

Precise measurements of global geodynamical effects by conventional instruments (gravity meters, strainmeters) : results and unsolved problems

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Global Geodynamical Phenomena

- *Earth Tides*
- *Nutations*
- *Polar motion*
- *Earth rotation*
- *Global Tectonics*
- *Sea Level Changes*

**Founder of modern global geodynamics
and tidal science**

**Baron Prof.
Paul Melchior
(1926-2004):**

**“Earth Tides
represent a bridge
between Astronomy
and Geophysics”**



The background of the image is a dark, almost black, night sky. In the upper right quadrant, a crescent moon is visible, showing a bright, yellowish-white crescent edge against a dark, reddish-brown background. Below the moon, several thin, wispy clouds are scattered across the sky, appearing as thin, orange-red streaks.

► Earth Tides

Earth Tides as a bridge between Astronomy and Geophysics are

- **forced vibrations of the Earth
powered by space-time variable
Luni-Solar gravitational potential**
- **the only geodynamical
phenomena where frequencies,
amplitudes and phases of force
are known precisely thanks to
astronomy**

For a fictitious Moon in the equator only one tidal period 12h 25m : M2

The inclination of the celestial body orbit creates a diurnal waves

Each orbital perturbation (inclination, eccentricity,) produces additional waves

The Tidal Families (Laplace)

$$P_2^2 = 3/2 \cos^2 \varphi \cos \lambda \quad \text{SD}$$

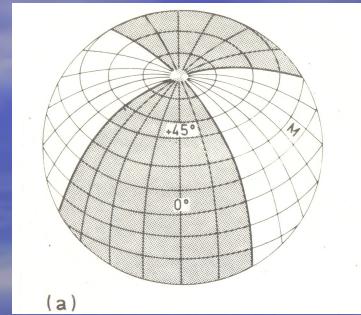
Braking the Earth
rotation
(lag of equatorial bulge)

$$P_2^1 = 3/2 \sin 2\varphi \cos \lambda \quad \text{D}$$

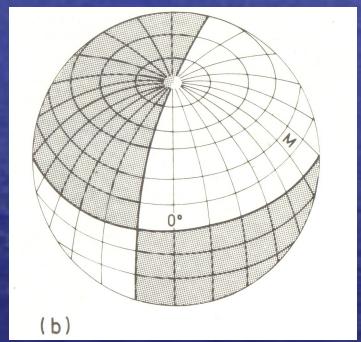
Precession and nutations
(equatorial torque)

$$P_2^0 = 1/2(3\sin^2 \varphi - 1) \quad \text{LP}$$

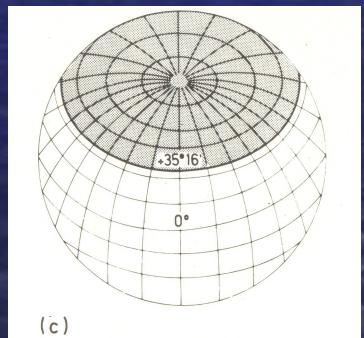
Change of speed of the Earth rotation
(Moment of inertia)



(a)



(b)



(c)

Tidal development

Effects of declination and ellipticity

Zonal: Luni-solar: $M_0 S_0$ principal

Moon: M_f fortnightly (declinational), M_m monthly (elliptic)

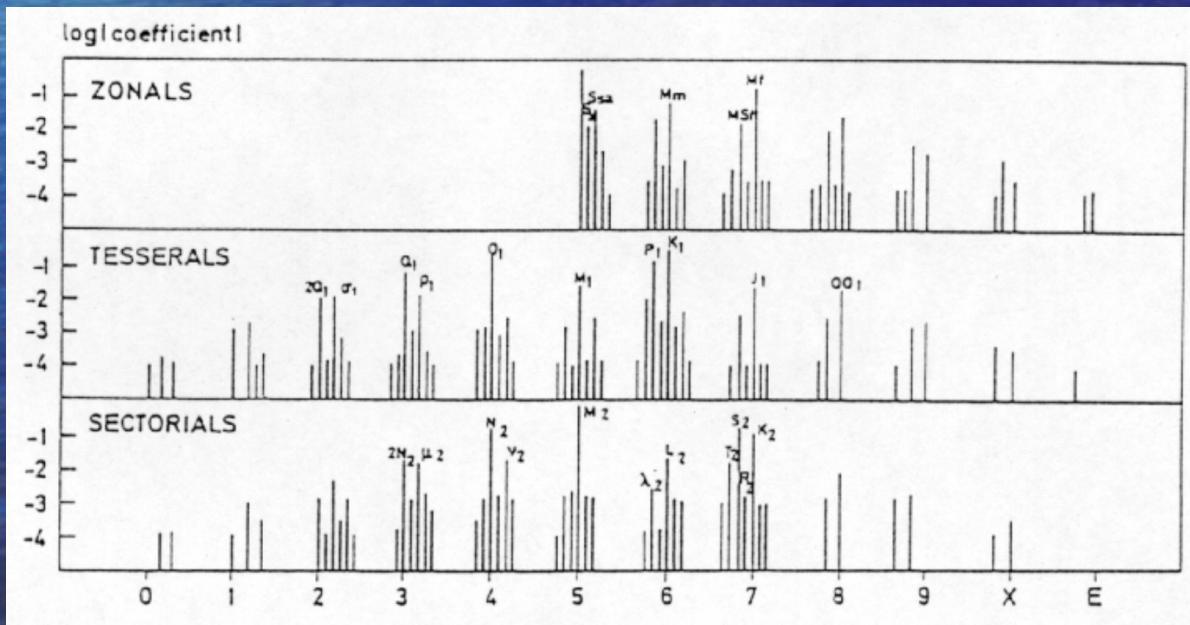
Sun: S_{sa} 6 month (declinational), S_a yearly (elliptic)

Diurnal: Moon: K_1 , O1 main declinational

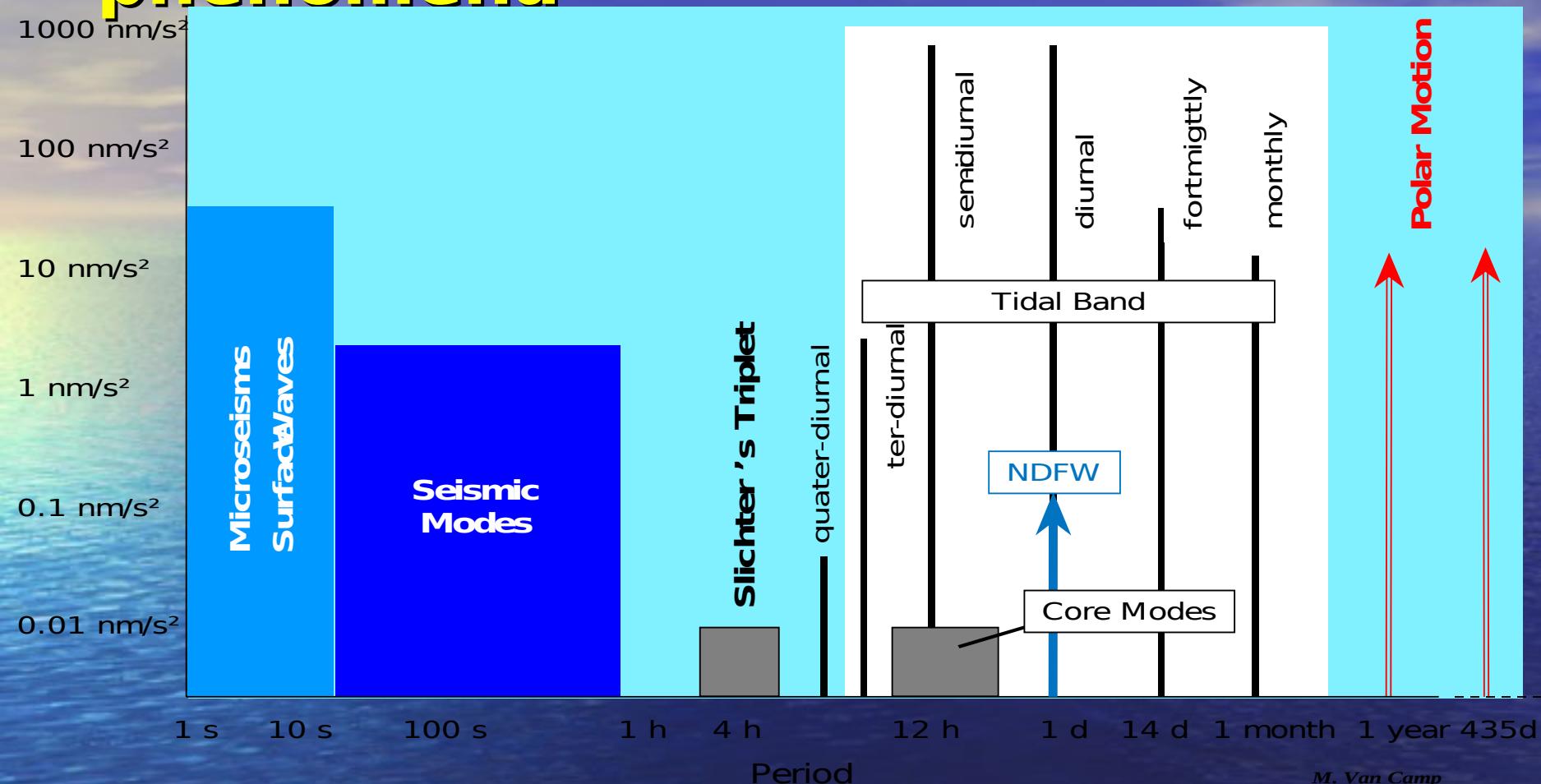
Sun: K_1, P_1 main declinational

Semi-diurnal: Moon: M_2 principal, N_2 and L_2 - elliptic

Sun: S_2 principal, T_2 and R_2 - elliptic



Spectrum of geodynamical phenomena



- Tidal observations bridge a frequency gap between seismic frequencies (periods larger than 1 hour) and polar motion signal.

M. Van Camp
Royal Observatory of Belgium

Earth Tides and Astronomy

- Diurnal tides and nutations are directly coupled
- Considering the solar argument h defining the tropic year we get symmetrically around K_1

	P_1	6 month nutation
-h	S_1	yearly nutation
-h	K_1 sidereal day	Precession
+h	ψ_1	yearly nutation
+h	ϕ_1	6 month nutation

The Nearly Diurnal Free Wobble (NDFW) located between K_1 and ψ_1 will modify the Earth's output to different waves and the associated nutations.

Earth Tides and Astronomy

- The NDFW can be determined from ground based tidal observations.
- We want to determine the transfer function of the Earth using as input a known tidal signal.
- As we know beforehand the spectrum of the tidal potential we work in the frequency domain.
- For each tidal wave we can determine a specific transfer function

Earth Tides Signal

- In fact as the astronomical or rigid Earth signal is well known we are only interested in the solid Earth response itself. It amounts:

15% for gravity

25% for tilt

100% for strain

- However the elastic deformation of the crust due to strain/tilt coupling (topography and cavity effects) badly affects the tilt and strain observations, so that the most reliable results are still obtained in tidal gravity

Observations of tidal phenomena

- **Tidal gravity variations**
- Tidal tilts
- Tidal strains

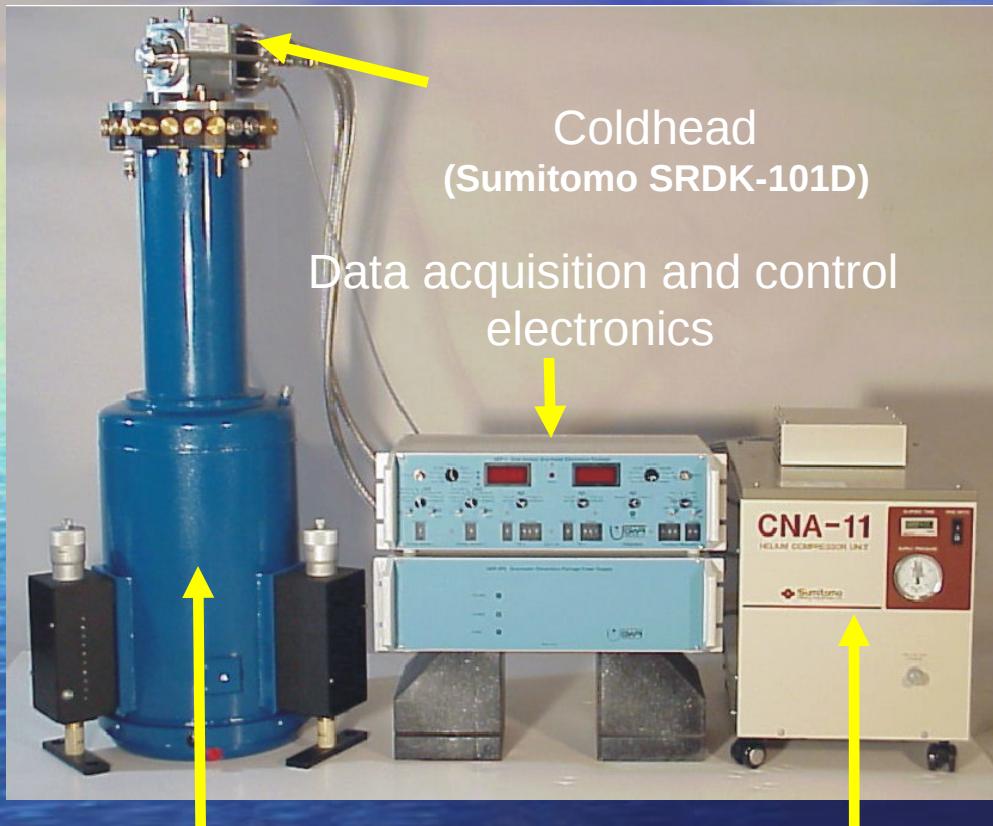
Oceanic tides and ...

Gravity Tides

- The most precise observations are performed using superconducting gravimeters.
 - The accuracy of the observations is limited by the calibration of the instruments
 - in amplitude: 0.15%
 - in phase: time lag within a few seconds (better than $0.^{\circ}02$ on M_2)

Superconducting Gravimeter (SG)

Most precise instrument for gravity variations



Liquid He filled Dewar
with Gravity Sensor

Compressor
(Sumitomo CAN-11C)

Performance

Gravity resolution: 10^{-11} m/s^2

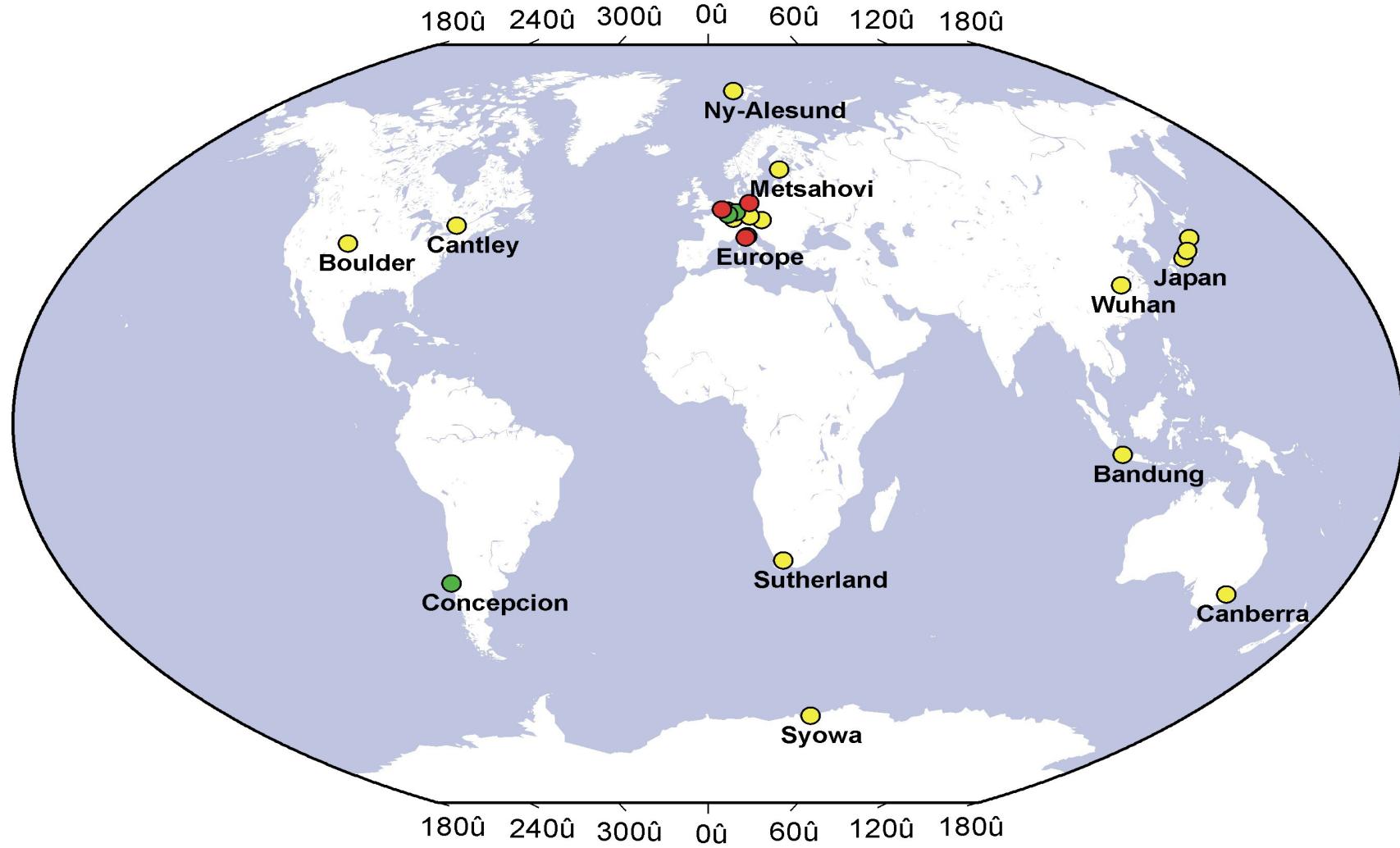
Measurement range:
from seconds to years
with a linear transfer function
Drift: $\sim 3 \mu\text{gal}/\text{year}$ linear

GWR observatory superconducting gravity meter



Global Geodynamics Project

GGP Stations 1997 - 2003



GWR
INSTRUMENTS, INC

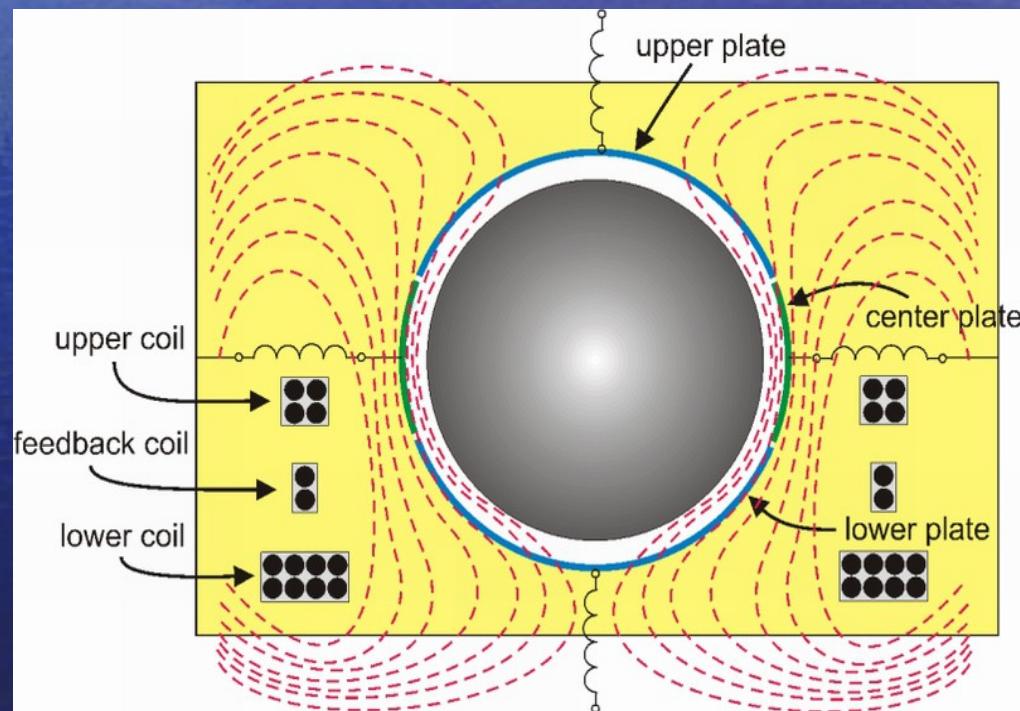


Source: <http://www.eas.slu.edu/GGP/ctspec.html>

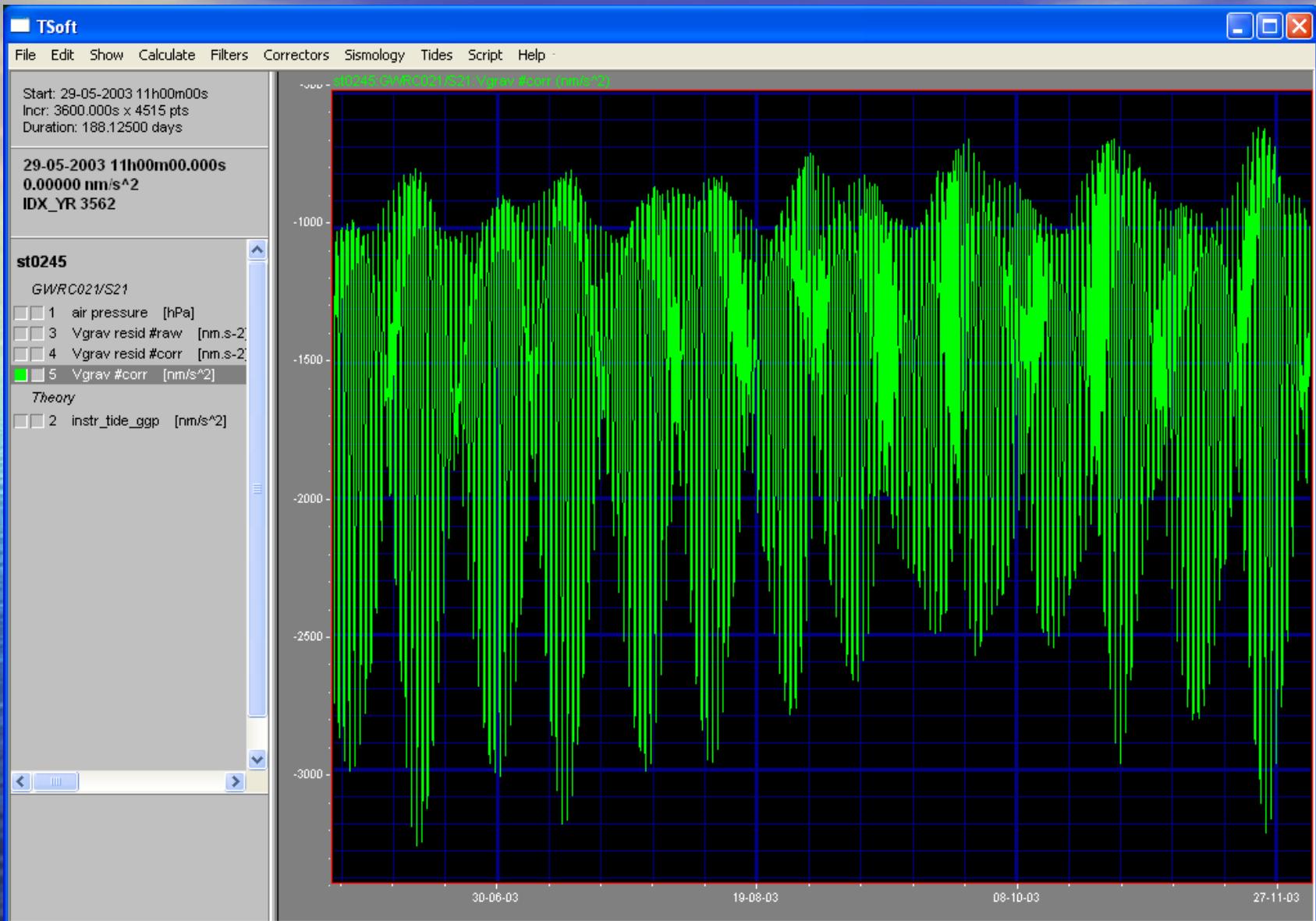


mvc

Accuracy of some nGal or $\sim 10^{-12}$ g



Example of tidal record with SG #C021



Tidal Gravity Observations

- The results have to be **corrected for**
 - the ocean loading
 - the atmospheric loading
 - the underground water effects
 - the instrumental coupling with meteorology (S1 and its harmonics, annual term and its harmonics)

Principal Tidal waves and its amplitudes in gravity

Long-periodic

Diurnal

Semi-Diurnal

M_0

Q_1

$2N_2$

S_0

Q_1

μ_2

S_a

LK_1

N_2

S_{sa}

NO_1

V_2

M_{SM}

p_1

M_2 *36 μGal*

M_m

P_1

λ_2

M_{SF}

S_1

T_2

M_f *6 μGal*

K^m_1

S_2 *17 μGal*

M_{STM}

K^s_1

R_2

M_{TM}

y_1

K^m_2

M_{SQM}

f_1

K^s_2 with largest amplitudes
in red

J_1

Typical observational periods:
1 month, 6 months, 1 year

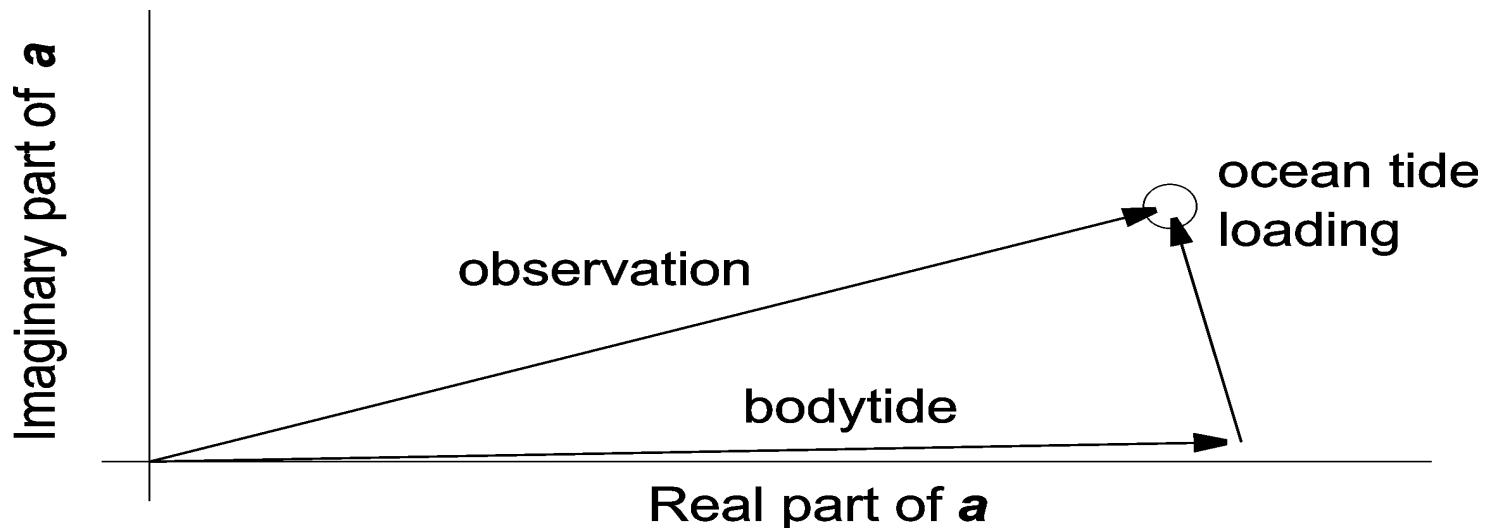
Model values of tidal parameters

- **Forced vibrations of the Earth powered by time-space varying Luni-Solar potential**
- **Spherically symmetrical PREM model is used**

Vectorial representation of Earth tides

$$\mathbf{a}_{bodytide} = \left(1 + h_2 - \frac{3}{2} k_2\right) \frac{\partial \mathbf{U}_2}{\partial r} = \delta \frac{\partial \mathbf{U}_2}{\partial r}$$

Displacement Redistribution Gravity due to Moon/Sun



Important Achievements

- Results from GGP network show general agreement with VLBI results on the determination of the **NDFW frequency**.
- The **Pole tide** is now determined with a precision of 1% on individual stations and 0.5% on the global adjustment of 9 GGP stations.

Fluid Core Resonance (Sato & al., 2002)

- Experimental determination of the fluid core resonance (stations Canberra, Esashi, Matsushiro and Membach)
Ocean model NAO99b

$T=429.66 \pm 1.43$ s.d.

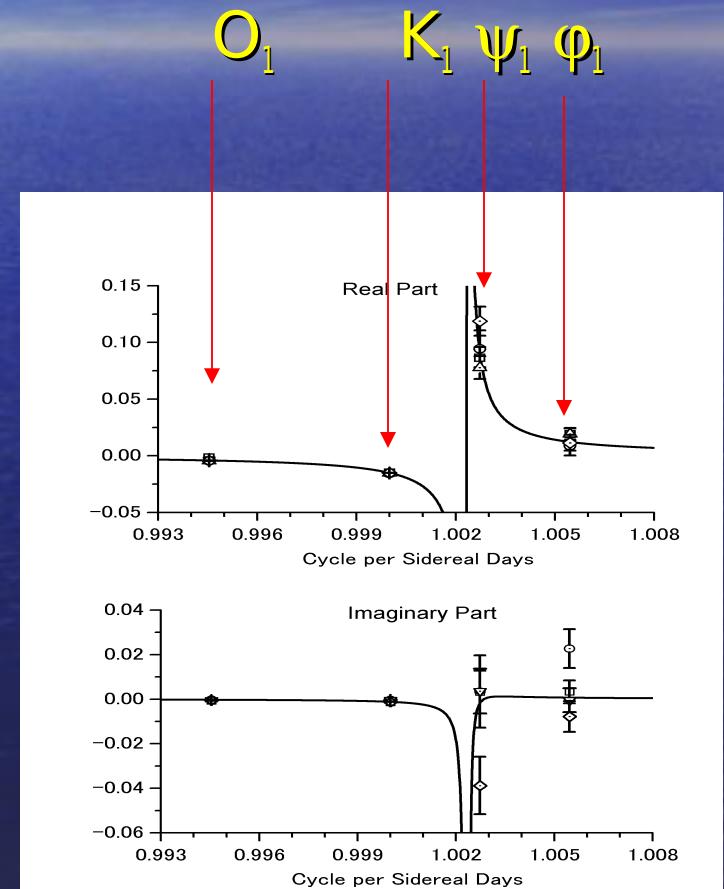
$Q=9,350 \sim 10,385$

- Theory (DDW99)

$T=456.98$ s.d. hydrostatic
 $T=431.37$ s.d. non hydro.

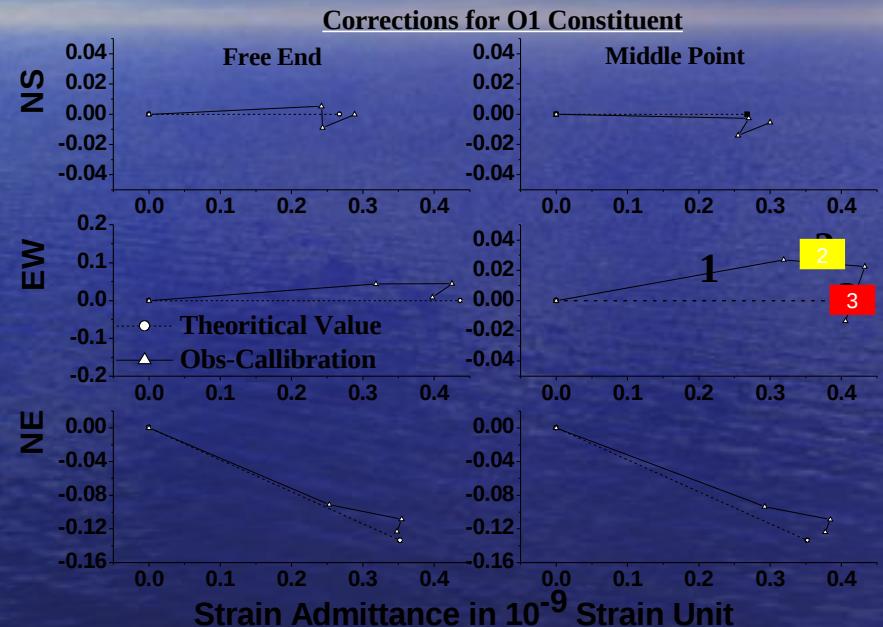
- VLBI

$T=429.5$ s.d.



Fluid Core Resonance by Strain Observation at Esashi station (J.Ping & al., 2004)

- Strain observations have to be corrected for **ocean loading** (3), atmospheric loading, meteorological and hydrological effects.
- These components are very sensitive to **local heterogeneities** (cavity effects) and **boundary conditions** (topography) (2). These effects have to be modelled using finite element techniques, which is always a very difficult task

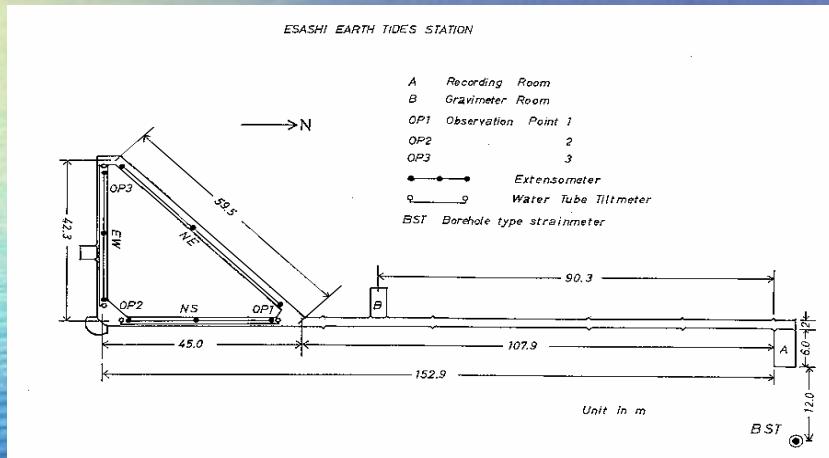


- 1 observed
- 2 local effect
- 3 ocean loading



Fluid Core Resonance by Strain

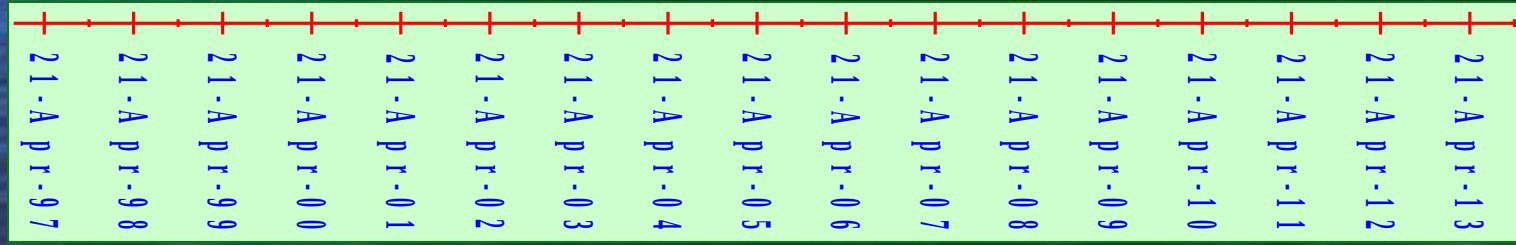
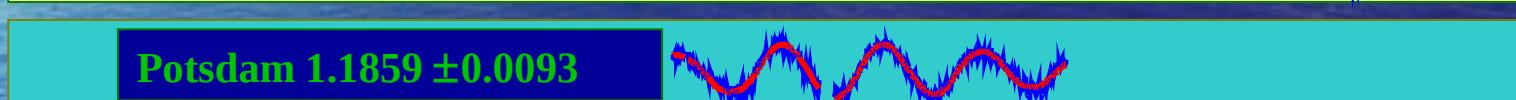
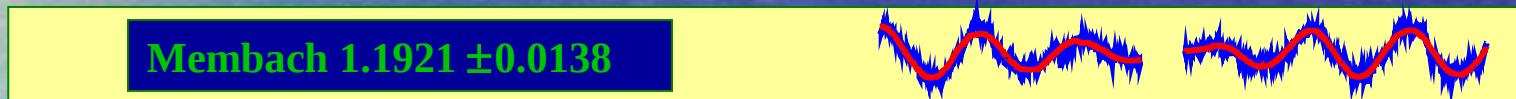
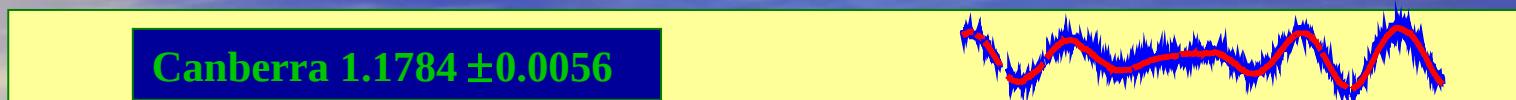
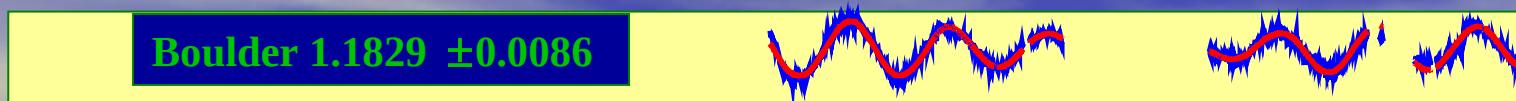
Observation at Esashi station (J.Ping & al., 2004)



VLBI
T=429.5 s.d

	T_{FCN} (s. d.)	Q
1.Free end	421.7 ± 1.6	10 500 ± 2 350
2.Mid point	410.6 ± 1.1	6 870 ± 830
1+2	419.9 ± 1.3	6 670 ± 770

Polar tide and Chandler pole motion effect from different SG locations

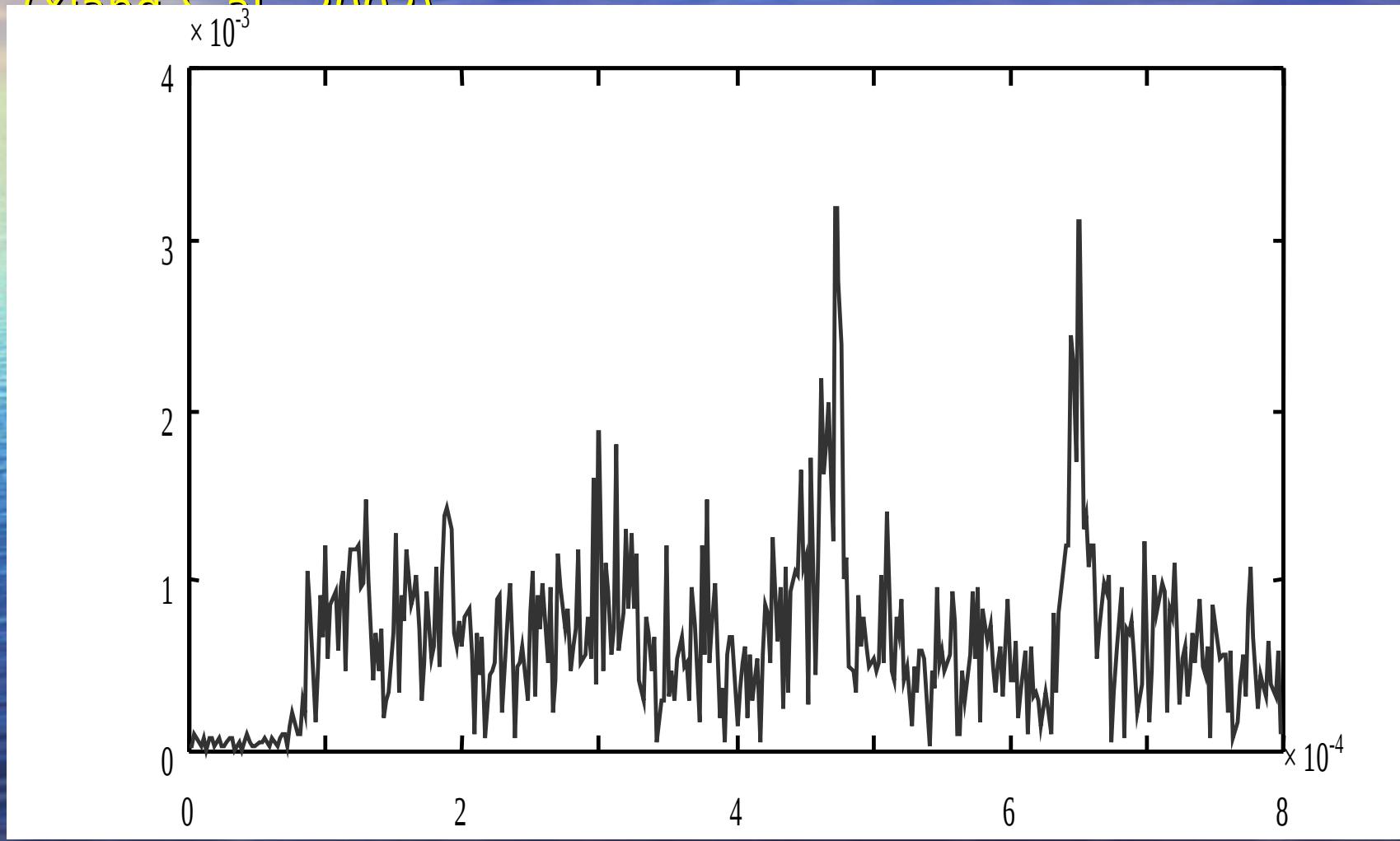


New Perspectives

- Superconducting gravimeters have a better signal to noise ratio than modern seismometers below .001Hz. They can thus improve the determination of the low overtones of the fundamental mode of the Earth free oscillations. A lot of efforts is now devoted to identify the inner core oscillation known as Slichter's mode.

Free oscillation spectrum (0-0.8 mHz)

(Xiong et al. 2002)

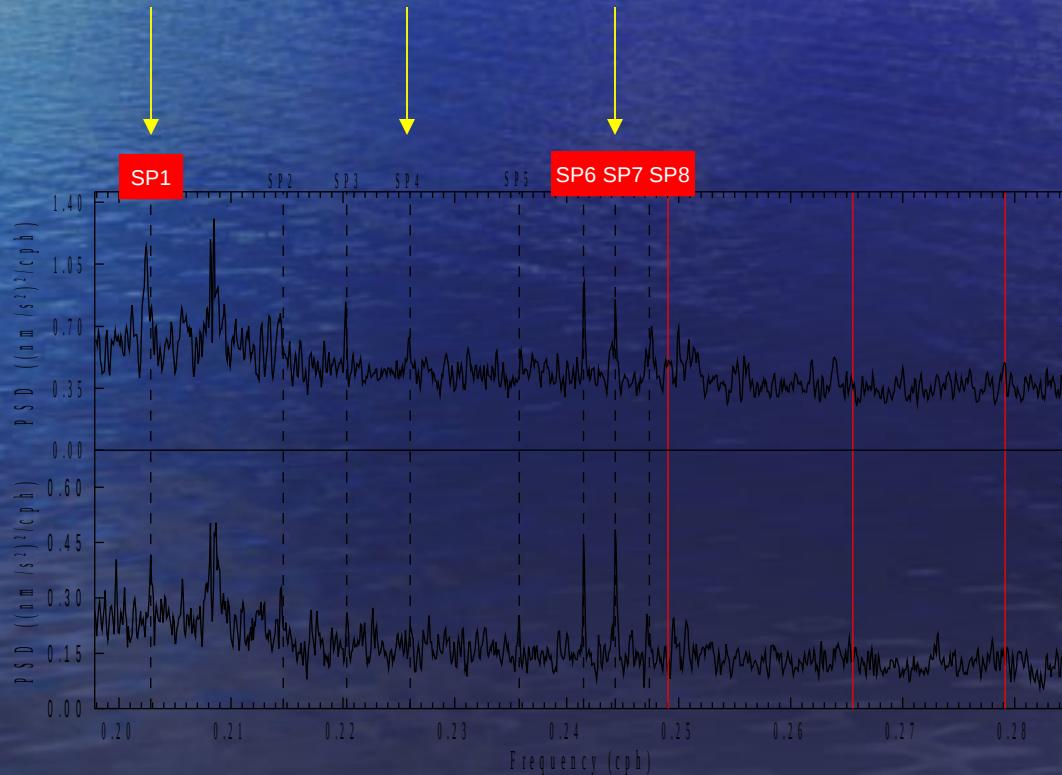


Search for Slichter's Triplet (Sun &al., 2003)

- Identification of peaks with non-linear tides

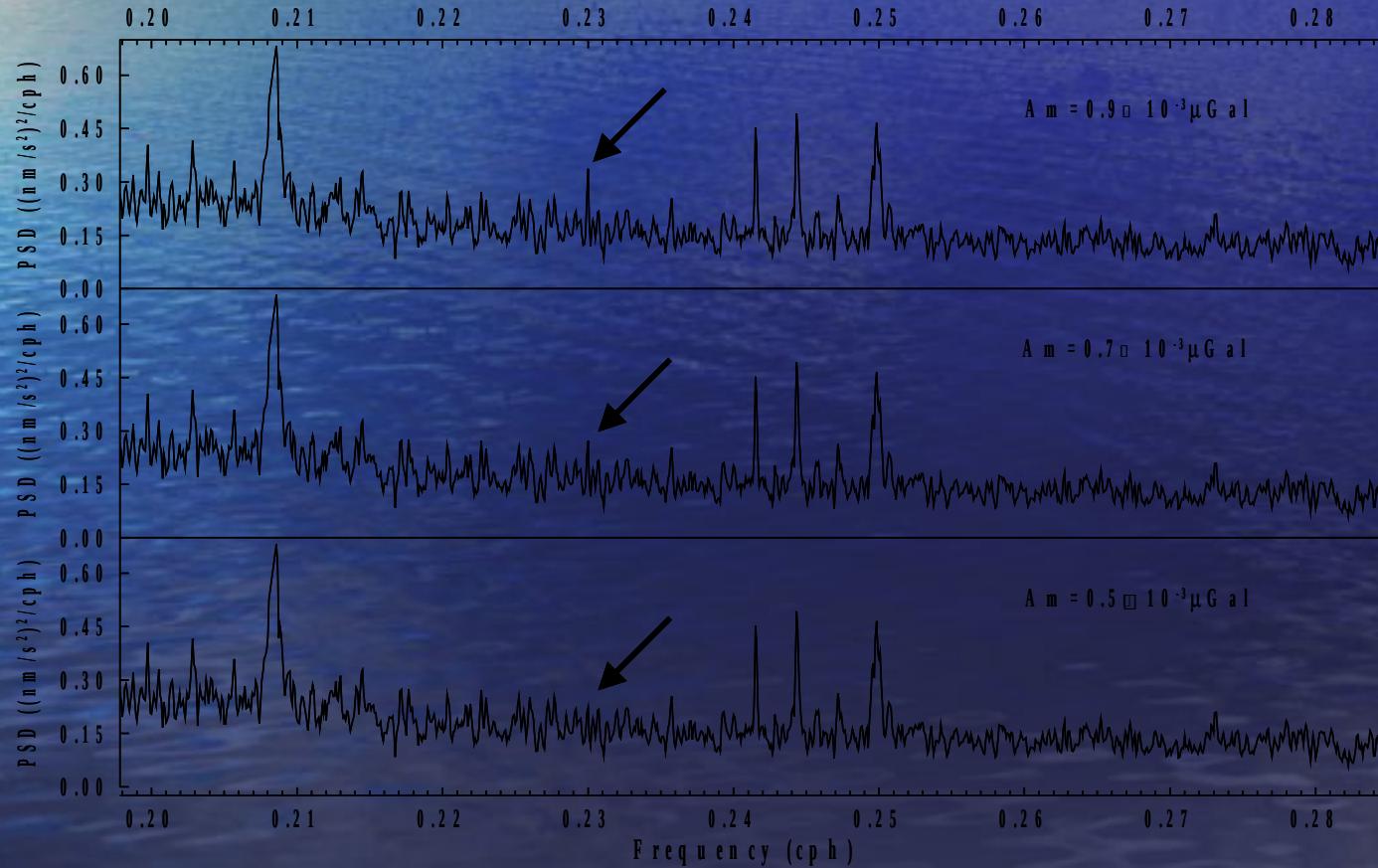
$SP1 \equiv 2MK5$, $SP6 \equiv M6$, $SP7 \equiv 2MS6$, $SP8 \equiv 2SM6$

- Possible triplets Smylie(1991), Smith(1976)



Search for Slichter's Triplet (Sun &al., 2003)

- A steady signal with an amplitude of 1 nanogal should be detected



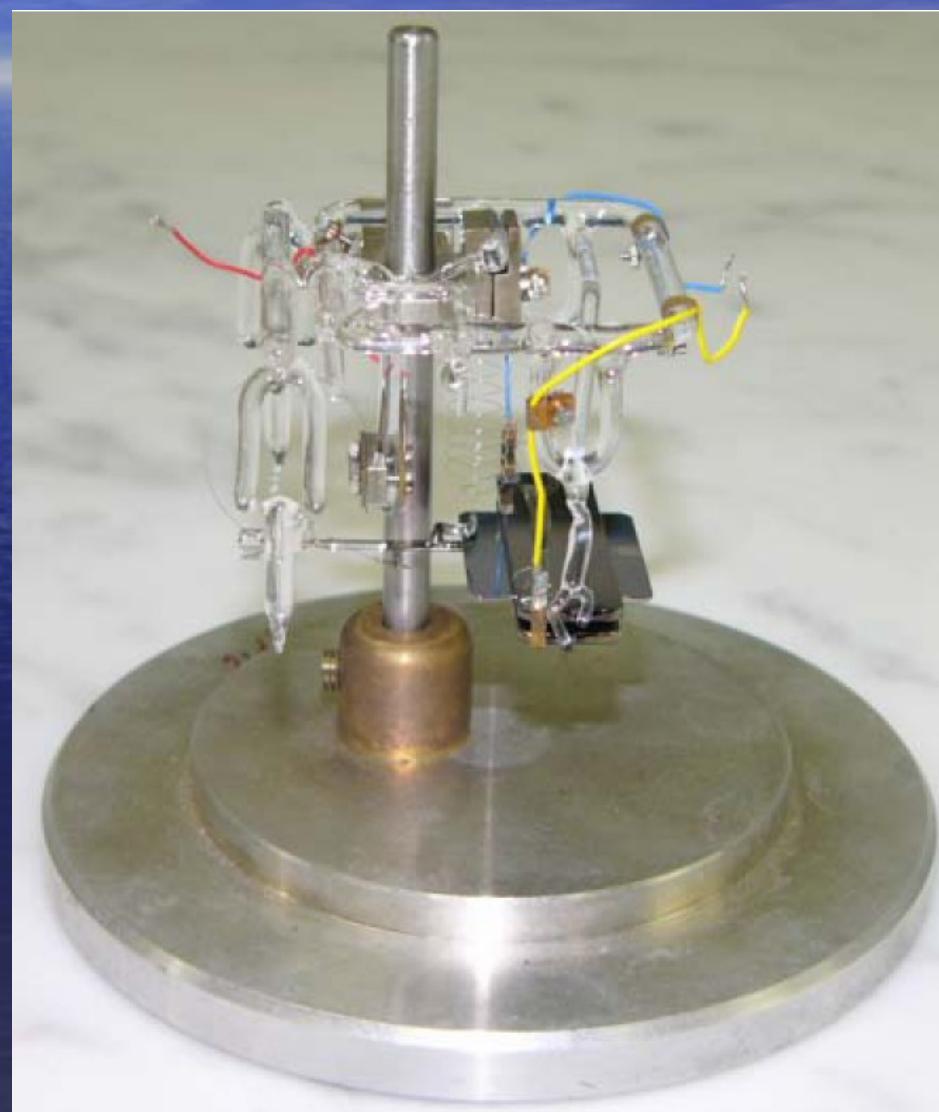
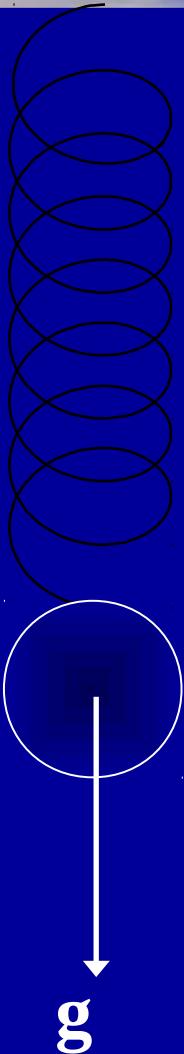
Tidal gravity observations at SAI MSU

Modern relative field gravity meters Scintrex CG-5 and ZLS-Burris



Sensitive system of Scintrex CG-5

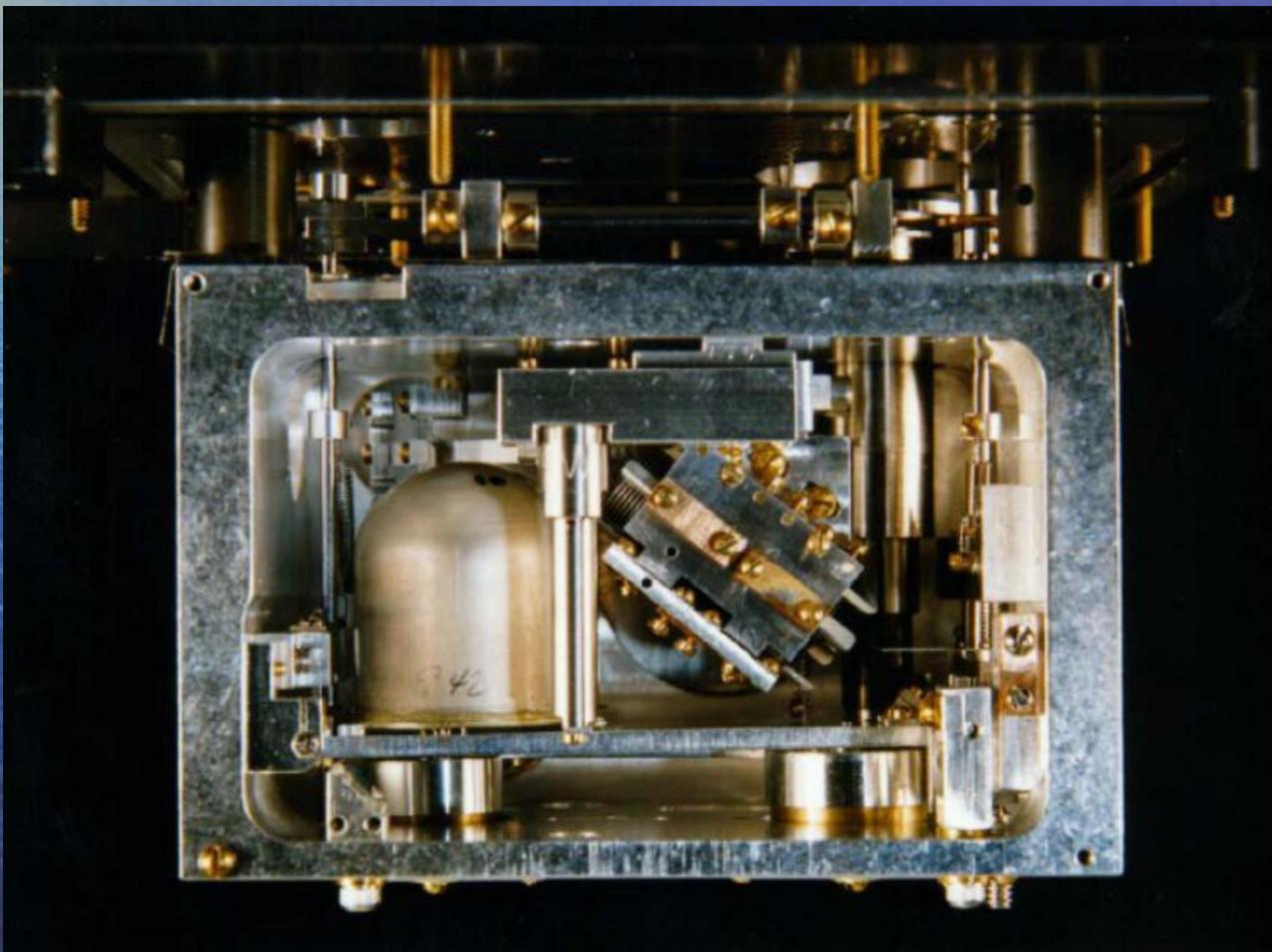
gravity meter



ZLS B018 gravity meter

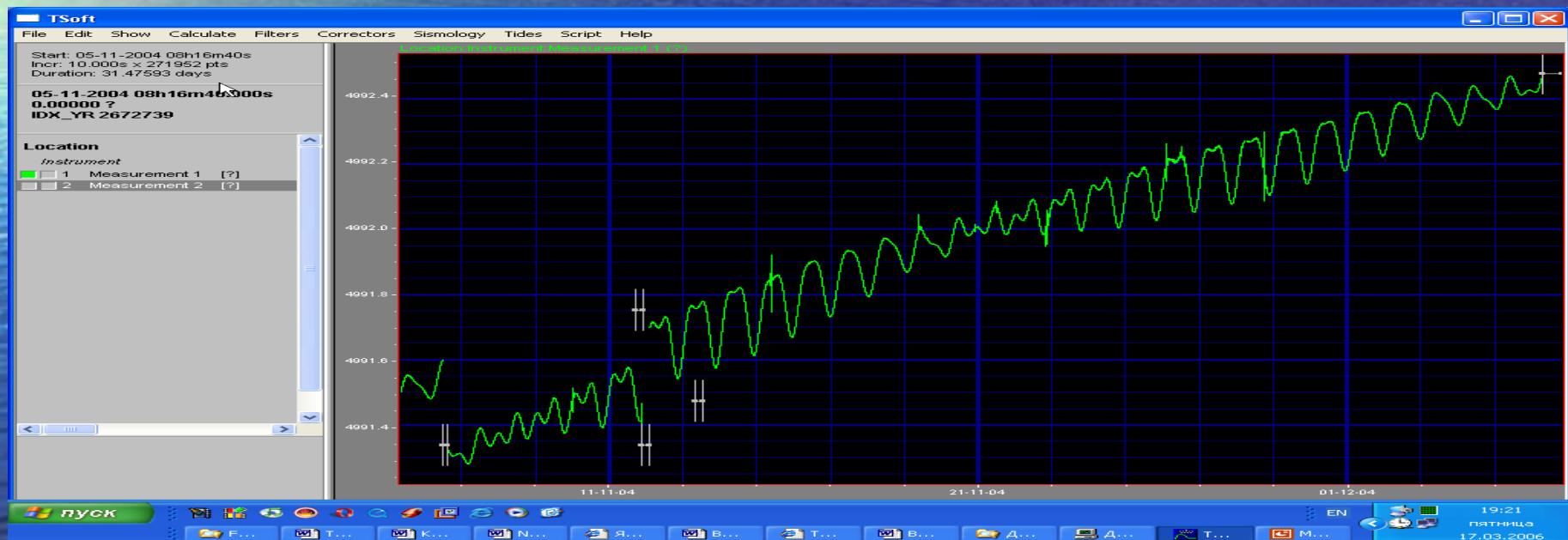


Sensitive system of ZLS-Burris gravity meter (astatized, same as LCR)



Problems of tidal observations

- **Systematic errors due to coherent meteorological noise (temperature variations, atmospheric pressure changes, ...)**
- **The observational room should be thermostatized (ideal case)**
- **Many months of observations are needed to:**
 - **1) increase the spectral resolution**
 - **2) improve the accuracy of parameters estimation using the accumulation of coherent signal**
 - **3) averaging the systematic influence of seasonal variations of coherent noises**
- **Calibration problem ...**
- **Is solved perfectly using laser strain meters only**

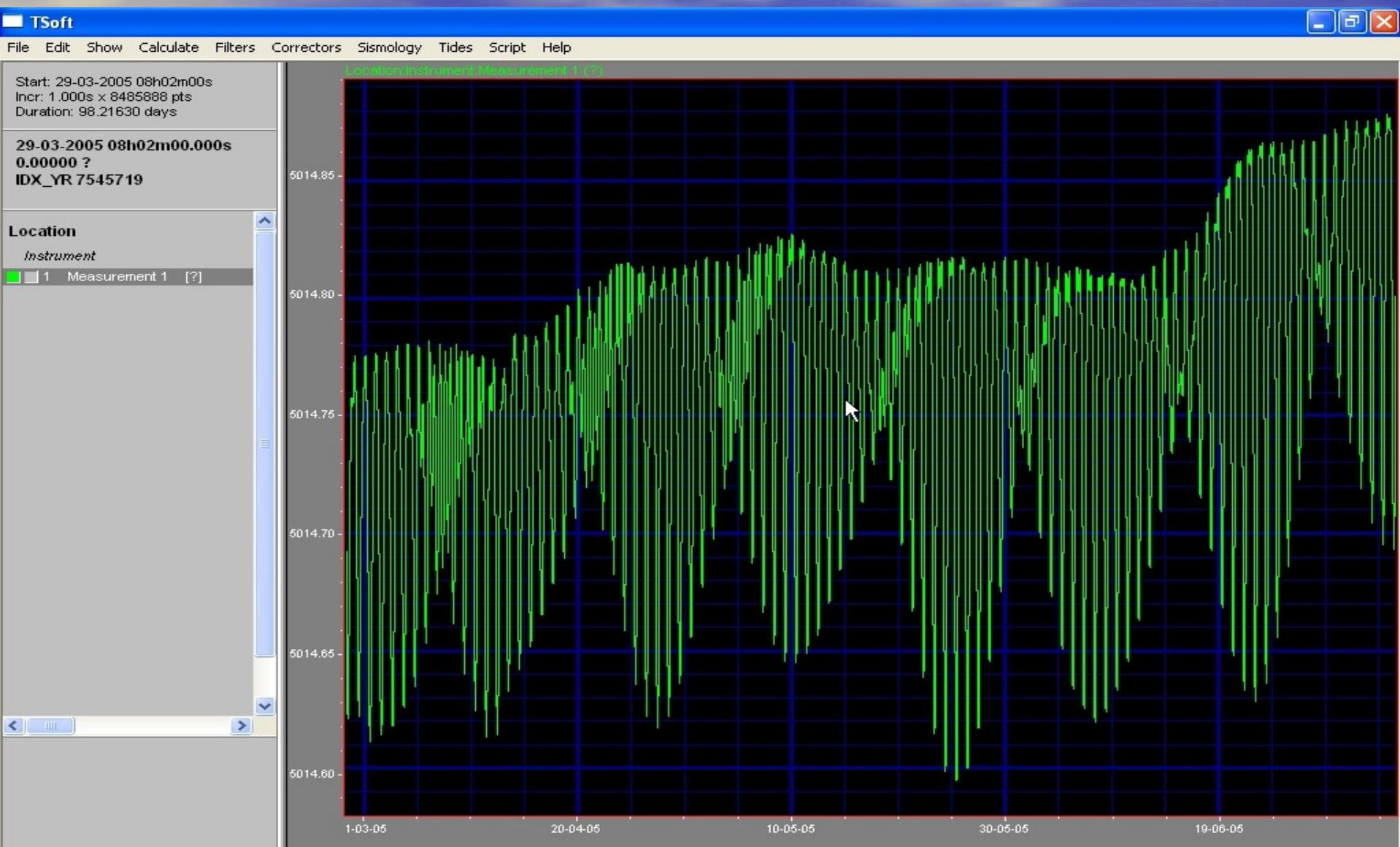


Examples of daily and monthly tidal records with ZLS gravity meters

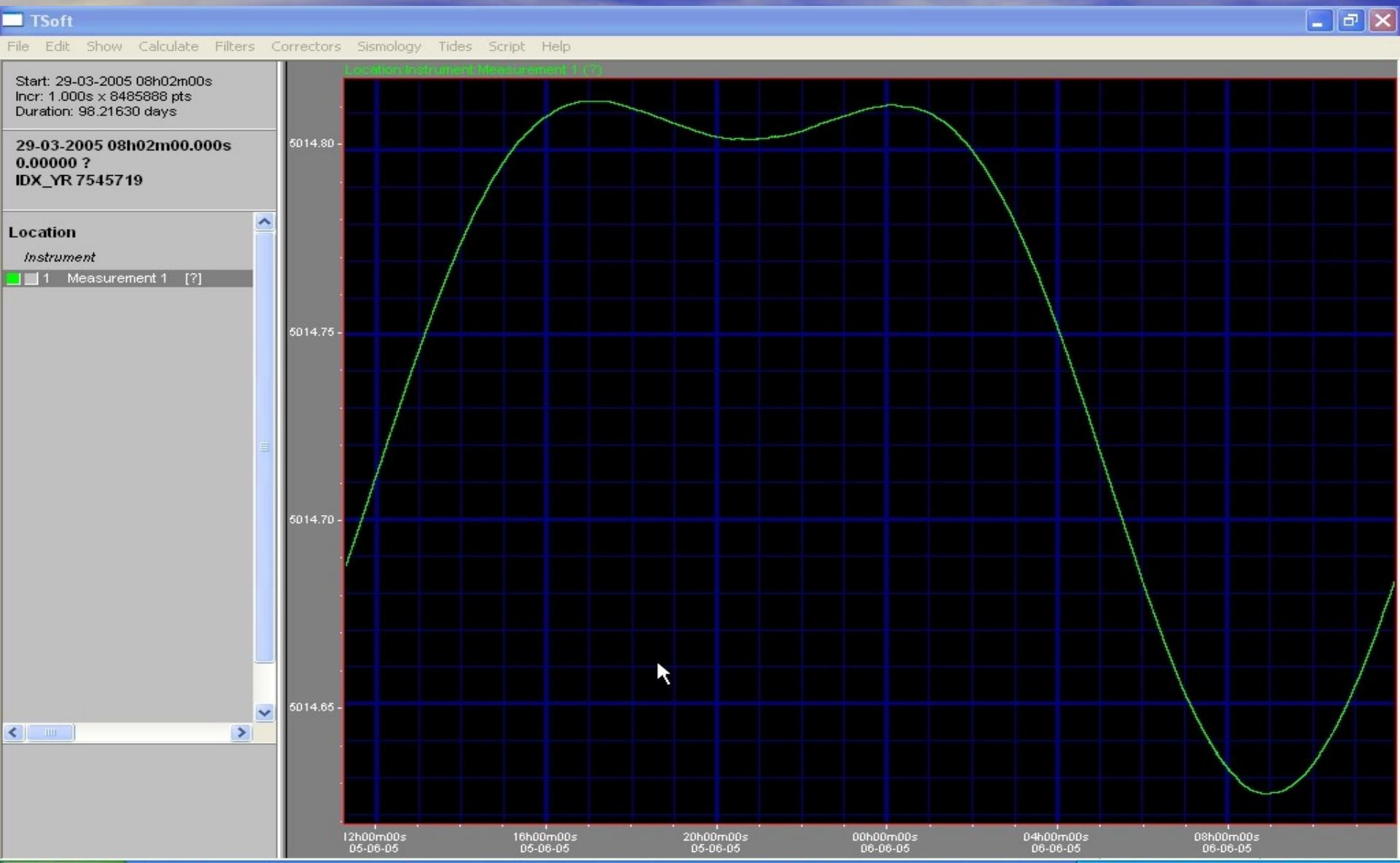
Gravity Units in SI and SGS

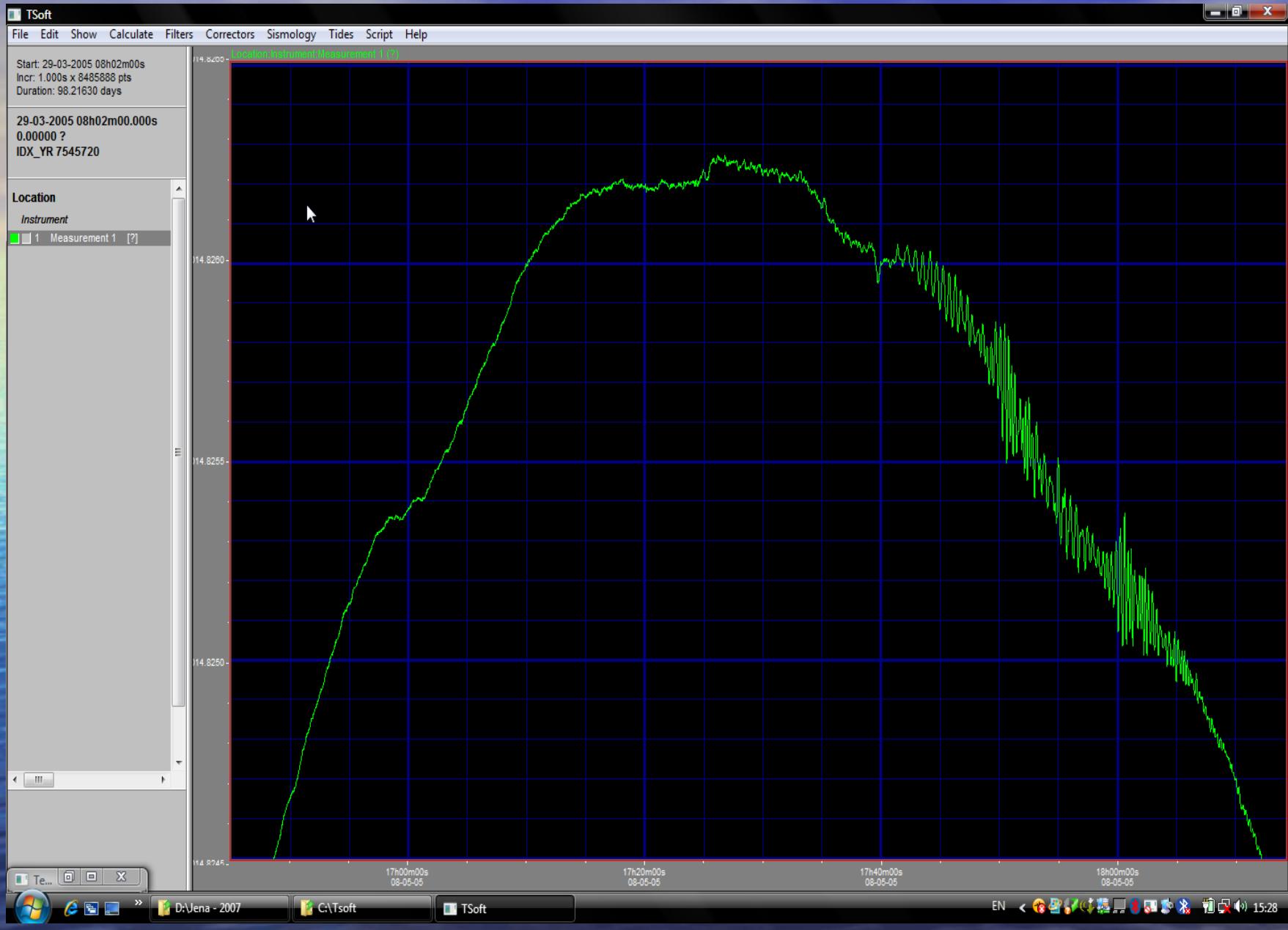
- $1 \text{ nm/s}^2 = 0.1 \mu\text{Gal} \sim 10^{-10} \text{ g}$
- $1 \mu\text{Gal} = 10 \text{ nm/s}^2 \sim 10^{-9} \text{ g}$

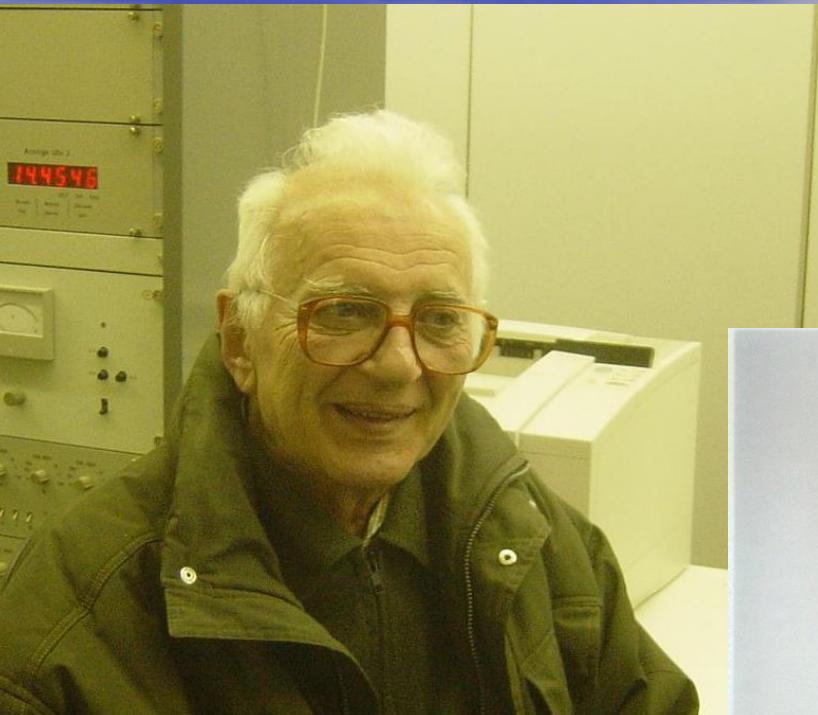
100 days of tidal gravity record with ZLS B-018 gravity meter



1-day record, noise of the order of 0.1 μ Gal







Prof. P. Melchior

Prof. A. Venedikov

Pioneers of tidal data processing

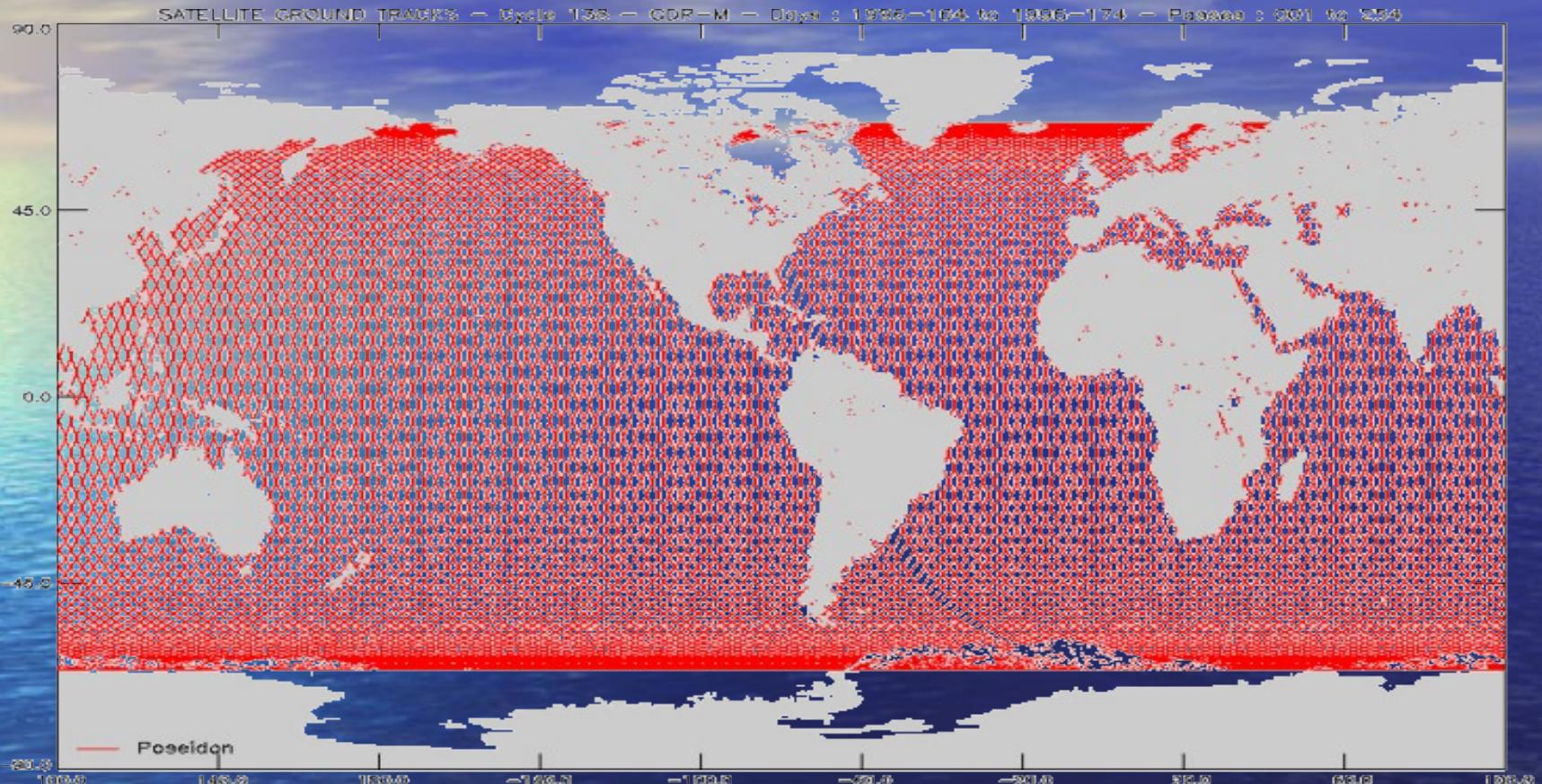
Prof. H.-G. Wenzel

Data processing of tidal observations with ETERNA, or VAV or BAYTAP-G programs uses the harmonic analysis on the base of LSM

- Decomposition of observational series into a sum of harmonic constituents (tidal waves), non-linear drift, atmospheric pressure response, observational noise, ...
- Gaps of any duration are no more problematic
- Better resolution than of spectral analysis

Sophisticated semi-automatic preprocessing with **Tsoft** and **PRETERNA** programs helps to remove steps, spikes and interpolate small gaps in data that are usually unavoidable ...

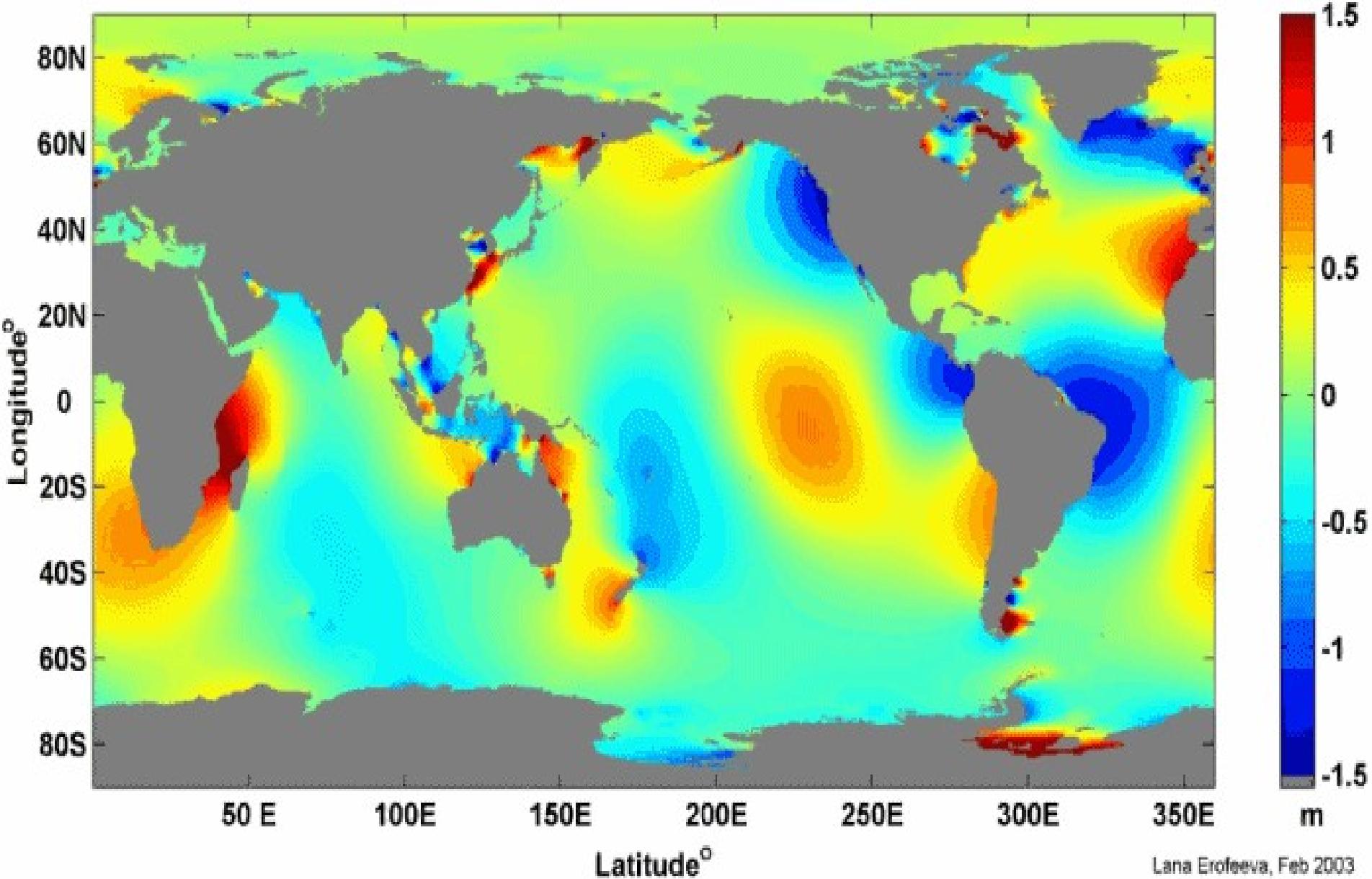
Accurate correction for oceanic and loading tides is necessary



FES'04, NAO'99, TPXO'7, CSR'4, GOT'00, AG'06 - newest oceanic tidal models on the base of satellite altimetry

Oceanic tides

TPXO6 elevations 03:17:2003 00:00GMT



Typical results of tidal observations analysis using ETERNA program

```
#####
# Gravimetric earth tide station Moscow, Russia          #
# Sternberg Astronomical Institute of Moscow State University   #
# Lat= 56.00 N, Lon= 38.0 E, H= 150 m, Vertical component      #
# Gravimeter ZLS B-018                                     #
# 2008.07.23 - 2008.08.21      98  days                   #
#####
```

Number of recorded days in total : 96.88

TAMURA 1987 tidal potential used.

HANN window used for least squares adjustment.

Numerical filter is PERTZEV 1959 with 51 coefficients.

Estimation of noise by FOURIER-spectrum of residuals

0.1 cpd band 9999.9999 nm/s**2	1.0 cpd band 0.5421 nm/s**2
2.0 cpd band 0.2940 nm/s**2	3.0 cpd band 0.2030 nm/s**2

adjusted tidal parameters :

from	to	wave	ampl.	signal/ ampl.fac.	stdv.	phase	lead	stdv.
------	----	------	-------	-------------------	-------	-------	------	-------

			nm/s**2	noise		[deg]		[deg]
286	428	Q1	63.304	116.8	1.14727	0.00982	1.7057	0.4906
429	488	01	330.763	610.2	1.14773	0.00188	1.6489	0.0939
489	537	M1	25.487	47.0	1.12450	0.02392	1.9682	1.2186
538	592	P1S1	459.234	847.2	1.13306	0.00134	1.8208	0.0676
593	634	J1	25.907	47.8	1.14306	0.02392	2.2203	1.1988
635	736	001	13.924	25.7	1.12280	0.04371	0.7173	2.2305
737	839	2N2	7.879	26.8	1.09619	0.04091	1.4245	2.1383
840	890	N2	53.881	183.2	1.19719	0.00653	1.6000	0.3127
891	947	M2	277.689	944.4	1.18132	0.00125	2.0230	0.0607
948	987	L2	7.588	25.8	1.14200	0.04425	3.3879	2.2203
988	1121	S2K2	128.416	436.7	1.17420	0.00269	1.1863	0.1312

Standard deviation

: 5.159 nm/s**2

The same without filters. Tchebyshev polinomials are used for drift approximation

- Number of recorded days in total : 96.88
- TAMURA 1987 tidal potential used.
- HANN window used for least squares adjustment.
- Numerical filter is NO FILTER with 1 coefficients.
- adjusted tidal parameters :

from	to	wave	ampl.	signal/ noise	ampl.fac.	stdv.	phase [deg]	lead [deg]	stdv.
91	153	Mf	81.018	8.2	1.18969	0.14430	-3.8539	6.9495	
286	428	Q1	63.345	110.3	1.14802	0.01041	1.6895	0.5197	
429	488	01	330.750	575.7	1.14768	0.00199	1.6427	0.0995	
489	537	M1	25.469	44.3	1.12374	0.02535	1.9920	1.2925	
538	592	P1S1	459.237	799.3	1.13306	0.00142	1.8198	0.0717	
593	634	J1	25.896	45.1	1.14258	0.02535	2.1625	1.2712	
635	736	001	13.931	24.2	1.12338	0.04633	0.7213	2.3630	
737	839	2N2	7.879	26.1	1.09624	0.04207	1.4431	2.1986	
840	890	N2	53.894	178.3	1.19750	0.00672	1.6041	0.3214	
891	947	M2	277.684	918.5	1.18130	0.00129	2.0209	0.0624	
948	987	L2	7.592	25.1	1.14264	0.04550	3.3674	2.2817	
988	1121	S2K2	128.437	424.8	1.17439	0.00276	1.1871	0.1349	
1122	1194	M3	2.994	15.9	1.15690	0.07260	1.3146	3.5954	
- Standard deviation : 40.796 nm/s**2
- Adjusted TSCHEBYSCHEFF polynomial bias parameters :

block	degree	bias	stdv.
1	0	7160.746951 nm/s**2	3.088640 nm/s**2
1	1	149.037851 nm/s**2	3.307733 nm/s**2
1	2	29.059356 nm/s**2	3.856850 nm/s**2
2	0	7863.797844 nm/s**2	3.086766 nm/s**2
2	1	317.611723 nm/s**2	3.306347 nm/s**2
2	2	155.205499 nm/s**2	3.854495 nm/s**2

Tidal observations at LNE, Trappes

- **gravimeter Scintrex CG-5 No 105
belonging to Paris Observatory**
- **2006-2007**

```

#####
# Gravimetric earth tide station Trappes, LNE          #
# Lat= 48.761 N, Lon= 1.983 E, H= 160 m, Vertical component   #
# Gravimeter Scintrex CG-5                                #
# 13.12.2006-11.05.2007      150  days                  #
# Installation:    S.Merlet, LNE-SYRTE                   #
# Data processing: A.Kopaev, M.Yarkov                    #
# Original Manufacturer Calibration                   #
#####
Summary of observation data :
20061213190000...20070126 20000  20070126190000...20070403230000
20070404170000...20070510230000
Number of recorded days in total : 146.83

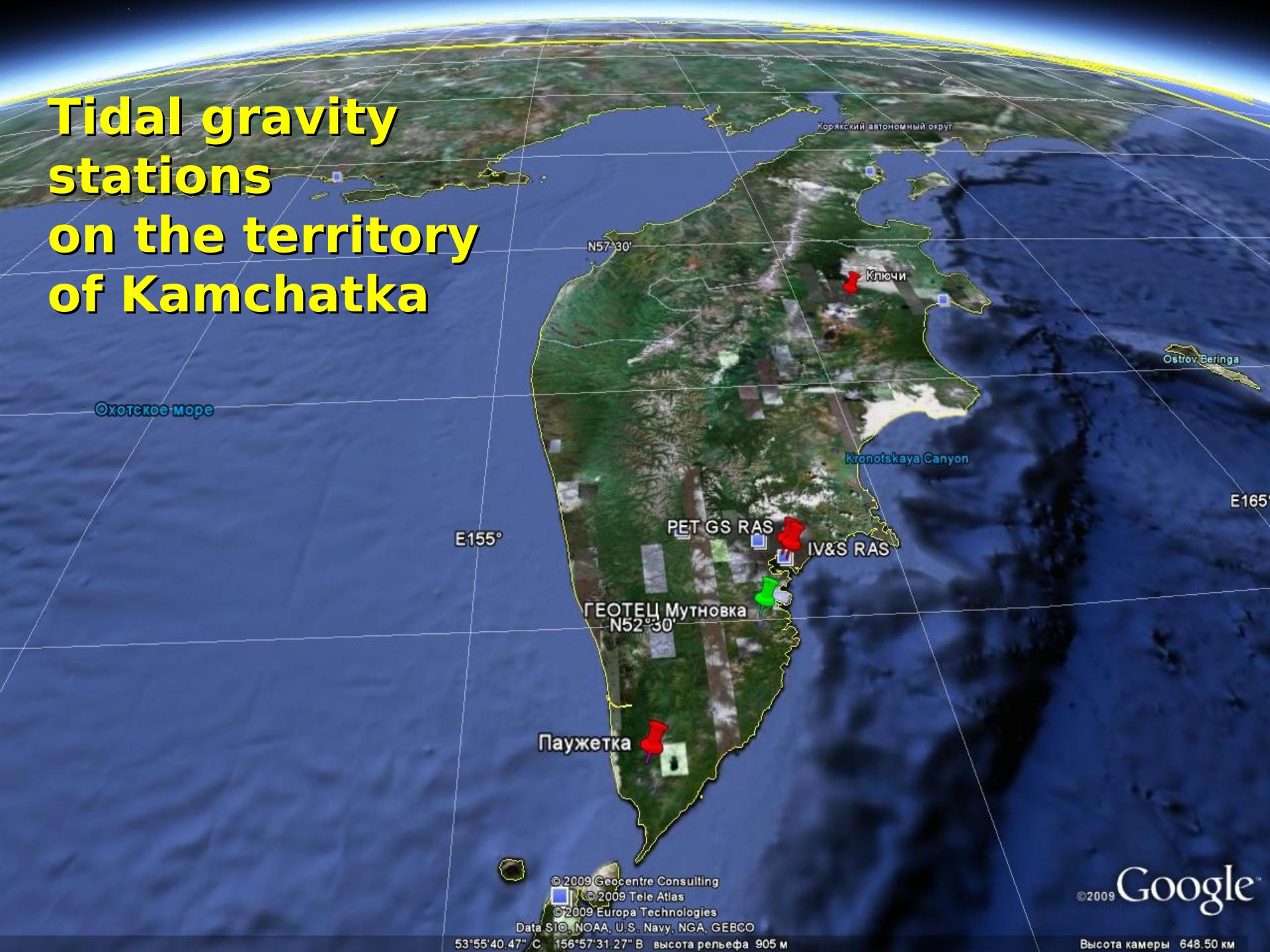
adjusted tidal parameters :
from    to    wave    ampl. signal/ ampl.fac.    stdv. phase lead    stdv.
              nm/s**2    noise                               [deg]    [deg]
286    428  Q1    66.855    112.9    1.13363    0.01004   -0.8808   0.5076
429    488  01    352.580   595.3    1.14466    0.00192    0.0029   0.0962
489    537  M1    28.293    47.8    1.16795    0.02445   -0.3015   1.1994
538    592  P1S1  493.424   833.1    1.13903    0.00137    0.3391   0.0688
593    634  J1    28.239    47.7    1.16575    0.02445    0.4235   1.2017
635    736  001   15.336    25.9    1.15708    0.04469    0.0265   2.2127
737    839  2N2   11.238    31.7    1.12560    0.03547    3.2582   1.8056
840    890  N2    73.322   207.0    1.17281    0.00566    3.6573   0.2767
891    947  M2    389.664  1100.3    1.19334    0.00108    3.3941   0.0521
948    987  L2    11.057    31.2    1.19796    0.03837   -0.7334   1.8352
988   1121  S2K2  182.547   515.5    1.20160    0.00233    1.3352   0.1112
1122   1194  M3     4.306    11.8    1.01643    0.08582   -3.2515   4.8376
Standard deviation : 7.042 nm/s**2

```

Tidal observations close to the sea/ocean are of special interest

- Oceanic tides cause direct attraction as well as deform the earth crust considerably on the distances up to hundreds of km
- Tidal gravity observations in “natural volcano-tectonic laboratory” of Kamchatka Peninsula have started recently by joint efforts of Institute of Volcanology and Seismology of RAS and SAI MSU

Tidal gravity stations on the territory of Kamchatka



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©2009 Europa Technologies

Data SIO, NOAA, U.S. Navy, NGA, GEBCO

53°55'40.47" С 156°57'31.27" В высота рельефа 905 м

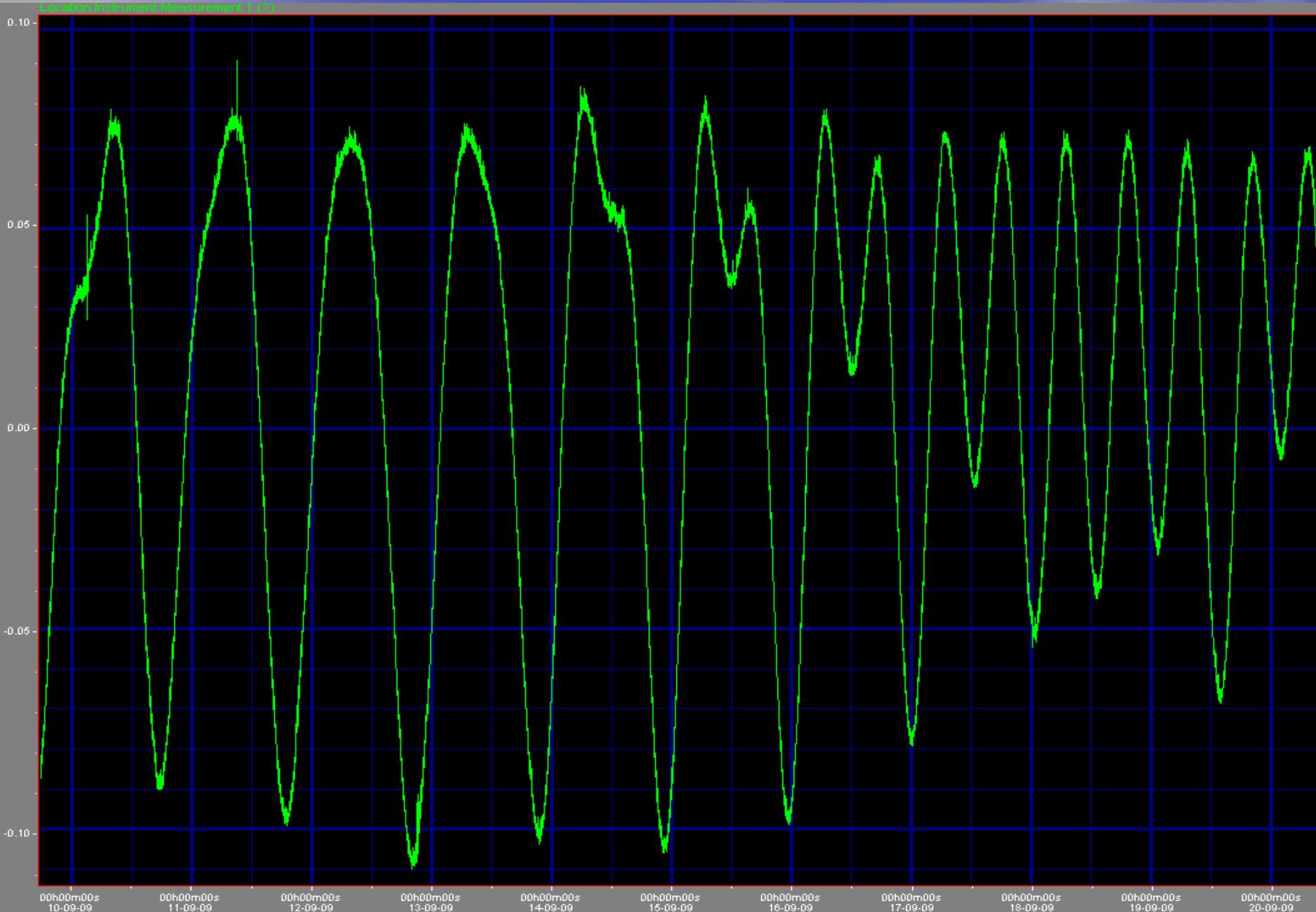
©2009 Google™

Высота камеры 648.50 км

Scintrex gravity meters №№ 448 и 450 at PET seismological station



Example of 10-days record at PET station



- Summary of observation data :

- 20090206 80000...20090412150000 20090413 80000...20090512140000
- 20090513 80000...20090626210000 20090723 80000...20091005170000

- Number of recorded days in total : **213.63**

- TAMURA 1987 tidal potential used.
- UNITY window used for least squares adjustment.
- Numerical filter is PERTZEV 1959 with 51 coefficients.

- Estimation of noise by FOURIER-spectrum of residuals

0.1 cpd band	9999.9999 nm/s**2	1.0 cpd band	1.0312 nm/s**2
2.0 cpd band	0.6191 nm/s**2	3.0 cpd band	0.4675 nm/s**2
4.0 cpd band	0.4072 nm/s**2		

- adjusted tidal parameters :

from	to	wave	ampl.	signal/	ampl.fac.	stdv.	phase	lead	stdv.
			nm/s**2	noise			[deg]		[deg]

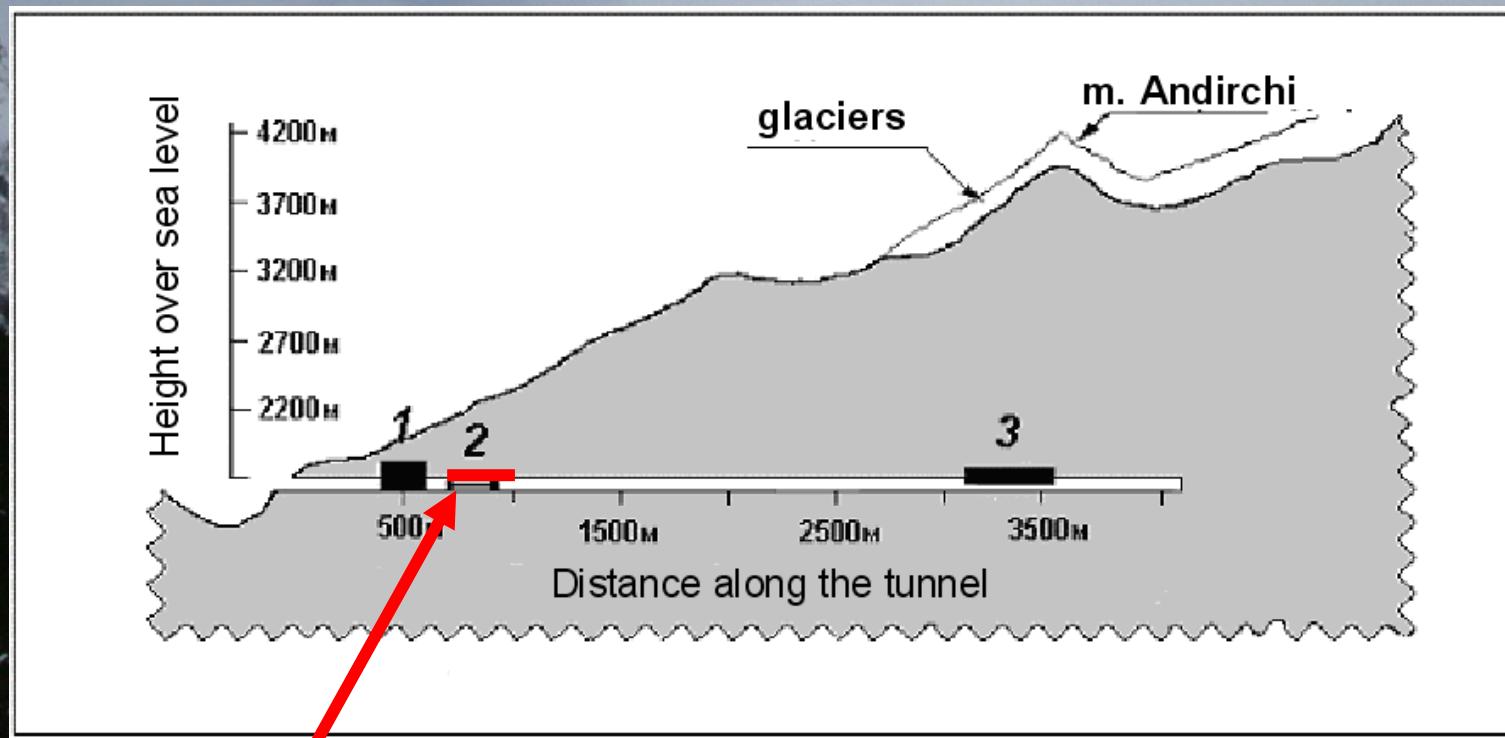
•	286	428	Q1	69.904	67.8	1.22219	0.01803	5.5661	0.8452
•	429	488	01	369.781	358.6	1.23784	0.00345	4.2251	0.1598
•	489	537	M1	29.994	29.1	1.27668	0.04389	-2.3567	1.9698
•	538	592	P1S1	510.853	495.4	1.21593	0.00245	2.3348	0.1157
•	593	634	J1	28.782	27.9	1.22511	0.04389	2.1967	2.0528
•	635	736	001	13.732	13.3	1.06828	0.08022	2.5686	4.3024
•	737	839	2N2	9.532	15.4	1.14524	0.07439	0.5280	3.7215
•	840	890	N2	59.106	95.5	1.13405	0.01188	2.3106	0.6002
•	891	947	M2	321.220	518.8	1.18000	0.00227	2.9618	0.1104
•	948	987	L2	10.696	17.3	1.39009	0.08046	-0.4495	3.3165
•	988	1121	S2K2	153.492	247.9	1.21192	0.00489	0.6920	0.2311
•	1122	1194	M3	4.042	8.6	1.25334	0.14493	6.0441	6.6254

Tidal strain observations at SAI MSU

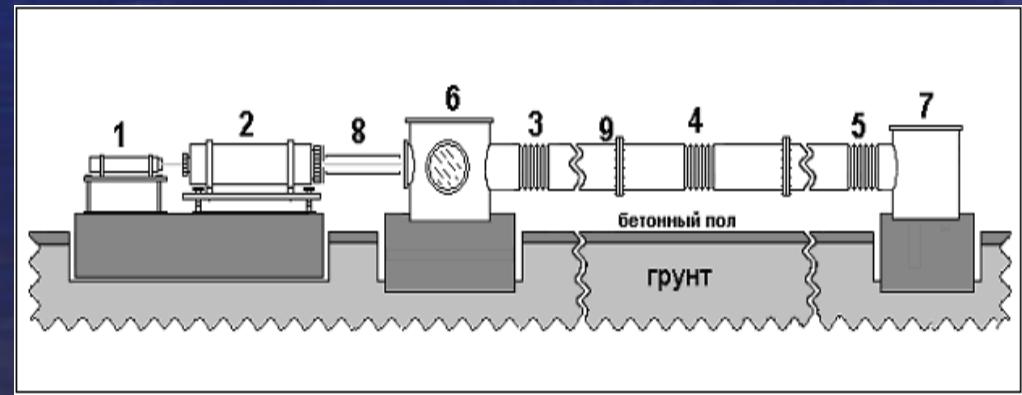
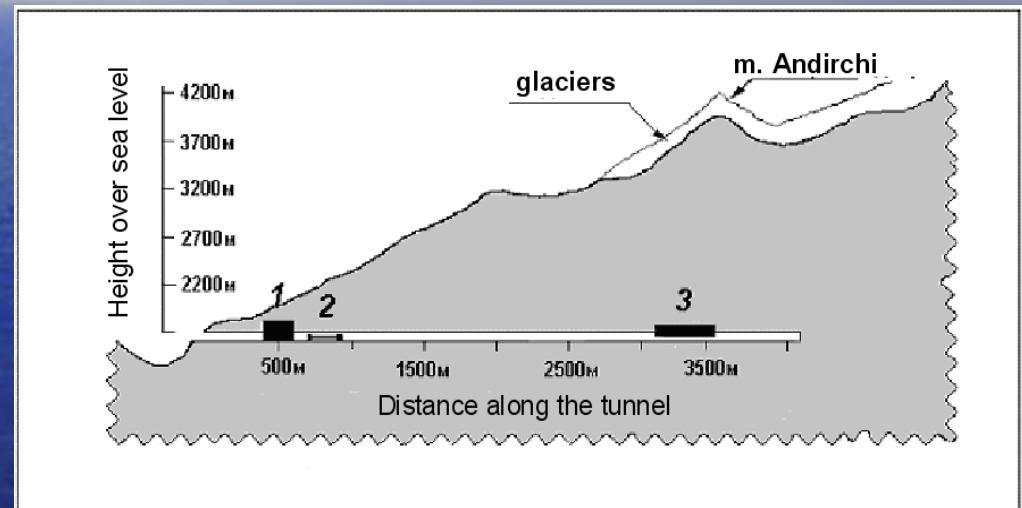
Baksan Geodynamical Observatory of Moscow University

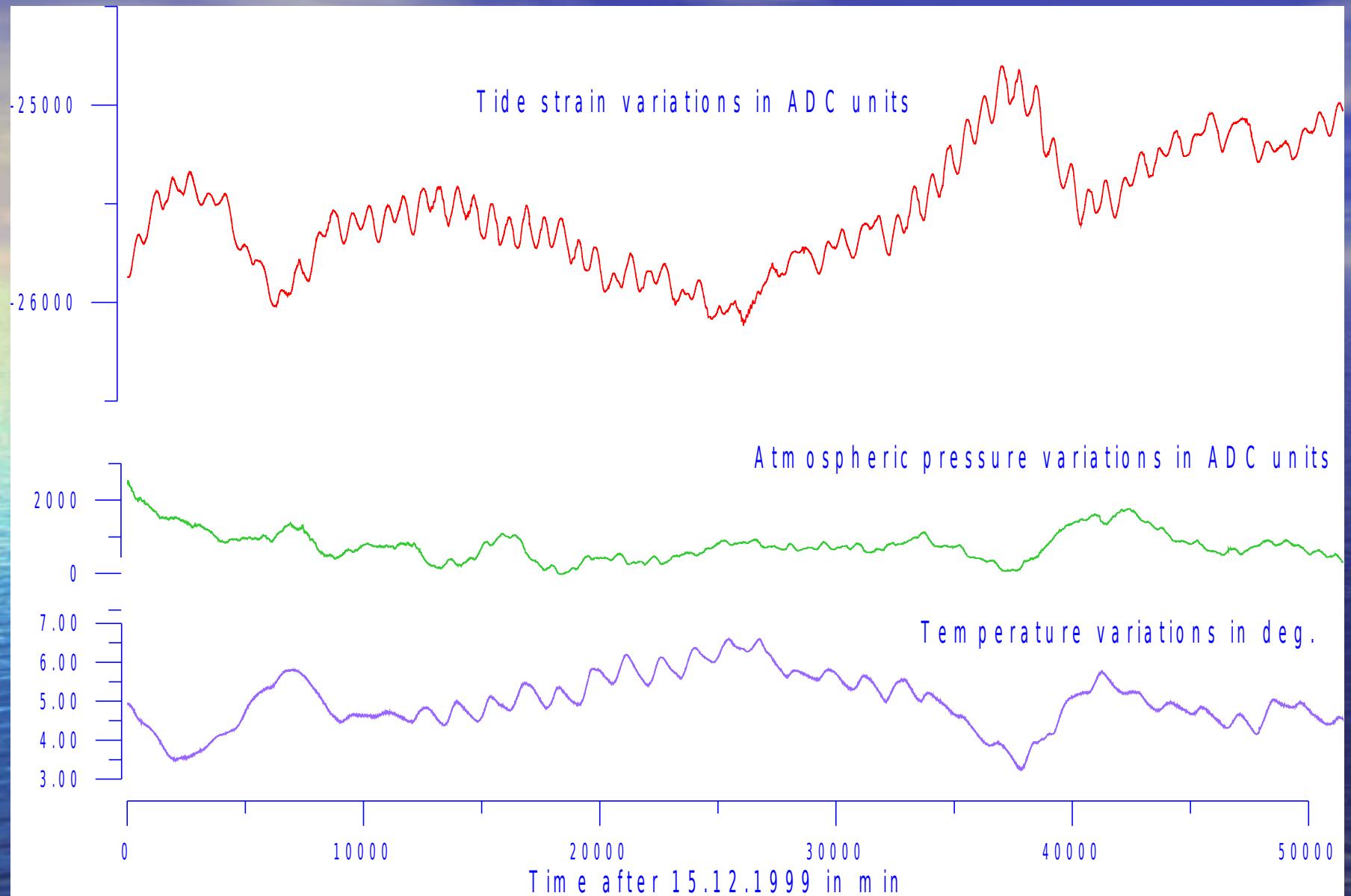
Location: Baksan canyon, 20 km apart from Elbrus sleeping volcano

Latitude $43^{\circ}12'$, Longitude $-42^{\circ}43'$,



Baksan laser strainmeter of SAI MSU with length of 75 m is located along the tunnel of Baksan Neutrino observatory of RAS on the depth of 650 m





Example of tidal strain record together with atmospheric pressure and temperature variations

Results of harmonic analysis with ETERNA of strain record during XI / 2003 - XI / 2006

from	to	wave	ampl. nstr	signal/ noise	ampl.fac.	stdv.	phase lead [deg]	stdv. [deg]
286	428	Q1	1.068	9.0	1.07133	0.11861	-4.2100	6.3433
429	488	O1	5.470	46.2	1.05024	0.02271	-1.4842	1.2389
489	537	M1	0.469	4.0	1.14541	0.28875	16.6051	14.4438
538	554	P1	2.178	18.4	0.89876	0.04881	-23.1604	3.1113
555	558	S1	2.159	18.3	7.67248	2.06352	-3.5701	3.1384
559	592	K1	6.145	52.0	0.83890	0.01615	-8.9855	1.1028
593	634	J1	0.358	3.0	0.87518	0.28876	-12.1582	18.9043
635	736	001	0.214	1.8	0.95552	0.52769	0.9469	31.6420
737	839	2N2	0.320	7.9	0.99216	0.12635	-2.3335	7.2965
840	890	N2	2.189	53.7	1.08435	0.02018	0.1335	1.0662
891	947	M2	11.595	284.6	1.09958	0.00386	-0.0483	0.2013
948	987	L2	0.300	7.4	1.00792	0.13668	2.2073	7.7694
988	1008	S2	5.281	129.6	1.07641	0.00830	0.0999	0.4420
1009	1121	K2	1.453	35.7	1.08930	0.03054	-0.2794	1.6065

M2: S/N ≈ 285

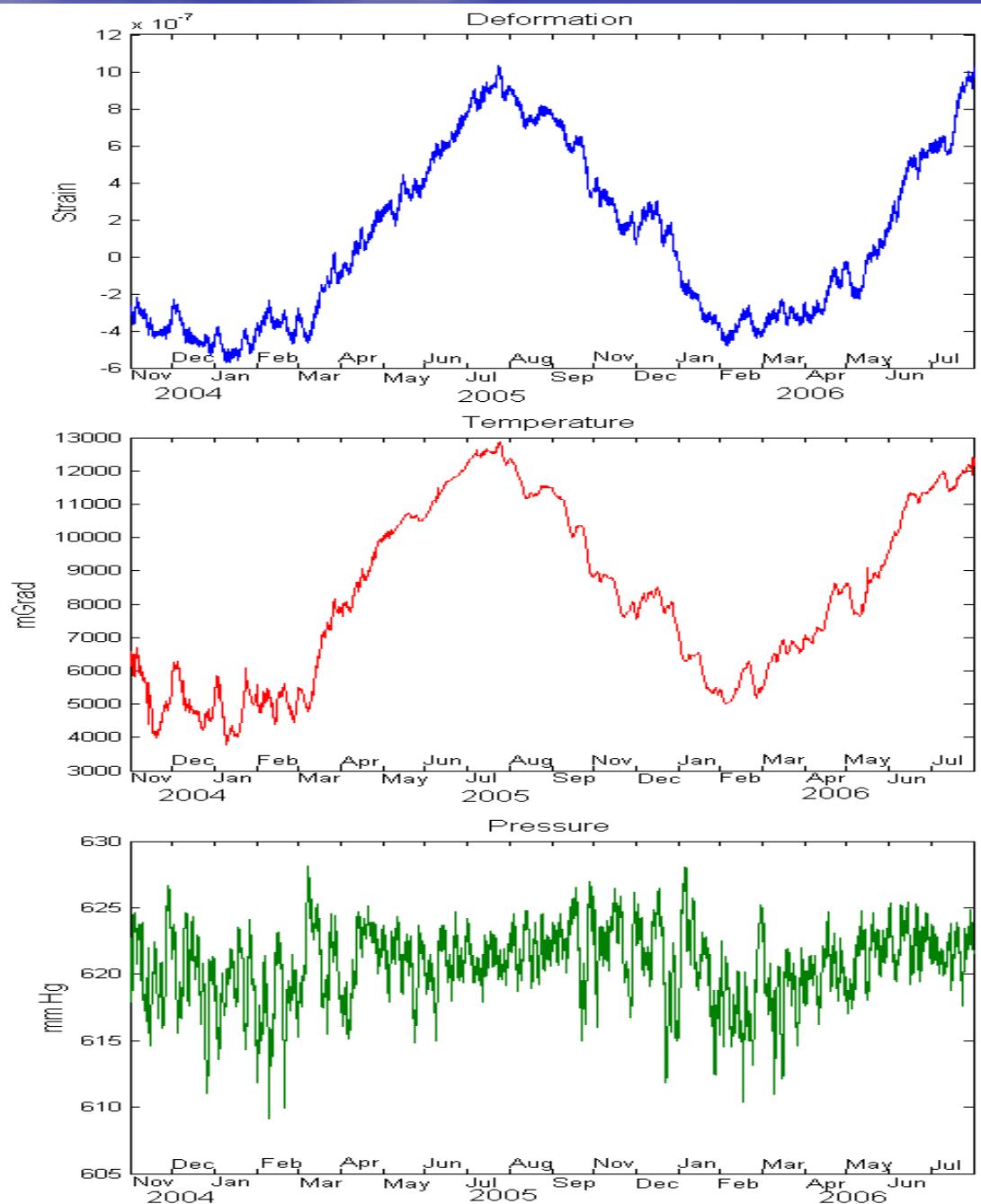
O1: S/N ≈ 46

K1 /O1 = 0.80 ± 0.02

**Strain variation
during 20
months (Nov
2004 - July
2006)**

**Temperature
variation of the
rock**

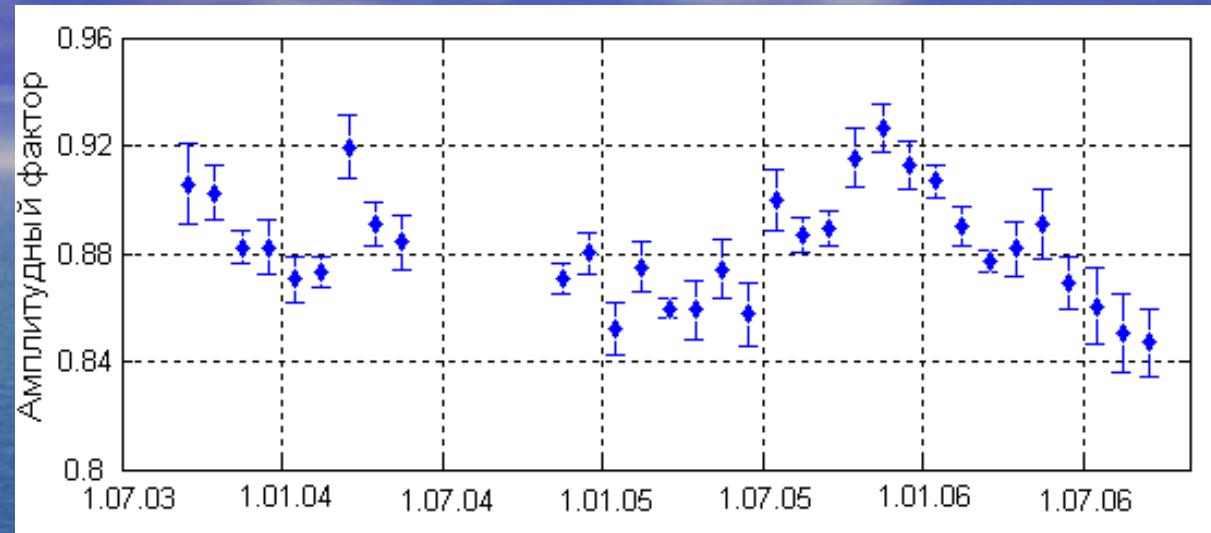
**Pressur
e
variatio
n**



Time stability of M2 and O1 amplitudes

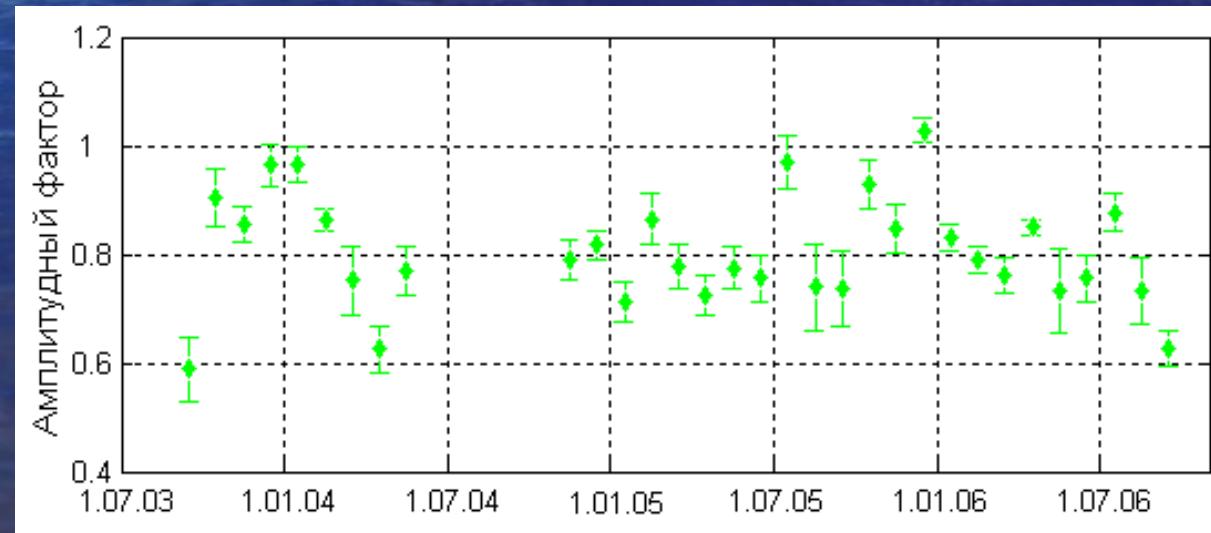
- M2

S/N ~ 100-200
mean anomaly:
12%



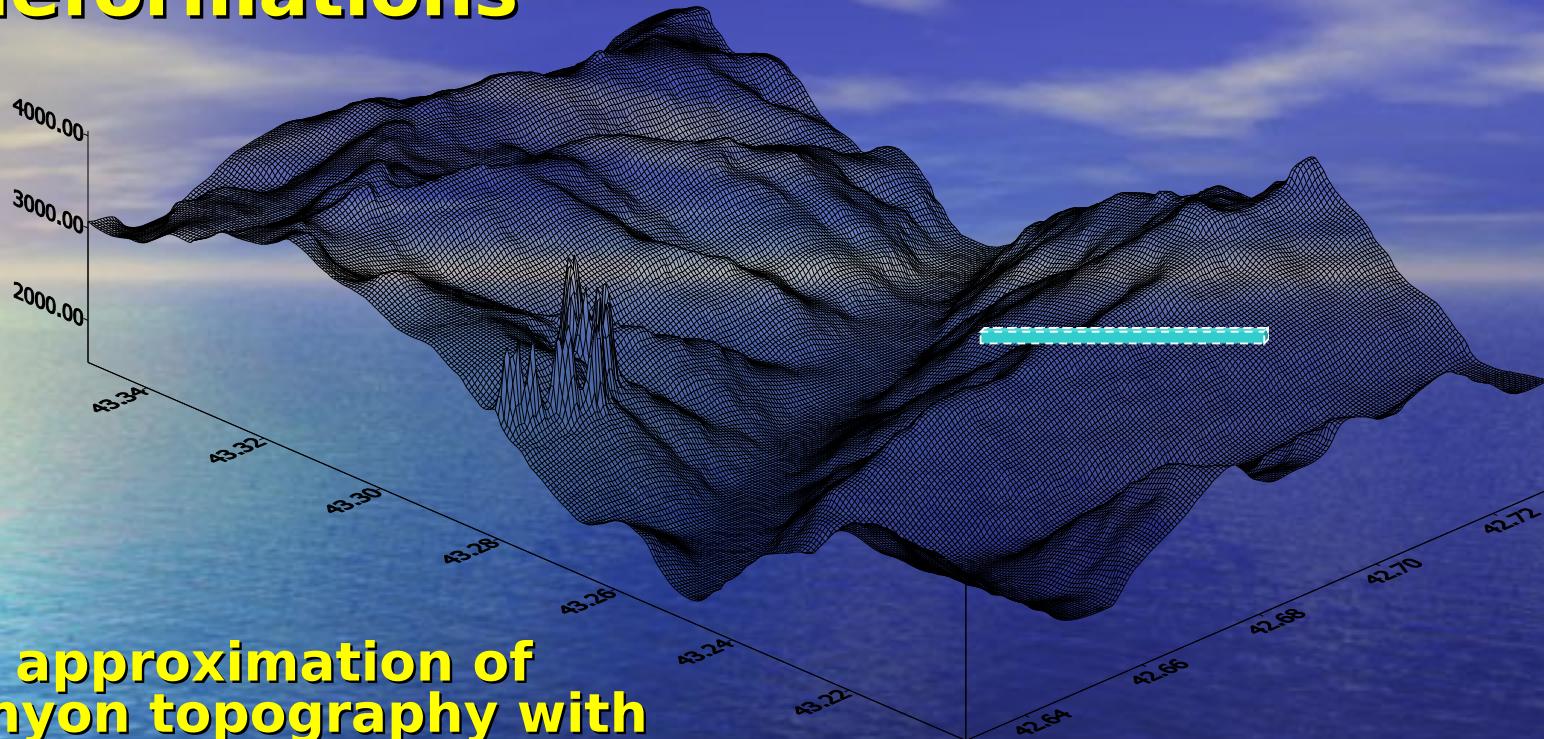
- O1

S/N ~ 20-50
mean anomaly:
20%



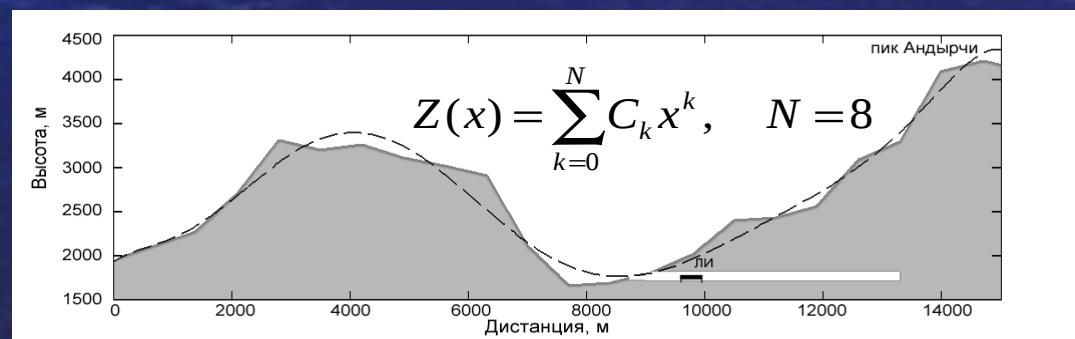
- We have developed recently the original (and probably optimal in presence of enormously large correlated noise of meteorological origin) techniques based on iterative application of TSoft, PRETERNA and ETERNA programs that helps to reduce its influence by 30-50 %

Topography correction in tidal deformations

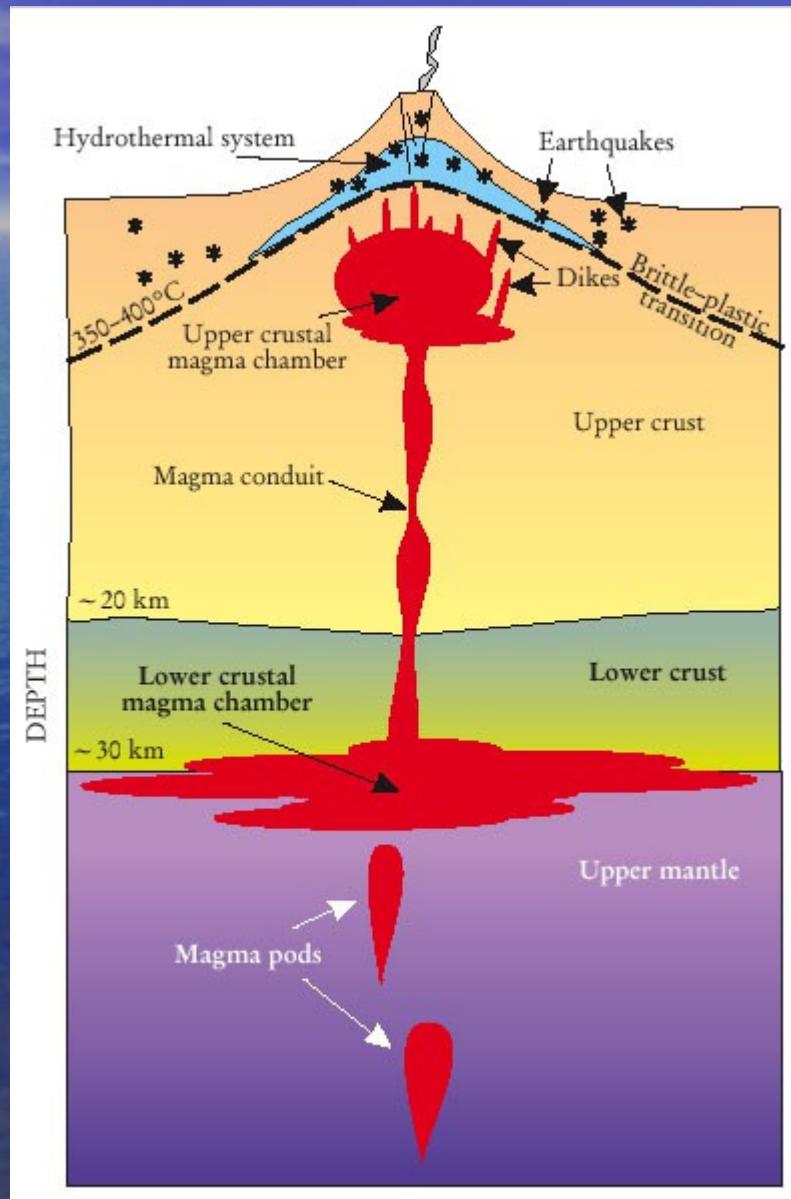


- 2D approximation of canyon topography with a 8th degree polynomial

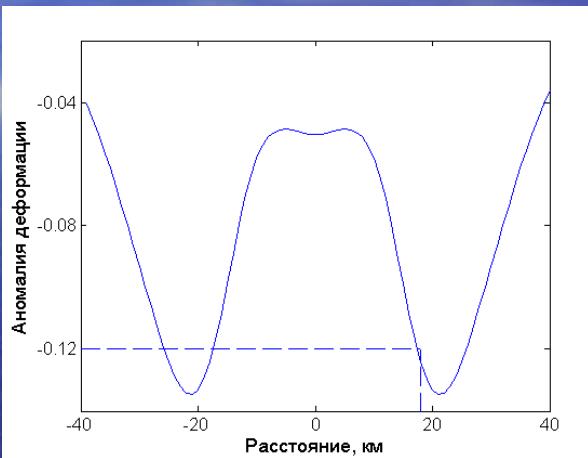
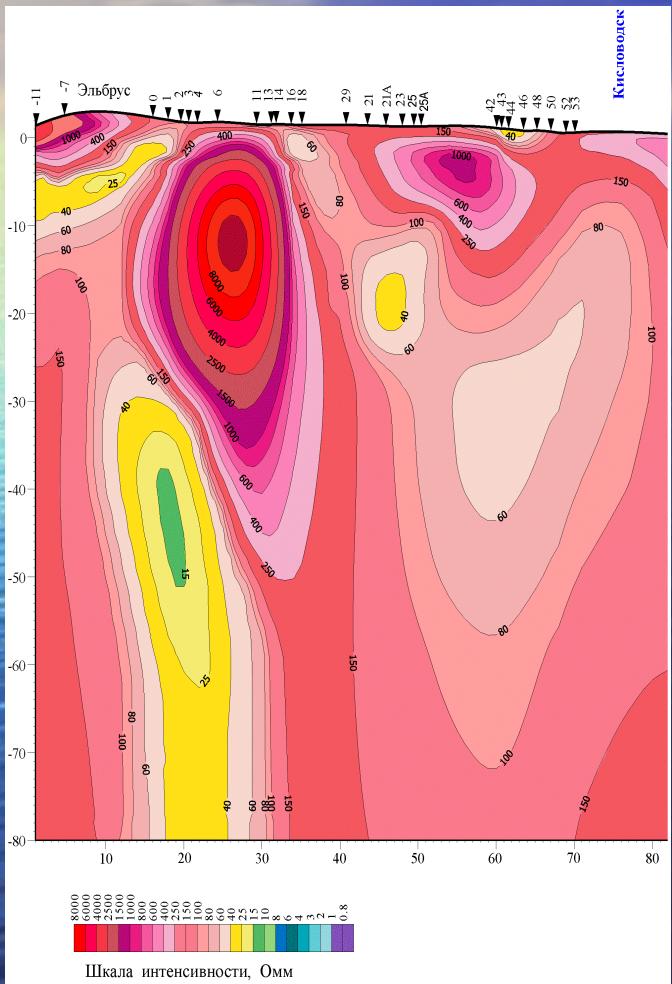
- Tidal deformations of relief increase
- observed values
- by $\sim 20\% \pm ??$



Continental volcanoes composition



Influence of magmagenenerating fault on tidal strains (Molodenskii, 1977)

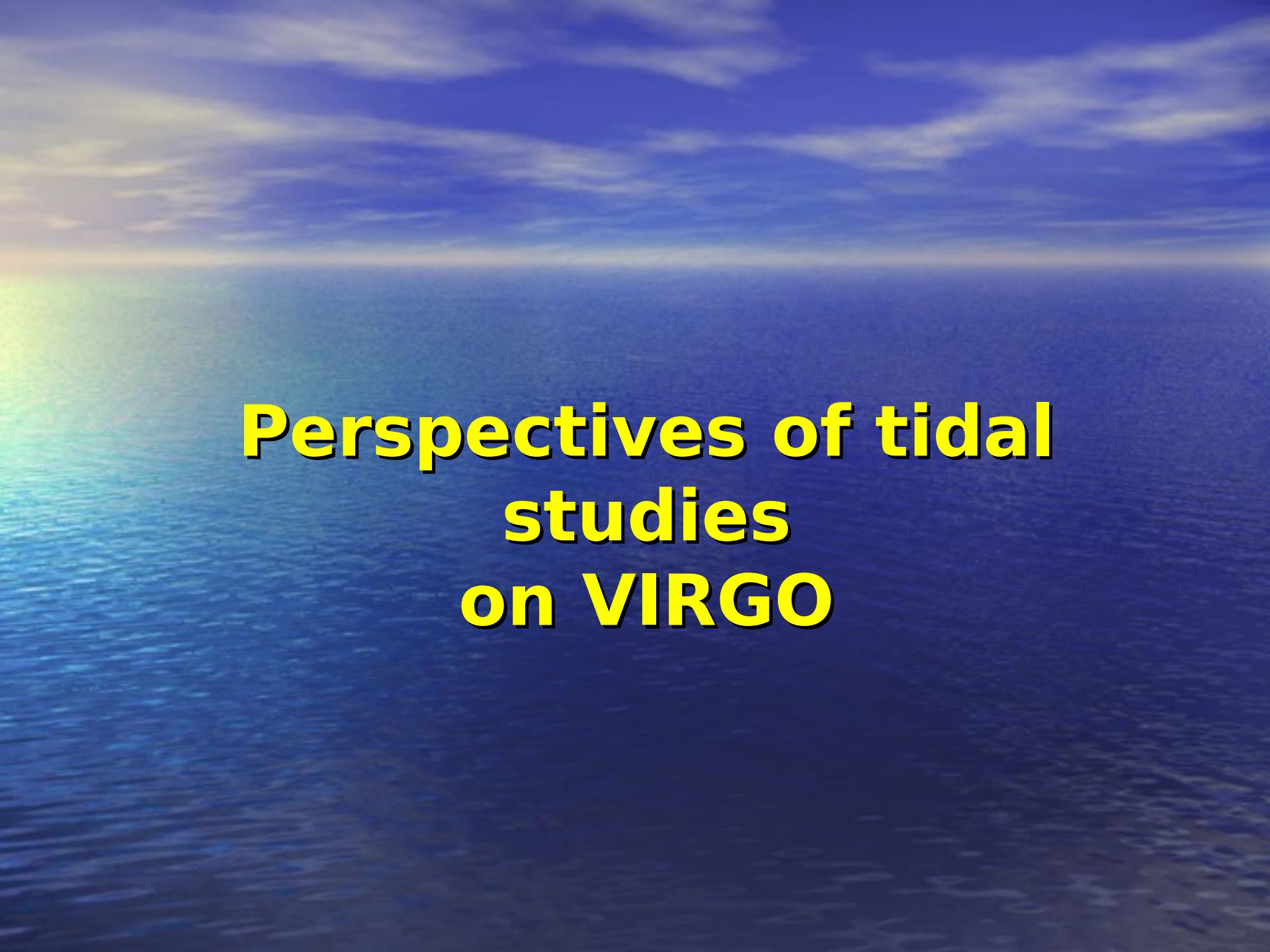


$\delta V_p / V_p \approx -0.25$;
 $\delta V_s / V_s \approx -0.25$;
 $\lambda \approx \mu$

Anomaly of 12%
on the distance of 18 km

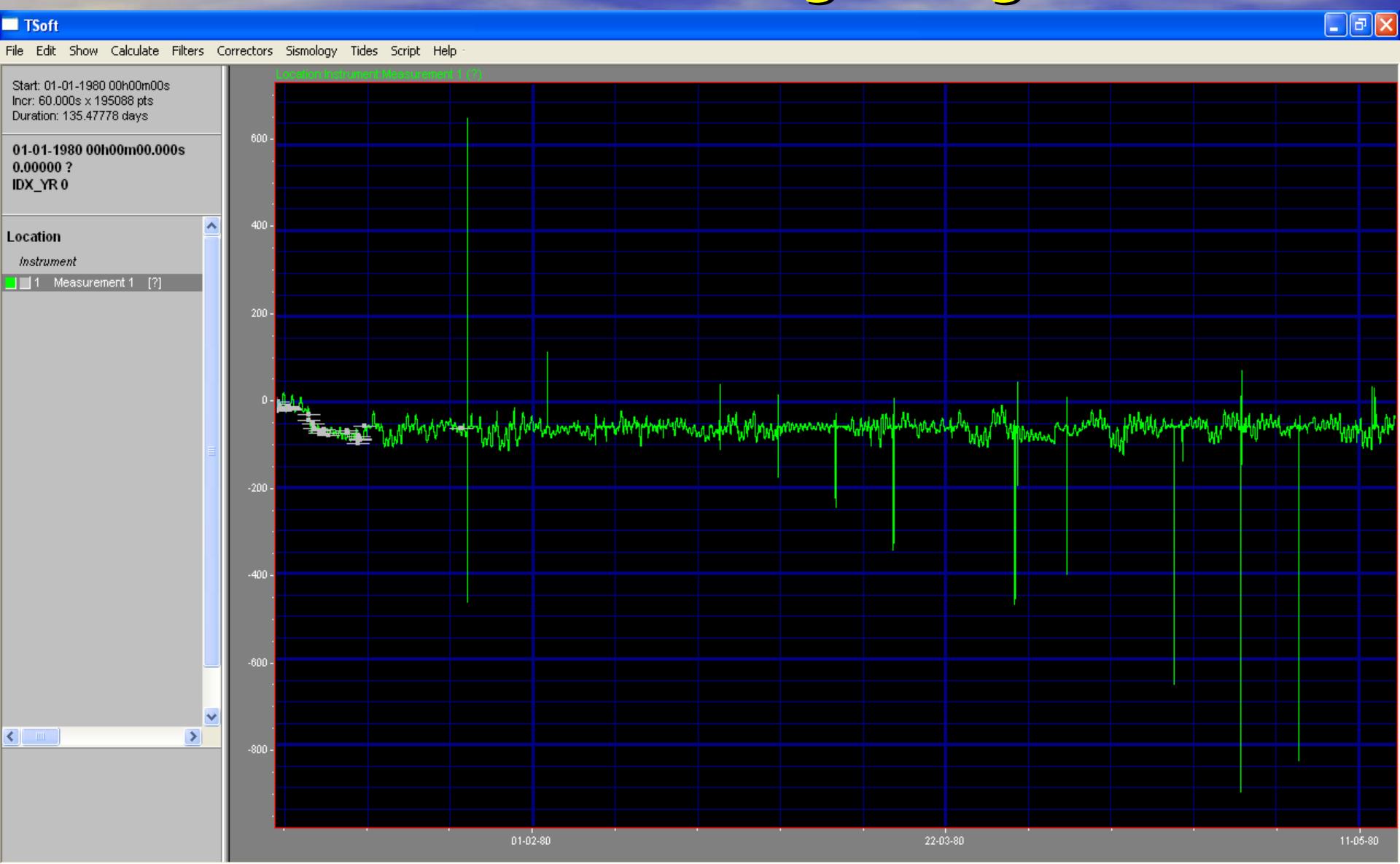
Conclusions

- Both superconducting GWR as well as field ZLS-Burris and Scintrex CG-5 gravity meters are able to record tidal gravity variations giving S/N ratio up to 1000 for main tidal waves
- Tidal strains could be effectively recorded with the help of laser strain meters. Due to the coherent meteorological noise influence the S/N ratio is hardly to achieve better than 100 resp. 300 for main tidal waves O1 and M2

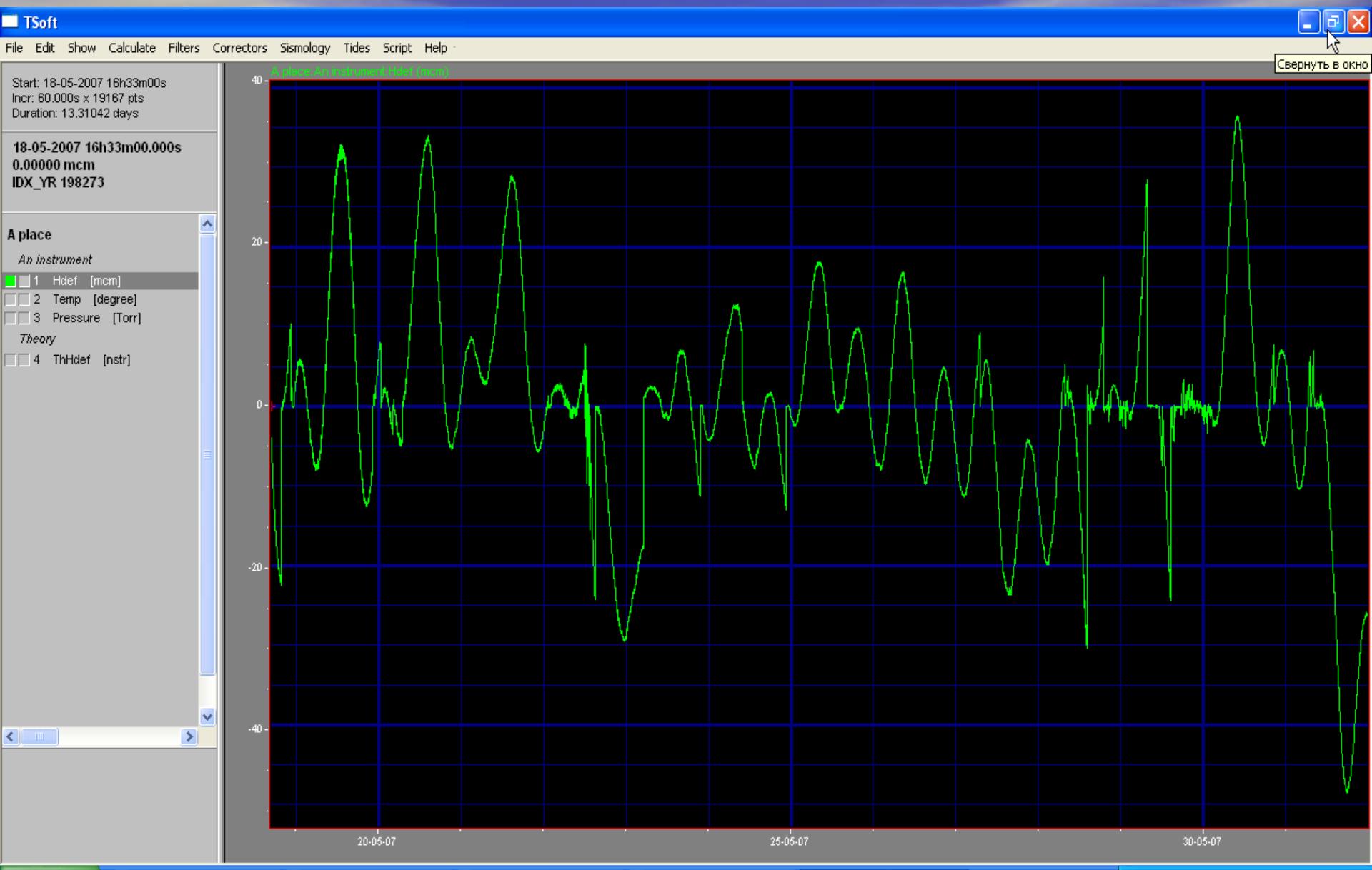


Perspectives of tidal studies on VIRGO

Example of low frequency VIRGO output, semi-automatic cleaning using TSoft



Beginning of record, tides are clearly visible



Start: 18-05-2007 16h33m00s
Incr: 60.000s x 19167 pts
Duration: 13.31042 days

18-05-2007 16h33m00.000s
0.00000 nstr
IDX_YR 198273

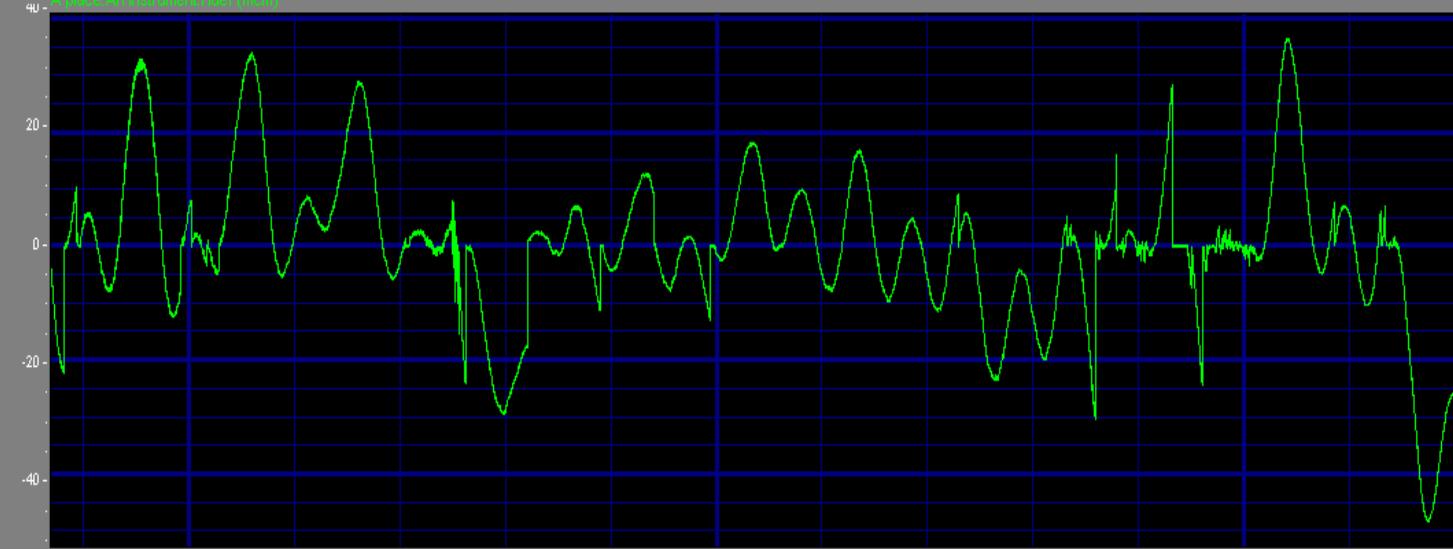
A place*An instrument*

- 1 Hdef [mcm]
- 2 Temp [degree]
- 3 Pressure [Torr]

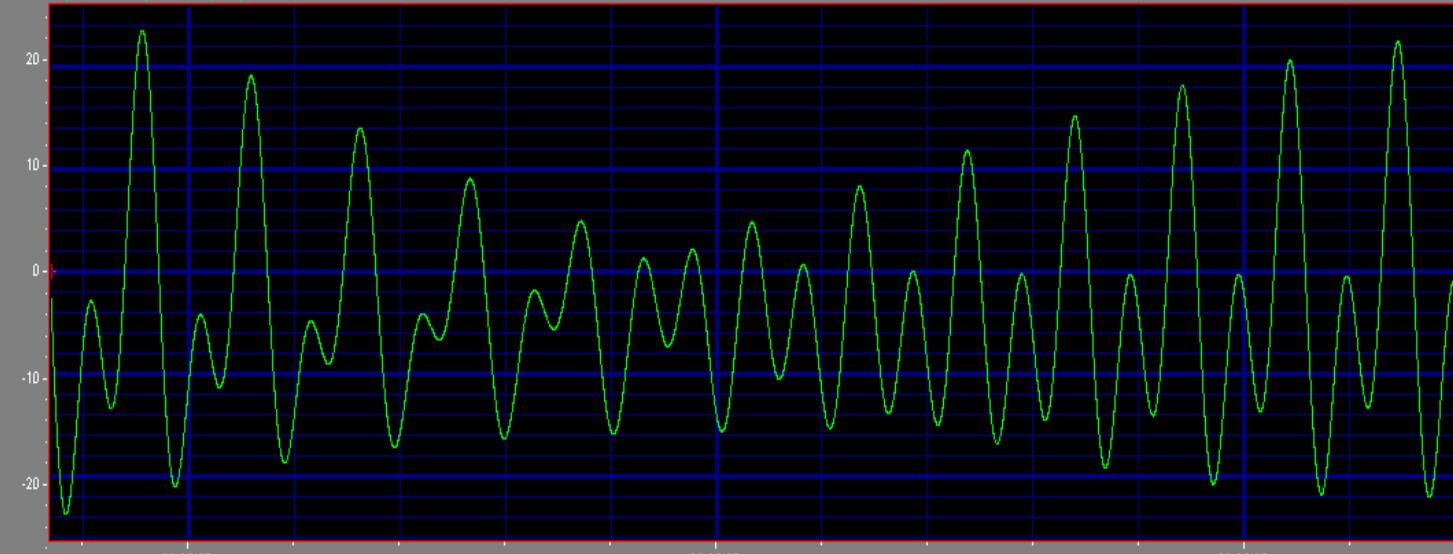
Theory

- 4 ThHdef [nstr]

A place/An instrument: level (picm)

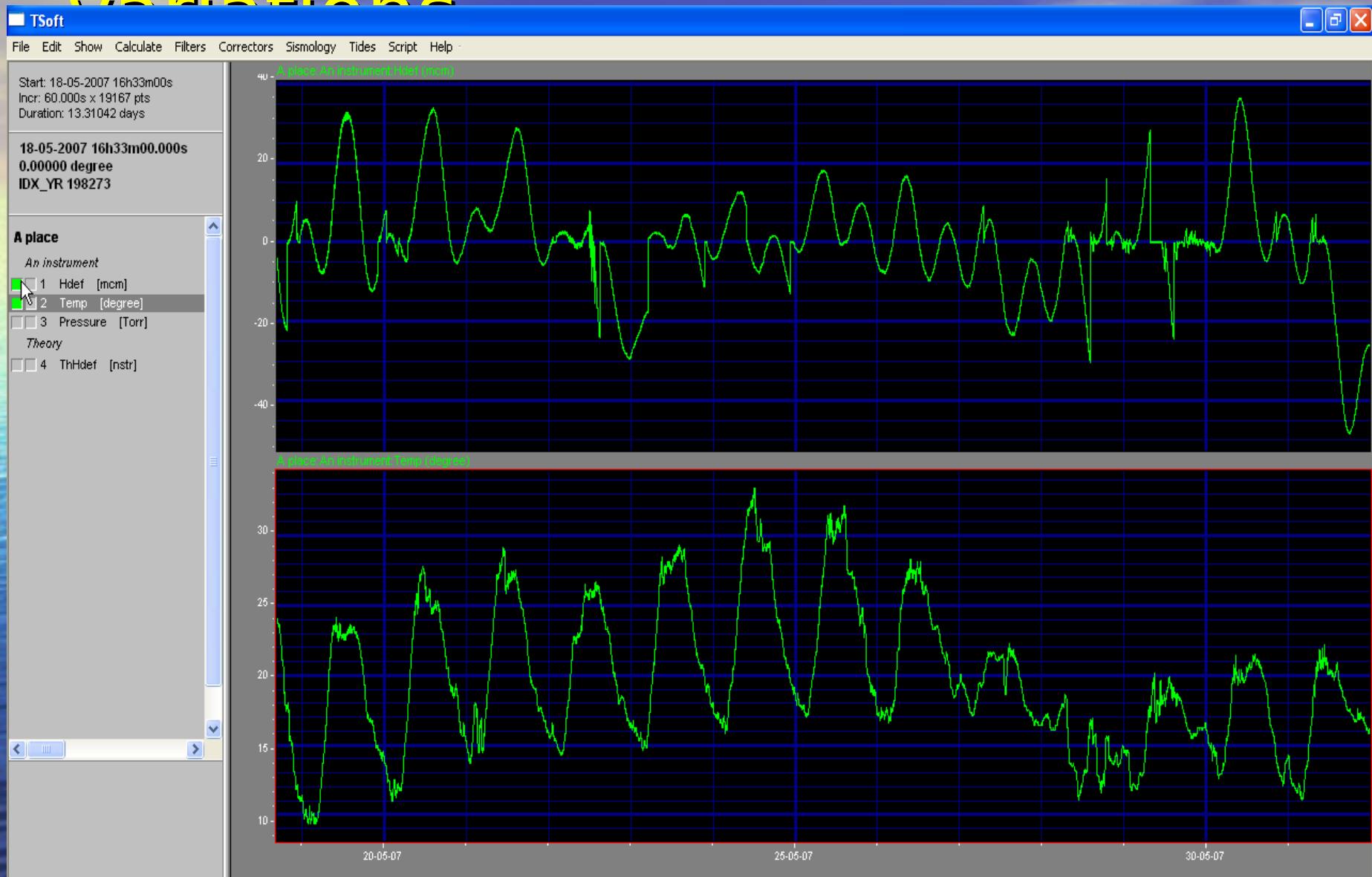


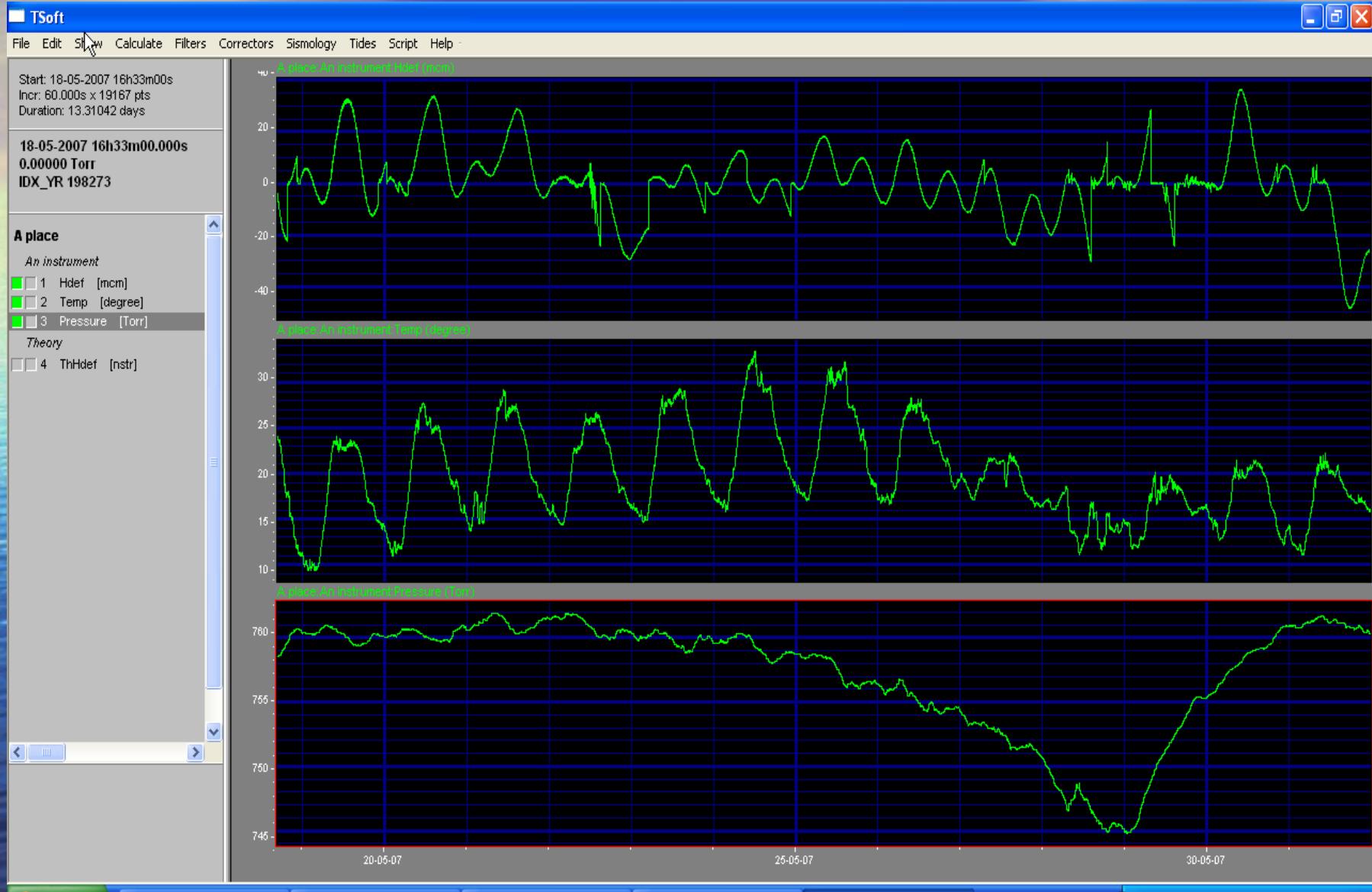
A place/Theory: ThHdef (nstr)



Tides and temperature

variations





Future Plans

- **Exhaustive data preprocessing with TSoft and PRETERNA**
- **Harmonic analysis with ETERNA**
- **Determination of pressure and temperature frequency dependant admittances**
- **Estimation of tidal parameters for main waves**
- **Improvement of low-frequency modeling of VIRGO suspension system**
- **Improvement the tidal modeling using ETGTAB**



**Thank you for attention
and/or patience!**