On the influence of ocean dynamics on gravity noise

Papp Gábor, Szűcs Eszter, Battha László, Benedek Judit

Geodetic and Geophysical Institute of the
Research Centre for Astronomy and Earth Sciences
Hungarian Academy of Sciences
Sopron - *Civitas Fidelissima*

Draft of the presentation

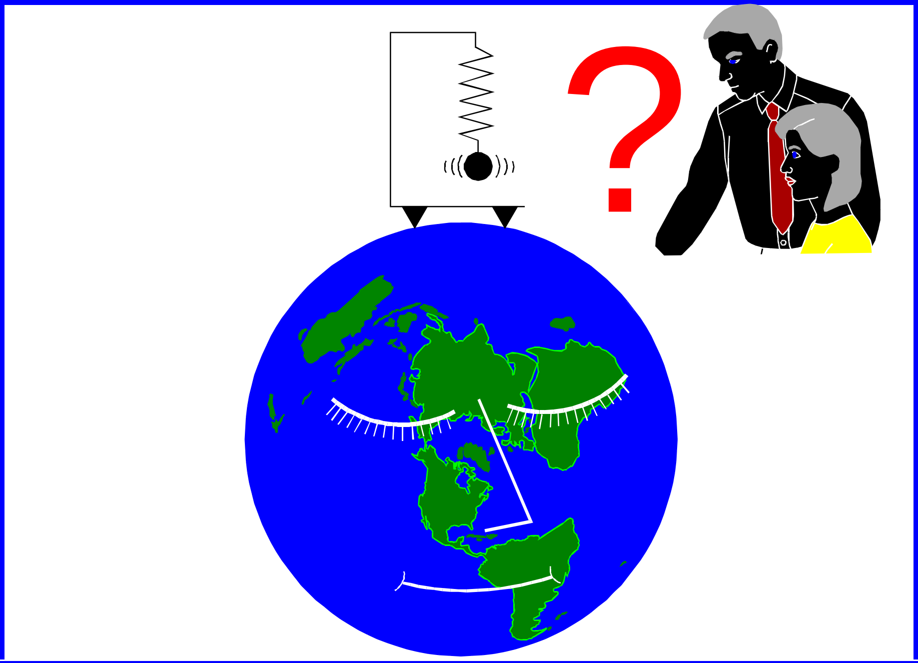
- "Eppur si muove..." - the lament of *homo gravimetricus*
- Non-gravitational effects in **g** observations
- Comparison of gravity tide and microseismic noise
- Level of the gravity noise observed in Sopronbánfalva Observatory (West Hungary) between 08.06.2010 és 04.01.2011
- Estimation of the sensitivity of gravimetric observations based on spectral analysis of co-located seismological records
- Identification of the sources of microseisms
- Spectral analysis of 1 Hz records (*preliminary results*)

Eppur si muove

- The lament of *homo gravimetricus*,

  i.e.

  Why does his instrument tremble when no earthquake can be felt?

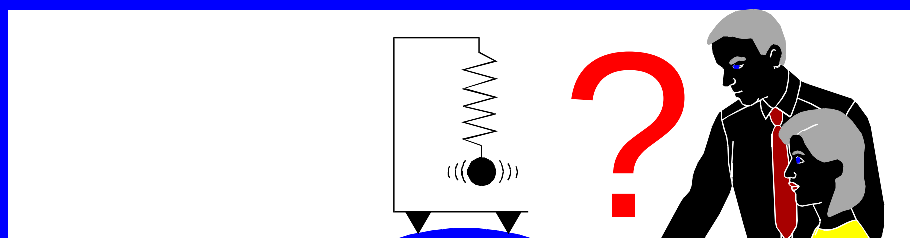


Eppur si muove

- The lament of *homo gravimetricus*,

  i.e.

  Why does his instrument tremble when no earthquake can be felt?



answers:

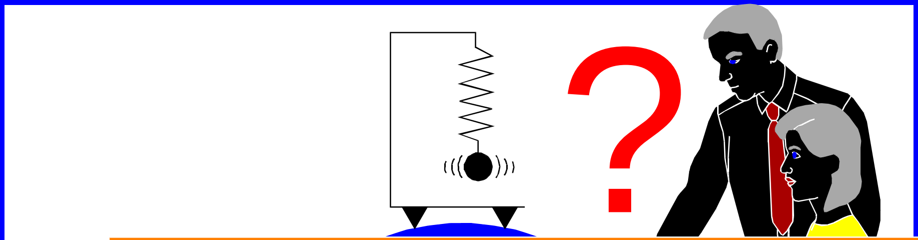
A) There are earthquakes all the time
B) If ¬A then there is microseismic activity
C) If ¬(A∧B) then there are road construction works close to the observatory

Eppur si muove

- The lament of *homo gravimetricus*,

  i.e.

  Why does his instrument tremble when no earthquake can be felt?



answers:

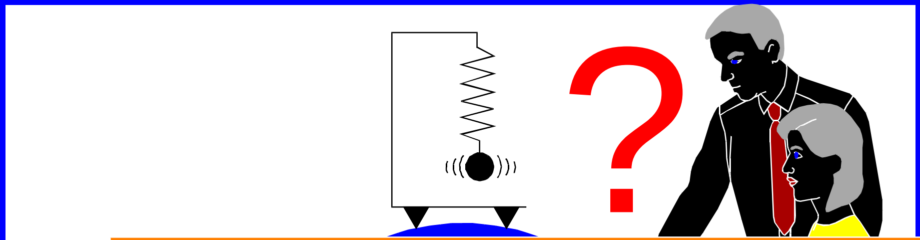
A) There are earthquakes all the time
B) If $\neg$A then there is microseismic activity
C) If $\neg$(A$\wedge$B) then there are road construction works close to the observatory

Eppur si muove

- The lament of *homo gravimetricus*,

  i.e.

  Why does his instrument tremble when no earthquake can be felt?



answers:

A) There are earthquakes all the time
B) If ¬A then there is microseismic activity
C) If ¬(A∧B) the … on
works close to t…

What is microseism?

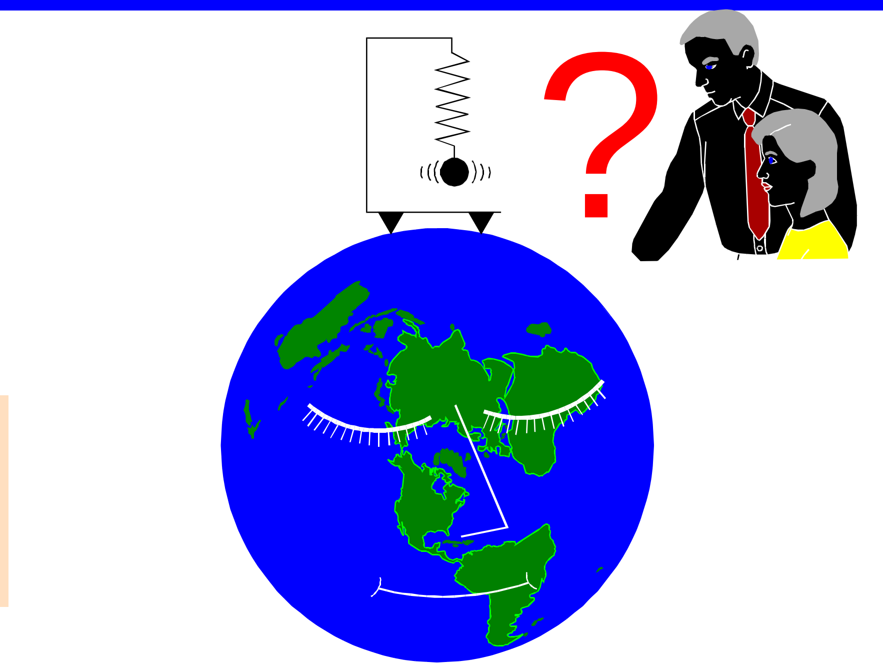
MTA CSFK GGI

Eppur si muove

- The lament of *homo gravimetricus*,

  i.e.

  Why does his instrument tremble when no earthquake can be felt?



atmosphere

↕

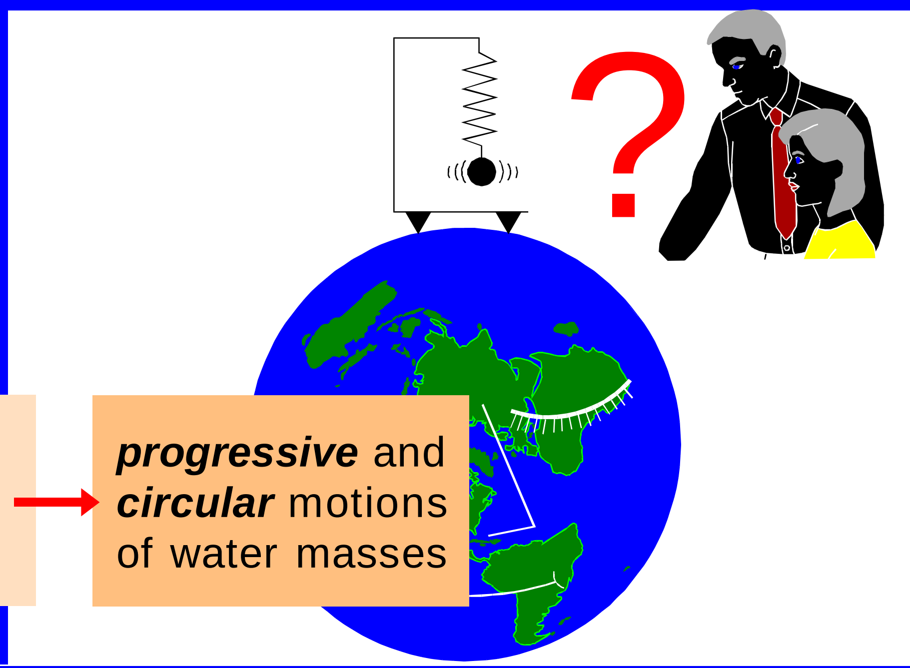
hydrosphere

Eppur si muove

- The lament of *homo gravimetricus*,

  i.e.

  Why does his instrument tremble when no earthquake can be felt?



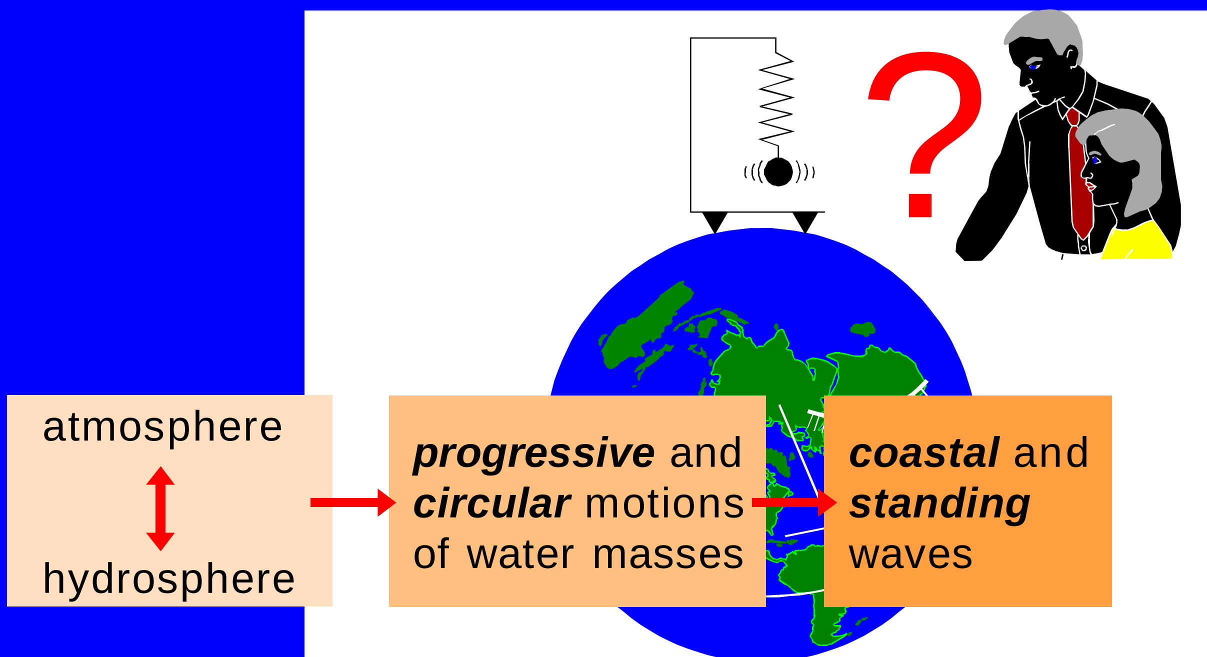
atmosphere ↕ hydrosphere → ***progressive*** and ***circular*** motions of water masses

Eppur si muove

- The lament of *homo gravimetricus*,

  i.e.

  Why does his instrument tremble when no earthquake can be felt?

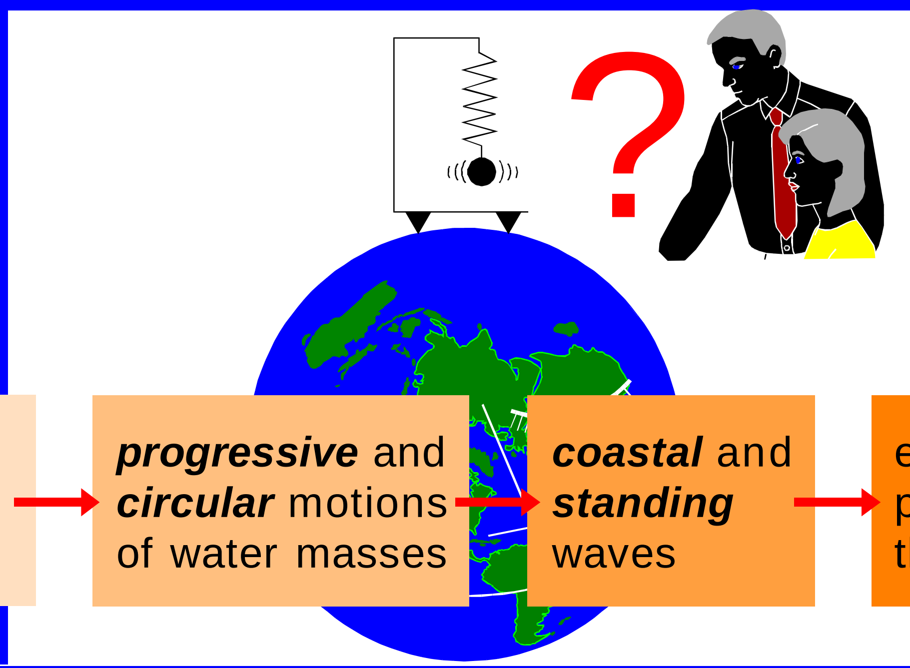


Eppur si muove

- The lament of *homo gravimetricus*,

  i.e.

  Why does his instrument tremble when no earthquake can be felt?



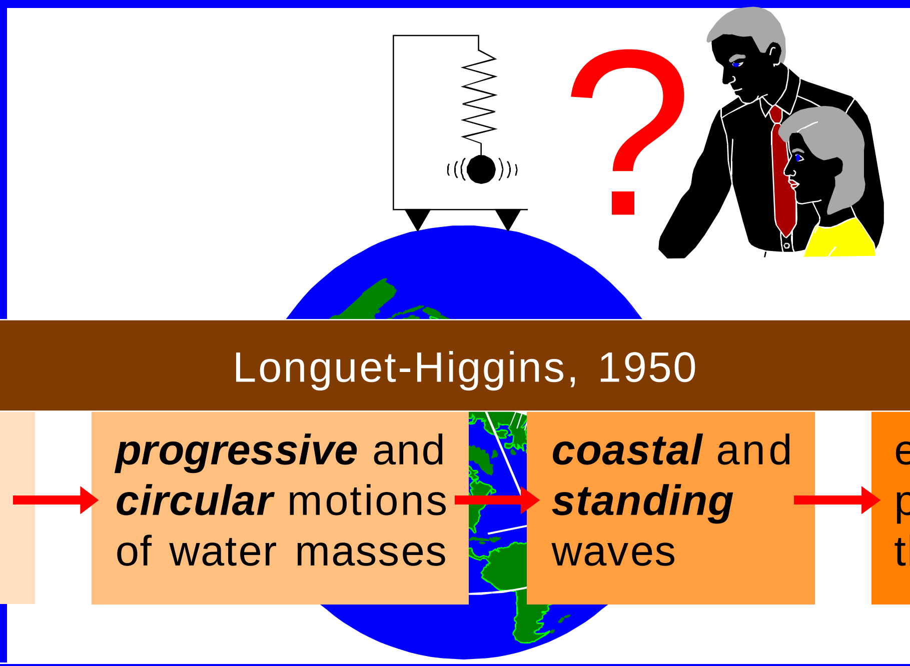
atmosphere ↕ hydrosphere → ***progressive*** and ***circular*** motions of water masses → ***coastal*** and ***standing*** waves → elastic waves propagating in the crust

Eppur si muove

- The lament of *homo gravimetricus*,

  i.e.

  Why does his instrument tremble when no earthquake can be felt?



Longuet-Higgins, 1950

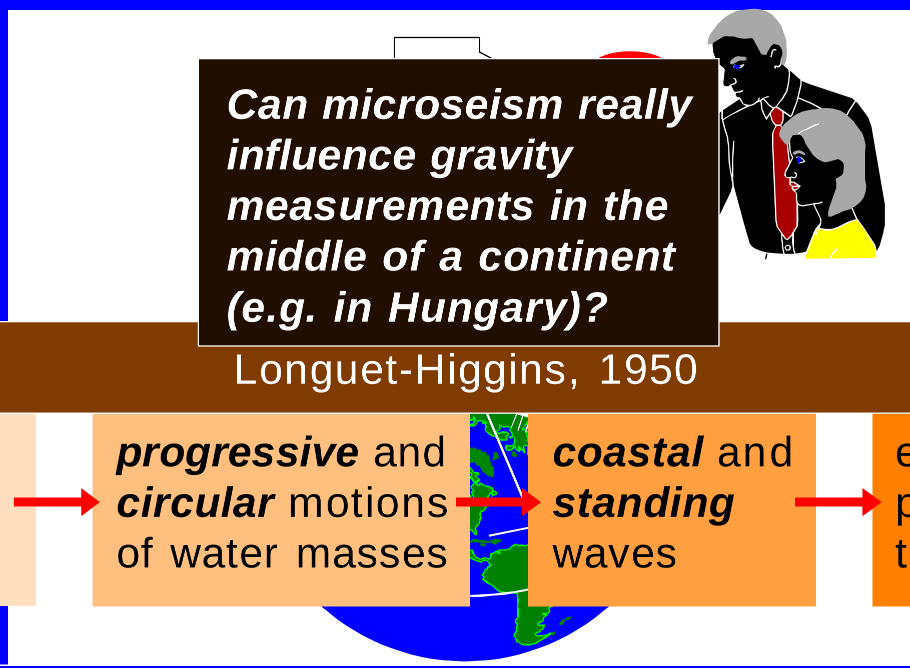
atmosphere ↕ hydrosphere → ***progressive*** and ***circular*** motions of water masses → ***coastal*** and ***standing*** waves → elastic waves propagating in the crust

Eppur si muove

- The lament of *homo gravimetricus*,

  i.e.

  Why does his instrument tremble when no earthquake can be felt?



Can microseism really influence gravity measurements in the middle of a continent (e.g. in Hungary)?

Longuet-Higgins, 1950

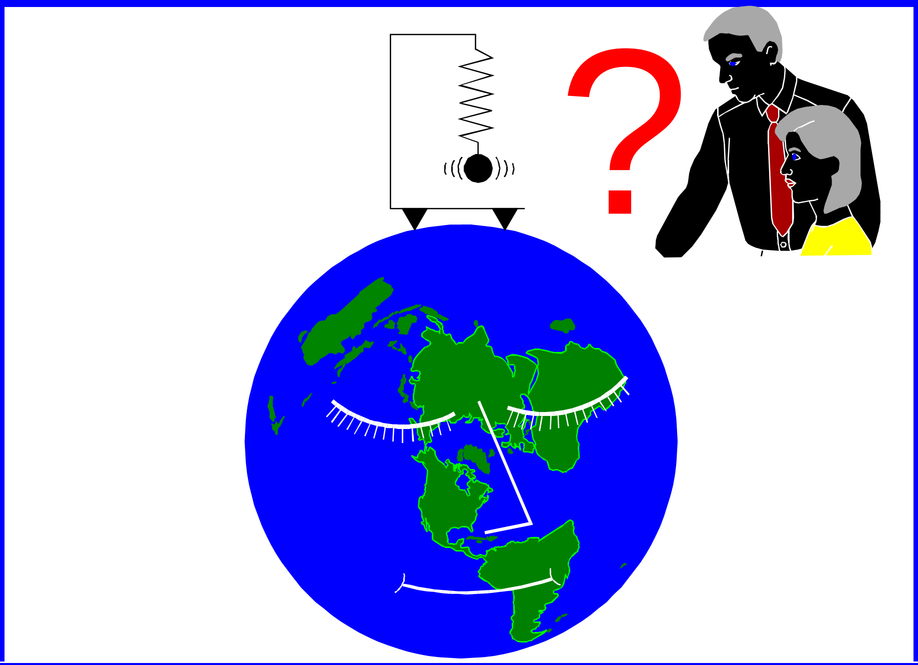
atmosphere ↕ hydrosphere → ***progressive*** and ***circular*** motions of water masses → ***coastal*** and ***standing*** waves → elastic waves propagating in the crust

Eppur si muove

- The lament of *homo gravimetricus*,

  i.e.

  Why does his instrument tremble when no earthquake can be felt?



Non-gravitational effects in **g** observations

The sum of time dependent effects (I) due to the change in motion of the observation point/instrument

Non-gravitational effects in **g** observations

The sum of time dependent effects (I) due to the change in motion of the observation point/instrument

$$\mathbf{g} = \mathbf{grad}W = \mathbf{g}_S(P) + \mathbf{g}_T(P,t)$$

$$g = |\mathbf{g}|$$

$$g_T(P,t) = g_I(P,t) + g_A(P,t)$$

Non-gravitational effects in g observations

Non-gravitational effects in g observations

The sum of time dependent effects (I) due to the change in motion of the observation point/instrument

$$\mathbf{g} = \mathbf{grad}W = \mathbf{g}_S(P) + \mathbf{g}_T(P,t)$$

$$g = |\mathbf{g}|$$

$$g_T(P,t) = g_I(P,t) + g_A(P,t)$$

interplanetary Newtonian attractions (direct + indirect)

MTA CSFK GGI

Non-gravitational effects in g observations

The sum of time dependent effects (I) due to the change in motion of the observation point/instrument

$$\mathbf{g} = \mathbf{grad}W = \mathbf{g}_S(P) + \mathbf{g}_T(P,t)$$

$$g = |\mathbf{g}|$$

$$g_T(P,t) = g_I(P,t) + g_A(P,t)$$

disturbing effects (noise)

interplanetary Newtonian attractions (direct + indirect)

Non-gravitational effects in **g** observations

The sum of time dependent effects (I) due to the change in motion of the observation point/instrument

$$\mathbf{g} = \mathbf{grad}W = \mathbf{g}_S(P) + \mathbf{g}_T(P,t)$$

$$g = |\mathbf{g}|$$

$$g_T(P,t) = g_I(P,t) + g_A(P,t)$$

disturbing effects (noise)

interplanetary Newtonian attractions (direct + indirect)

Non-gravitational effects in **g** observations

- anthropogenic - technogenic effects
- geodynamics (e.g. seismicity)

The sum of time dependent effects (I) due to the change in motion of the observation point/instrument

$$\mathbf{g} = \mathbf{grad}W = \mathbf{g}_S(P) + \mathbf{g}_T(P,t)$$

$$g = |\mathbf{g}|$$

$$g_T(P,t) = g_I(P,t) + g_A(P,t)$$

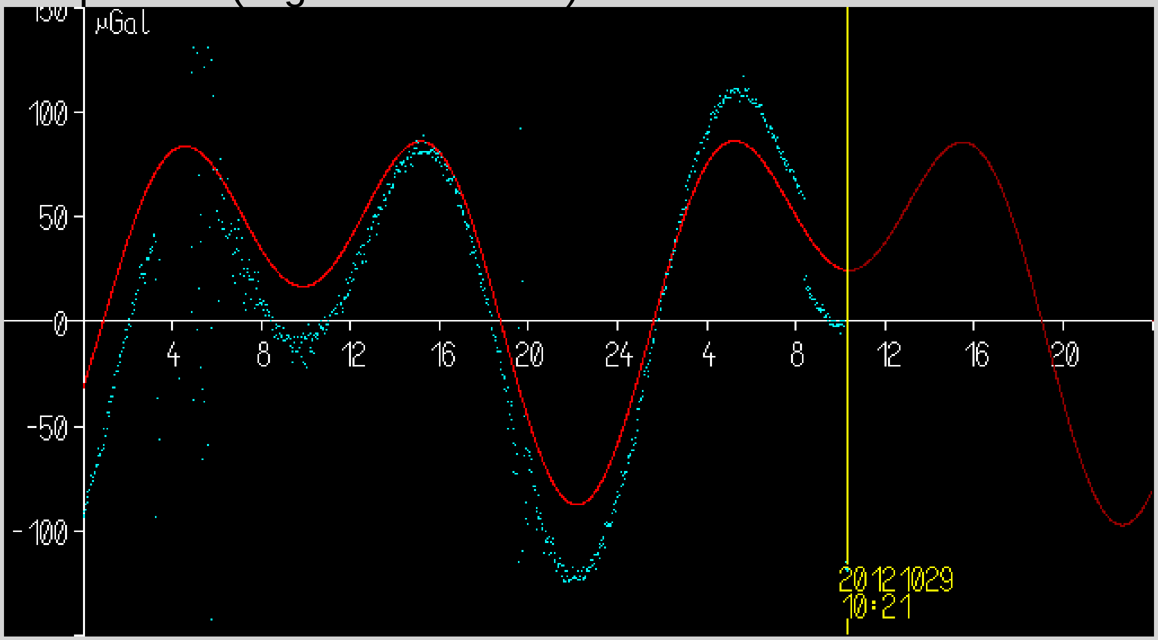
disturbing effects (noise)

interplanetary Newtonian attractions (direct + indirect)

Non-gravitational effects in g observations

- anthropogenic - technogenic effects
- geodynamics (e.g. seismicity)

earthquakes (e.g. 2012.10.28)

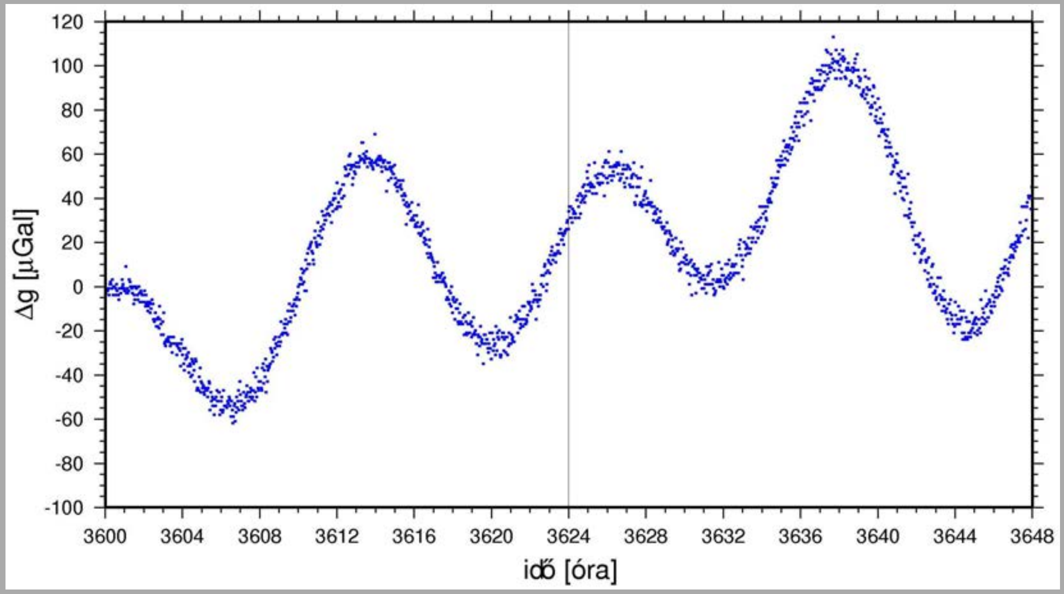


Non-gravitational effects in g observations

- anthropogenic - technogenic effects
- geodynamics (e.g. seismicity)

earthquakes (e.g. 2012.10.28)

microseisms (e.g. 2012.10.01-02.)

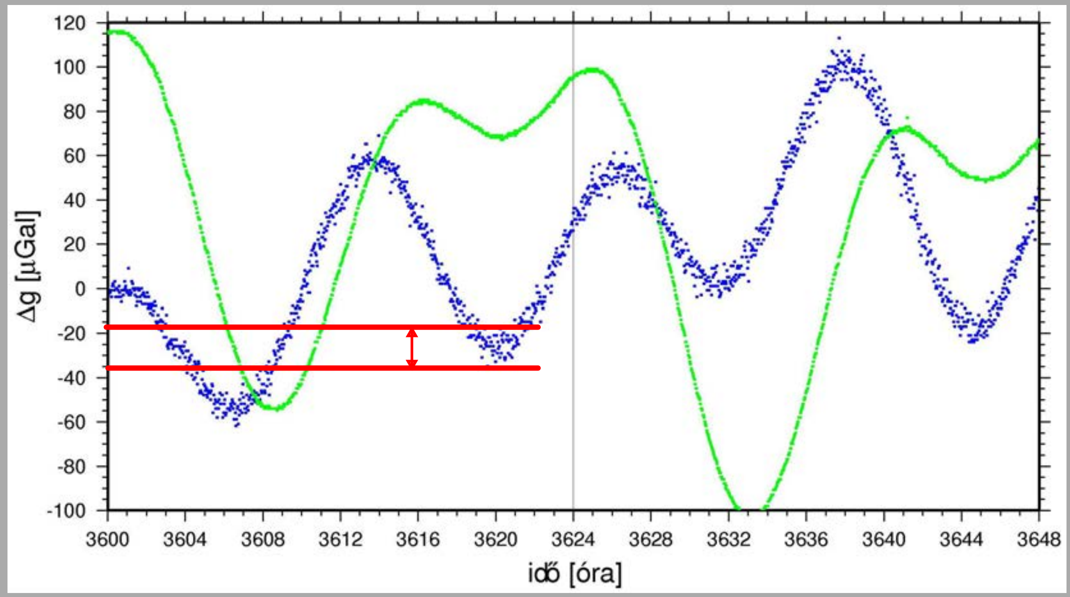


Non-gravitational effects in g observations

- anthropogenic - technogenic effects
- geodynamics (e.g. seismicity)

earthquakes (e.g. 2012.10.28)

microseisms (e.g. 2012.10.01-02.)



Comparison of gravity tide to microseismic noise

- Spectral decomposition of gravity tide

The most dominant components of gravity tide at Φ=47.6° (Baker, 1984)

component	description	T_i cycle time [h/day]	a_i amplitude [μGal]
M_2	semidiurnal lunar	12.42	34.1
S_2	semidiurnal solar	12.00	15.8
N_2	lunar elliptic	12.66	6.5
K_2	lunisolar decl.	11.97	4.3
O_1	diurnal lunar	25.82	30.9
K_1	lunisolar decl.	23.93	43.5
P_1	diurnal solar	24.07	14.4
M_f	lunar forthnightly	13.66 day	4.1
M_m	lunar monthly	27.55 day	2.1
S_{sa}	solar half yearly	182.62 day	1.9

Comparison of gravity tide to microseismic noise

- Spectral decomposition of gravity tide

The most dominant components of gravity tide at Φ=47.6° (Baker, 1984)

component	description	T_i cycle time [h/day]	a_i amplitude [μGal]
M_2	semidiurnal lunar	12.42	34.1
S_2	semidiurnal solar	12.00	15.8
N_2	lunar elliptic	12.66	6.5
K_2	lunisolar decl.	11.97	4.3
O_1	diurnal lunar	25.82	30.9
K_1	lunisolar decl.	23.93	43.5
P_1	diurnal solar	24.07	14.4
M_f	lunar forthnightly	13.66 day	4.1
M_m	lunar monthly	27.55 day	2.1
S_{sa}	solar half yearly	182.62 day	1.9

Comparison of gravity tide to microseismic noise

Comparison of gravity tide to microseismic noise

- Spectral decomposition of gravity tide
- Inertial acceleration due to tidal deformation

Comparison of gravity tide to microseismic noise

- Spectral decomposition of gravity tide
- Inertial acceleration due to tidal deformation

elementary harmonic deformation model:

$$H(t)=H_0+A\sin(2\pi t/T)$$

Comparison of gravity tide to microseismic noise

- Spectral decomposition of gravity tide
- Inertial acceleration due to tidal deformation

elementary harmonic deformation model:

$$H(t)=H_0+A\sin(2\pi t/T)$$

vertical displacement

Comparison of gravity tide to microseismic noise

- Spectral decomposition of gravity tide
- Inertial acceleration due to tidal deformation

elementary harmonic deformation model:

$$H(t)=H_0+A\sin(2\pi t/T)$$

vertical displacement

$H_0=H(t=t_0)$ reference height

Comparison of gravity tide to microseismic noise

- Spectral decomposition of gravity tide
- Inertial acceleration due to tidal deformation

elementary harmonic deformation model:

$$H(t)=H_0+A\sin(2\pi t/T)$$

vertical displacement

H_0=H(t
referen
height

amplitude of the displacement

Comparison of gravity tide to microseismic noise

- Spectral decomposition of gravity tide
- Inertial acceleration due to tidal deformation

elementary harmonic deformation model:

$$H(t)=H_0+A\sin(2\pi t/T)$$

vertical displacement

H_0=H(t… referen… height

amplitu… the disp…

cycle time of the displacement

Comparison of gravity tide to microseismic noise

- Spectral decomposition of gravity tide
- Inertial acceleration due to tidal deformation

elementary harmonic deformation model:

$$H(t)=H_0+A\sin(2\pi t/T)$$

elementary harmonic acceleration model:

$$a(A,T,t)=d^2H/dt^2=-A(4\pi^2/T^2)\sin(2\pi t/T)$$

MTA CSFK GGI

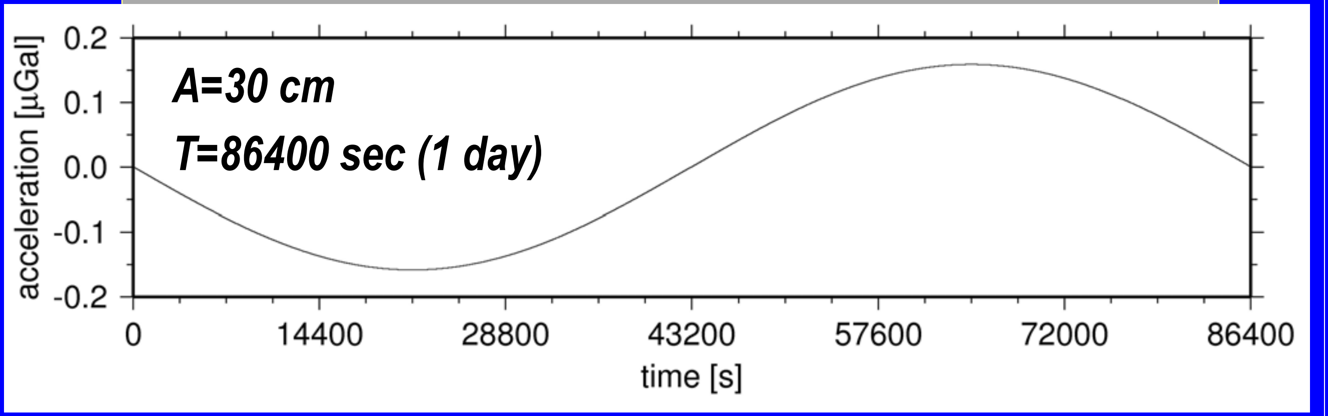
Comparison of gravity tide to microseismic noise

- Spectral decomposition of gravity tide
- Inertial acceleration due to tidal deformation

elementary harmonic deformation model:

$$H(t)=H_0+A\sin(2\pi t/T)$$

elementary harmonic acceleration model:



Comparison of gravity tide to microseismic noise

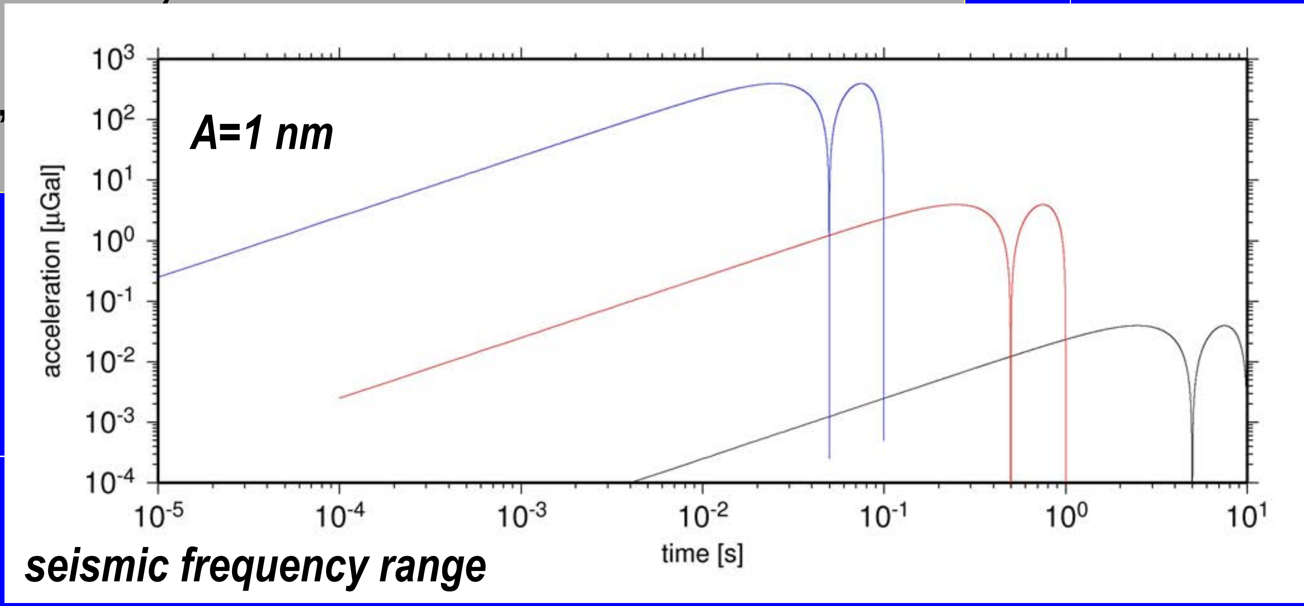
- Spectral decomposition of gravity tide
- Inertial acceleration due to tidal deformation

elementary harmonic deformation model:

$H(t)=H_0+A\sin(2\pi t/T)$

elementary harmonic acceleration model:

a(A,



Level of gravity noise in Sopron, Hungary

- observation period: June 08. 2010 - January 04. 2011

Level of gravity noise in Sopron, Hungary

- observation period: June 08. 2010 - January 04. 2011
- instrument: LCR G949 + CCD ocular

Level of gravity noise in Sopron, Hungary

- observation period: June 08. 2010 - January 04. 2011
- instrument: LCR G949 + CCD ocular
- sampling rate: 2 min (microseism was not in focus!!)

Level of gravity noise in Sopron, Hungary

- observation period: June 08. 2010 - January 04. 2011
- instrument: LCR G949 + CCD ocular
- sampling rate: 2 min (microseism was not in focus!!)
- the change of hourly noise level during observations

$$\nu_{d,k,l} = (g_{d,k,l} - \bar{g}_{d,k}) - m_d(\Gamma_{d,k,l} - \bar{\Gamma}_{d,k})$$

d=1,2,...,214
k=1,2,...,24
l=1,2,...,30

Level of gravity noise in Sopron, Hungary

- observation period: June 08. 2010 - January 04. 2011
- instrument: LCR G949 + CCD ocular
- sampling rate: 2 min (microseism was not in focus!!)
- the change of hourly noise level during observations

$$\nu_{d,k,l} = (g_{d,k,l} - \bar{g}_{d,k}) - m_d(\Gamma_{d,k,l} - \bar{\Gamma}_{d,k})$$

214
24
30

observed tidal acceleration

Level of gravity noise in Sopron, Hungary

- observation period: June 08. 2010 - January 04. 2011
- instrument: LCR G949 + CCD ocular
- sampling rate: 2 min (microseism was not in focus!!)
- the change of hourly noise level during observations

$$\nu_{d,k,l}=(g_{d,k,l}-\bar{g}_{d,k}) - m_d(\Gamma_{d,k,l}-\bar{\Gamma}_{d,k})$$

observed tid
acceleration

hourly mean value of tidal acceleration

Level of gravity noise in Sopron, Hungary

- observation period: June 08. 2010 - January 04. 2011
- instrument: LCR G949 + CCD ocular
- sampling rate: 2 min (microseism was not in focus!!)
- the change of hourly noise level during observations

$$\nu_{d,k,l} = (g_{d,k,l} - \bar{g}_{d,k}) - m_d(\Gamma_{d,k,l} - \bar{\Gamma}_{d,k})$$

observed tid[al] acceleration

hourly mean value of tida[l] acceleration

synthetical tidal effect (ETERNA3.4)

Level of gravity noise in Sopron, Hungary

- observation period: June 08. 2010 - January 04. 2011
- instrument: LCR G949 + CCD ocular
- sampling rate: 2 min (microseism was not in focus!!)
- the change of hourly noise level during observations

$$\nu_{d,k,l} = (g_{d,k,l} - \bar{g}_{d,k}) - m_d(\Gamma_{d,k,l} - \bar{\Gamma}_{d,k})$$

observed tid
acceleration

hourly mean
value of tida
acceleration

synthe
tidal e
(ETER

hourly mean value of synthetical tidal effect

MTA CSFK GGI

Level of gravity noise in Sopron, Hungary

- observation period: June 08. 2010 - January 04. 2011
- instrument: LCR G949 + CCD ocular
- sampling rate: 2 min (microseism was not in focus!!)
- the change of hourly noise level during observations

$$\nu_{d,k,l}=(g_{d,k,l}-\bar{g}_{d,k}) - m_d(\Gamma_{d,k,l}-\bar{\Gamma}_{d,k})$$

observed tid
acceleration

acceleratio

daily scale factor

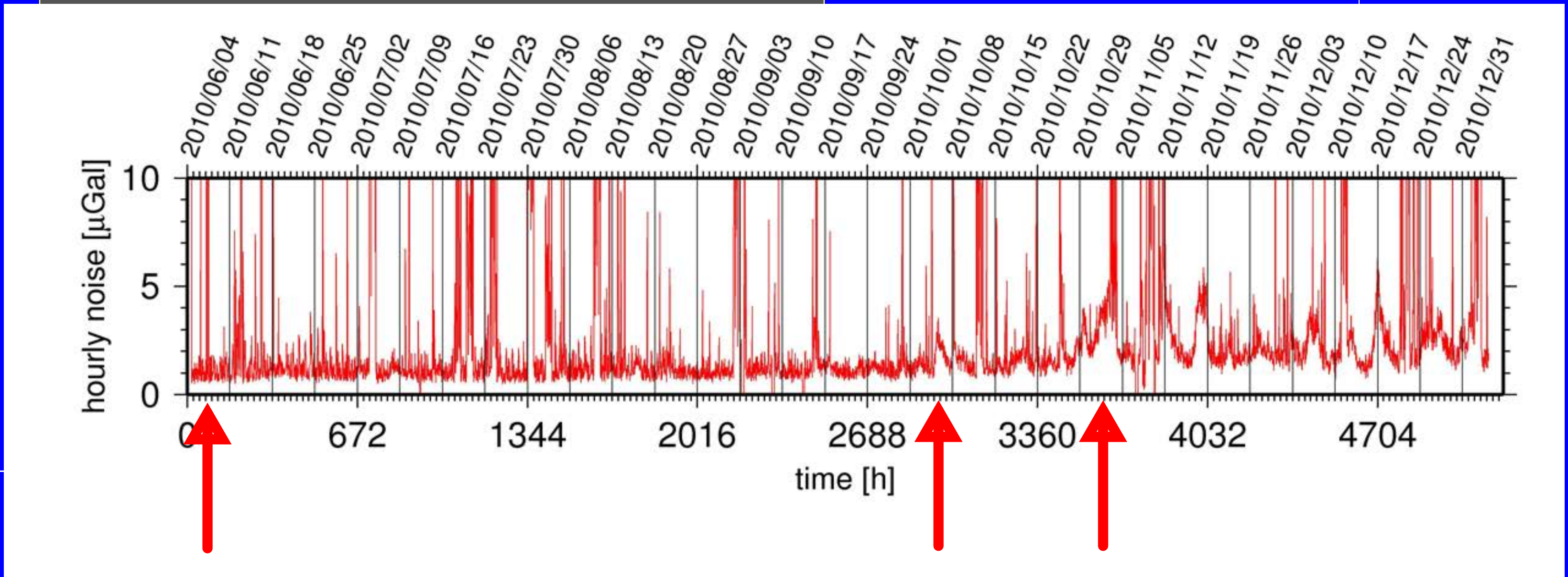
(ETER

hourly mean value of synthetical tidal effect

Level of gravity noise in Sopron, Hungary

- observation period: June 08. 2010 - January 04. 2011
- instrument: LCR G949 + CCD ocular
- sampling rate: 2 min (microseism was not in focus!!)
- the change of hourly noise level during observations

$$\nu_{d,k,l} = (g_{d,k,l} - \bar{g}_{d,k}) - m_d(\Gamma_{d,k,l} - \bar{\Gamma}_{d,k})$$

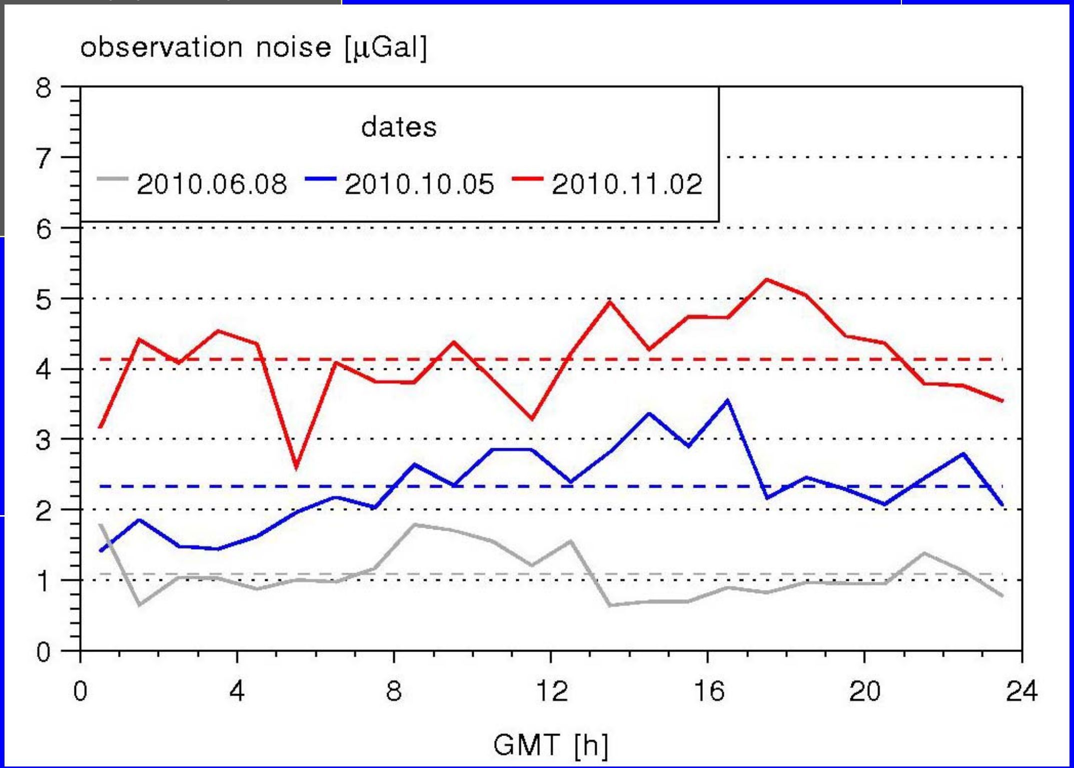


Level of gravity noise in Sopron, Hungary

- observation period: June 08. 2010 - January 04. 2011
- instrument: LCR G949 + CCD ocular
- sampling rate: 2 min (microseism was not in focus!!)
- the change of hourly noise level during observations

$$\nu_{d,k,l} = (g_{d,k,l} - \bar{g}_{d,k}) - m_d(\Gamma_{d,k,l} - \bar{\Gamma}_{d,k})$$

d=1,2,...,214
k=1,2,...,24
l=1,2,...,30



Sensitivity estimation of **g** observations

Co-located measurements with SOP station of the Hungarian National Seismological Network
(Streckeisen STS-2 broadband 3D instrument)

Sensitivity estimation of g observations

- Co-located measurements with SOP station of the Hungarian National Seismological Network
(Streckeisen STS-2 broadband 3D instrument)

ground velocity time series:
$v_x(t_i)$, $v_y(t_i)$, $v_z(t_i)$ (i=1,…,N)
$\Delta t = t_{i+1} - t_i = 0.05$ s (20 Hz)

Sensitivity estimation of g observations

- Co-located measurements with SOP station of the Hungarian National Seismological Network (Streckeisen STS-2 broadband 3D instrument)

ground velocity time series:
$v_x(t_i)$, $v_y(t_i)$, $v_z(t_i)$ (i=1,…,N)
$\Delta t = t_{i+1} - t_i = 0.05$ s (20 Hz)

vertical displacement time series:

$$z(t_i) = \sum_{i=1}^{N} v_z(t_i)\Delta t$$

Sensitivity estimation of g observations

- Co-located measurements with SOP station of the Hungarian National Seismological Network (Streckeisen STS-2 broadband 3D instrument)

ground velocity time series:

$v_x(t_i)$, $v_y(t_i)$, $v_z(t_i)$ (i=1,...,N)

$\Delta t = t_{i+1} - t_i = 0.05$ s (20 Hz)

vertical displacement time series:

$$z(t_i) = \sum_{i=1}^{N} v_z(t_i) \Delta t$$

$z(t) \longleftrightarrow A(f) = A(1/T)$

amplitude Fourier spectrum

Sensitivity estimation of g observations

- Co-located measurements with SOP station of the Hungarian National Seismological Network
  (Streckeisen STS-2 broadband 3D instrument)
- Relation between the elementary acceleration model and the amplitude Fourier spectrum of ground displacement

$$z(t) \longleftrightarrow A(f)=A(1/T)$$

amplitude Fourier spectrum

Sensitivity estimation of **g** observations

- Co-located measurements with SOP station of the Hungarian National Seismological Network
(Streckeisen STS-2 broadband 3D instrument)
- Relation between the elementary acceleration model and the amplitude Fourier spectrum of ground displacement

elementary acceleration model:

$$a(A,T,t)=-A(4\pi^2/T^2)\sin(2\pi t/T)=a(A(T\ ),t)$$

$$z(t) \longleftrightarrow A(f)=A(1/T)$$

amplitude Fourier spectrum

Sensitivity estimation of g observations

- Co-located measurements with SOP station of the Hungarian National Seismological Network
(Streckeisen STS-2 broadband 3D instrument)
- Relation between the elementary acceleration model and the amplitude Fourier spectrum of ground displacement

elementary acceleration model:

$$a(A,T,t)=-A(4\pi^2/T^2)\sin(2\pi t/T)=a(A(T),t)$$

$$z(t) \longleftrightarrow A(f)=A(1/T)$$

amplitude Fourier spectrum

Sensitivity estimation of g observations

- Co-located measurements with SOP station of the Hungarian National Seismological Network (Streckeisen STS-2 broadband 3D instrument)
- Relation between the elementary acceleration model and the amplitude Fourier spectrum of ground displacement

maximum inertial acceleration

$a_{max}(A,T)=abs(-4A\pi^2/T^2)$

:

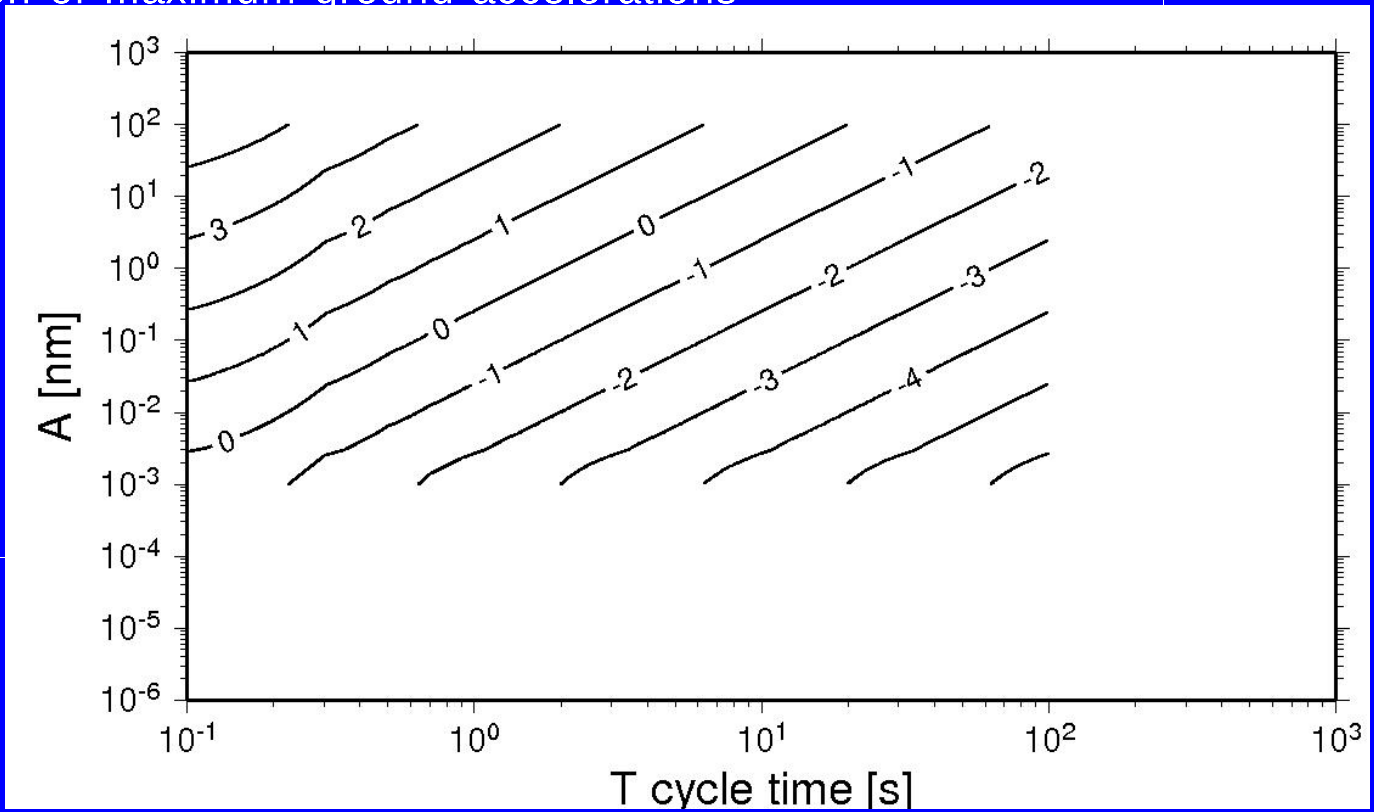
(A(T),t)

$z(t) \longleftrightarrow A(f)=A(1/T)$

amplitude Fourier spectrum

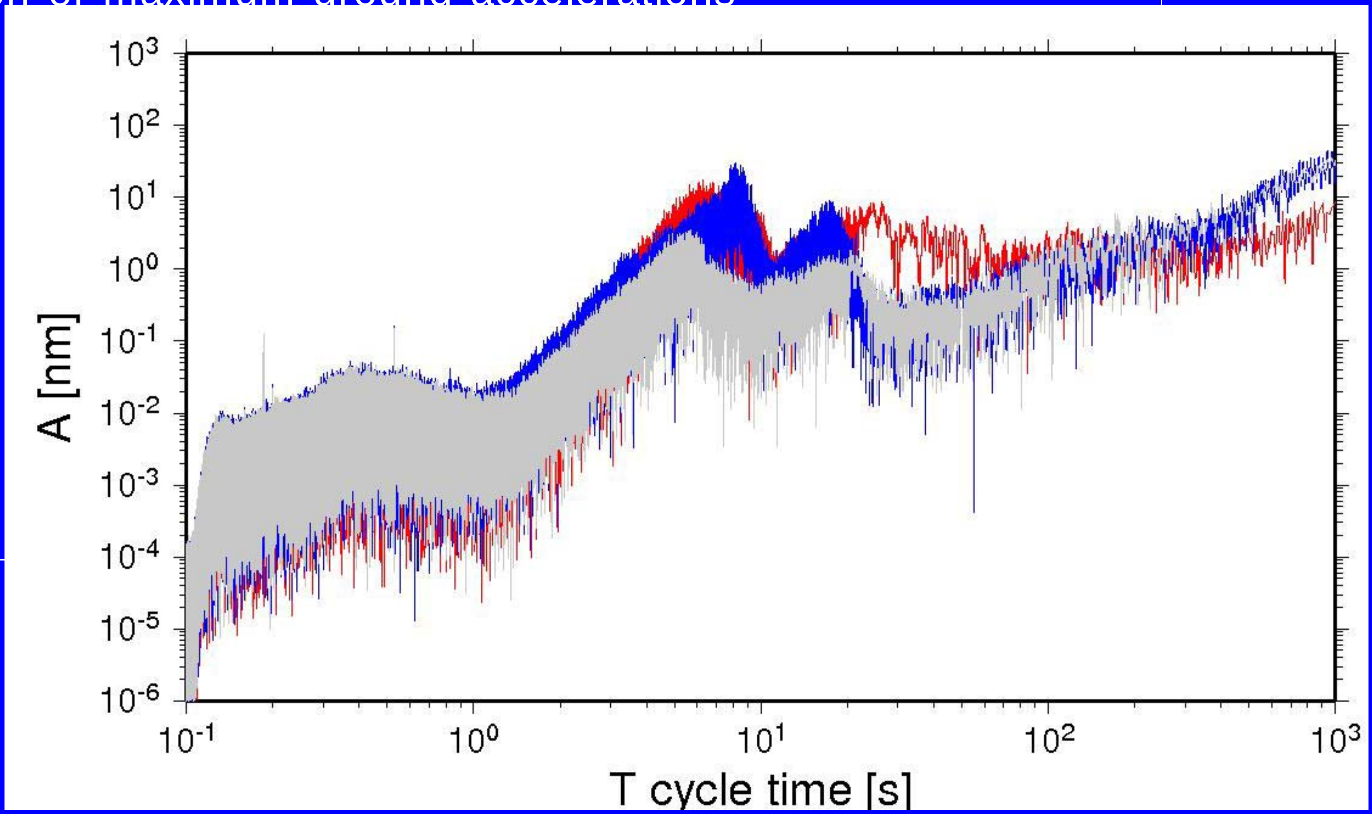
Sensitivity estimation of g observations

- Co-located measurements with SOP station of the Hungarian National Seismological Network
  (Streckeisen STS-2 broadband 3D instrument)
- Relation between the elementary acceleration model and the amplitude Fourier spectrum of ground displacement
- Determination of maximum ground accelerations



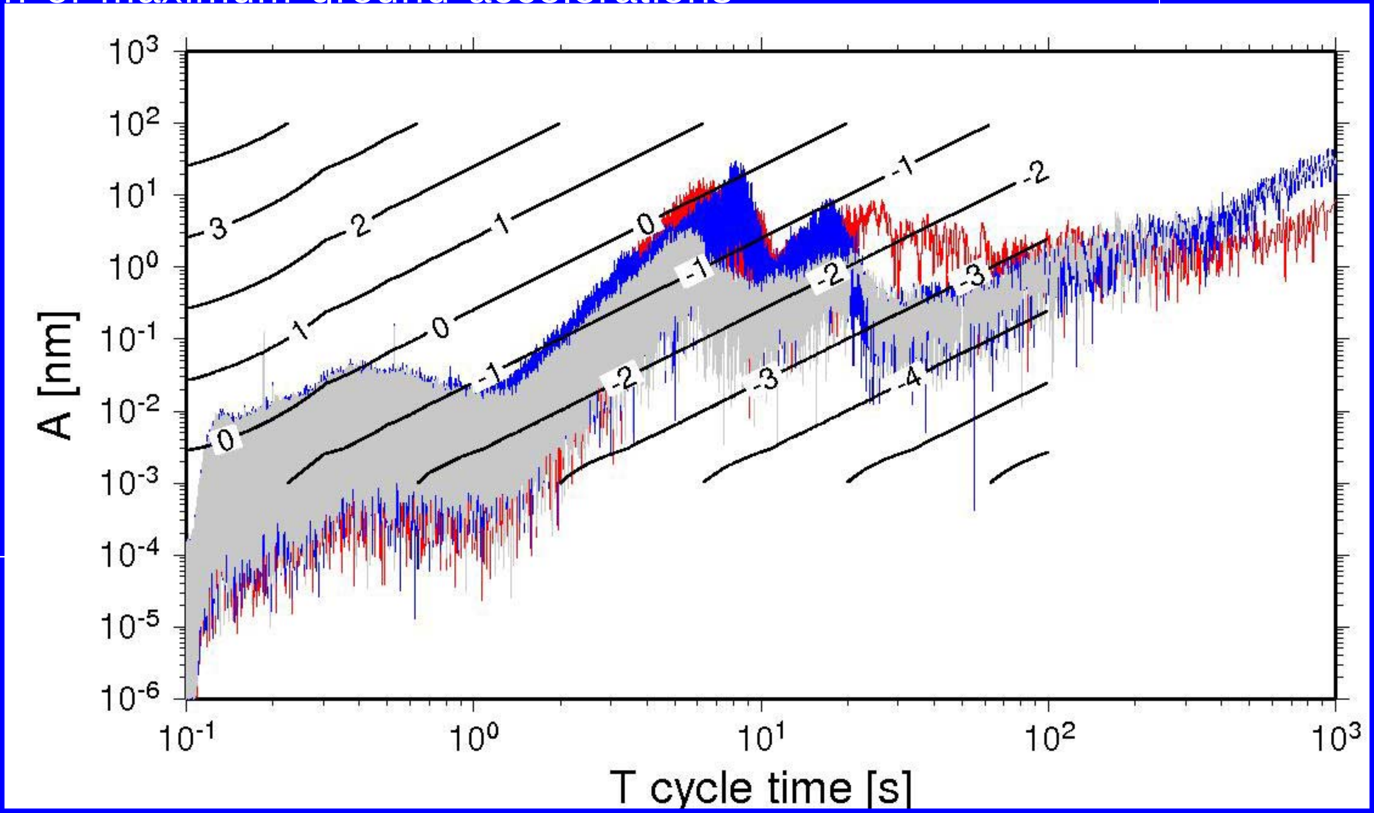
Sensitivity estimation of **g** observations

- Co-located measurements with SOP station of the Hungarian National Seismological Network
  (Streckeisen STS-2 broadband 3D instrument)
- Relation between the elementary acceleration model and the amplitude Fourier spectrum of ground displacement
- Determination of maximum ground accelerations



Sensitivity estimation of **g** observations

- Co-located measurements with SOP station of the Hungarian National Seismological Network (Streckeisen STS-2 broadband 3D instrument)
- Relation between the elementary acceleration model and the amplitude Fourier spectrum of ground displacement
- Determination of maximum ground accelerations



Identification of the sources of microseisms

- The origin of microseismic "noise" (Longuet-Higgins, 1950)

Dynamical interactions between the hydrosphere and atmosphere

Surface waves generated by the swelling of ocean’s surface

1) coastal waves
(primary source)
10 s < T < 16 s

2) standing waves
(secondary source)
4 s < T < 8 s

Identification of the sources of microseisms

- The origin of microseismic "noise" (Longuet-Higgins, 1950)
- Monitoring of ocean weather (e.g. Oceanweather Inc. USA)

Identification of the sources of microseisms

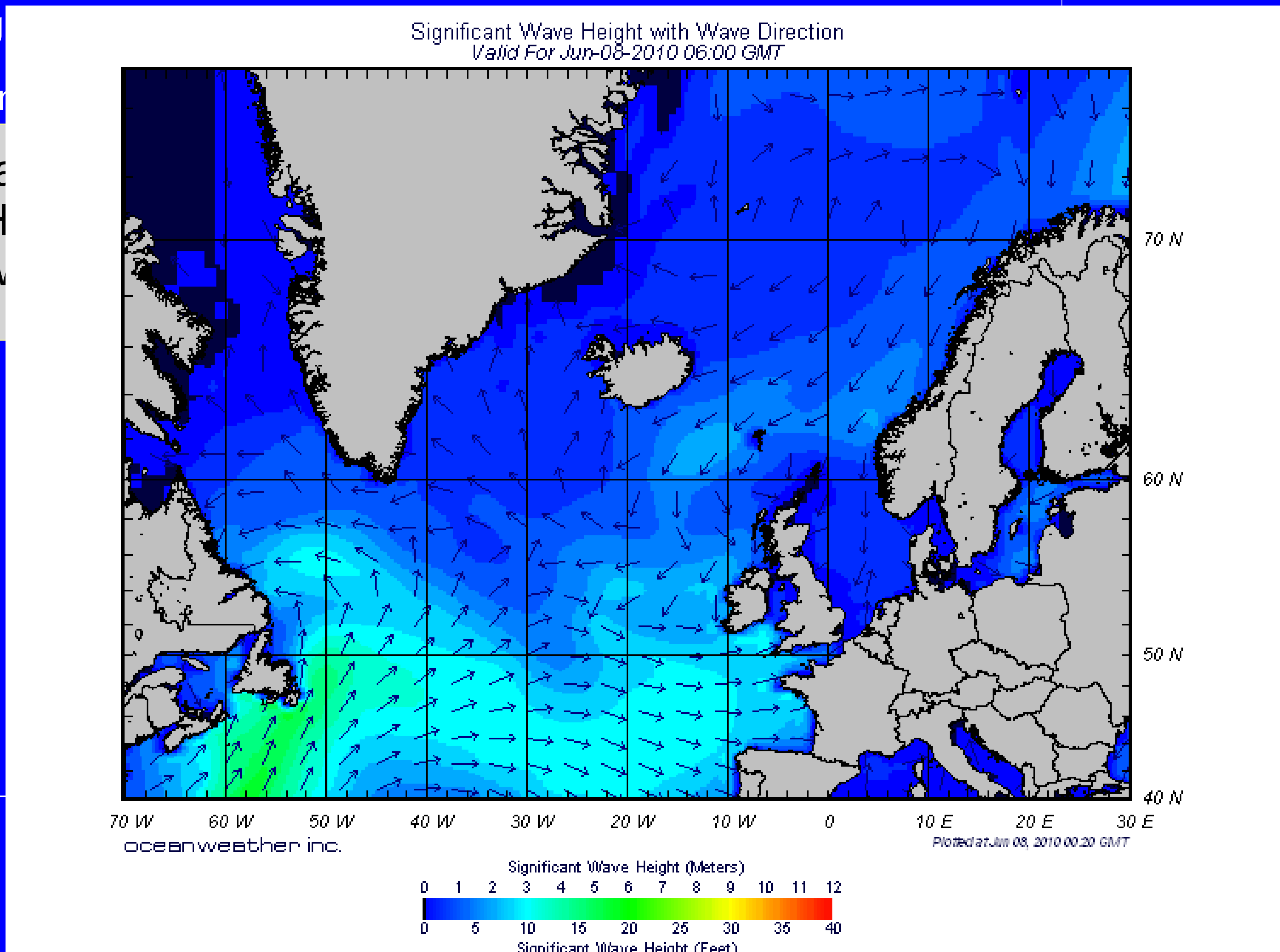
- The origin of microseismic "noise" (Longuet-Higgins, 1950)
- Monitoring of ocean weather (e.g. Oceanweather Inc. USA)

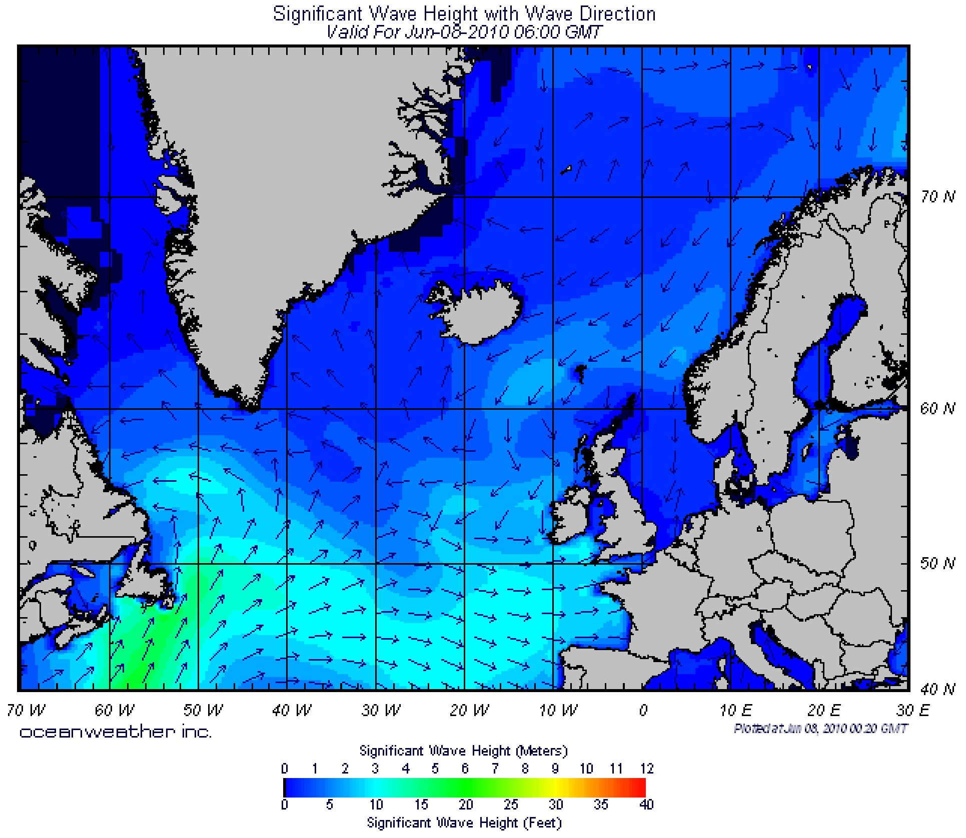
weather maps (4 maps/day)
- H_{sw} - significant wave height
- wave direction

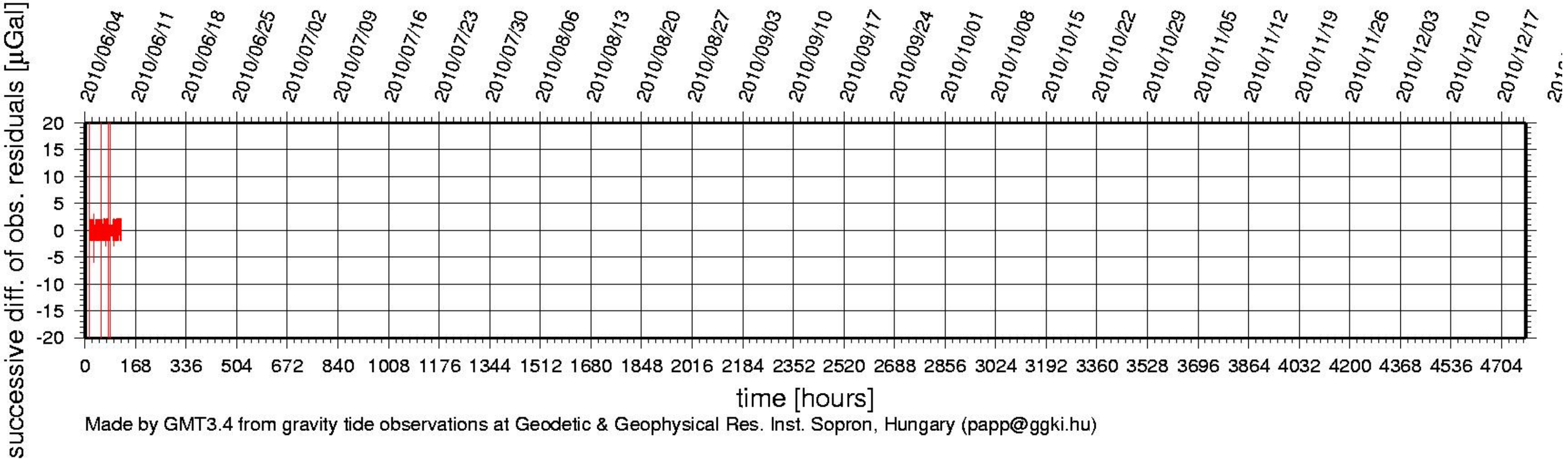
Identification of the sources of microseisms

- The orig
- Monitori

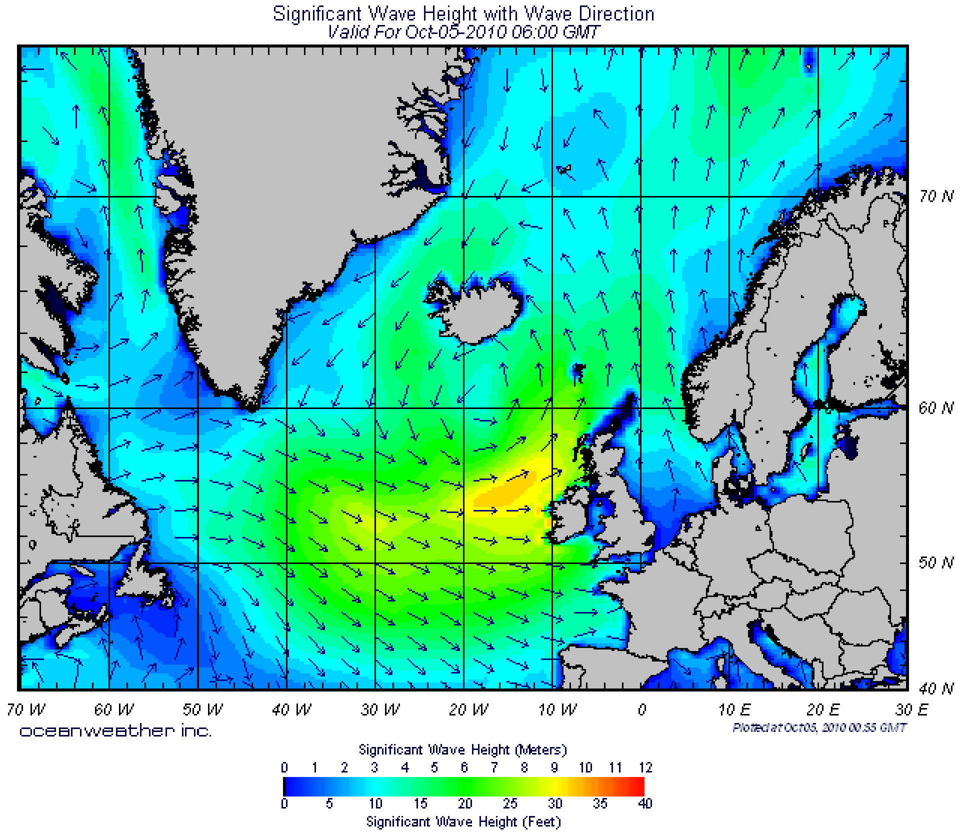
wea
- H
- w



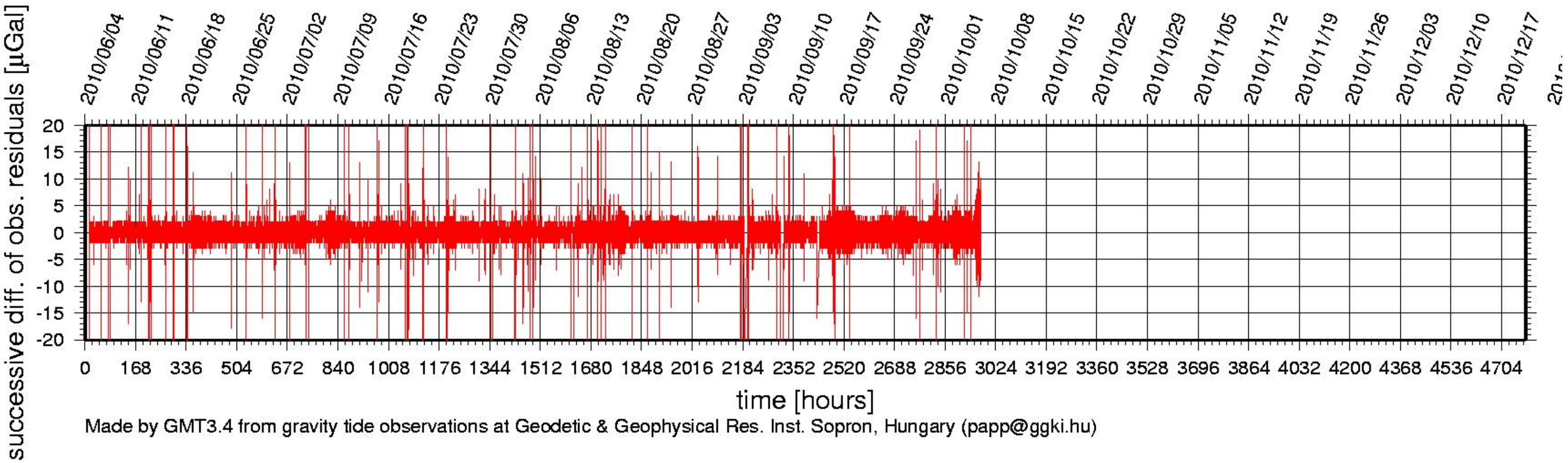




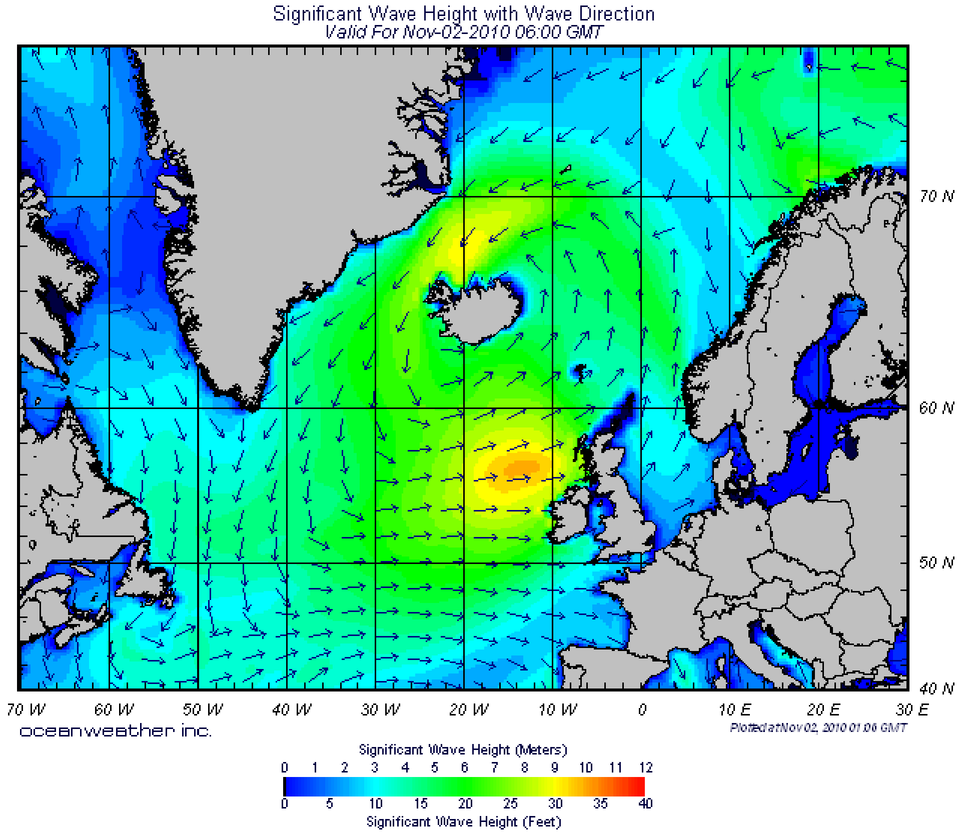
Made by GMT3.4 from gravity tide observations at Geodetic & Geophysical Res. Inst. Sopron, Hungary (papp@ggki.hu)

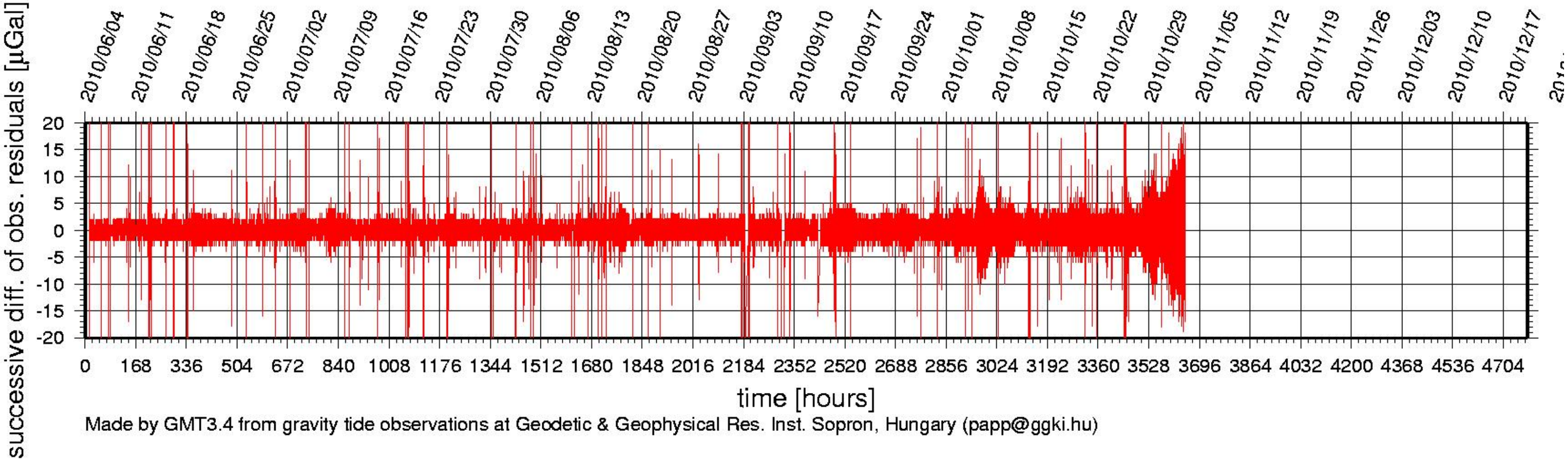


Significant Wave Height with Wave Direction
Valid For Oct-05-2010 06:00 GMT
70 N
60 N
50 N
40 N
70 W
60 W
50 W
40 W
30 W
20 W
10 W
0
10 E
20 E
30 E
oceanweather inc.
Plotted at Oct05, 2010 00:55 GMT
Significant Wave Height (Meters)
0 1 2 3 4 5 6 7 8 9 10 11 12
0 5 10 15 20 25 30 35 40
Significant Wave Height (Feet)



successive diff. of obs. residuals [µGal]
2010/06/04
2010/06/11
2010/06/18
2010/06/25
2010/07/02
2010/07/09
2010/07/16
2010/07/23
2010/07/30
2010/08/06
2010/08/13
2010/08/20
2010/08/27
2010/09/03
2010/09/10
2010/09/17
2010/09/24
2010/10/01
2010/10/08
2010/10/15
2010/10/22
2010/10/29
2010/11/05
2010/11/12
2010/11/19
2010/11/26
2010/12/03
2010/12/10
2010/12/17
20
15
10
5
0
-5
-10
-15
-20
0 168 336 504 672 840 1008 1176 1344 1512 1680 1848 2016 2184 2352 2520 2688 2856 3024 3192 3360 3528 3696 3864 4032 4200 4368 4536 4704
time [hours]
Made by GMT3.4 from gravity tide observations at Geodetic & Geophysical Res. Inst. Sopron, Hungary (papp@ggki.hu)





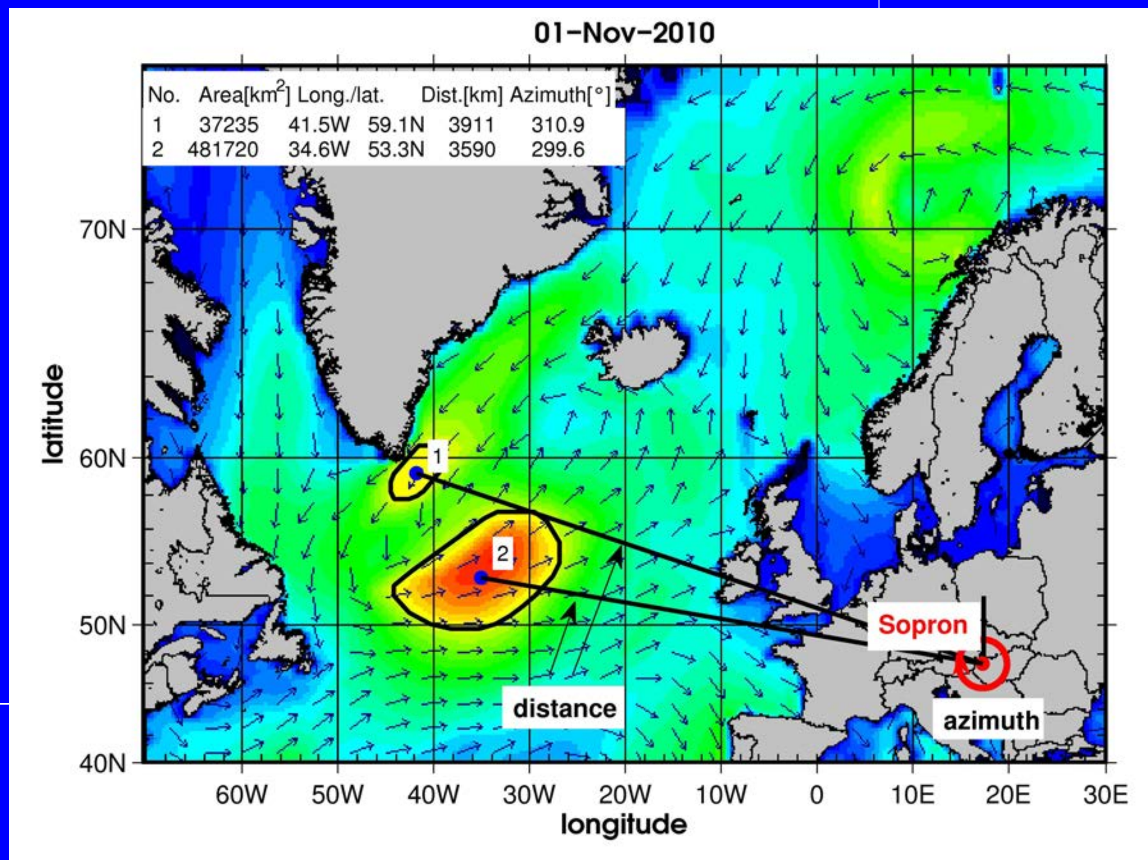
Made by GMT3.4 from gravity tide observations at Geodetic & Geophysical Res. Inst. Sopron, Hungary (papp@ggki.hu)

Identification of the sources of microseisms

- The origin of microseismic "noise" (Longuet-Higgins, 1950)
- Monitoring of ocean weather (e.g. Oceanweather Inc. USA)
- Parameterization of triggering events (storm zones)

- distance (C(φ,λ))
- azimuth
- S area of storm zone ($H_{sw} > 6.5$ m)
- significant wave volume:

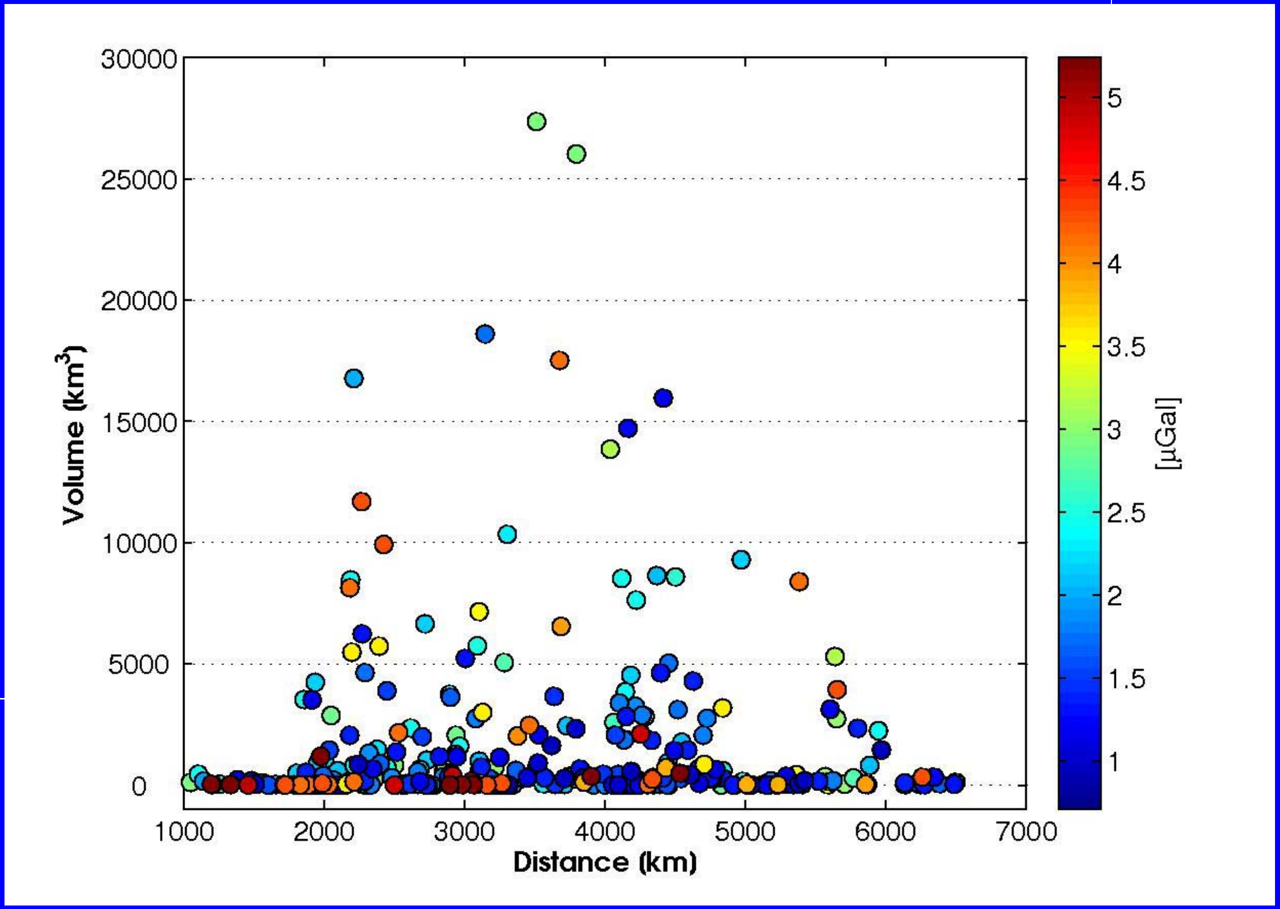
$$V_{sw} = \sum_{i=1}^{M} S_i (H_{sw})_i$$



Identification of the sources of microseisms

- Relations between the parameters of triggering events and the observed noise level

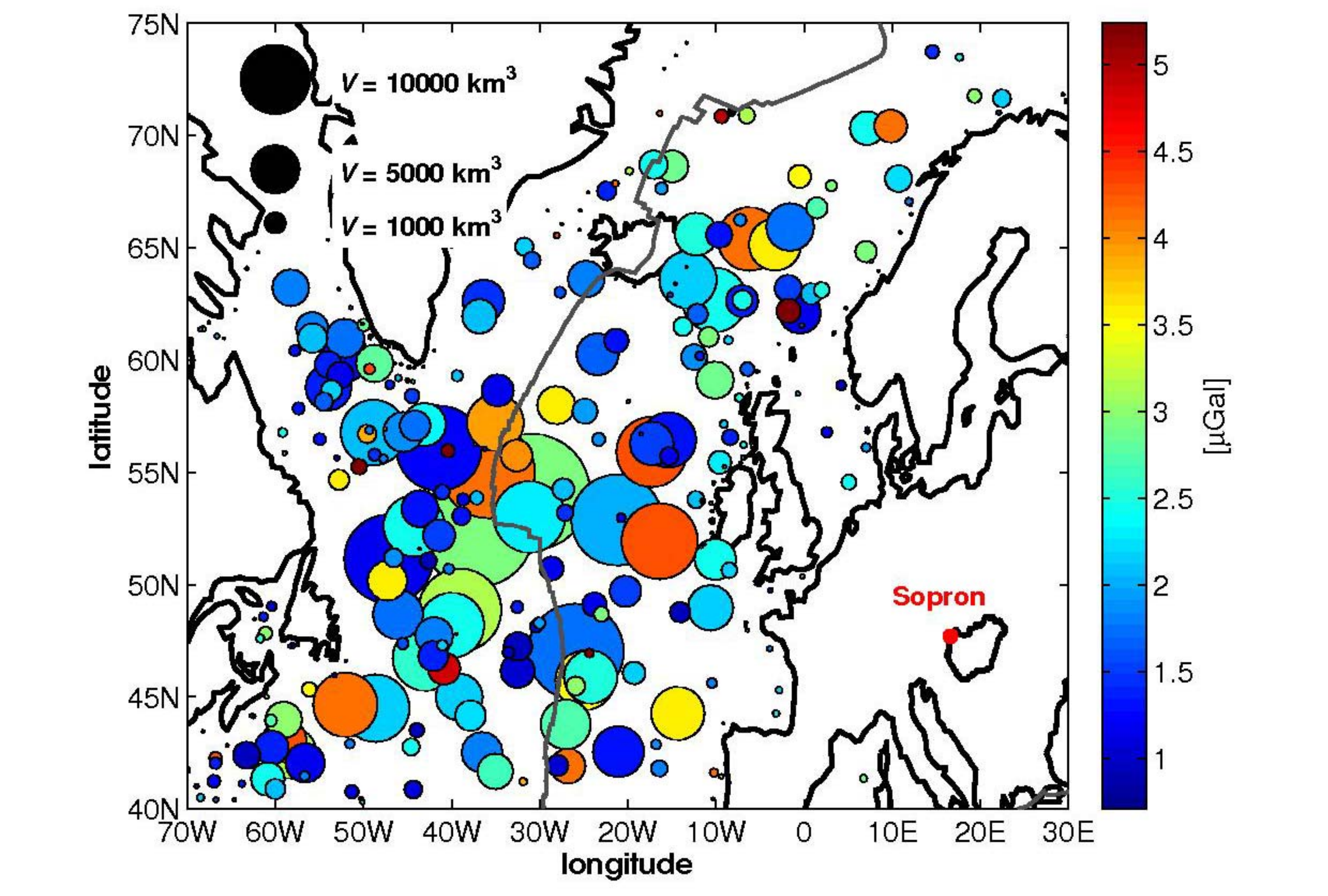
distance + V_{SW} vs. noise level



Identification of the sources of microseisms

- Relations between the parameters of triggering events and the observed noise level

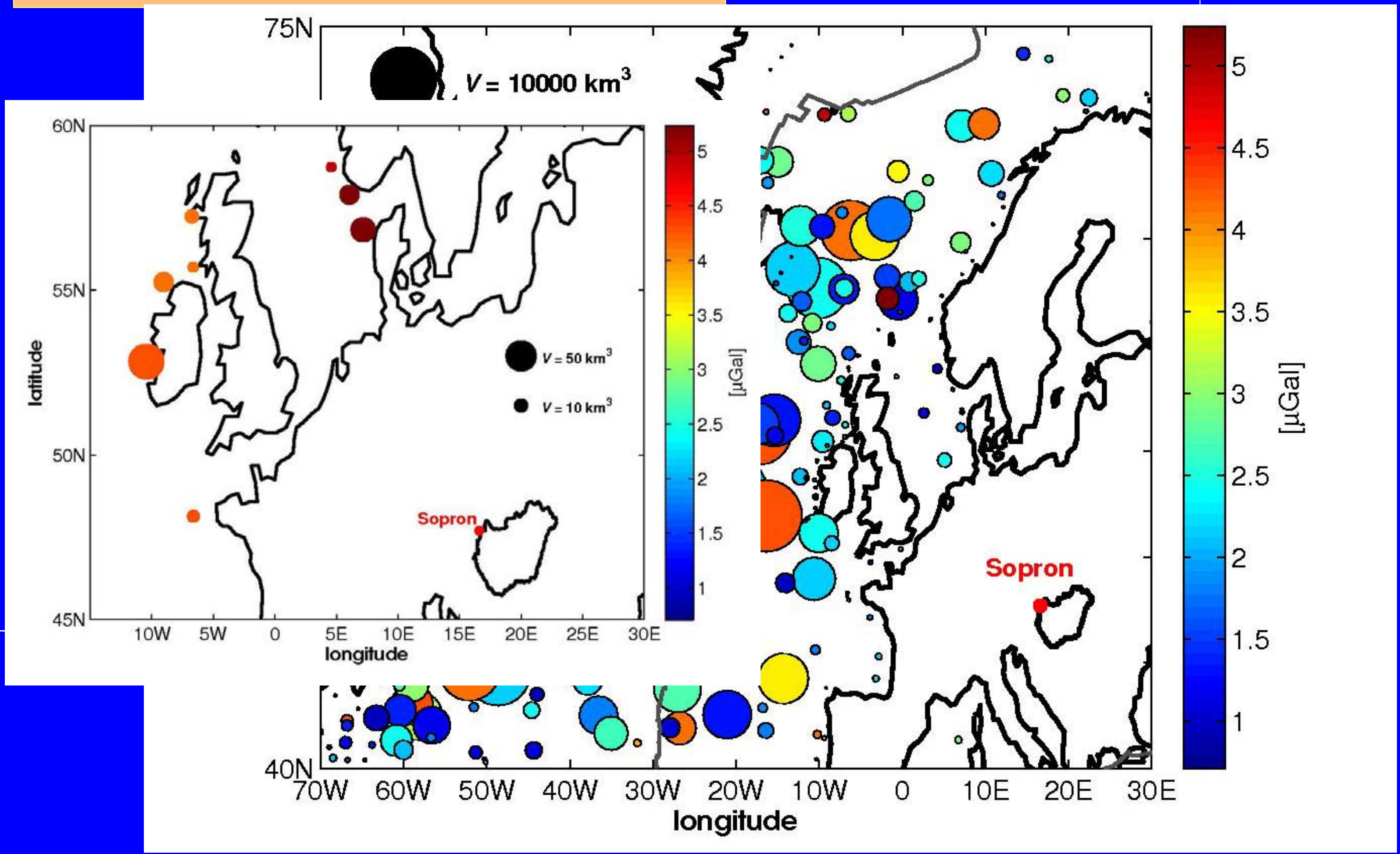
$C(\varphi,\lambda) + V_{SW}$ vs. noise level



Identification of the sources of microseisms

- Relations between the parameters of triggering events and the observed noise level

C(φ,λ) + V_{SW} vs. noise level



Spectral analysis of 1 Hz records

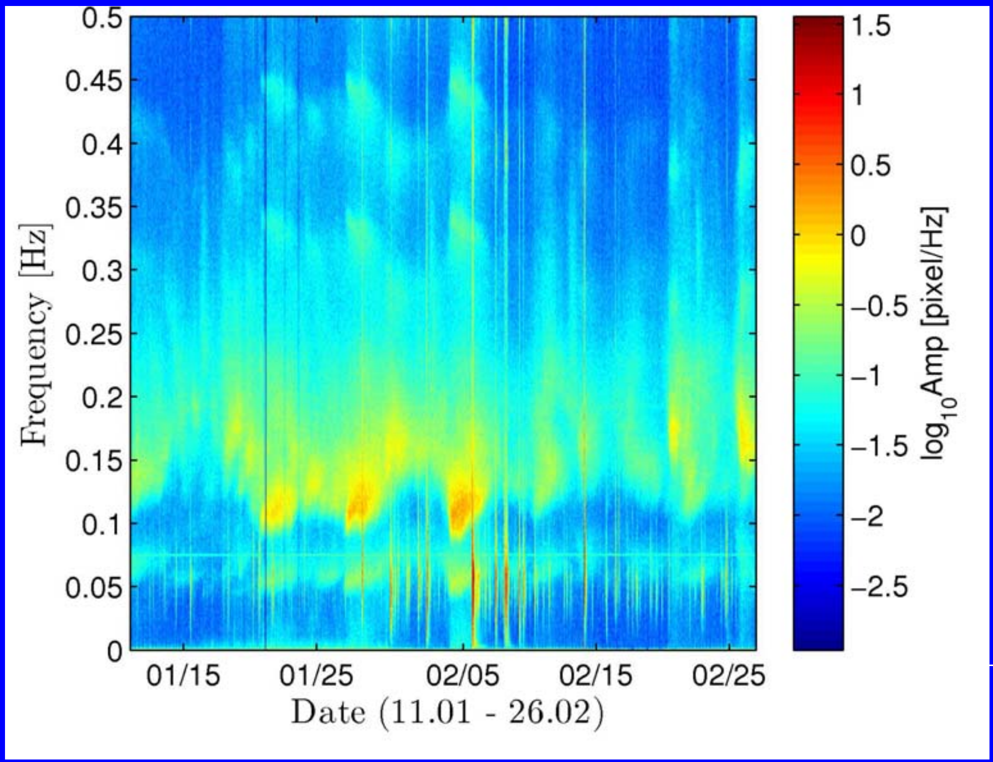
- Co-located observations with spring and superconducting gravity meters in the Conrad Observatory (ZAMG), Austria
  Time period: January 12. 2012 - May 2. 2013
  Instruments: GWR SG025 (ZAMG)
  Scintrex CG (Univ. Vienna)
  LCR G220 (ELGI)
  LCR G949 (MTA CSFK GGI)

Spectral analysis of 1 Hz records

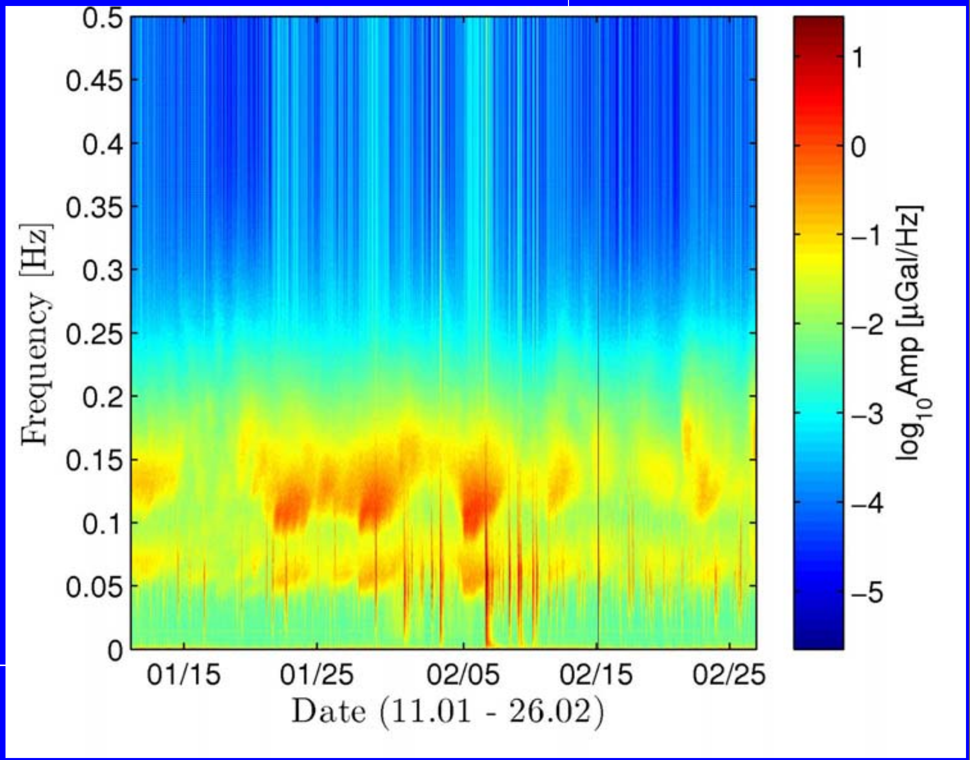
- Direct comparison of spectra of recorded time series

Dynamic spectra from 1 h long record segments

LCR G949



GWR SG025

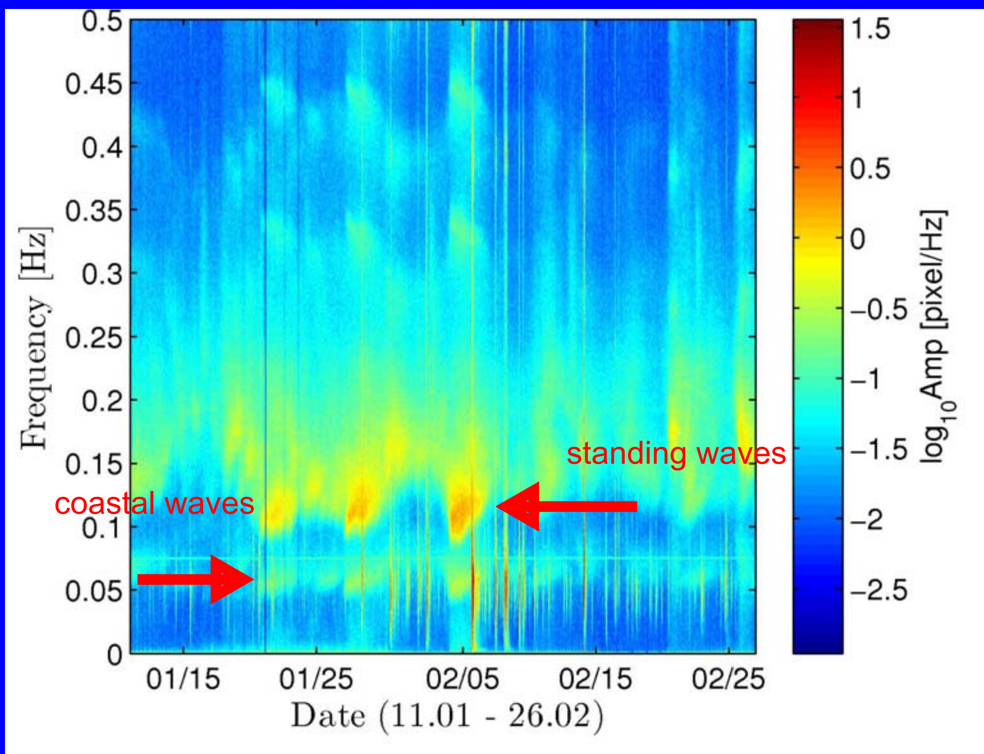


Spectral analysis of 1 Hz records

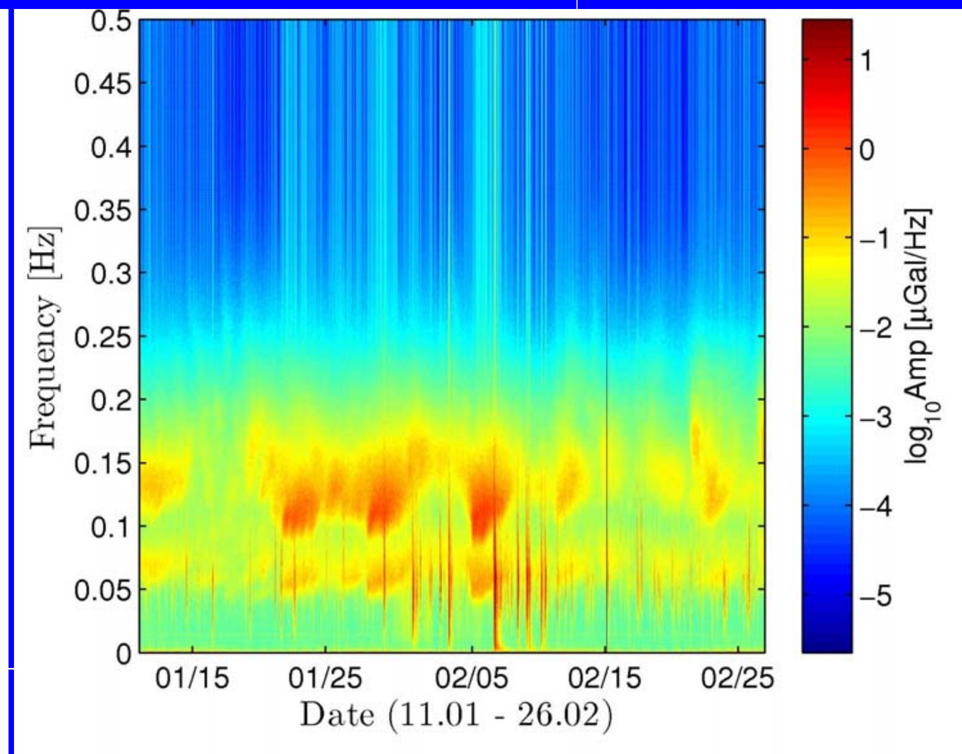
- Direct comparison of spectra of recorded time series

Dynamic spectra from 1 h long record segments

LCR G949



GWR SG025

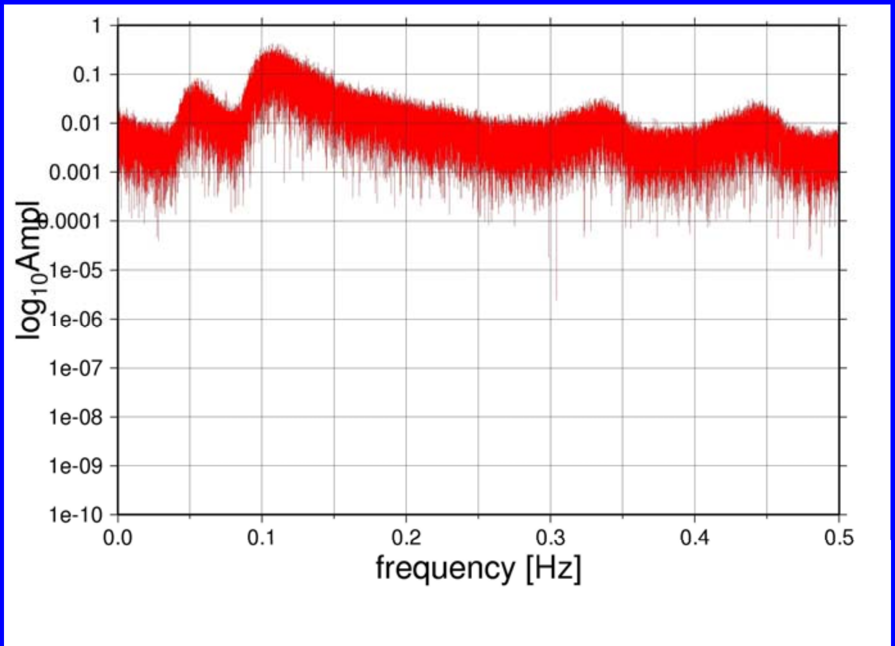


Spectral analysis of 1 Hz records

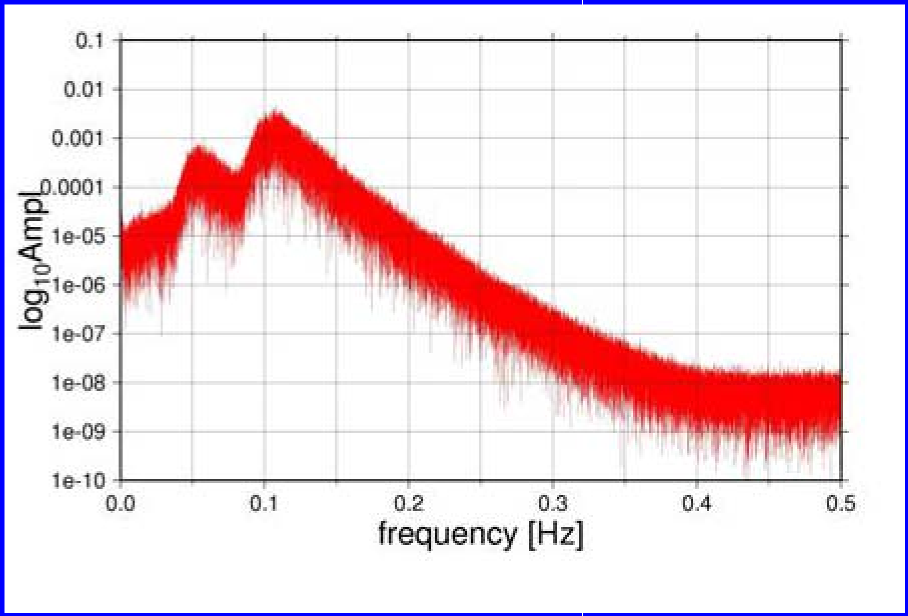
- Direct comparison of spectra of recorded time series

Spectra for the period 24.02.2013 - 26.02.2013 Conrad Observatory (Austria)

LCR G949



SG 025



Acknowledgements

- Many thanks to our colleagues at ZAMG, Austria (esp. Dr. Roman Leonhard), University of Vienna (Dr. Bruno Meurers) and Eötvös Loránd Geophysical Institute, Hungary (Dr. Márta Kis, Dr. András Koppán) for the excellent observational facilities, data sharing and collaboration
- Many thanks for the travel support of the LOC (esp. Dr. Harald Lück)
- Many thanks for your kind and patient attention