THE BALTIC SEA TIDAL AND OCEAN TIDAL LOADING MODELS COMPARED WITH EARTH TIDE TILT OBSERVATIONS - CASE LOHJA, FINLAND

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OUTLINE

Michelson-Gale NS and EW tiltmeter observations Yerkes, USA 1914-1917 and modern predictions for their obs using earth model tilt and Schwiderski OTL model.

Recent NSiWT tilt meter observations Lohja, Tytyri mine, southern Finland 2008 - 2014

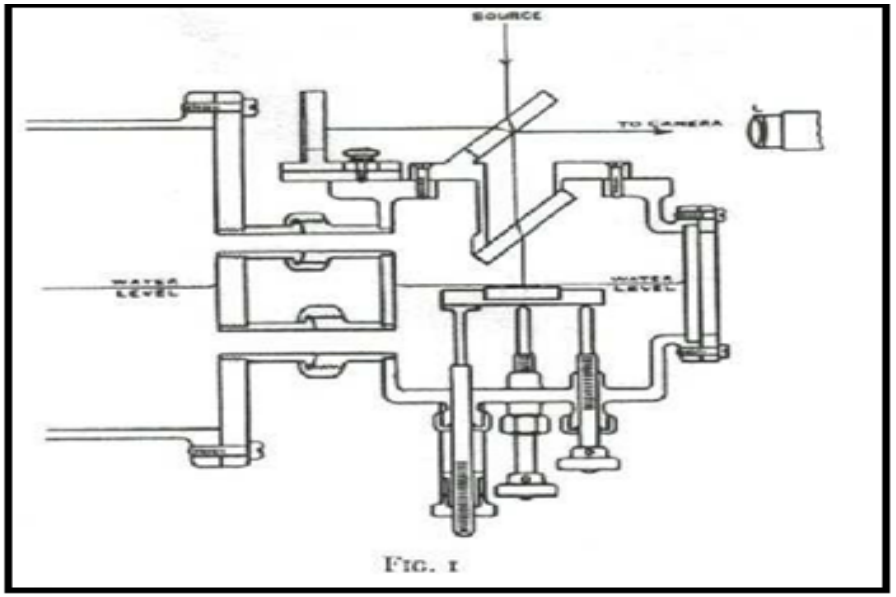
NSiWT earth tide harmonic analysis results combined with OTL models and compared to earth tide model tilt

NSiWT tilt analyse results combined to Schwiderski, FES2004 , CSR4.0, TPXO7.0 and the Baltic Sea harmonic tidal loading model and comparisons to earth tide model tilt.

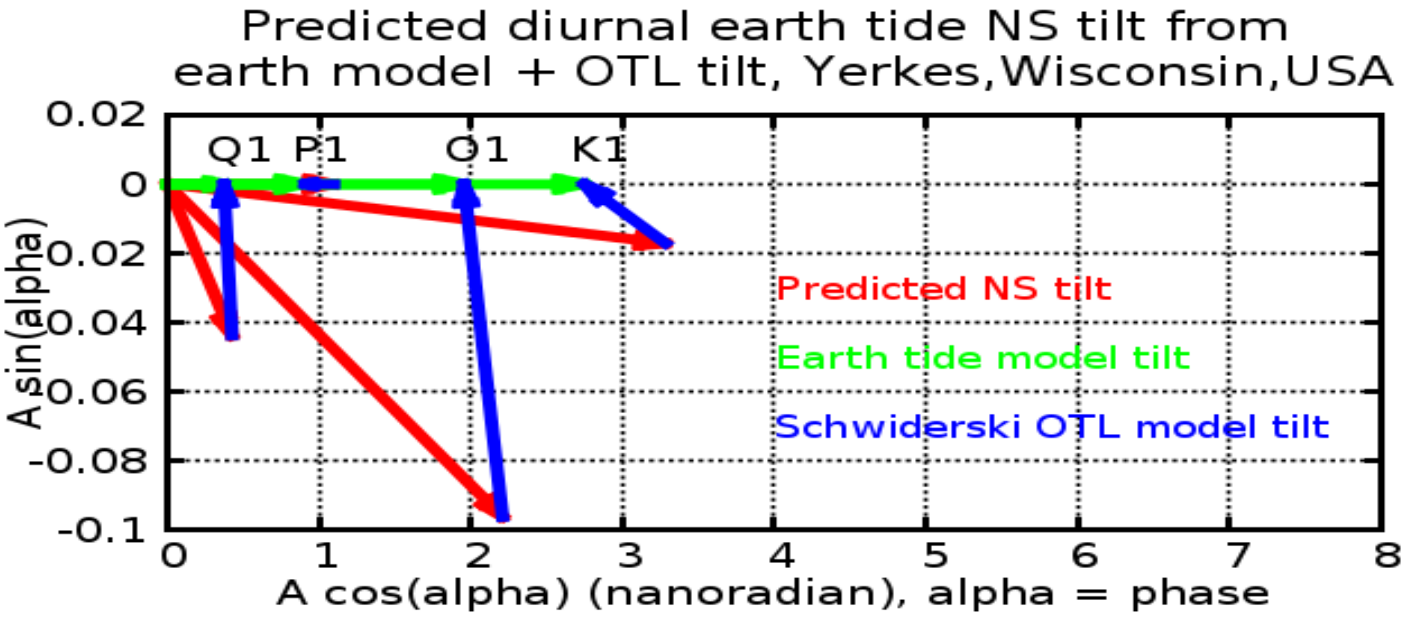
Conclusions

Michelson-Gale tiltmeters (NS-WT & EW-WT, 150 m long half filled tubes with Michelson interferometers) 1914-1917 operating at the Yerkes observatory, Wisconsin,USA

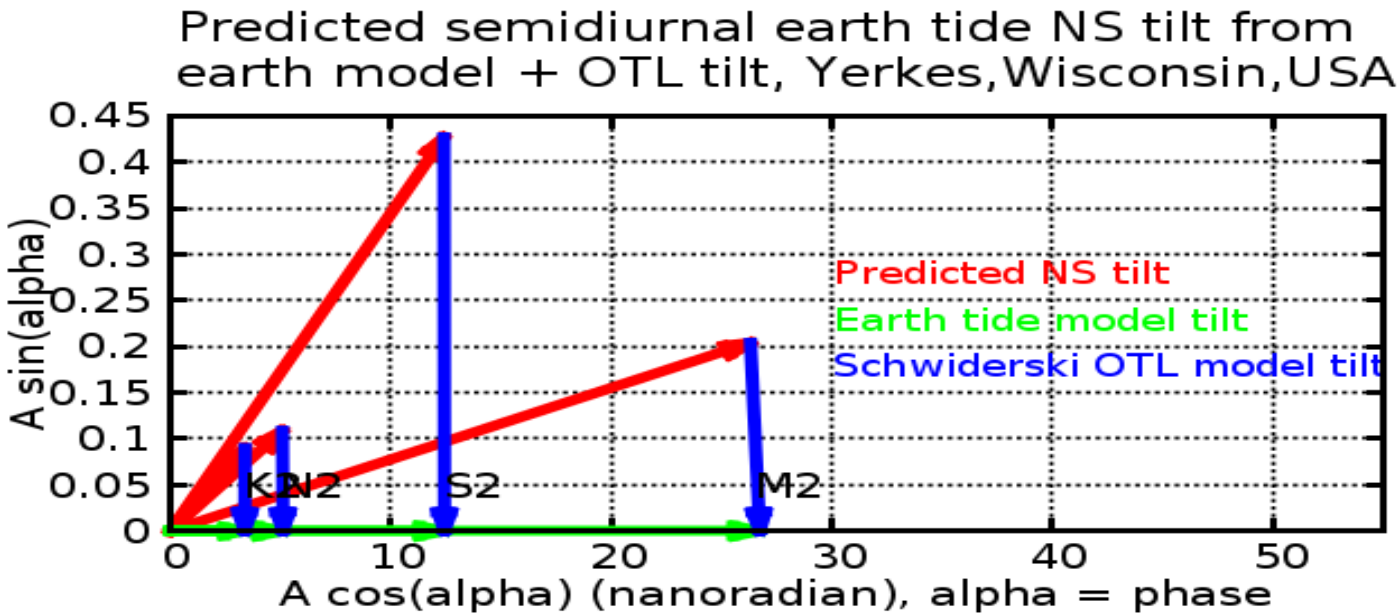
http://fi.wikipedia.org/wiki/Albert_Abraham_Michelson



Source: Michelson A., A., and H. Gale, (1919), The rigidity of the Earth, Astrophys. J., 50, pp. 330−345.



Ruotsalainen, H. Pure Appl. Geophys. (2017).
https://doi.org/10.1007/s00024-017-1562-6



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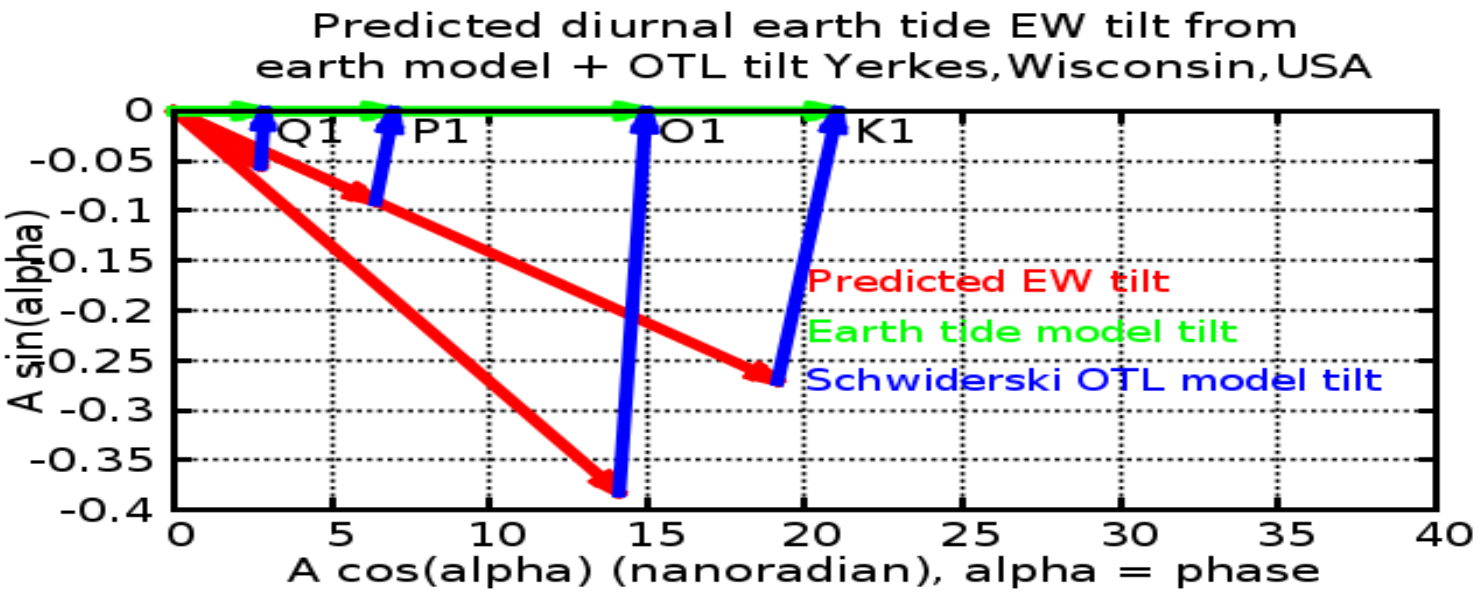

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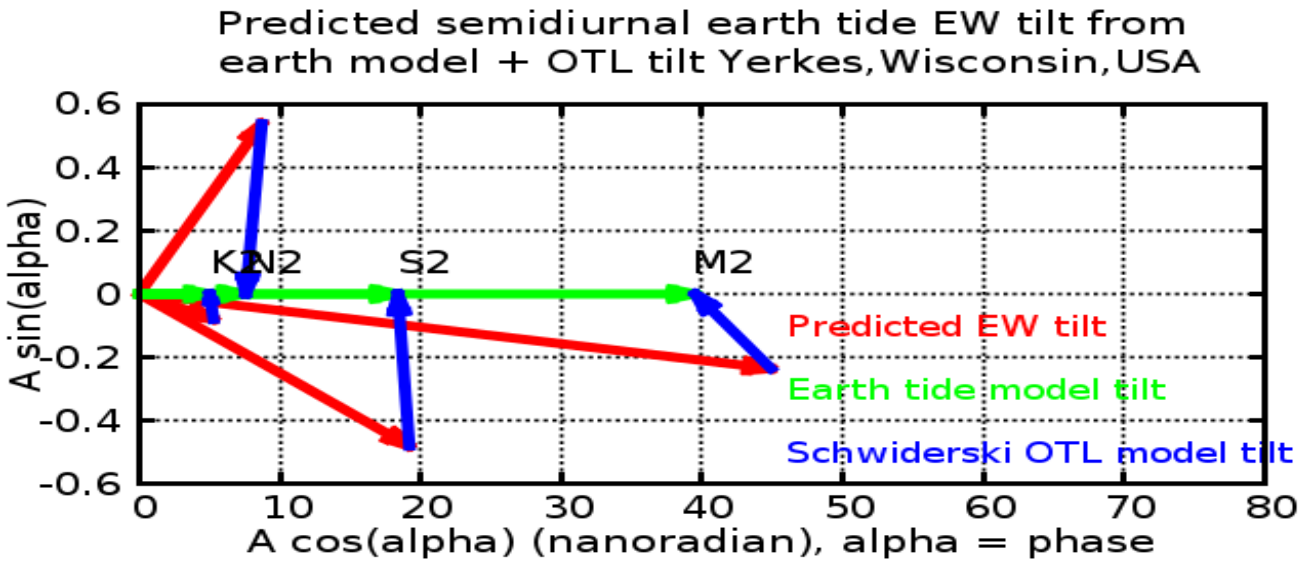
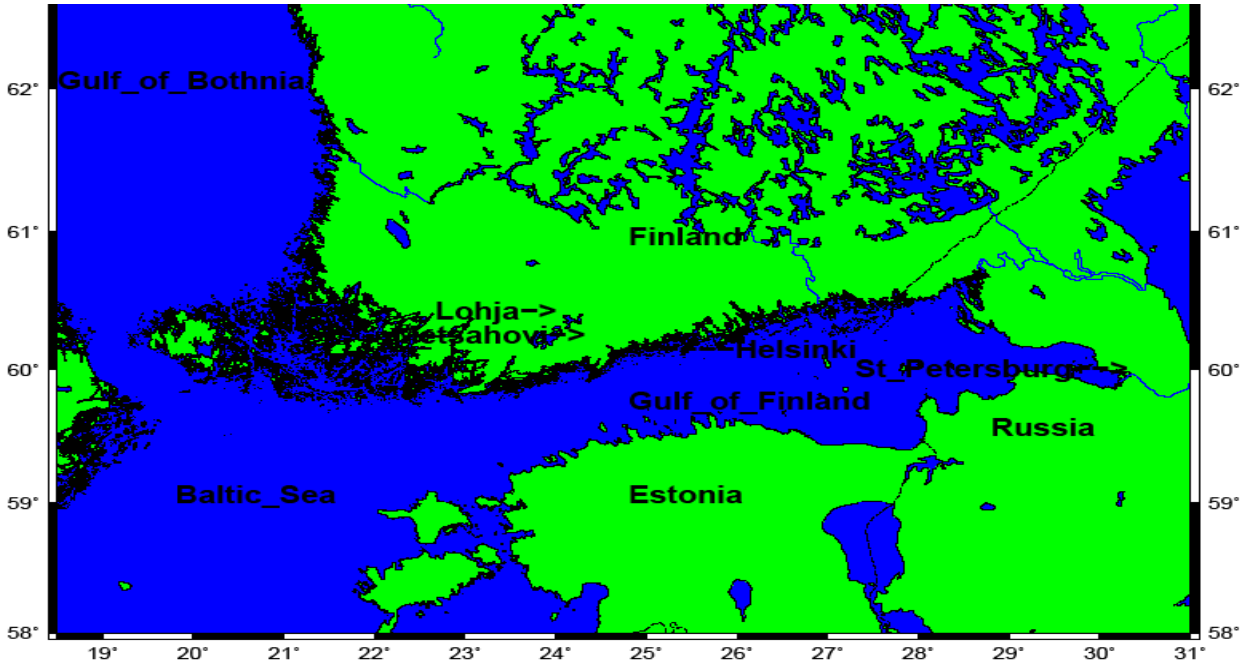
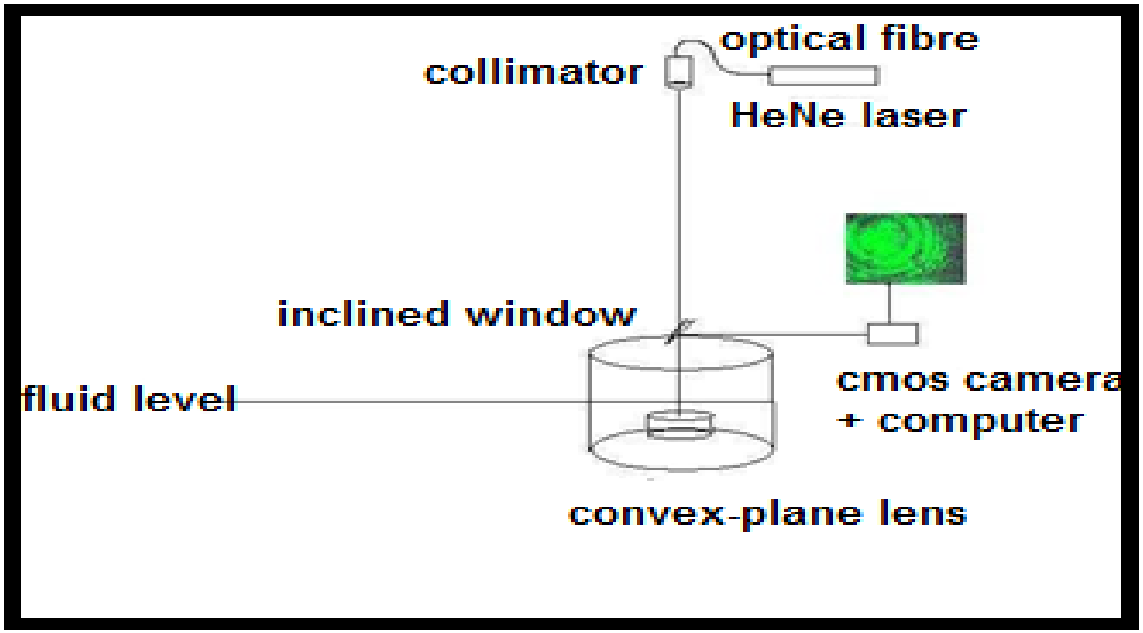


Ruotsalainen, H. Pure Appl. Geophys. (2017).
https://doi.org/10.1007/s00024-017-1562-6

LOCATION OF LOHJA2 GEODYNAMIC TILT STATION





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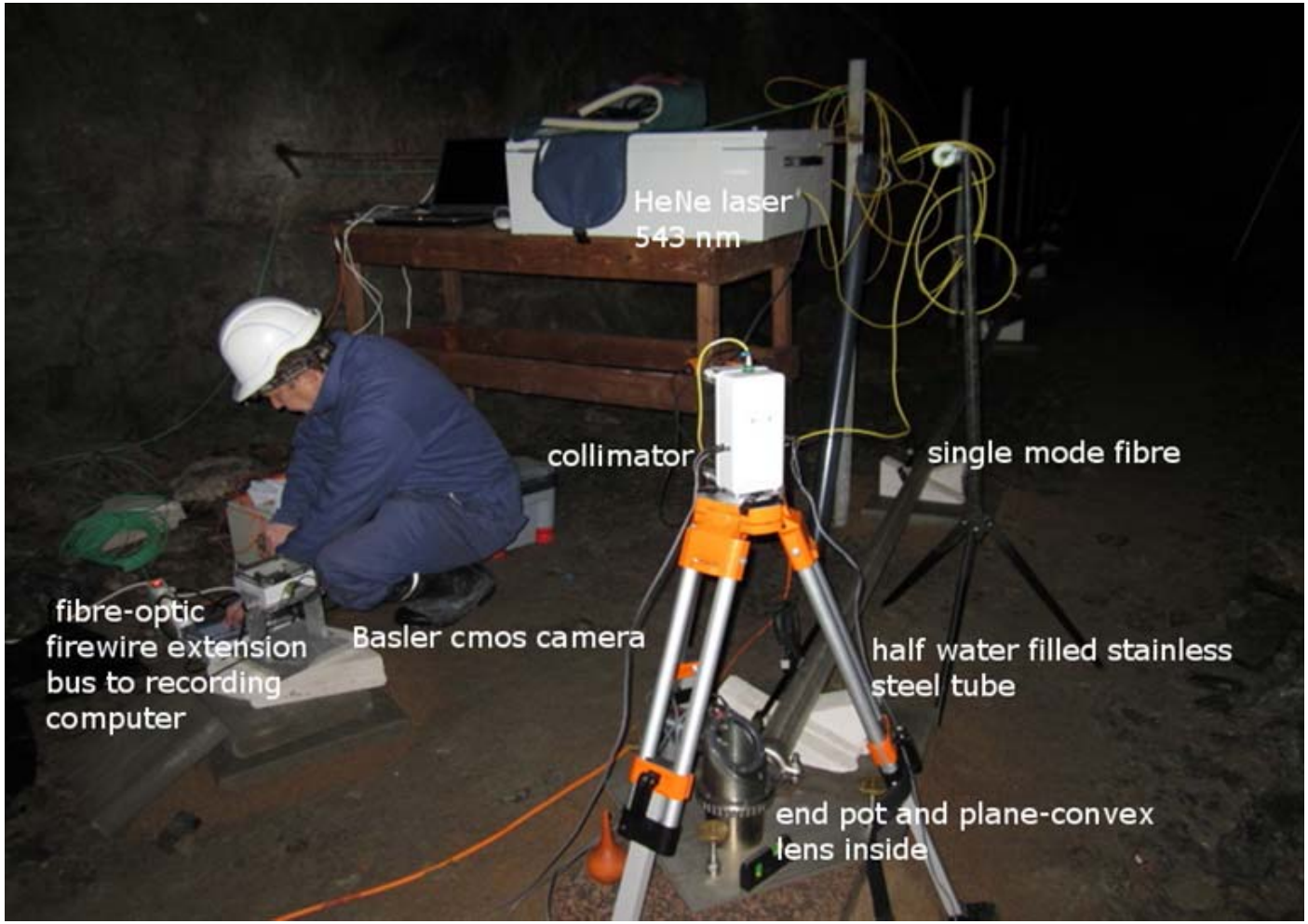
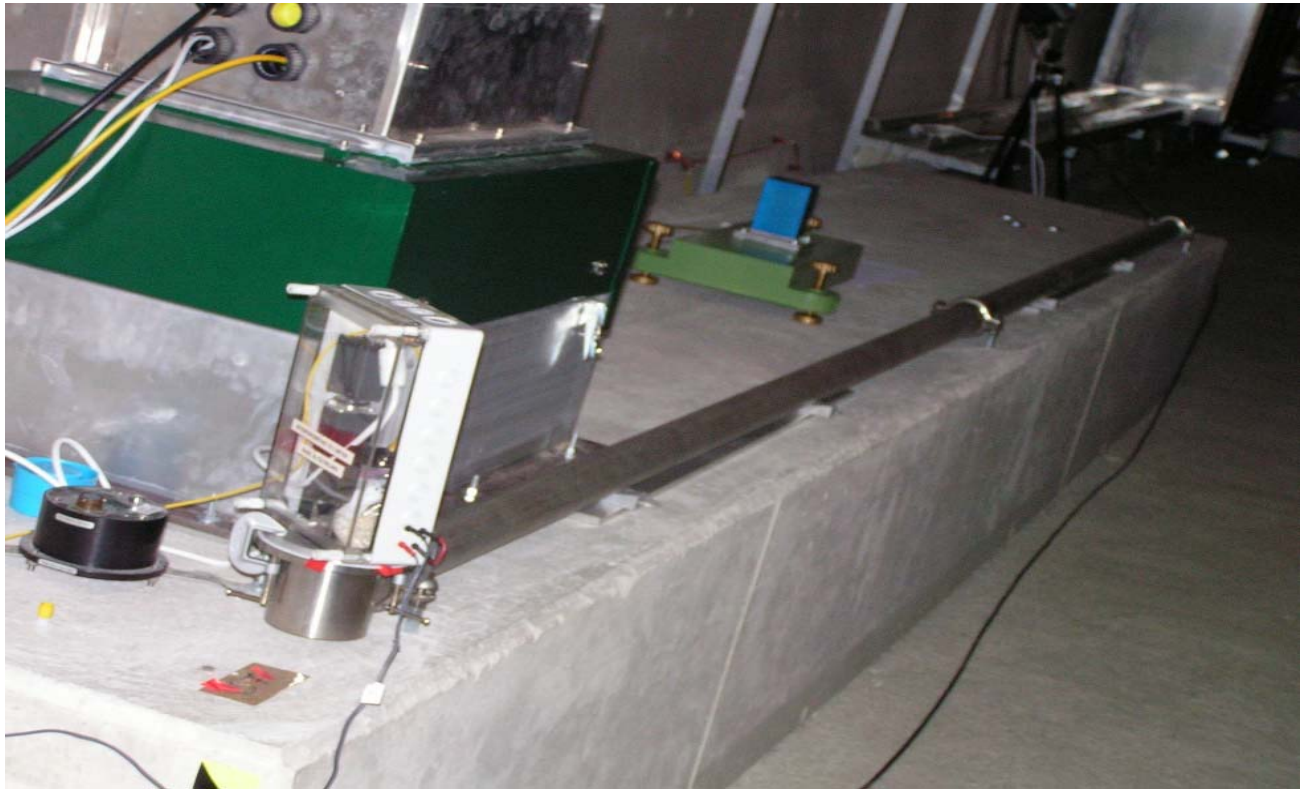
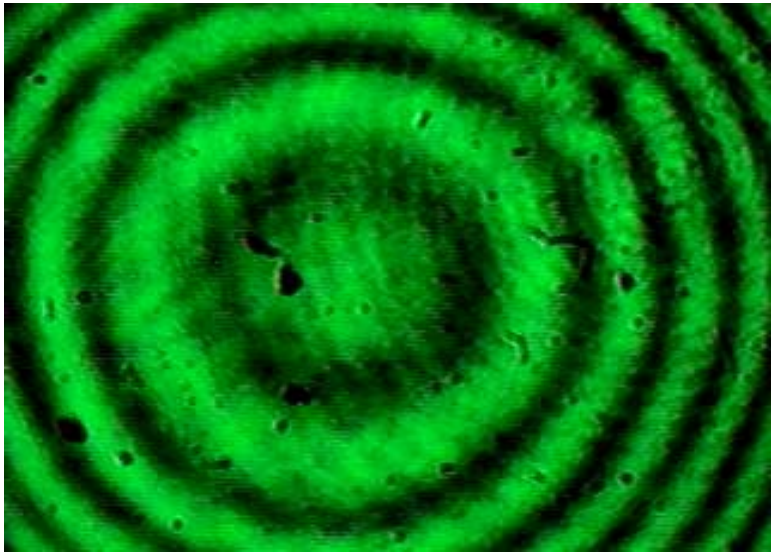
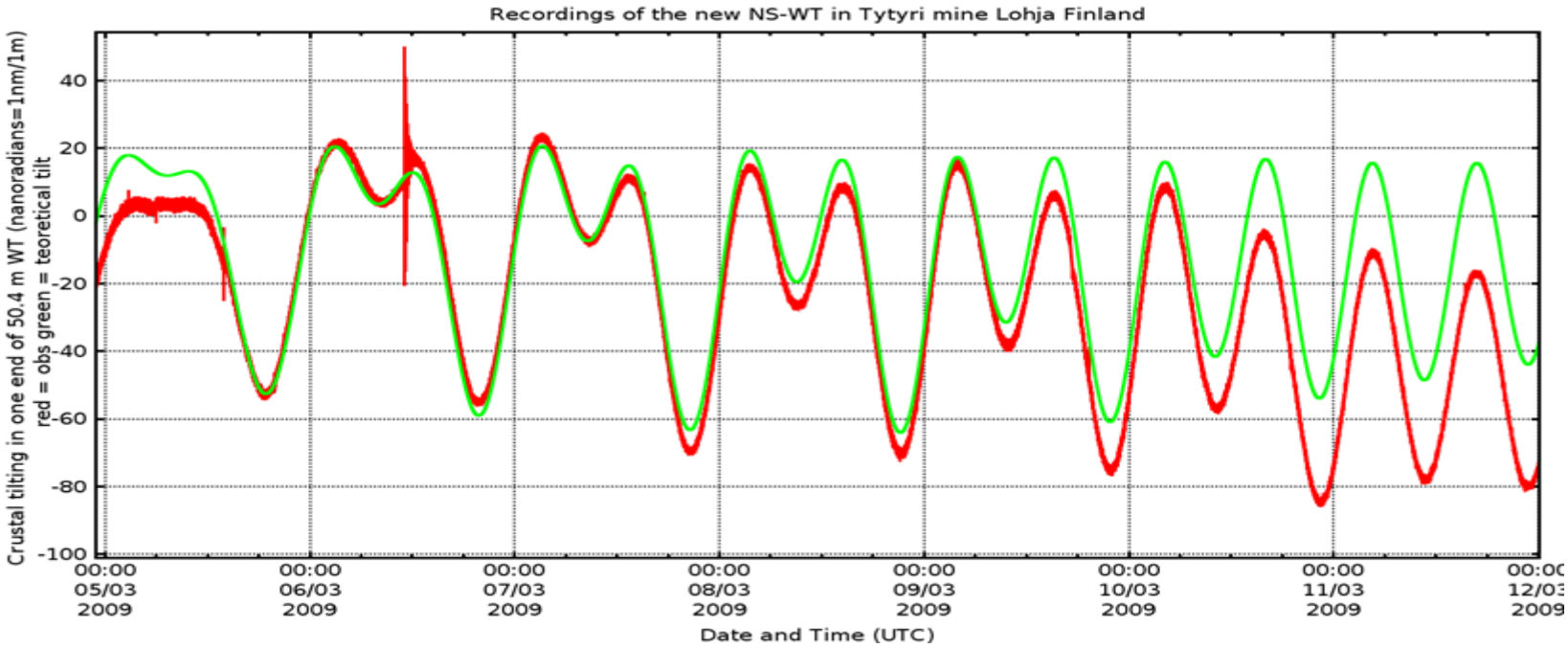

HeNe laser
543 nm
collimator
single mode fibre
fibre-optic
firewire extension
bus to recording
computer
Basler cmos camera
half water filled stainless
steel tube
end pot and plane-convex
lens inside



W_iWT tilt meter one end prototype recording parallel with the Lippman type 2D tilt meter at Conrad observatory, Austria, in Hungary - Austria co-operation



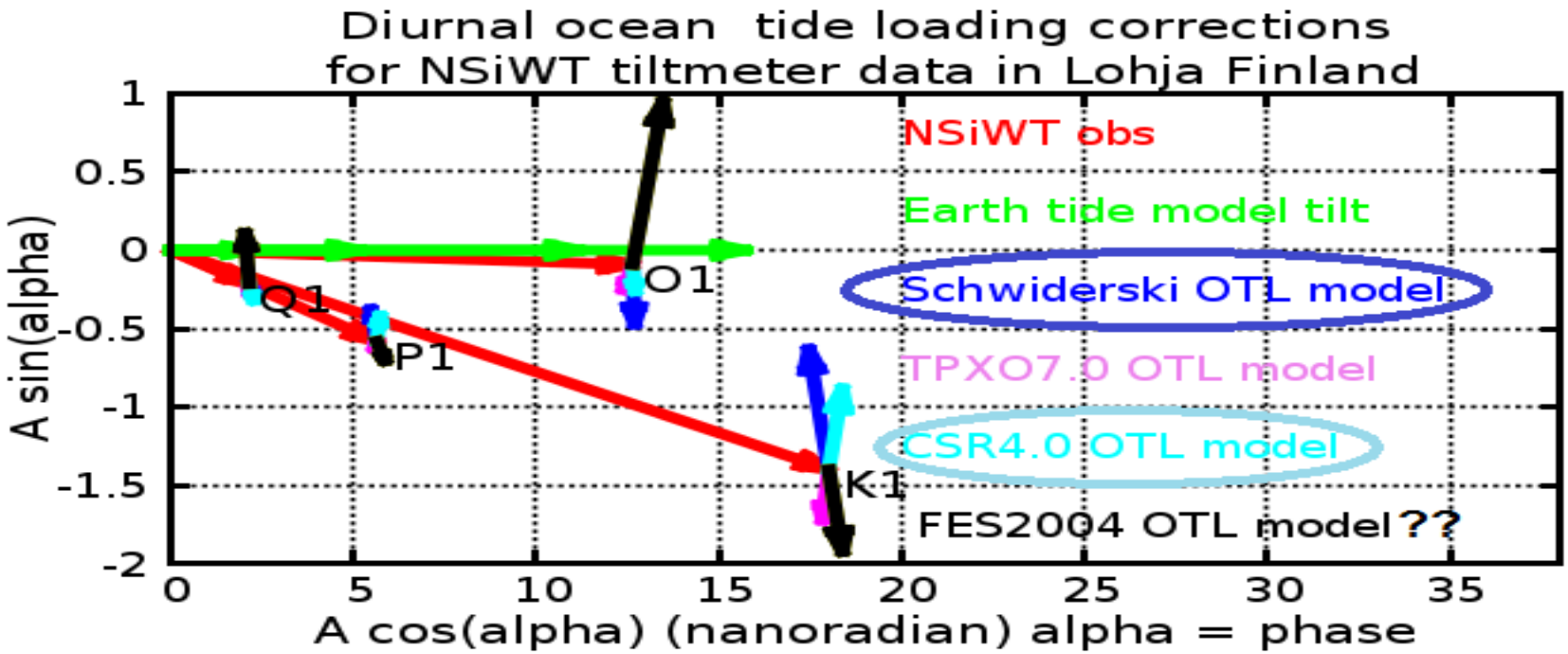
Level interferometer on-line video


Recordings of the new NS-WT in Tytyri mine Lohja Finland
Crustal tilting in one end of 50.4 m WT (nanoradians=1nm/1m)
red = obs green = teoretical tilt
40
20
0
-20
-40
-60
-80
-100
00:00 05/03 2009
00:00 06/03 2009
00:00 07/03 2009
00:00 08/03 2009
00:00 09/03 2009
00:00 10/03 2009
00:00 11/03 2009
00:00 12/03 2009
Date and Time (UTC)

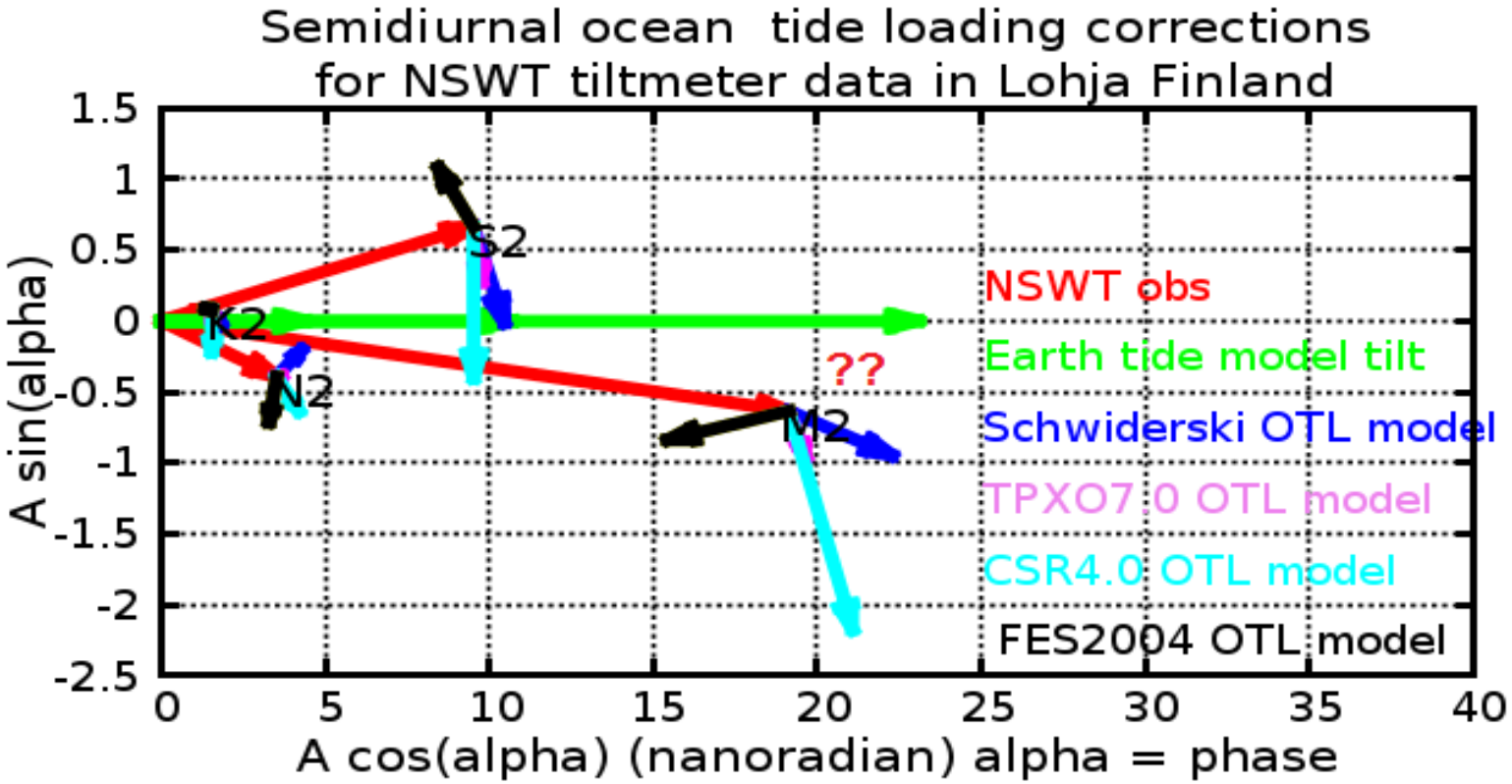
```
Program , version ET34ANASTE
Variant: NSWT0814
#############################################################
# EARTH TIDE STATION LOHJA NR.891 FINLAND                   #
# FINNISH GEODETIC INSTITUTE FINLAND                        #
# 60.253N 24.080E H97 M HORIZONTAL COMPONENT                #
# 50.4 m NS LONG WATERTUBE WITH INTERFEROMETRIC RECORDING   #
# INTERNAL CALIBRATION BASED ON OPTICAL INTERFEROMETRY      #
# 2008.02.19  2014.08.06 1056 DAYS                          #
# INSTALLATION RUOTSALAINEN                                 #
# MAINTENANCE RUOTSALAINEN                                  #
#                                                           #
#############################################################
```

```
0.887327 0.894010 Q1   0.6310 0.70429 0.037357 5.6995 3.0391
0.895216 0.906315 RO1  0.1198 1.05705 0.192300 9.0028 10.4233
0.921941 0.932583 O1   3.2958 0.79091 0.007144 0.4181 0.5175
0.932583 0.940487 TAU1 0.0430 1.08733 0.462210 38.2014 24.3558
0.958086 0.968565 M1   0.2591 0.85032 0.085721 10.4038 5.7759
0.968566 0.974188 CHI1 0.0496 1.32241 0.482262 33.3613 20.8948
0.989049 0.994755 PI1  0.0896 0.88008 0.257253 19.2153 16.7479
0.995143 0.998028 P1   1.5333 0.76327 0.015394 5.8756 1.1555
0.999853 1.000147 S1   0.0362 2.43249 0.953534 58.1743 22.4598
1.001825 1.003651 K1   4.6334 0.80408 0.005415 4.4427 0.3858
1.005329 1.005623 PSI1 0.0363 0.37852 0.652588 12.4936 98.7808
1.007595 1.011099 PHI1 0.0660 0.48833 0.348622 31.8854 40.9042
1.013689 1.034320 TET1 0.0496 1.14358 0.442246 8.5012 22.1575
1.034467 1.044800 J1   0.2592 0.72512 0.090340 0.1197 7.1383
1.064841 1.073202 SO1  0.0430 0.80534 0.560243 9.1395 39.8585
1.073349 1.080797 OO1  0.1417 0.95843 0.174175 13.1426 10.4123
```

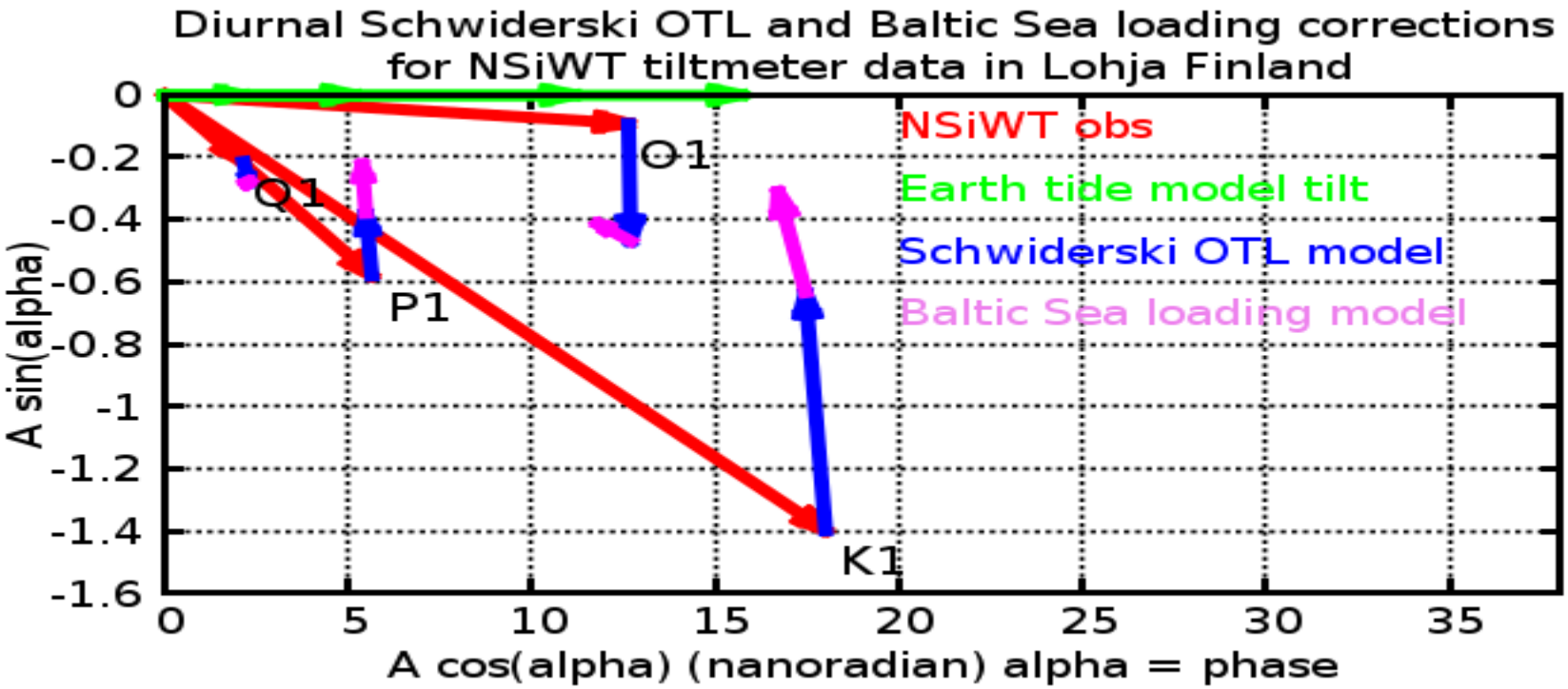
1.719381	1.827343	3N2	0.0194	0.29450	0.438403	81.4238	85.2916
1.827799	1.853920	EPS2	0.0503	0.81852	0.180863	4.4192	12.6603
1.854524	1.863634	2N2	0.1724	0.61255	0.054984	9.4909	5.1430
1.864091	1.872142	MU2	0.2081	0.62585	0.043346	13.9863	3.9683
1.888387	1.900529	N2	1.3030	0.55996	0.007066	8.5098	0.7230
1.900545	1.906462	NU2	0.2475	0.55535	0.036207	4.1706	3.7355
1.923766	1.942753	M2	6.8054	0.57530	0.001304	2.5306	0.1299
1.958233	1.966446	LAM2	0.0502	0.68103	0.175595	20.8274	14.7730
1.966447	1.976926	L2	0.1924	0.67307	0.035374	6.6820	3.0112
1.991787	1.998287	T2	0.1850	0.53570	0.050636	12.2600	5.4157
1.999706	2.000766	S2	3.1660	0.63303	0.003020	3.8640	0.2734
2.002591	2.002885	R2	0.0264	0.50932	0.291730	54.4713	32.8178
2.003032	2.031288	K2	0.8602	0.60535	0.011895	2.2379	1.1259
2.031435	2.044652	ETA2	0.0481	0.74941	0.207456	0.1261	15.8610
2.047243	2.182843	2K2	0.0126	1.08306	0.666941	0.3989	35.2824
2.892640	2.935615	M3	0.0664	0.88470	0.078838	2.2202	5.1058
3.791964	3.937897	M4	0.0006	7.99083	4.889658	106.0663	35.0598



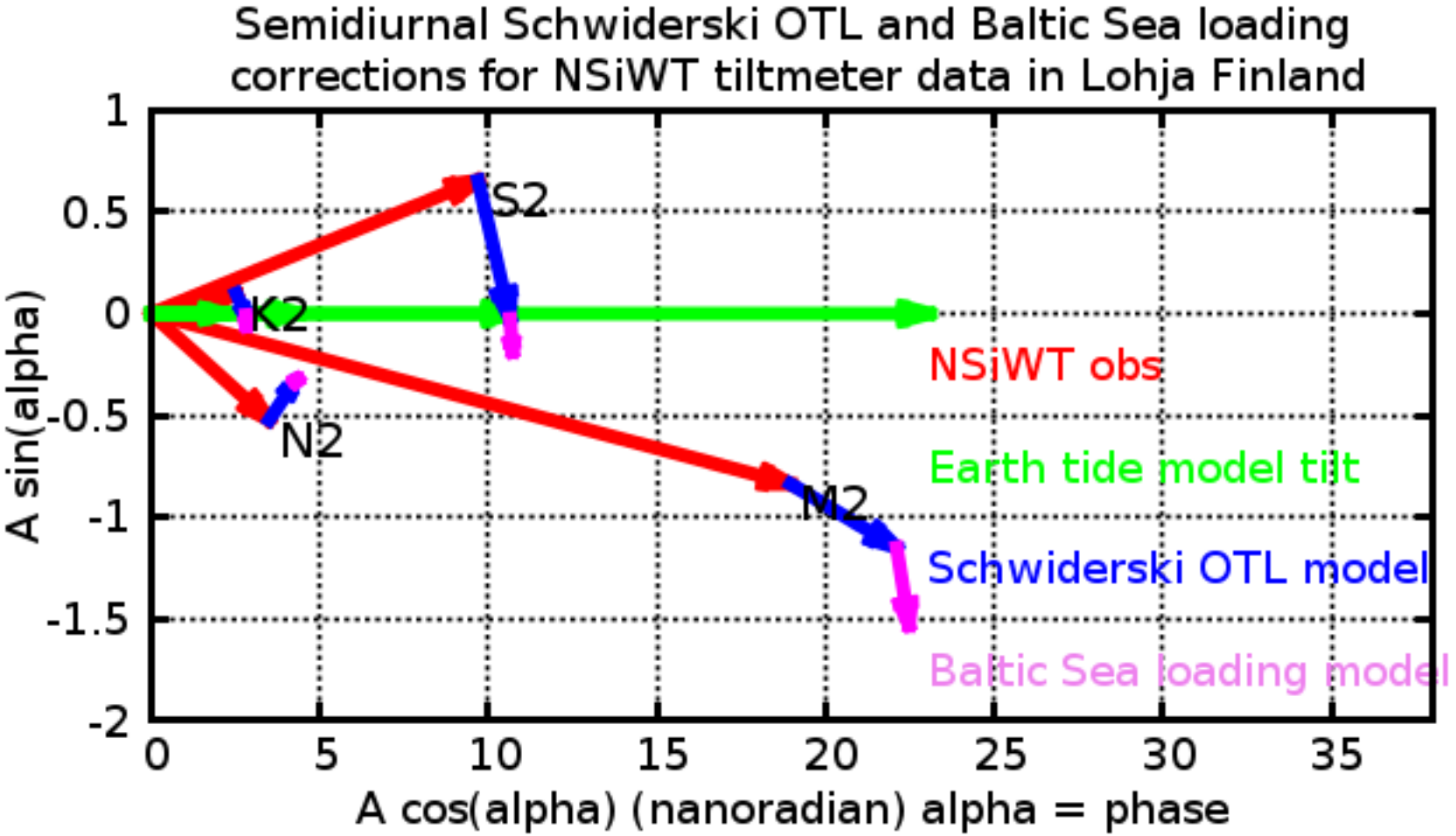
Harmonic earth tide analysis by ET-34-X-V52 program of Wenzel - Schüller (Schüller 2015, 2016)

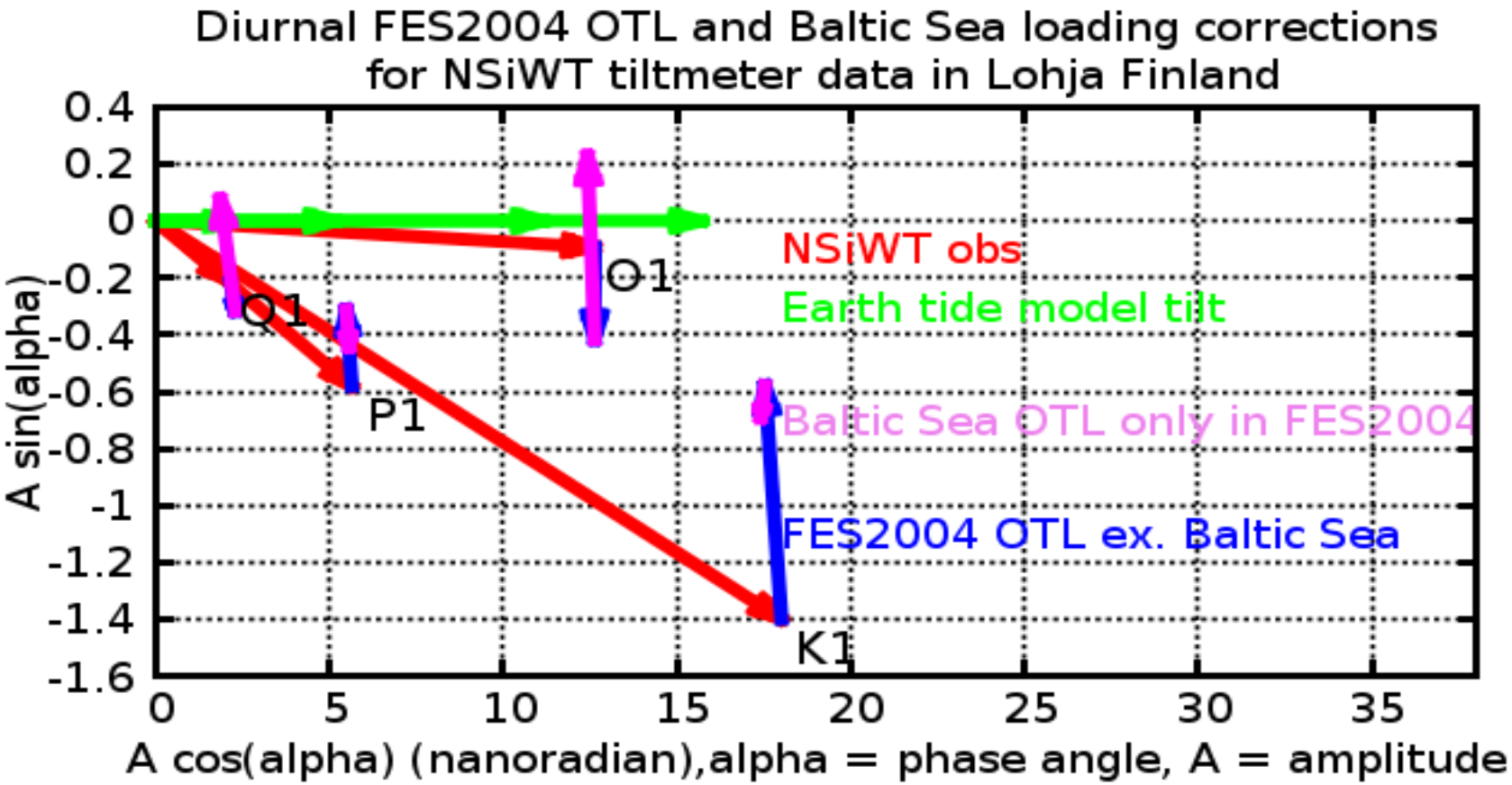


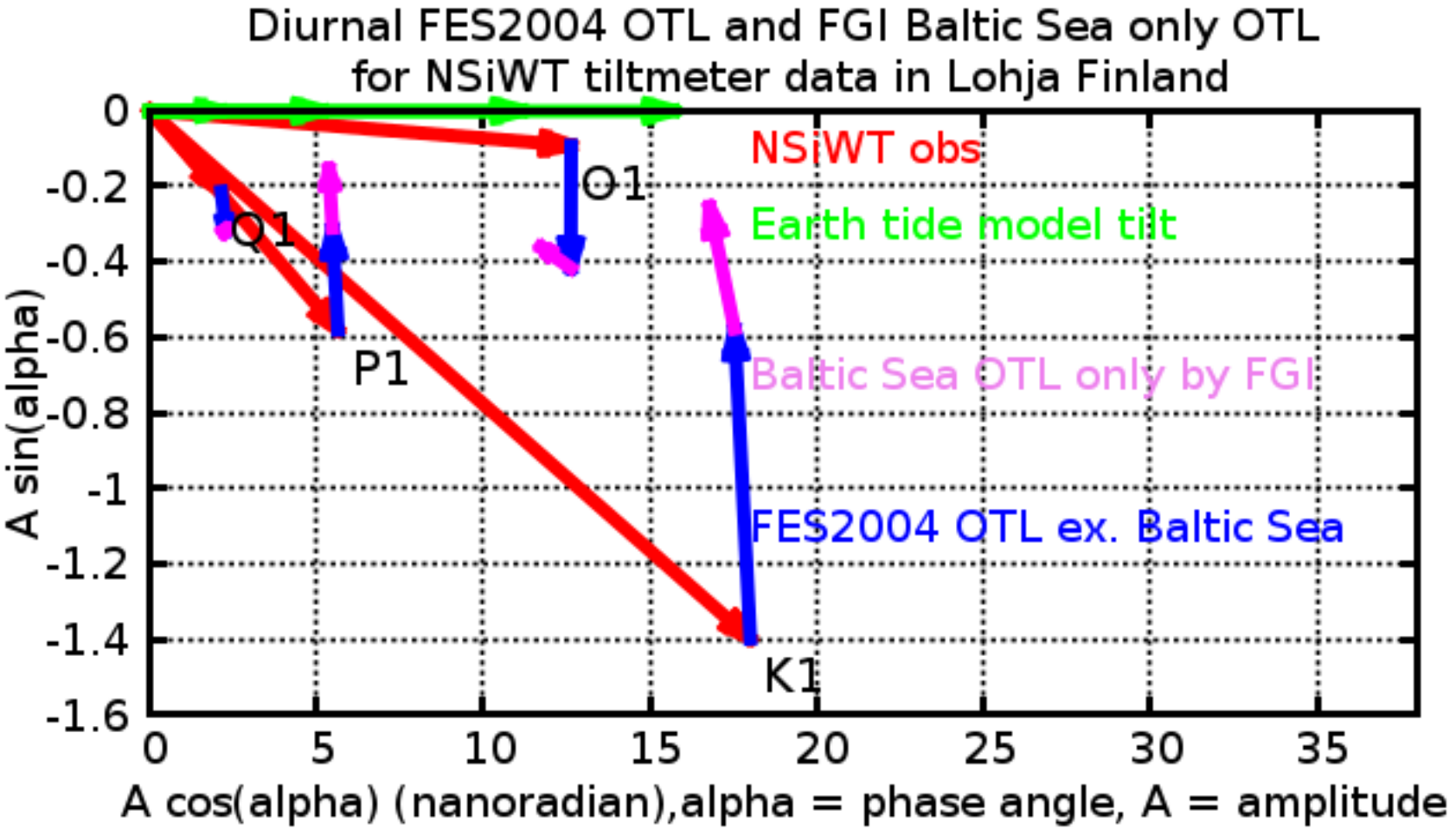
Harmonic earth tide analysis by ET-34-X-V52 program of
Wenzel - Schüller (Schüller 2015, 2016)

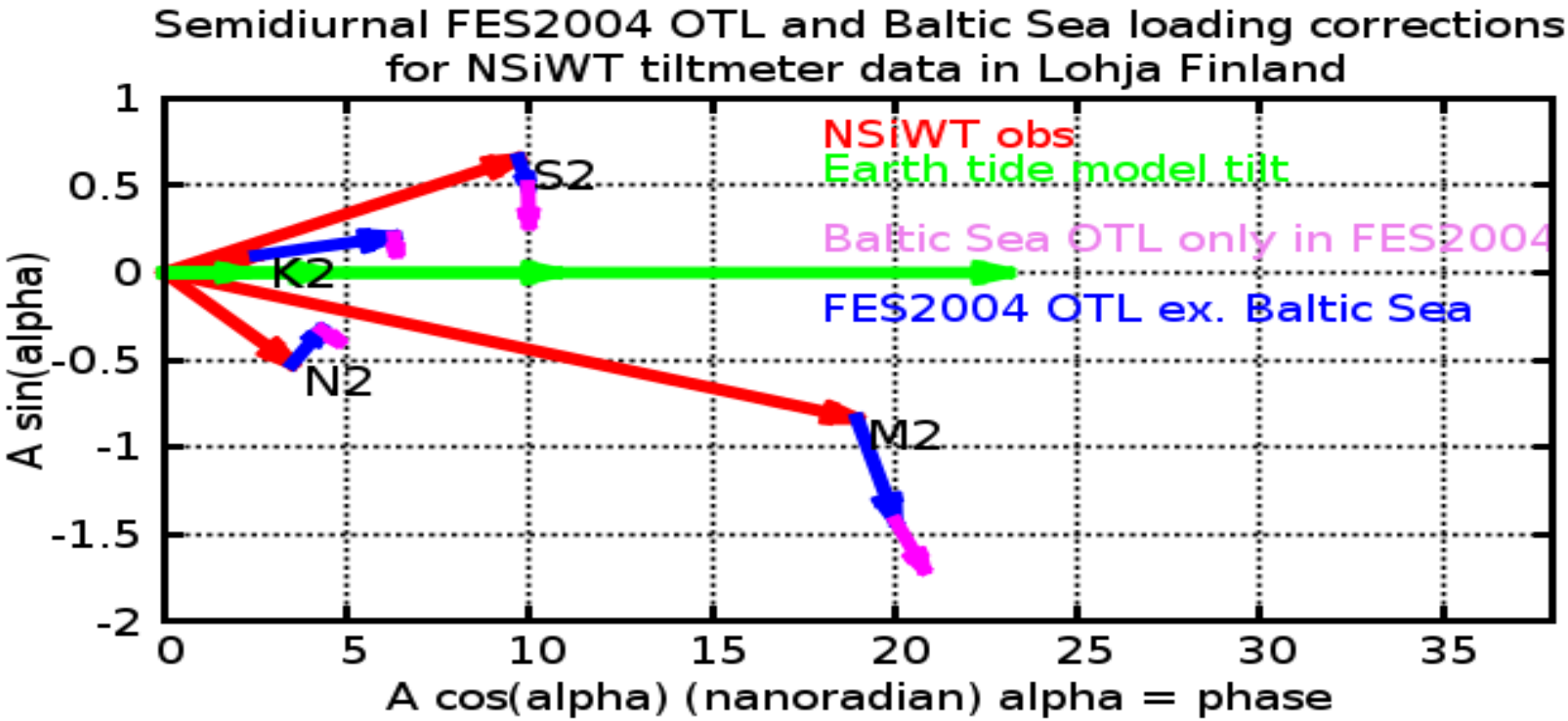


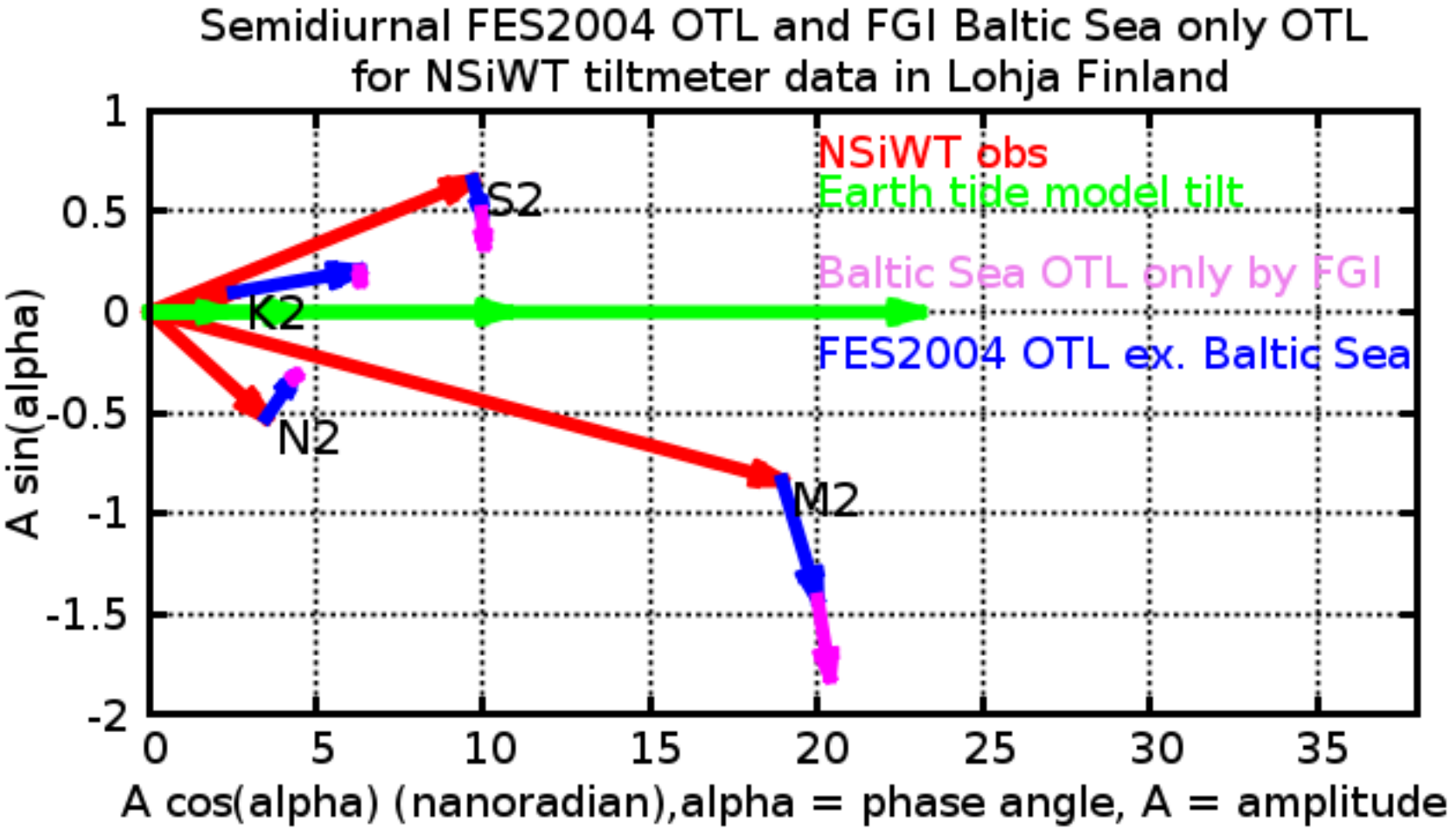
Baltic Sea mass model by H.Virtanen, Loading model tilt by M. Nordman and harmonic tidal modelling by H.Ruotsalainen

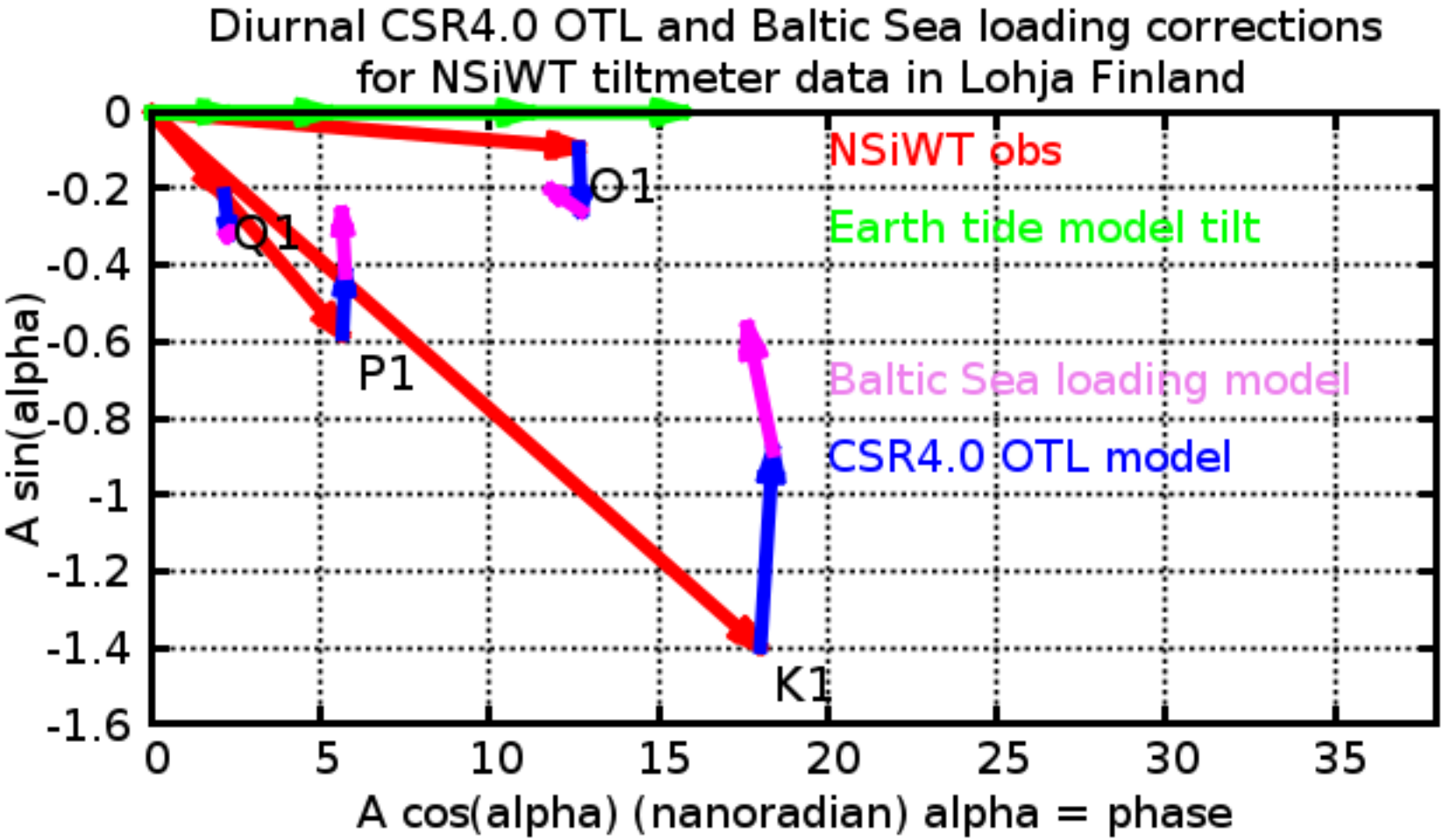

Semidiurnal Schwiderski OTL and Baltic Sea loading
corrections for NSiWT tiltmeter data in Lohja Finland
A sin(alpha)
A cos(alpha) (nanoradian) alpha = phase
1
0.5
0
-0.5
-1
-1.5
-2
0
5
10
15
20
25
30
35
S2
K2
N2
M2
NSiWT obs
Earth tide model tilt
Schwiderski OTL model
Baltic Sea loading model

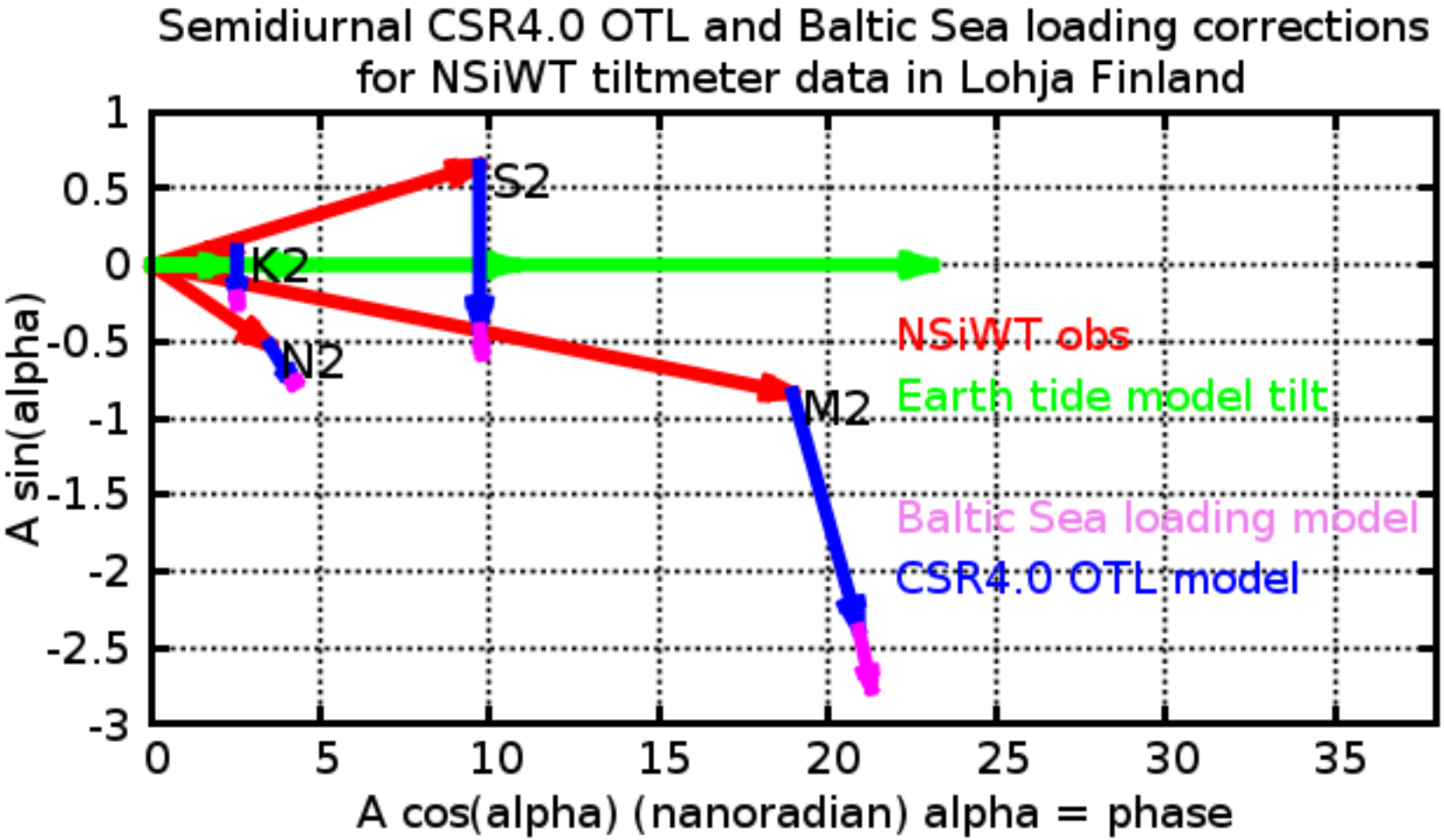

Diurnal FES2004 OTL and Baltic Sea loading corrections
for NSiWT tiltmeter data in Lohja Finland
A sin(alpha)
A cos(alpha) (nanoradian),alpha = phase angle, A = amplitude
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
0
5
10
15
20
25
30
35
NSiWT obs
Earth tide model tilt
Baltic Sea OTL only in FES2004
FES2004 OTL ex. Baltic Sea
O1
O1
P1
K1

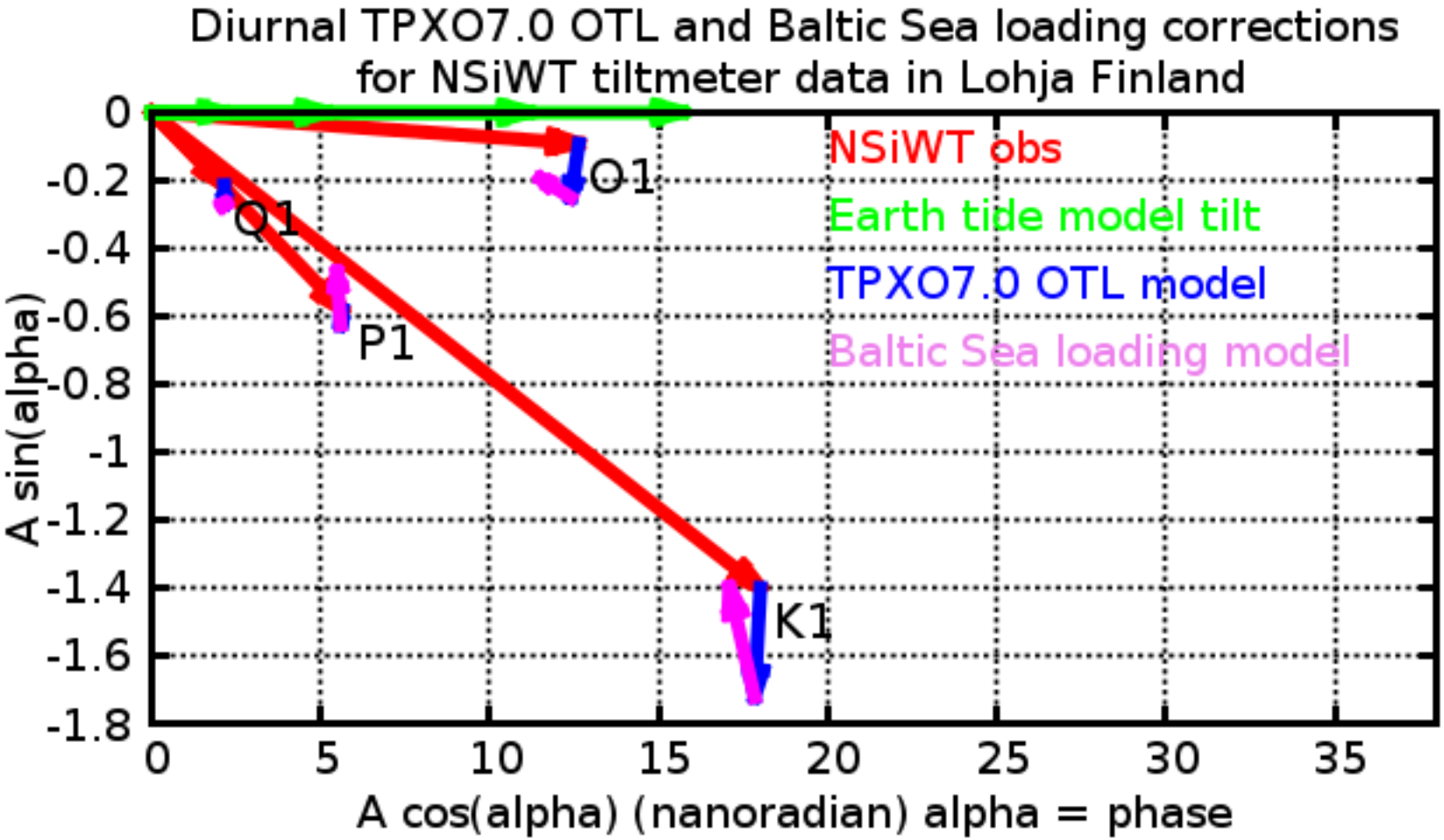

Diurnal FES2004 OTL and FGI Baltic Sea only OTL
for NSiWT tiltmeter data in Lohja Finland
NSiWT obs
Earth tide model tilt
Baltic Sea OTL only by FGI
FES2004 OTL ex. Baltic Sea
O1
Q1
P1
K1
A sin(alpha)
A cos(alpha) (nanoradian),alpha = phase angle, A = amplitude
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
0
5
10
15
20
25
30
35

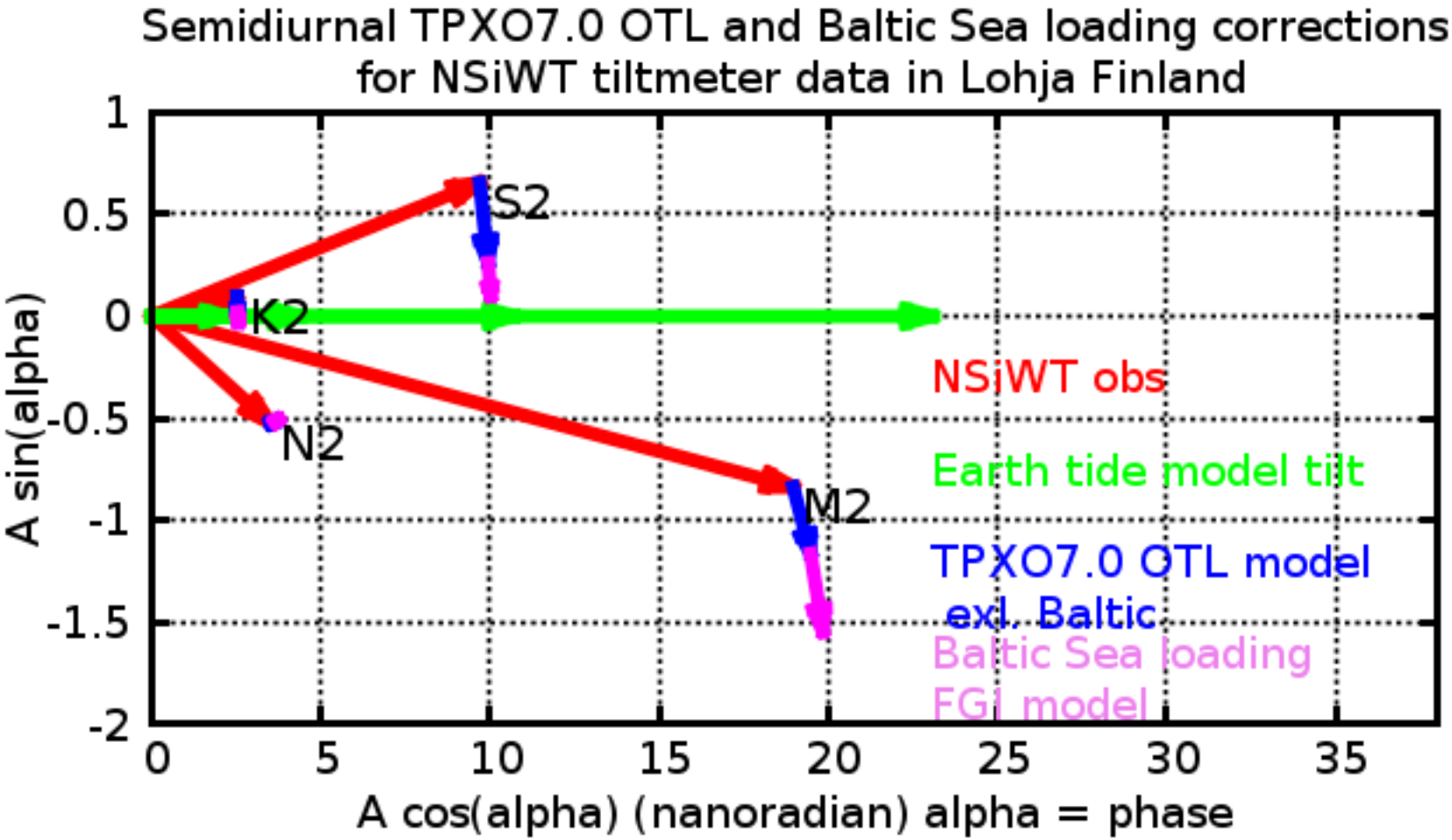

Semidiurnal FES2004 OTL and Baltic Sea loading corrections
for NSiWT tiltmeter data in Lohja Finland
NSiWT obs
Earth tide model tilt
Baltic Sea OTL only in FES2004
FES2004 OTL ex. Baltic Sea
S2
K2
N2
M2
A sin(alpha)
A cos(alpha) (nanoradian) alpha = phase
1
0.5
0
-0.5
-1
-1.5
-2
0
5
10
15
20
25
30
35


Semidiurnal FES2004 OTL and FGI Baltic Sea only OTL
for NSiWT tiltmeter data in Lohja Finland
NSiWT obs
Earth tide model tilt
Baltic Sea OTL only by FGI
FES2004 OTL ex. Baltic Sea
S2
K2
N2
M2
A sin(alpha)
A cos(alpha) (nanoradian),alpha = phase angle, A = amplitude
1
0.5
0
-0.5
-1
-1.5
-2
0
5
10
15
20
25
30
35


Diurnal CSR4.0 OTL and Baltic Sea loading corrections
for NSiWT tiltmeter data in Lohja Finland
NSiWT obs
Earth tide model tilt
Baltic Sea loading model
CSR4.0 OTL model
O1
Q1
P1
K1
A sin(alpha)
A cos(alpha) (nanoradian) alpha = phase
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
0
5
10
15
20
25
30
35

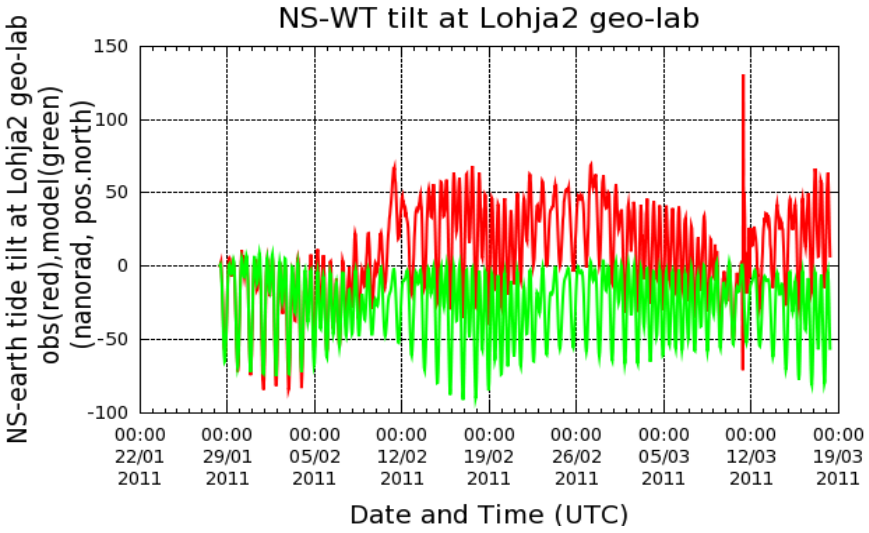

Semidiurnal CSR4.0 OTL and Baltic Sea loading corrections
for NSiWT tiltmeter data in Lohja Finland
A sin(alpha)
A cos(alpha) (nanoradian) alpha = phase
S2
K2
N2
M2
NSiWT obs
Earth tide model tilt
Baltic Sea loading model
CSR4.0 OTL model

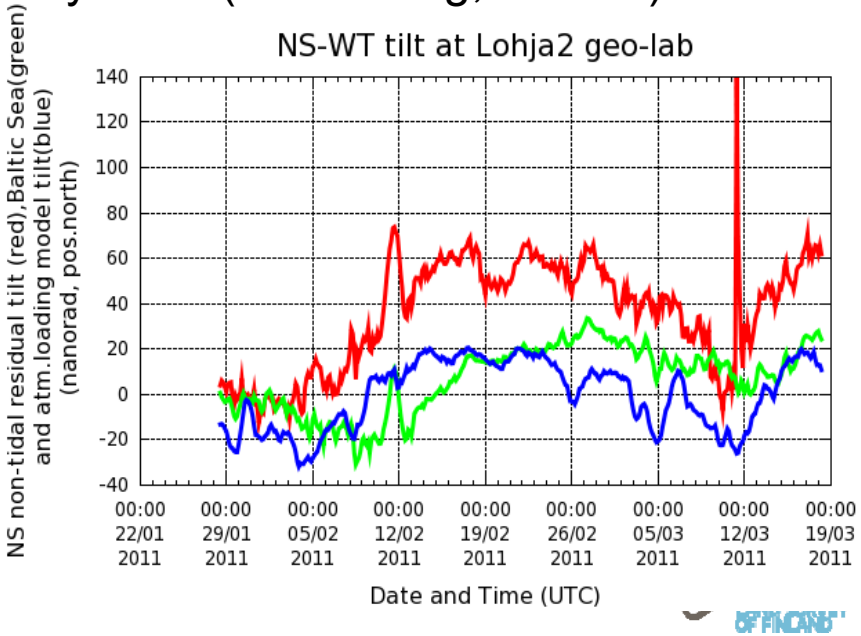

Diurnal TPXO7.0 OTL and Baltic Sea loading corrections
for NSiWT tiltmeter data in Lohja Finland
NSiWT obs
Earth tide model tilt
TPXO7.0 OTL model
Baltic Sea loading model
O1
Q1
P1
K1
A sin(alpha)
A cos(alpha) (nanoradian) alpha = phase
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
0
5
10
15
20
25
30
35


Semidiurnal TPXO7.0 OTL and Baltic Sea loading corrections
for NSiWT tiltmeter data in Lohja Finland
A sin(alpha)
A cos(alpha) (nanoradian) alpha = phase
1
0.5
0
-0.5
-1
-1.5
-2
0
5
10
15
20
25
30
35
S2
K2
N2
M2
NSiWT obs
Earth tide model tilt
TPXO7.0 OTL model
excl. Baltic
Baltic Sea loading
FGI model

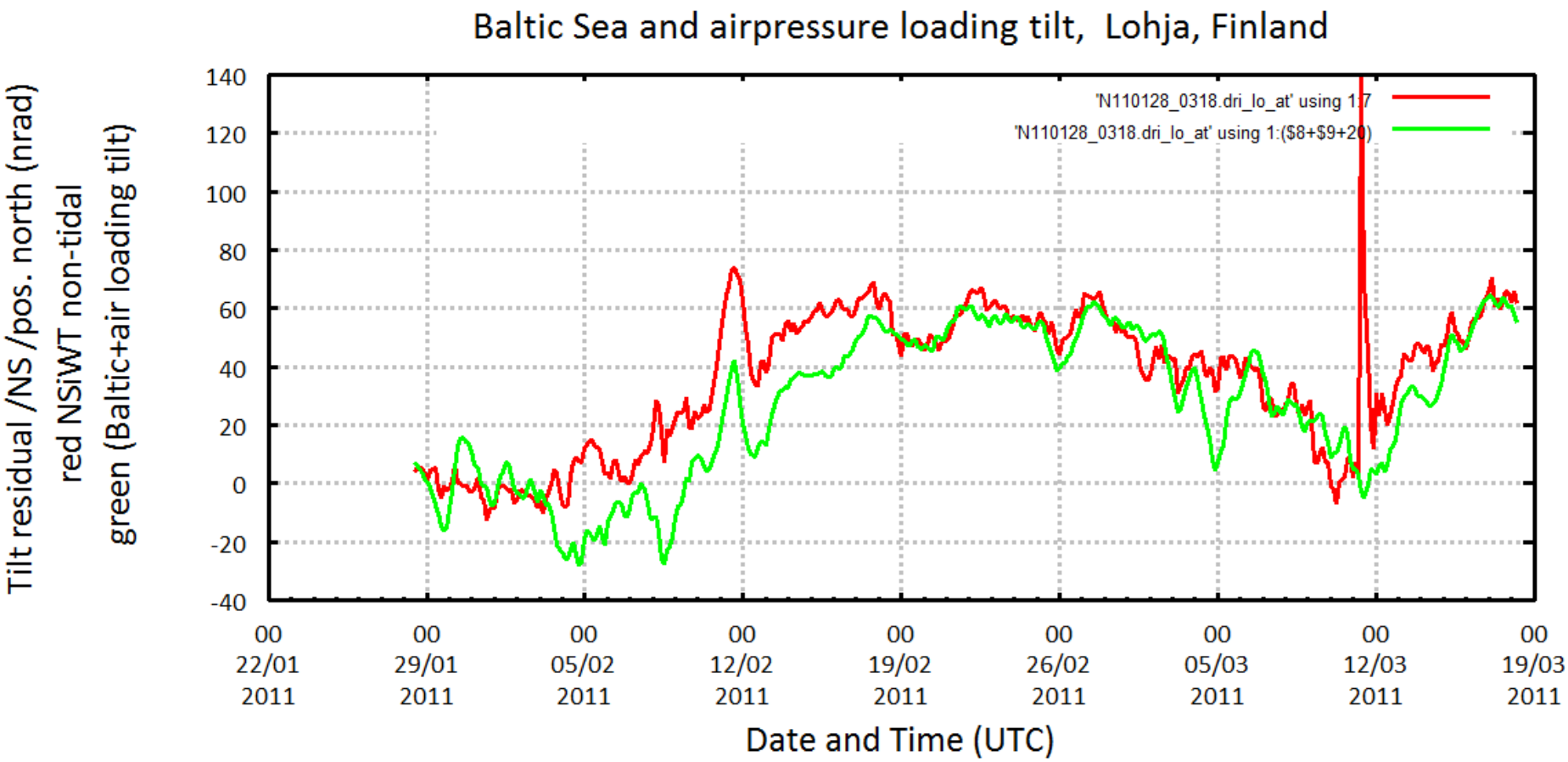
NON-TIDAL BALTIC SEA AND ATMOSPHERIC LOADING IN LOHJA TILT RESIDUAL

Ruotsalainen, Nordman, Virtanen (FGI), Boy et al. (Strasbourg, France)





[Source: Ruotsalainen et al. J. Geod.Sci. 2015;5;156-162]


Baltic Sea and airpressure loading tilt, Lohja, Finland
Tilt residual /NS /pos. north (nrad)
red NSiWT non-tidal
green (Baltic+air loading tilt)
'N110128_0318.dri_lo_at' using 1:7
'N110128_0318.dri_lo_at' using 1:($8+$9+20)
140
120
100
80
60
40
20
0
-20
-40
00 22/01 2011
00 29/01 2011
00 05/02 2011
00 12/02 2011
00 19/02 2011
00 26/02 2011
00 05/03 2011
00 12/03 2011
00 19/03 2011
Date and Time (UTC)

CONCLUSIONS

- Schwiderski OTL model explains the positive lag (lead) semidiurnal NS tilt observations of Michelson and Gale 100 years ago
- OTL models combined with Baltic Sea harmonic tidal model fit quite well in diurnal band with observations of NSiWT but not in M2 in semidiurnal band?
- NSiWT non-tidal observations fit well with combined the Baltic Sea (FGI) and atmospheric loading model by Boy et.al.

ACKNOWLEDGEMENTS

- Agnew D.C: Ocean loading programs.
- Bos M.-Scherneck H.G.: Ocean tide loading provided.
- Boy J.P.,et al.: Atmospheric loading data Lohja.
- Schüller: Modernized harmonic earth tide analysis program package ET-34-X-V52 from original of H.G. Wenzel
- Virtanen H.: Baltic Sea tide gauge mass modelling.

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Kääriäinen, J., ja Ruotsalainen, H., 1989, Tilt measurements in the underground laboratory Lohja2, Finland in 1977 – 1988, Publication of the Finnish Geodetic Institute No. 110, Helsinki.

Lisitzin, E., 1959, Uninodal seiches in the oscillation system Baltic proper, Gulf of Finland, Tellus, 4: 459-466.

Nordman, M., H. Virtanen, S. Nyberg, ja J. Mäkinen, 2015, Non-tidal loading by the Baltic Sea: Comparison of modelled deformation with GNSS time series, GeoResJ., Vol. 7, 14-21.

Ruotsalainen, H., 2001, Modernizing the Finnish Long Water-Tube Tilt meter, J. Geod. Soc. of Japan, Vol. 47, 1:28-33.

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