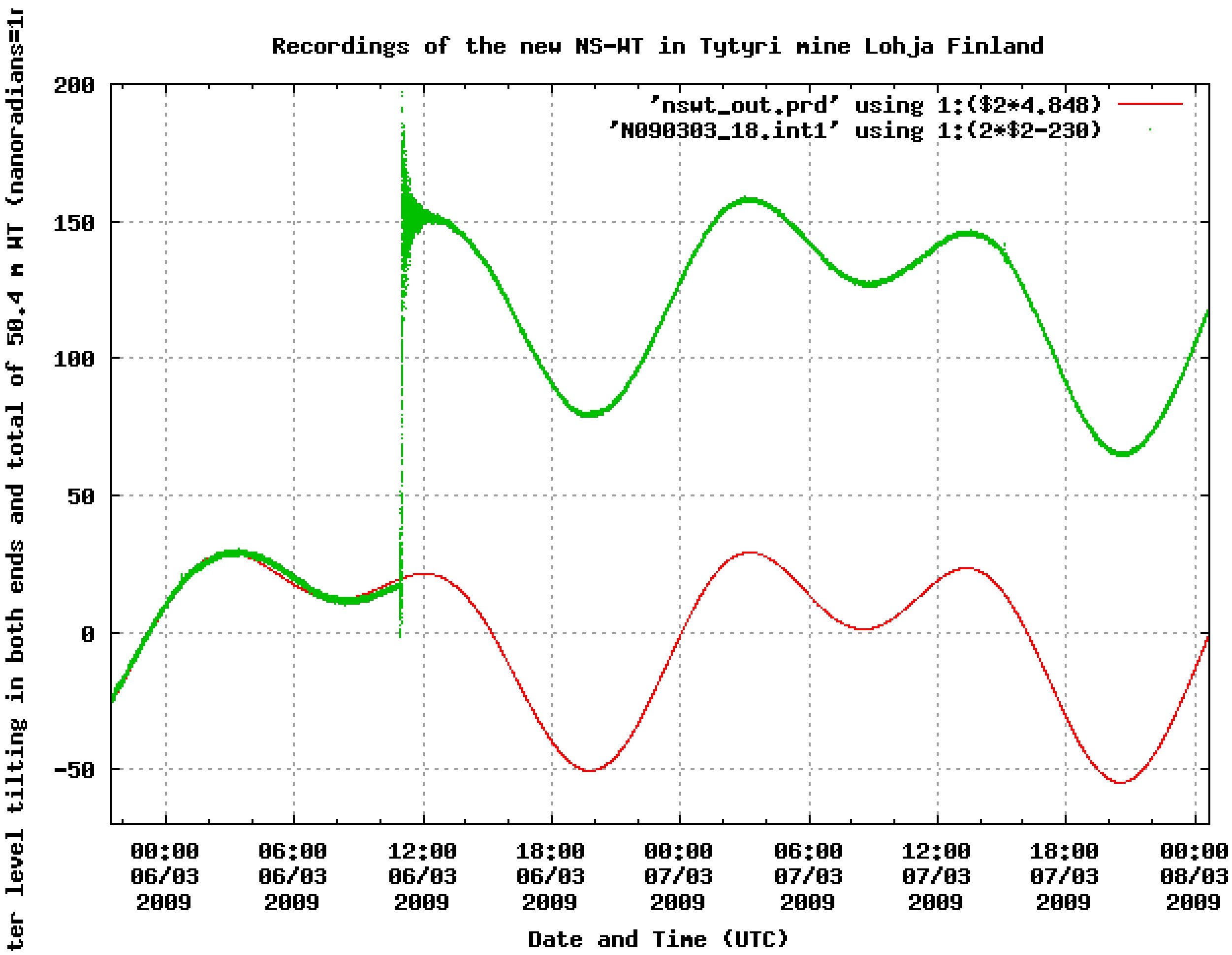


Metsahovi:T020:Gres TA310 (nm/s^2)



Lohja:NSWT:Crustal tilt (BPIsq 0.100,0.5010x nanorad (10x nanorad)





Recordings of the new NS-WT in Tytyri mine Lohja Finland
'nswt_out.prd' using 1:($2*4.848)
'N090303_18.int1' using 1:(2*$2-230)
ter level tilting in both ends and total of 50.4 m WT (nanoradians=1r
200
150
100
50
0
-50
00:00 06/03 2009
06:00 06/03 2009
12:00 06/03 2009
18:00 06/03 2009
00:00 07/03 2009
06:00 07/03 2009
12:00 07/03 2009
18:00 07/03 2009
00:00 08/03 2009
Date and Time (UTC)

Comparison of old and new NSWT earth tide analyse result (main waves)
Wenzel Eterna 3.3 version
Adjusted tidal parameters of NSWT, Hartmann-Wenzel potential developent 1995 used :

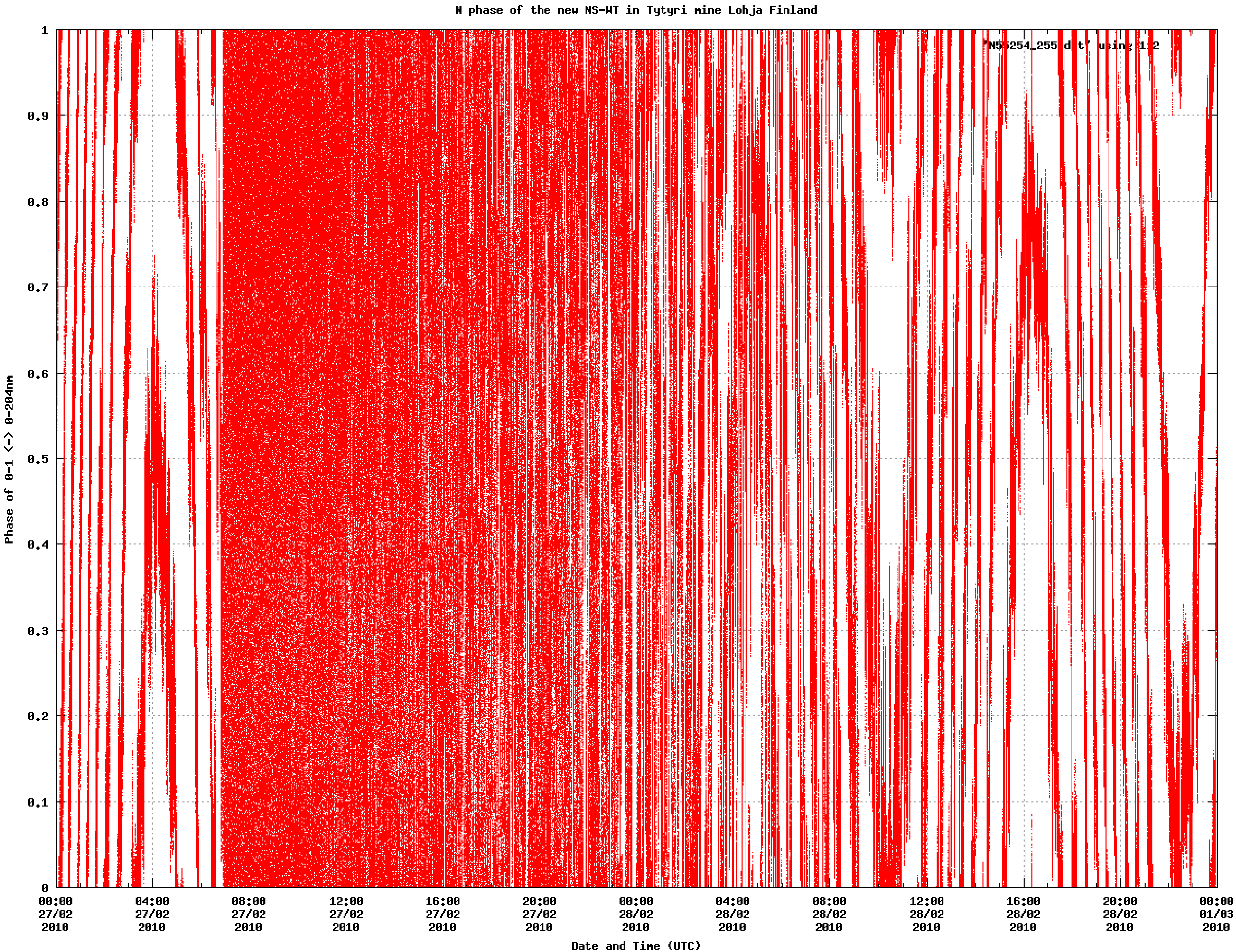
from [cpd]	to [cpd]	wave	ampl. [mas]	ampl.fac.	stdv.	ph. lead [deg]	stdv. [deg]

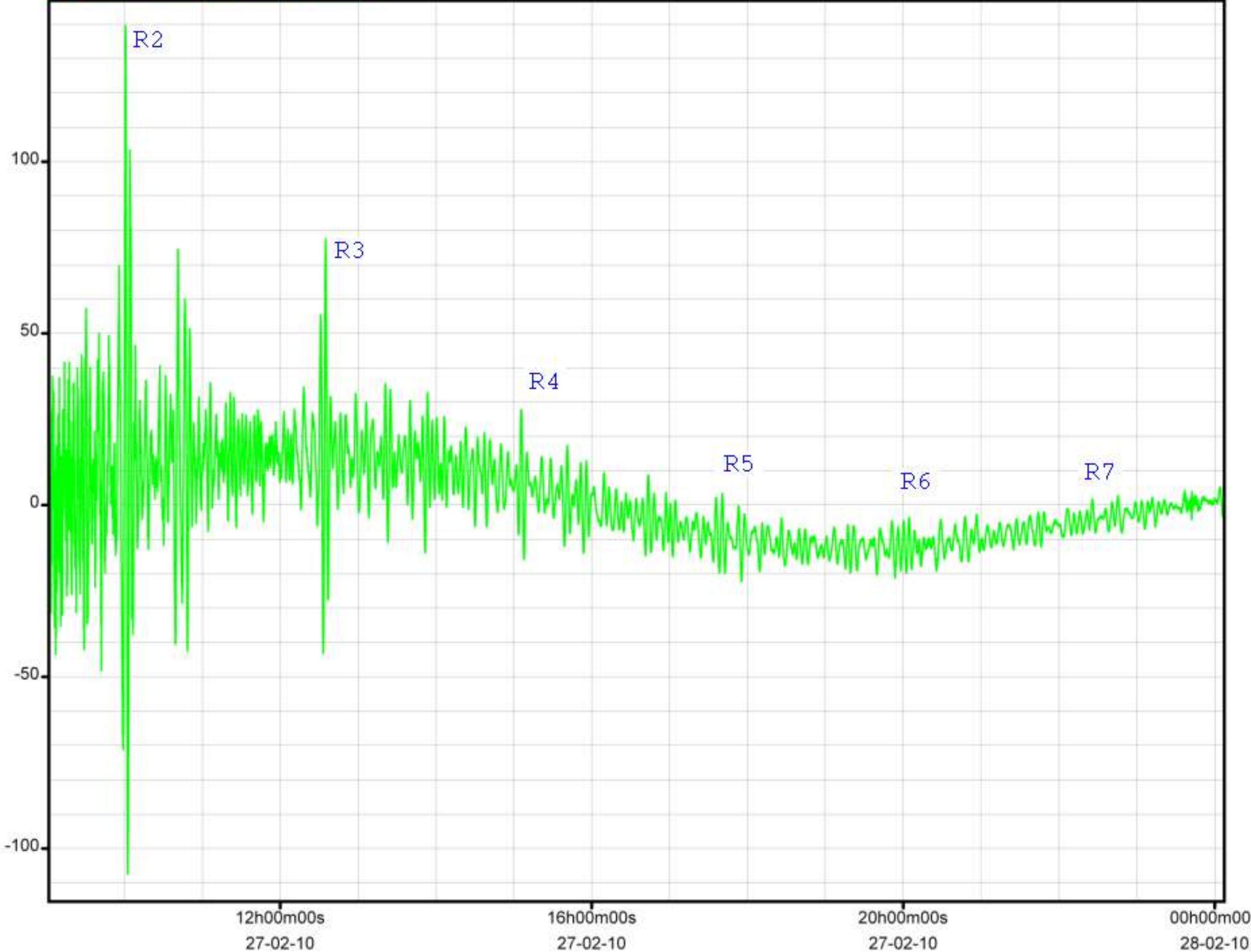
OLD NSWT (1054 days)

from [cpd]	to [cpd]	wave	ampl. [mas]	ampl.fac.	stdv.	ph. lead [deg]	stdv. [deg]
0.921941	0.940487	O1	2.4248	0.73570	0.02763	-1.4338	2.1525
0.989049	0.998028	P1	1.2143	0.79193	0.06957	-8.2180	5.0347
1.001825	1.003651	K1	3.5895	0.77469	0.02159	-5.5863	1.5964
1.923766	1.942754	M2	3.8793	0.57006	0.01521	-1.9471	1.5293
1.991787	2.002885	S2	1.9563	0.61795	0.03249	3.2626	3.0117

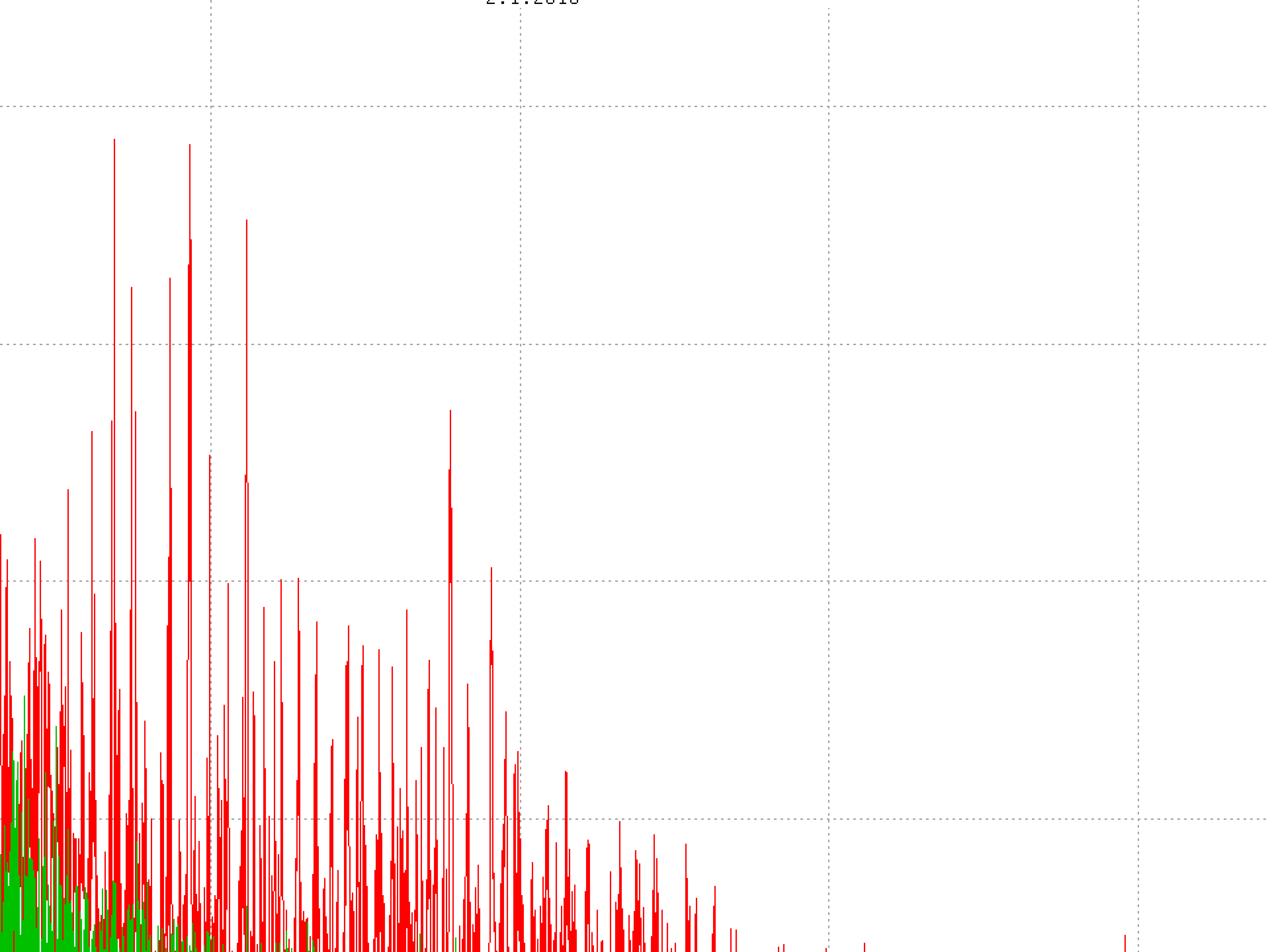
NEW NSWT (97 days)

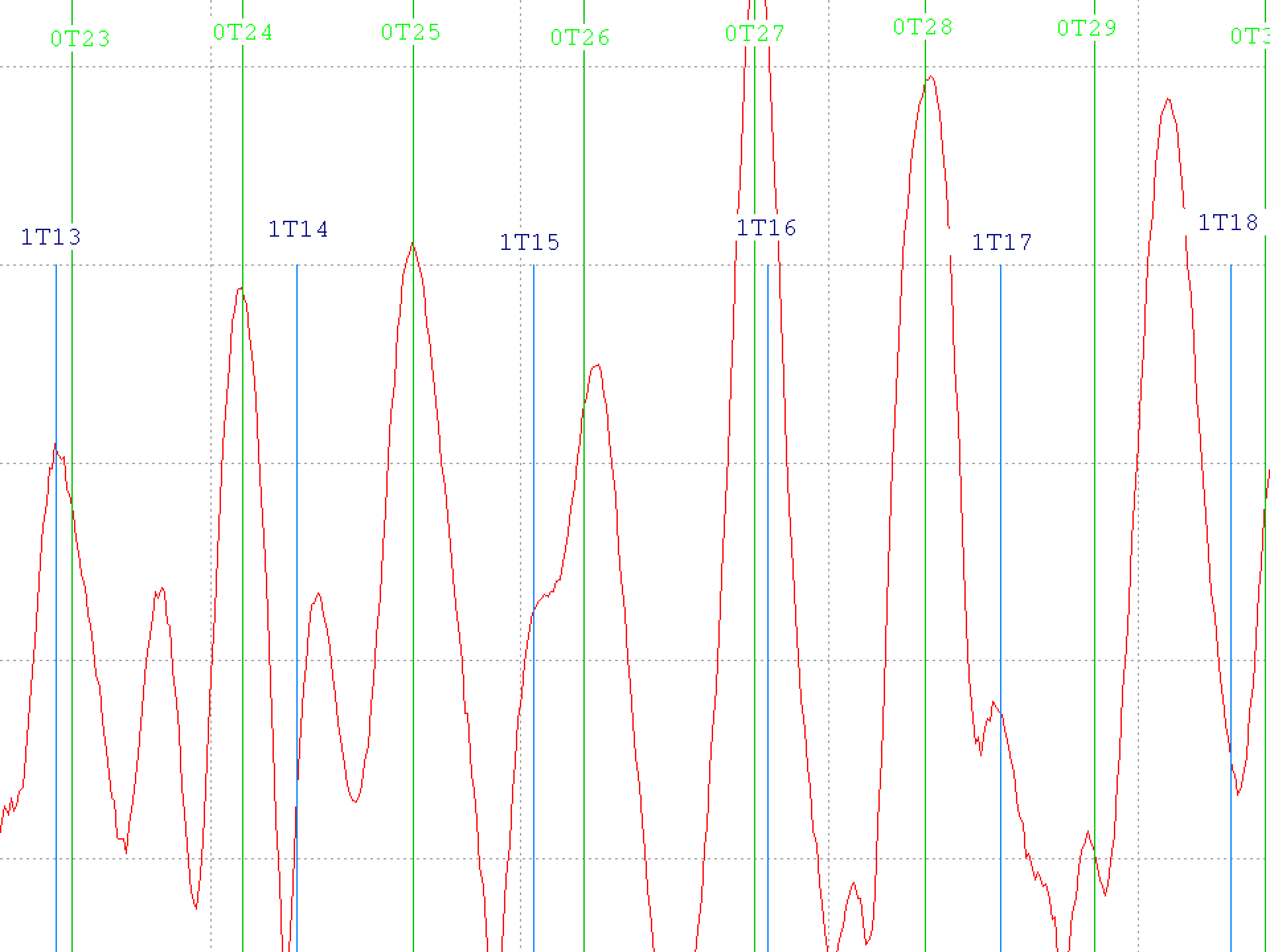
from [cpd]	to [cpd]	wave	ampl. [mas]	ampl.fac.	stdv.	ph. lead [deg]	stdv. [deg]
0.921941	0.932583	O1	2.4760	0.75147	0.07876	-1.0836	6.0283
0.995143	0.998028	P1	1.2673	0.82665	0.19441	-1.1736	13.4770
1.001825	1.003651	K1	3.7231	0.80346	0.05991	-5.1887	4.2762
1.923766	1.942753	M2	3.9471	0.58027	0.04309	-3.7515	4.2552
1.999706	2.000766	S2	1.8655	0.58944	0.09111	4.4365	8.8273


N phase of the new NS-WT in Tytyri mine Lohja Finland
Phase of 0-1 <-> 0-204nm
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
00:00 27/02 2010
04:00 27/02 2010
08:00 27/02 2010
12:00 27/02 2010
16:00 27/02 2010
20:00 27/02 2010
00:00 28/02 2010
04:00 28/02 2010
08:00 28/02 2010
12:00 28/02 2010
16:00 28/02 2010
20:00 28/02 2010
00:00 01/03 2010
Date and Time (UTC)

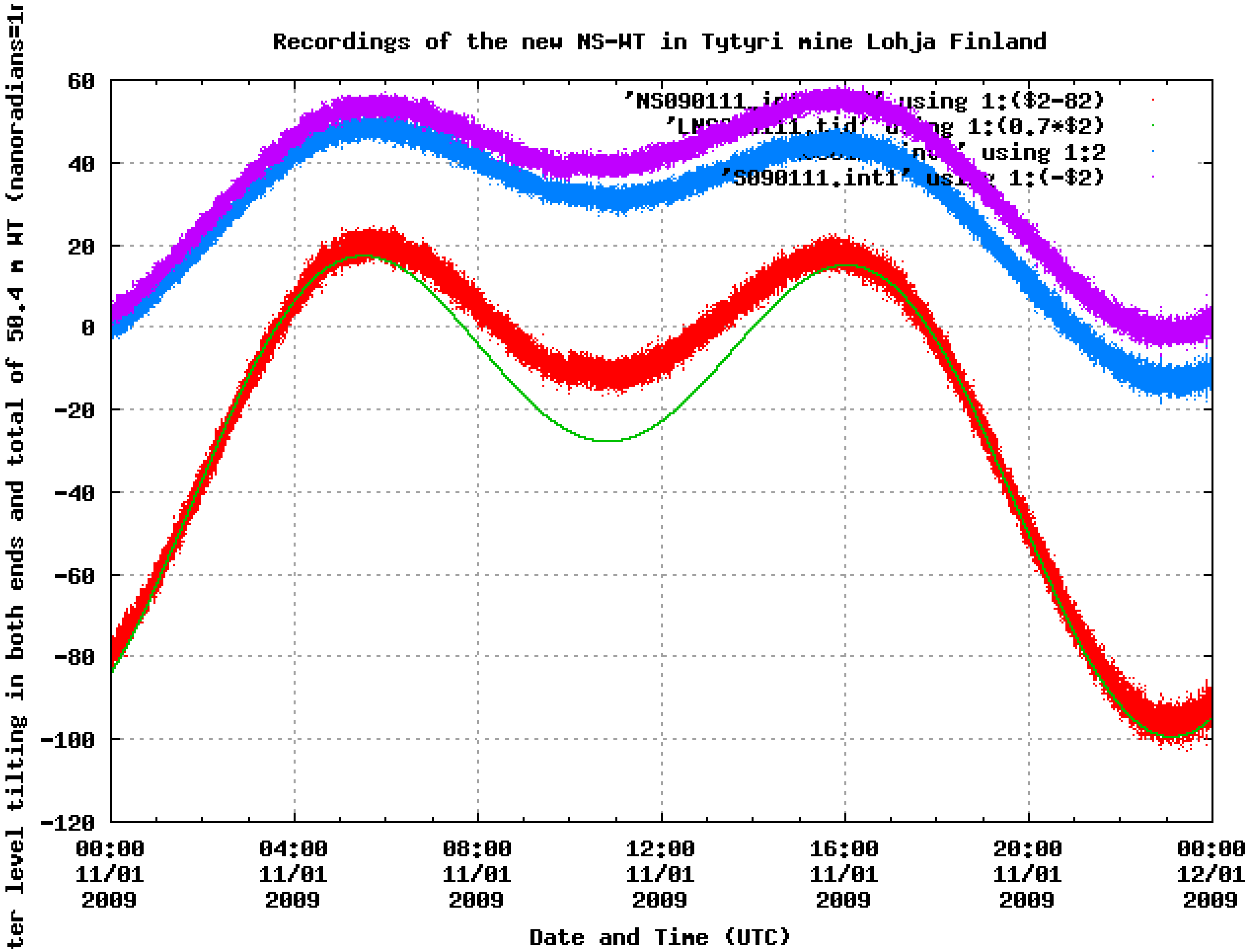


R2
R3
R4
R5
R6
R7
100
50
0
-50
-100
12h00m00s
27-02-10
16h00m00s
27-02-10
20h00m00s
27-02-10
00h00m00
28-02-10



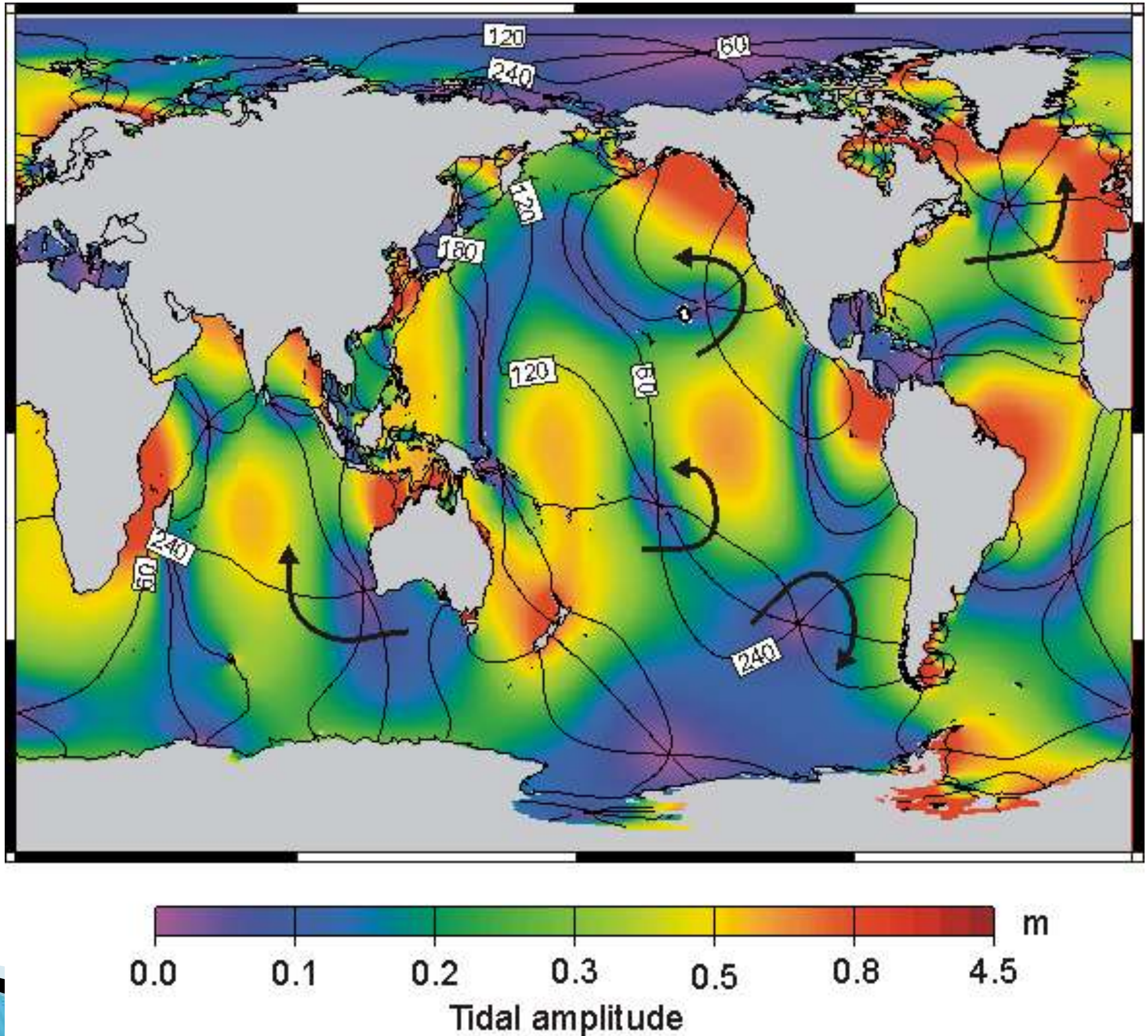


0T23
0T24
0T25
0T26
0T27
0T28
0T29
1T13
1T14
1T15
1T16
1T17
1T18

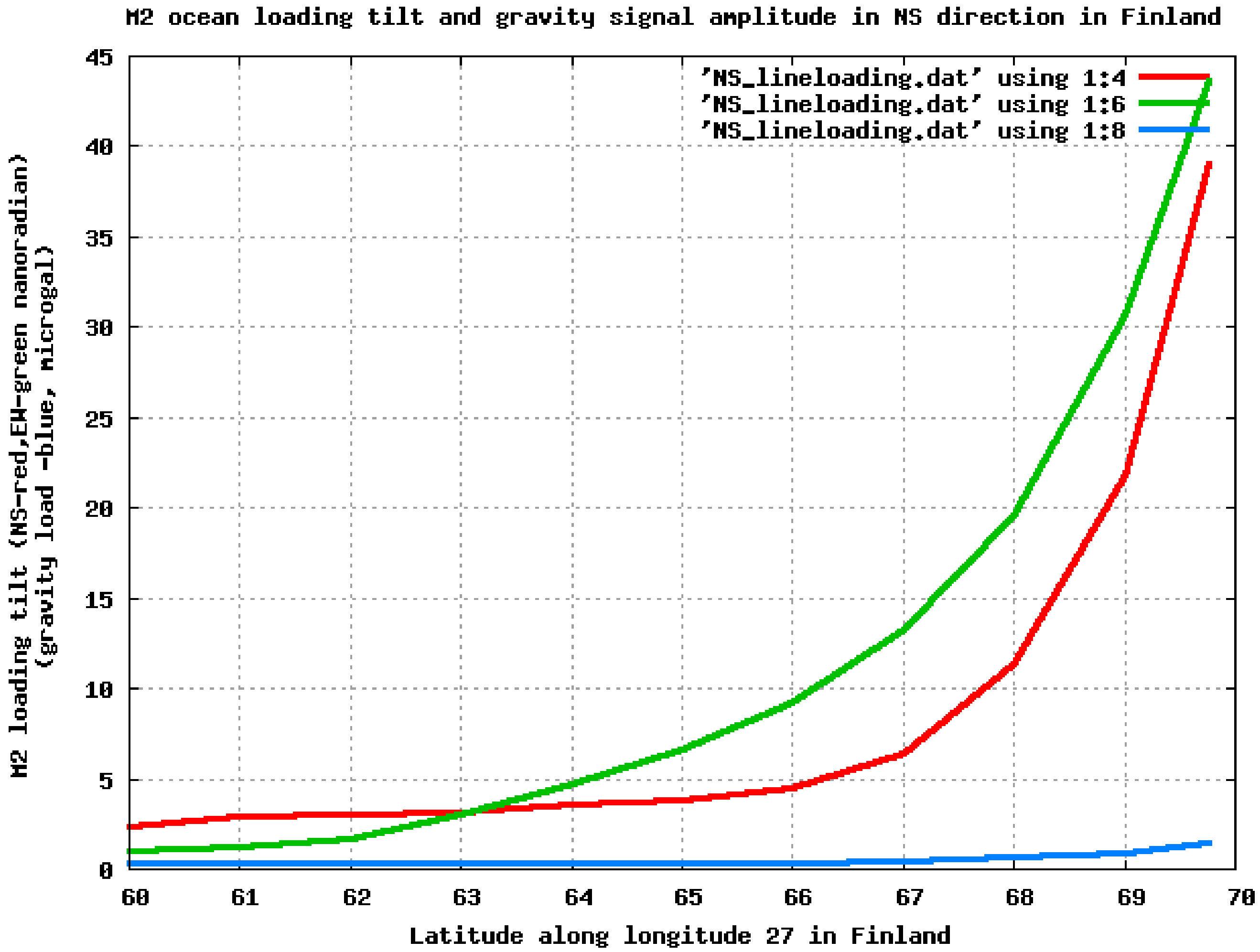


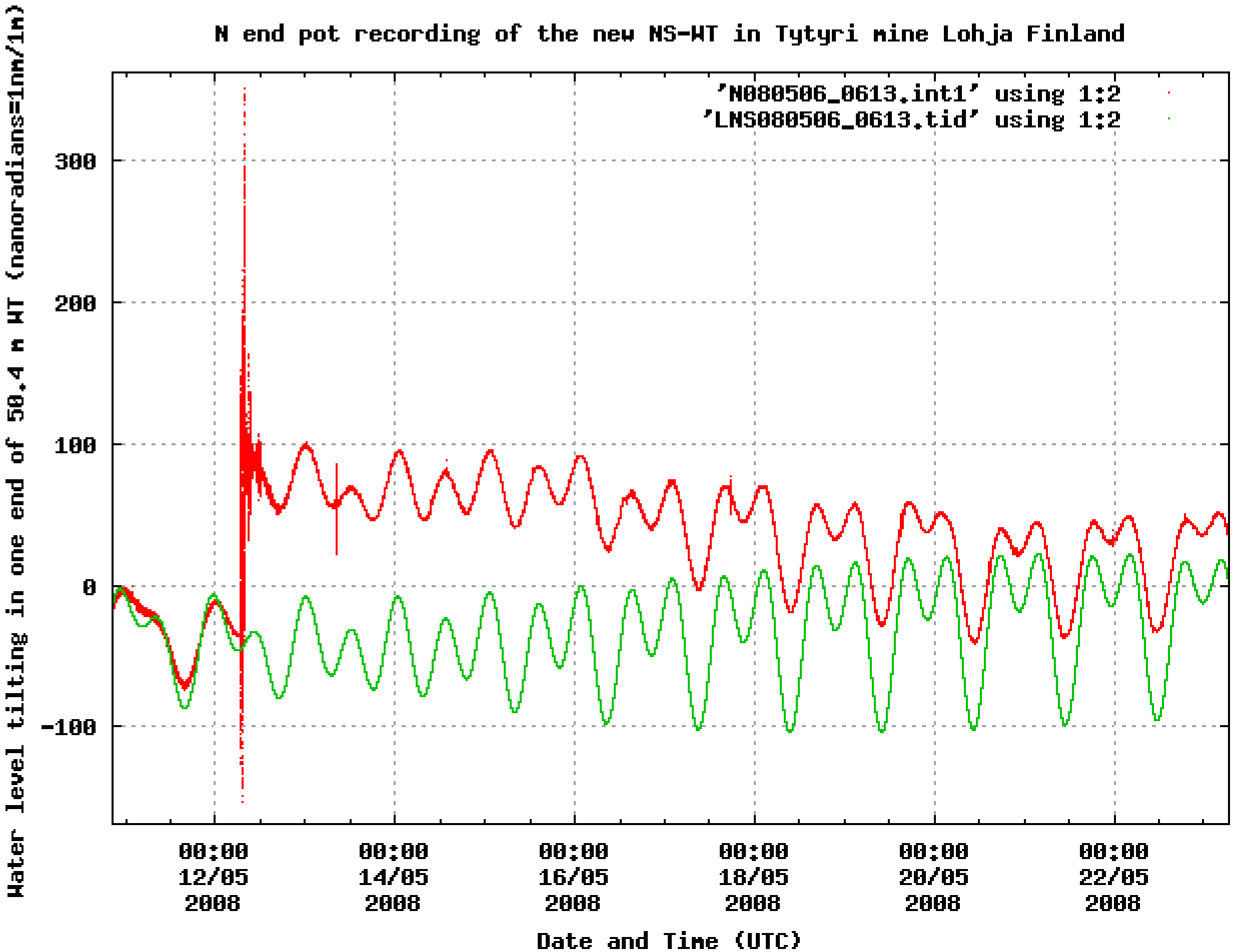
Recordings of the new NS-WT in Tytyri mine Lohja Finland
using 1:($2-82)
using 1:(0.7*$2)
using 1:2
'S090111.int1'
1:(-$2)
60
40
20
0
-20
-40
-60
-80
-100
-120
00:00 11/01 2009
04:00 11/01 2009
08:00 11/01 2009
12:00 11/01 2009
16:00 11/01 2009
20:00 11/01 2009
00:00 12/01 2009
Date and Time (UTC)
ter level tilting in both ends and total of 50.4 m WT (nanoradians=1r

M2 ocean tide map by H.G. Scherneck, OSO,Sweden



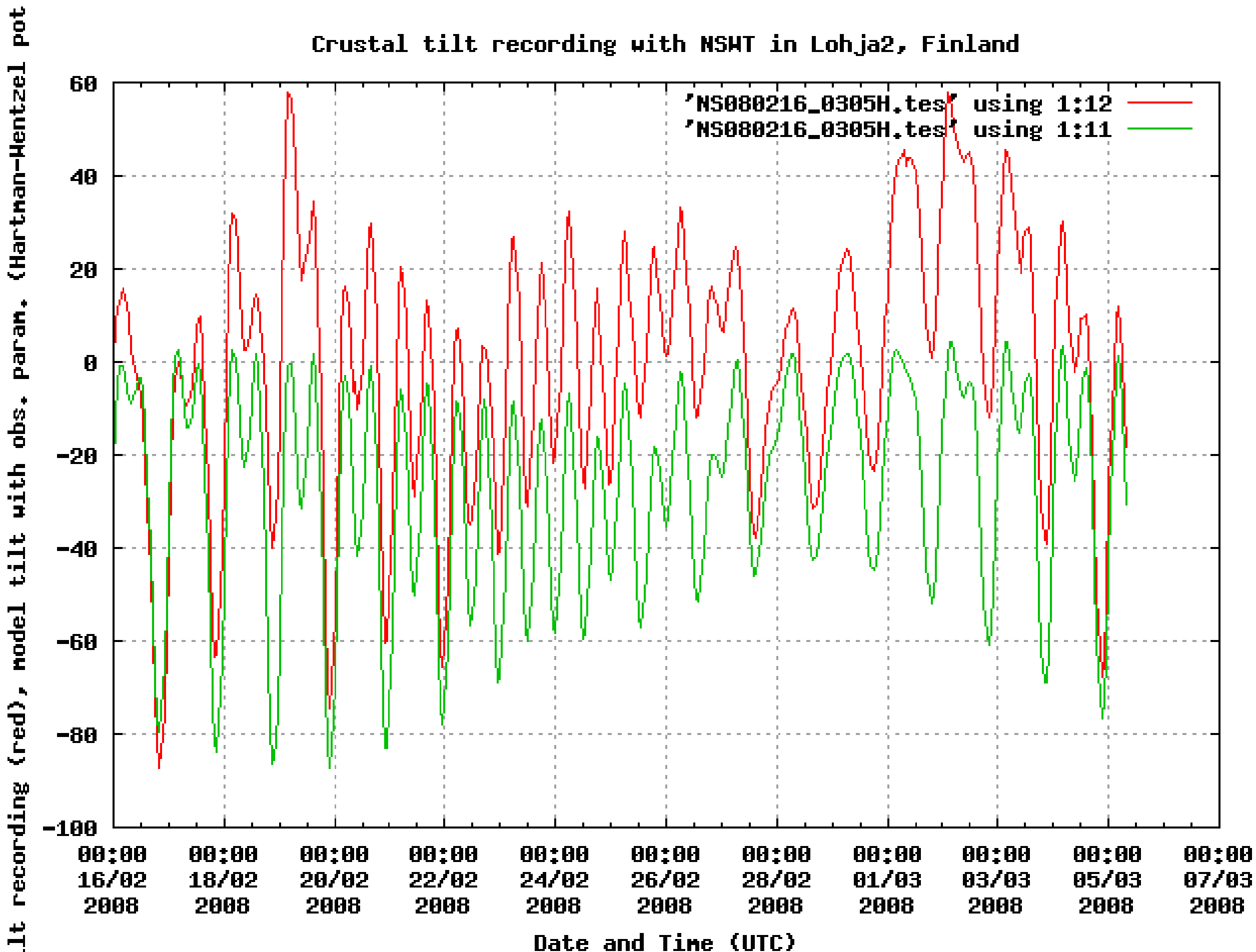
M2 loadings along latitude 27 by D.C Agnew, (1997) NLOADF program and CSR4.0 model.





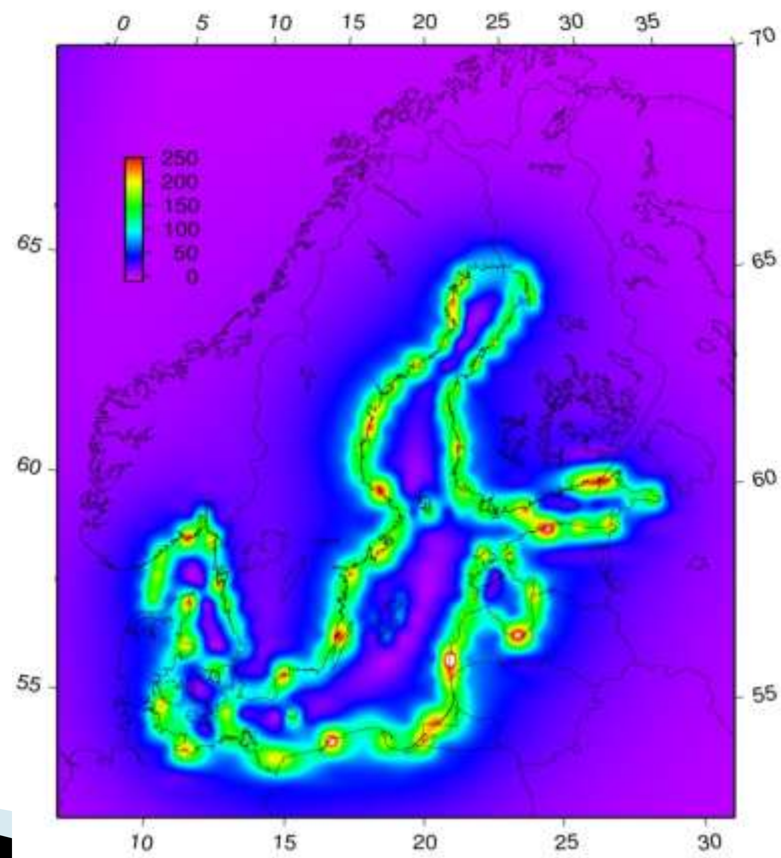
Courtesy: Hannu Ruotsalainen, FGI

NS-WT RECORDING IN LOHJA, 16.2. – 05.03. 2008
Green theoretical model tilt – red observed tilt



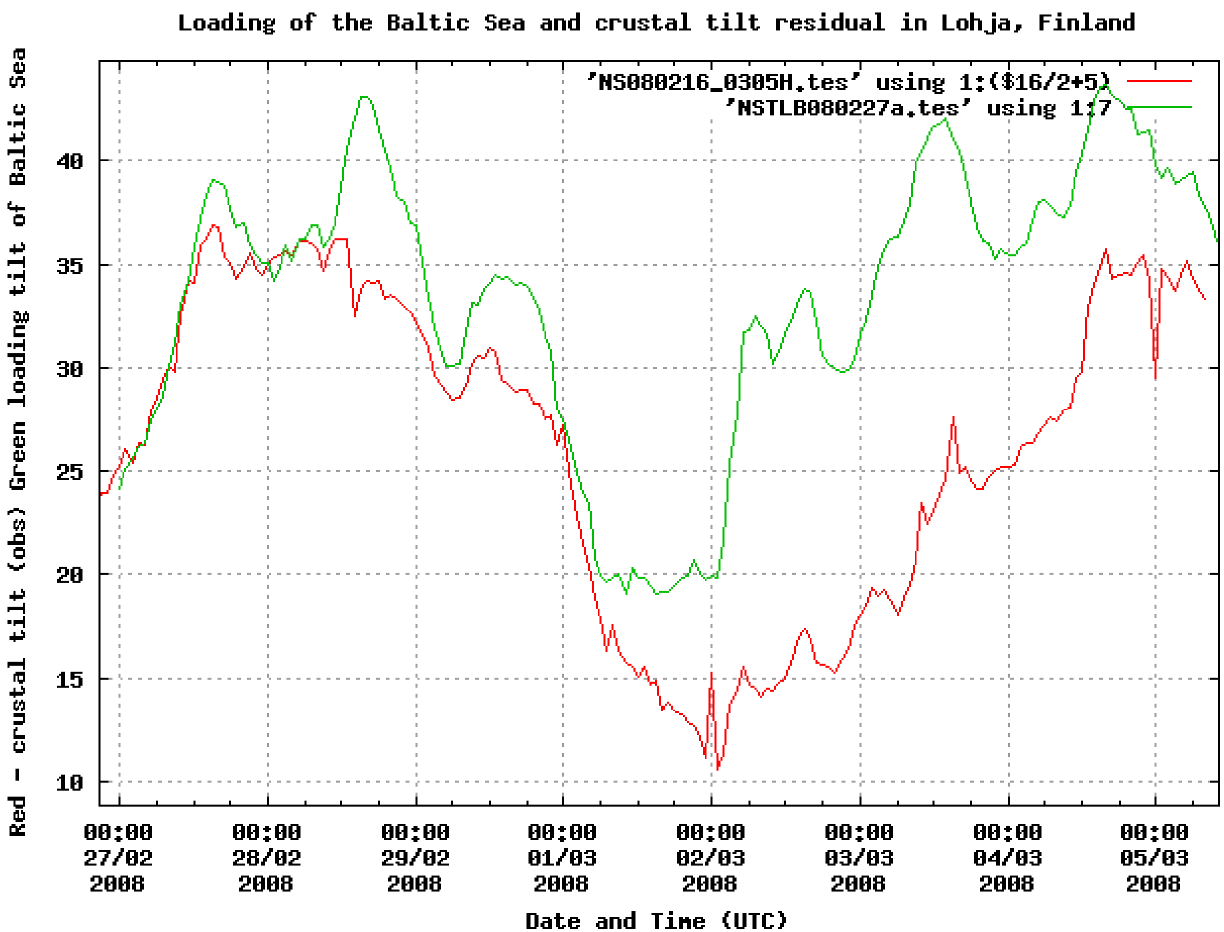
Courtesy: Hannu Ruotsalainen, FGI

Crustal loading tilt model of the Baltic Sea with 1 m standard level load
D.C.Agnew's program NLOADF compiled by Maaria Nordman



Courtesy of map: M. Nordman, FGi

RED - NON-TIDAL RESIDUAL TILT of the NSWT
GREEN- CRUSTAL LOADING MODEL OF BALTIC SEA,
NLOADF, (Agnew 1997) and Baltic Sea level data from the Finnish Institute of Marine Research, and BOOS database



Courtesy: H. Ruotsalainen and M. Nordman FGI

Conclusions

- Modern Michelson-Gale type interferometric water level tilt meter (WT) with absolute scale can be modified to different lenghts from 1m to several hundreds of meters in different atsimutes.

- WT can record broad spectrum of geodynamical signals from microseism and free oscillations and earth tide tilt. Toroidal modes of the free oscillations have been observed, which are not possible detect with gravimeters

- M2 ocean tidal loading tilt signal observed – origin possibly from the Arctic Sea

- Loading tilt signal of Baltic Sea also observed

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