Deterministic Atmospheric Effects in the Hum - Band

by

Walter Zürn (BFO)

Hum – Day
September 12, 2014, LMU Munich

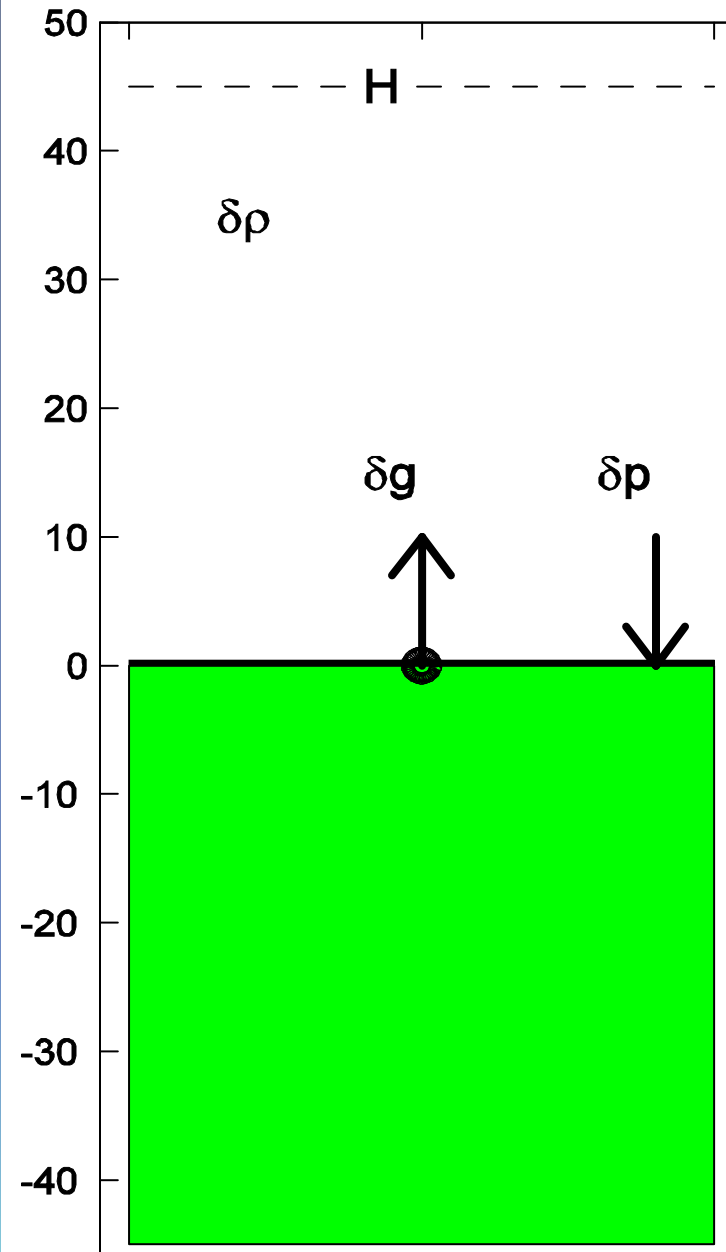
-- We cannot see the vertical hum in a 24 hr-record

-- The most precise records of gravity variations clearly show the Newtonian attraction and loading of the crust by atmospheric masses

-- Since deformation is involved, at higher frequencies inertial effects (~w^2) must play a role

-- A simple model and a unique record will be presented demonstrating that the combination of the gravitational, free air and inertial effects cancel at some frequency in the hum-band

Bouguer plate model (BPM)



atmosphere above rigid halfspace

homogeneous & laterally infinite

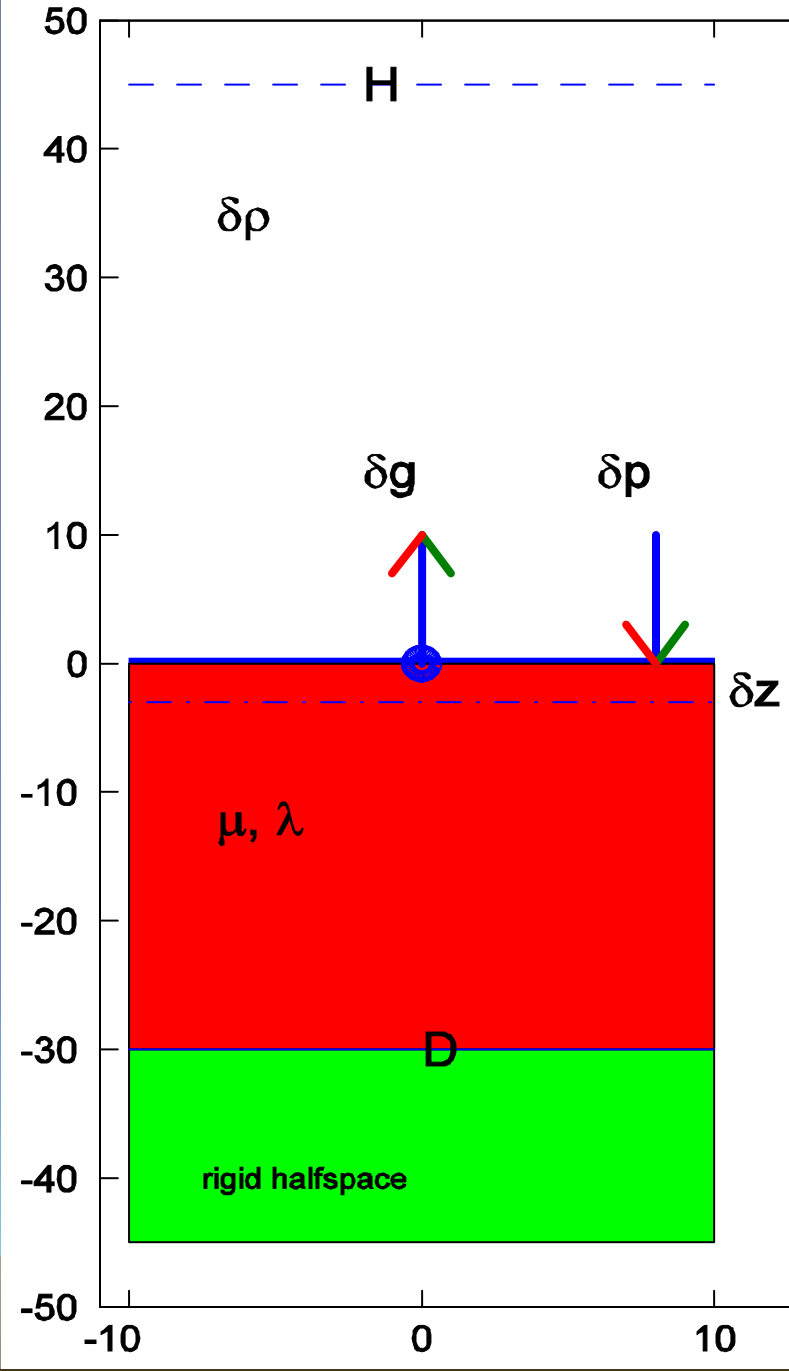
$$\delta p = H\, g_0\, \delta\rho$$

$$\delta g = -2\ \pi\ G\ H\ \delta\rho$$

$$\delta g/\delta\rho = -2\ \pi\ G/g_0 = -2\ \pi\ r_E^2/m_E$$

$$= -4.27\ \text{nm}\cdot\text{s}^{-2}/\text{hPa}$$

Improved Bouguer plate model (IBPM)



atmosphere above elastic layer
on top of rigid halfspace
homogeneous & laterally infinite

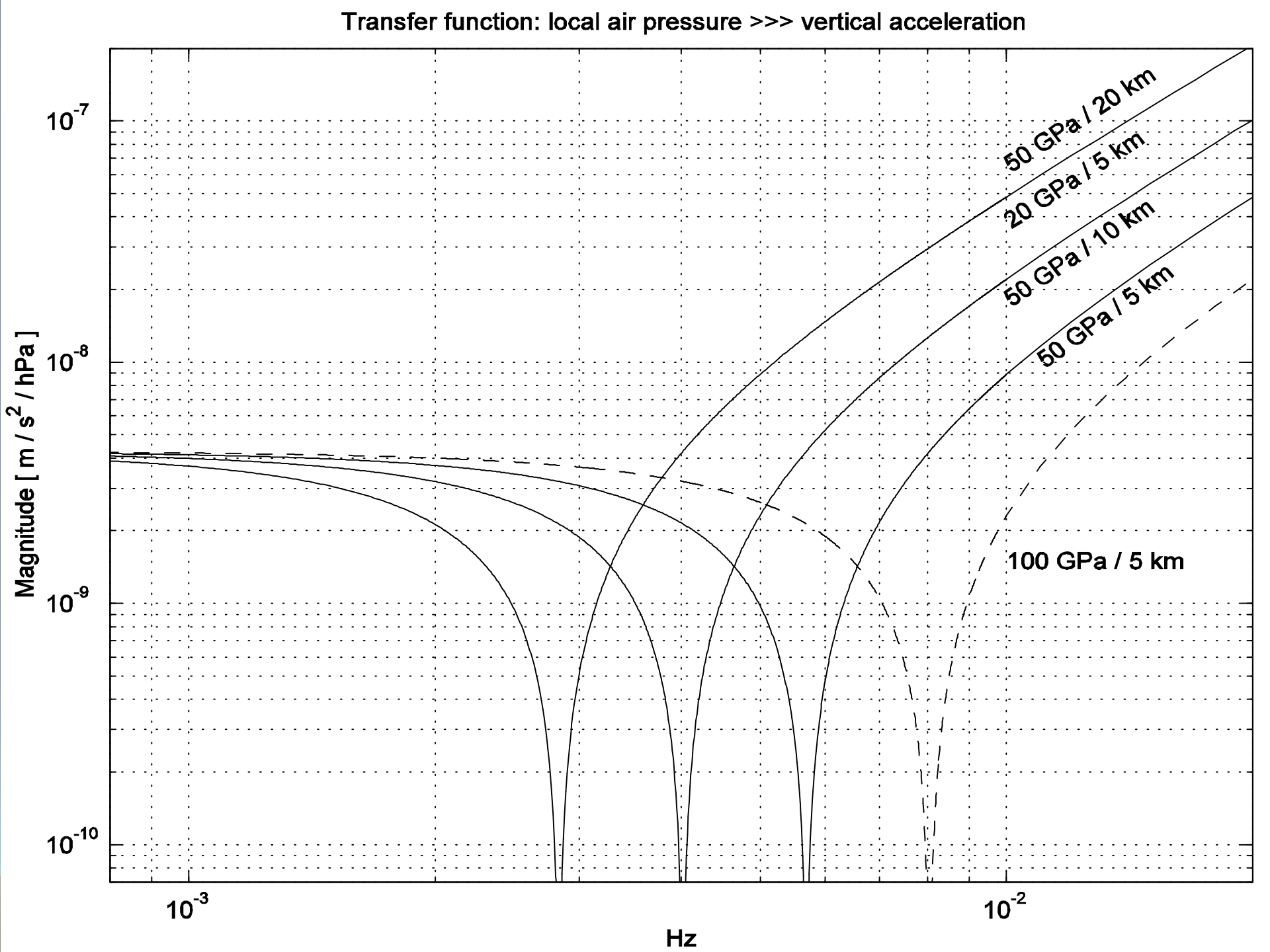
$$\delta z = D\,\delta p / (\lambda + 2\,\mu)$$

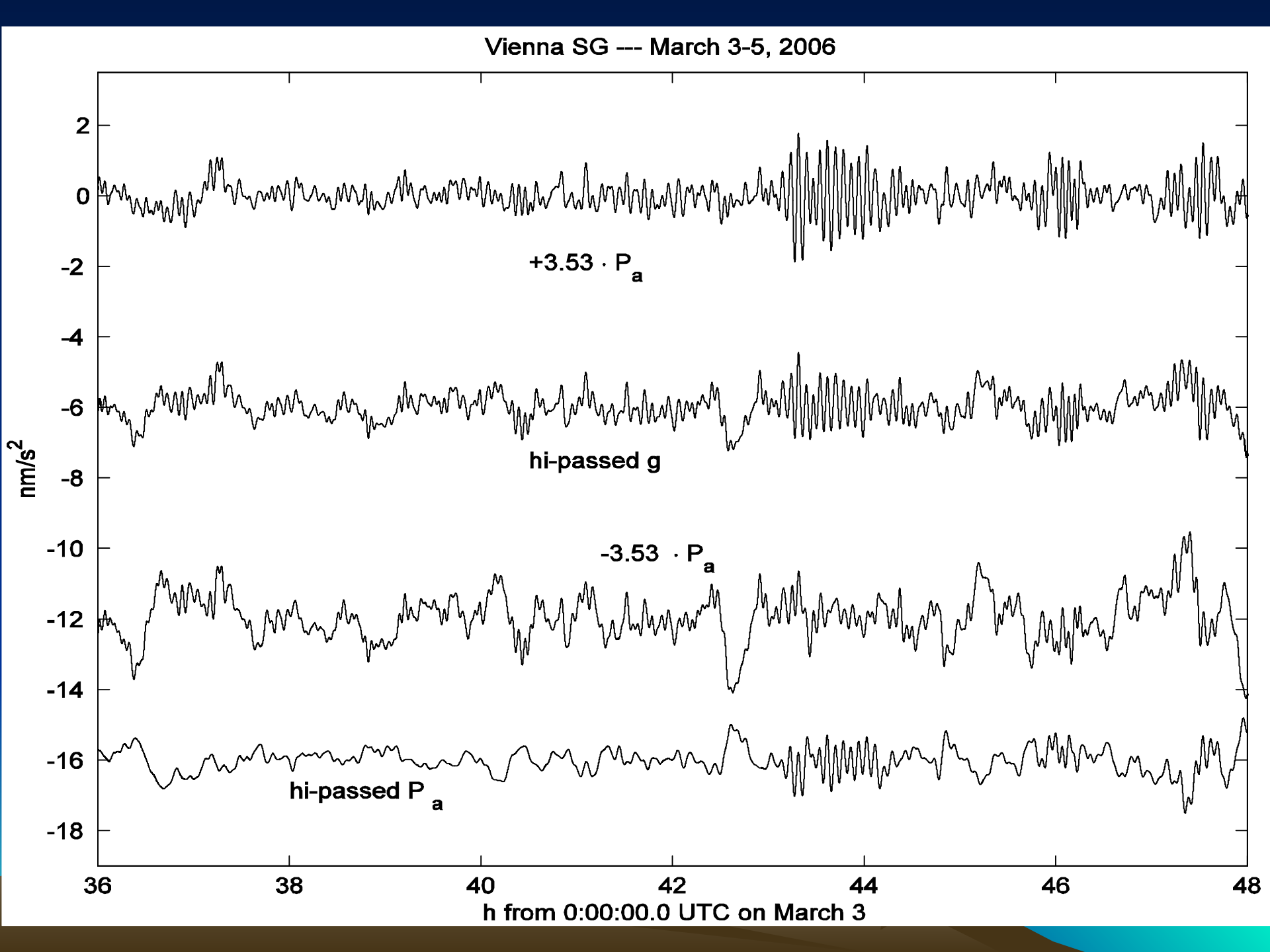
$$\delta g_{free\ air} = \gamma\,\delta z$$

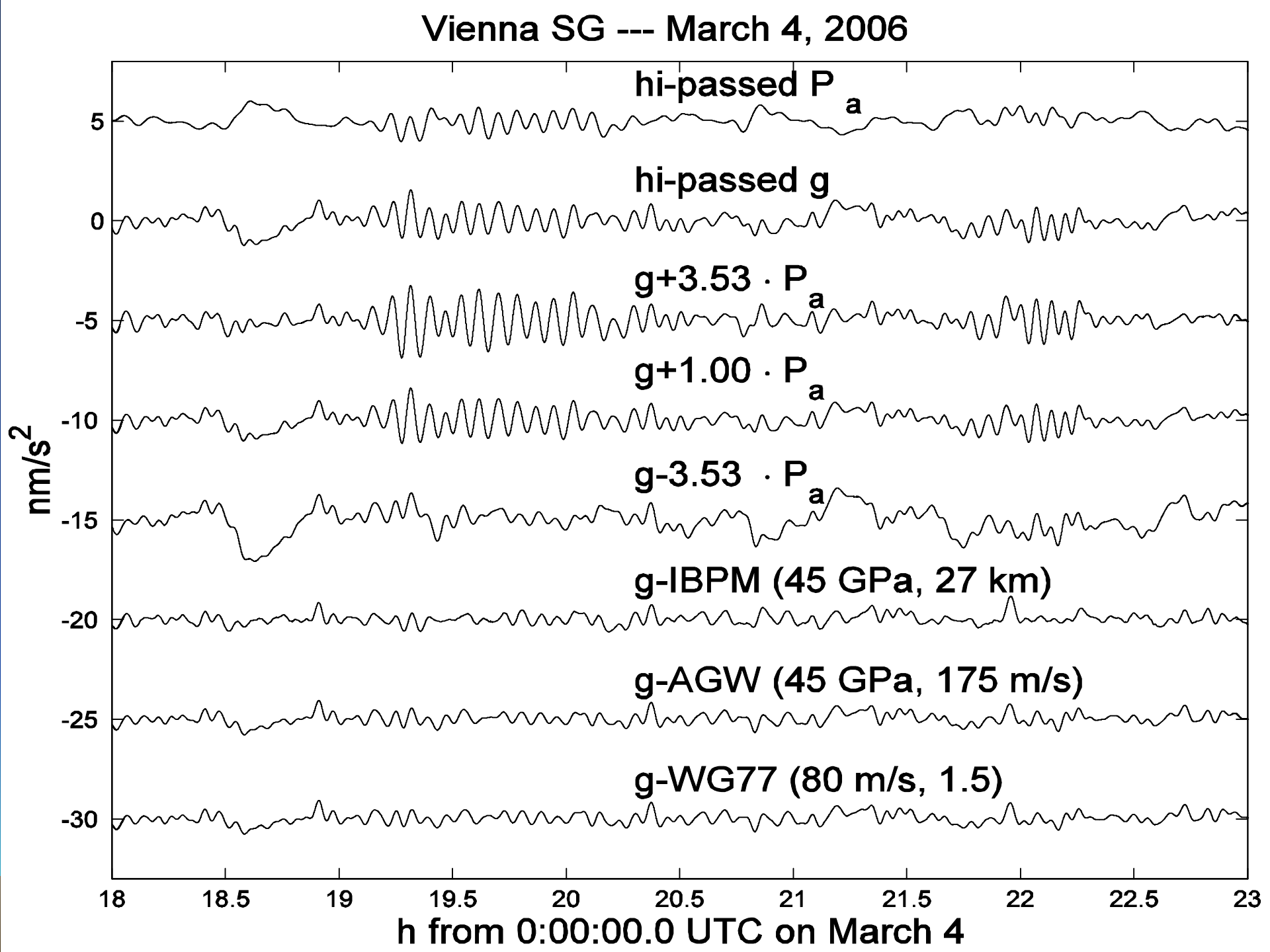
$$\delta g_{inertial} = \omega^2\,\delta z$$

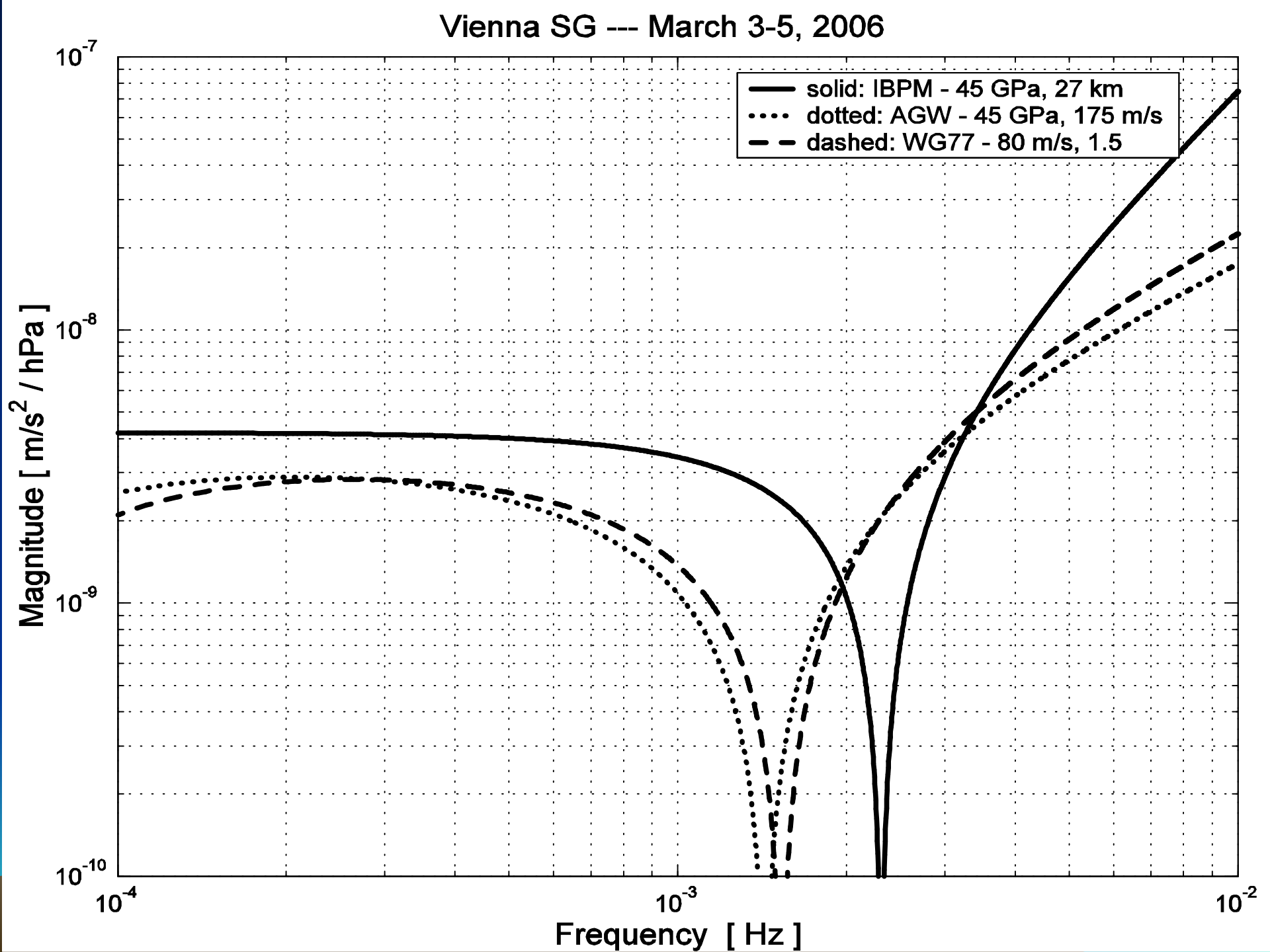
$$\delta g_{total}/\delta p = -2\,\pi\,G/g_0 + \ldots$$

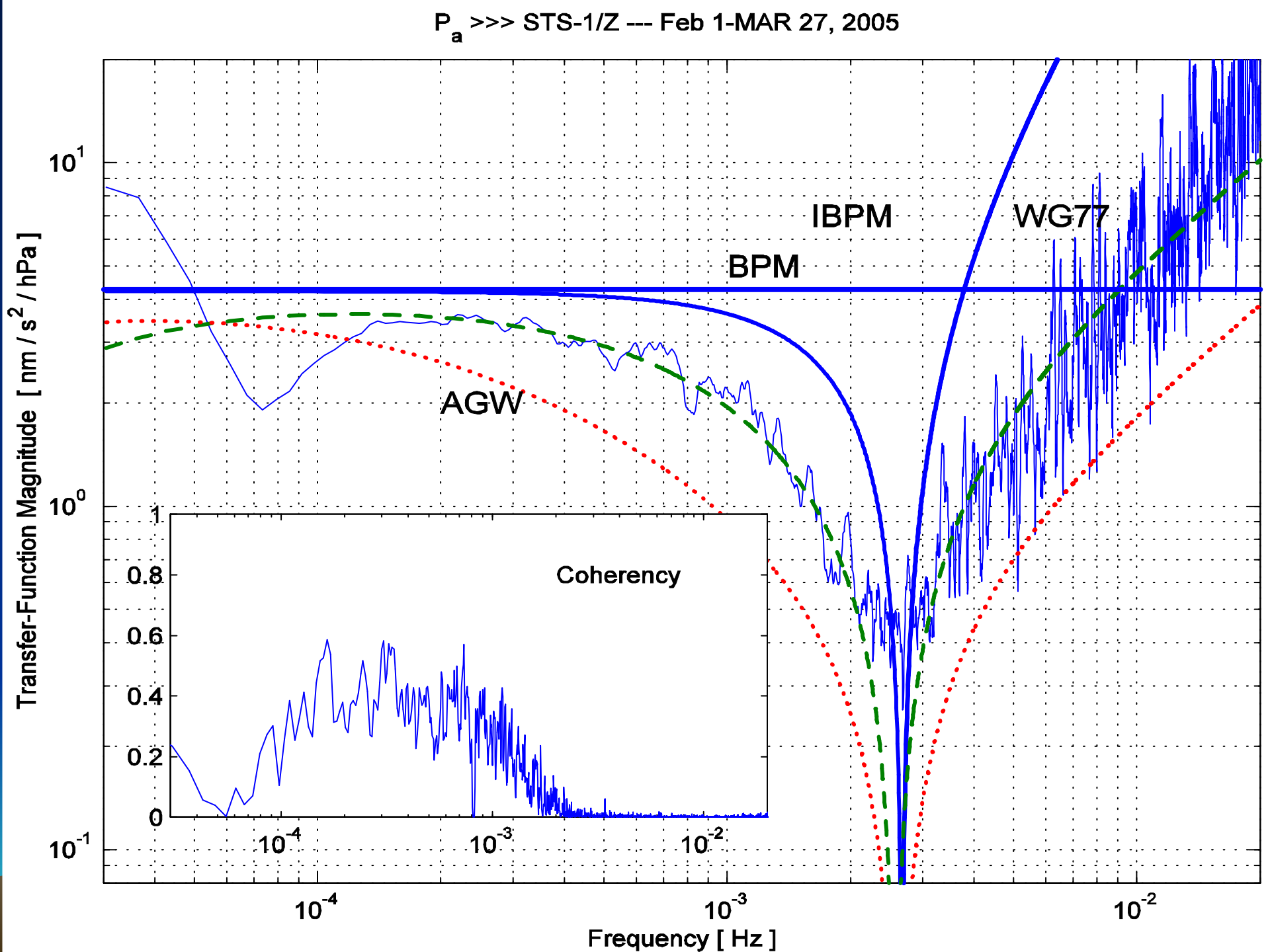
$$+D\,(\gamma + \omega^2)/(\lambda + 2\,\mu)$$


Transfer function: local air pressure >>> vertical acceleration
Magnitude [m / s2 / hPa]
10-7
10-8
10-9
10-10
10-3
10-2
Hz
50 GPa / 20 km
20 GPa / 5 km
50 GPa / 10 km
50 GPa / 5 km
100 GPa / 5 km


Vienna SG --- March 3-5, 2006
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
nm/s2
+3.53 · Pa
hi-passed g
-3.53 · Pa
hi-passed Pa
36
38
40
42
44
46
48
h from 0:00:00.0 UTC on March 3


Vienna SG --- March 4, 2006
hi-passed P a
hi-passed g
g+3.53 · P a
g+1.00 · P a
g-3.53 · P a
g-IBPM (45 GPa, 27 km)
g-AGW (45 GPa, 175 m/s)
g-WG77 (80 m/s, 1.5)
5
0
-5
-10
-15
-20
-25
-30
nm/s2
18
18.5
19
19.5
20
20.5
21
21.5
22
22.5
23
h from 0:00:00.0 UTC on March 4


Vienna SG --- March 3-5, 2006
solid: IBPM - 45 GPa, 27 km
dotted: AGW - 45 GPa, 175 m/s
dashed: WG77 - 80 m/s, 1.5
Magnitude [m/s2 / hPa]
Frequency [Hz]
10-7
10-8
10-9
10-10
10-4
10-3
10-2


P a >>> STS-1/Z --- Feb 1-MAR 27, 2005
Transfer-Function Magnitude [nm / s2 / hPa]
Frequency [Hz]
IBPM
WG77
BPM
AGW
Coherency
10^1
10^0
10^-1
10^-4
10^-3
10^-2
1
0.8
0.6
0.4
0.2
0

Thank you for your attention !

Discussions with and materials from

Erhard Wielandt
Rudolf Widmer-Schnidrig
Thomas Forbriger
Udo Neumann
Bruno Meurers
Jan Exß

are appreciated as well as financial support from

Deutsche Forschungsgemeinschaft

On noise reduction in vertical seismic records below 2 mHz using local barometric pressure.
W.Zürn and R. Widmer
Geophys. Res. Lett. (1995) 22, 3537 -3540

##########

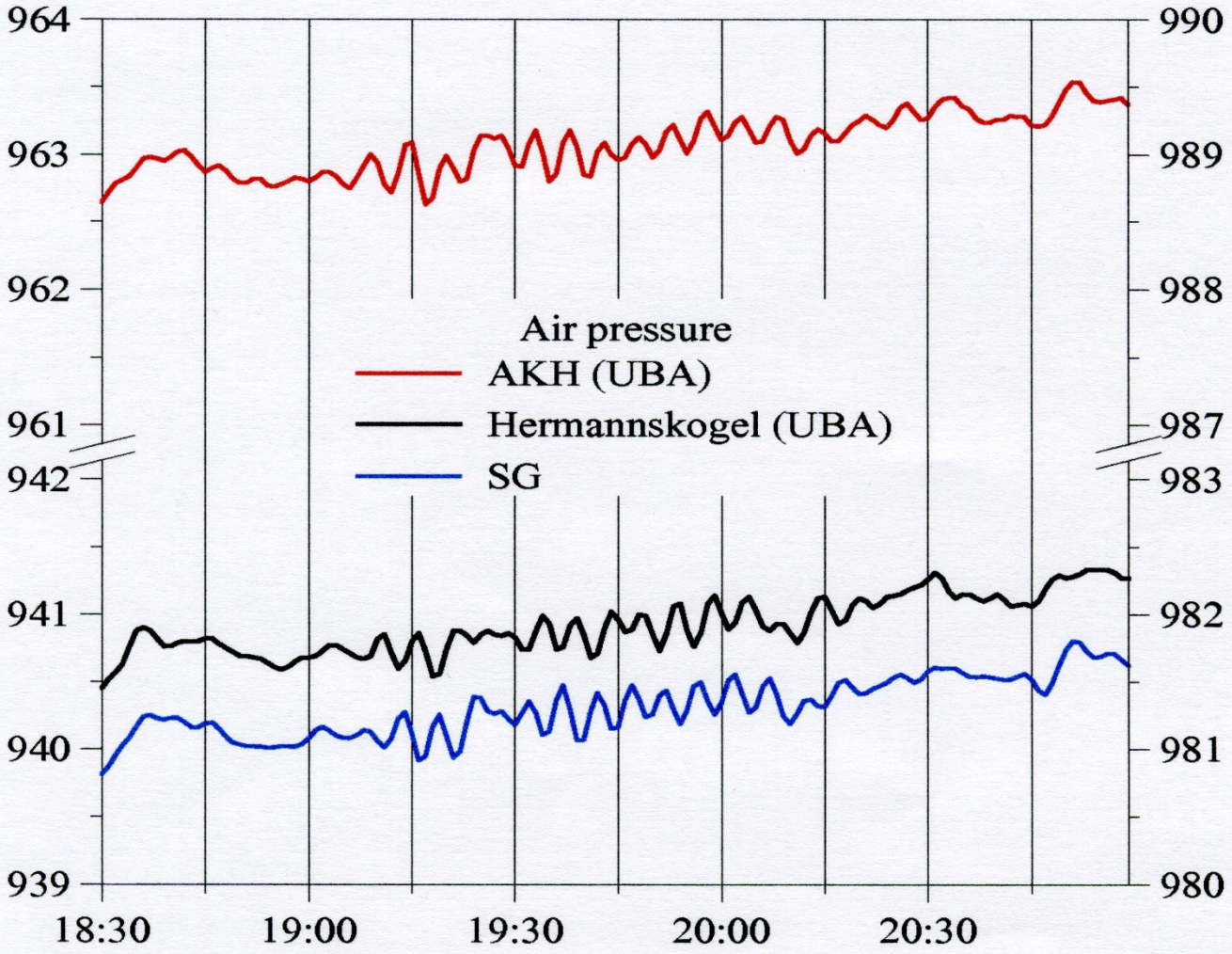
On the minimum of vertical seismic noise near 3 mHz
W. Zürn and E. Wielandt
Geophys. J. Int. (2007) **168,** *647 - 658*

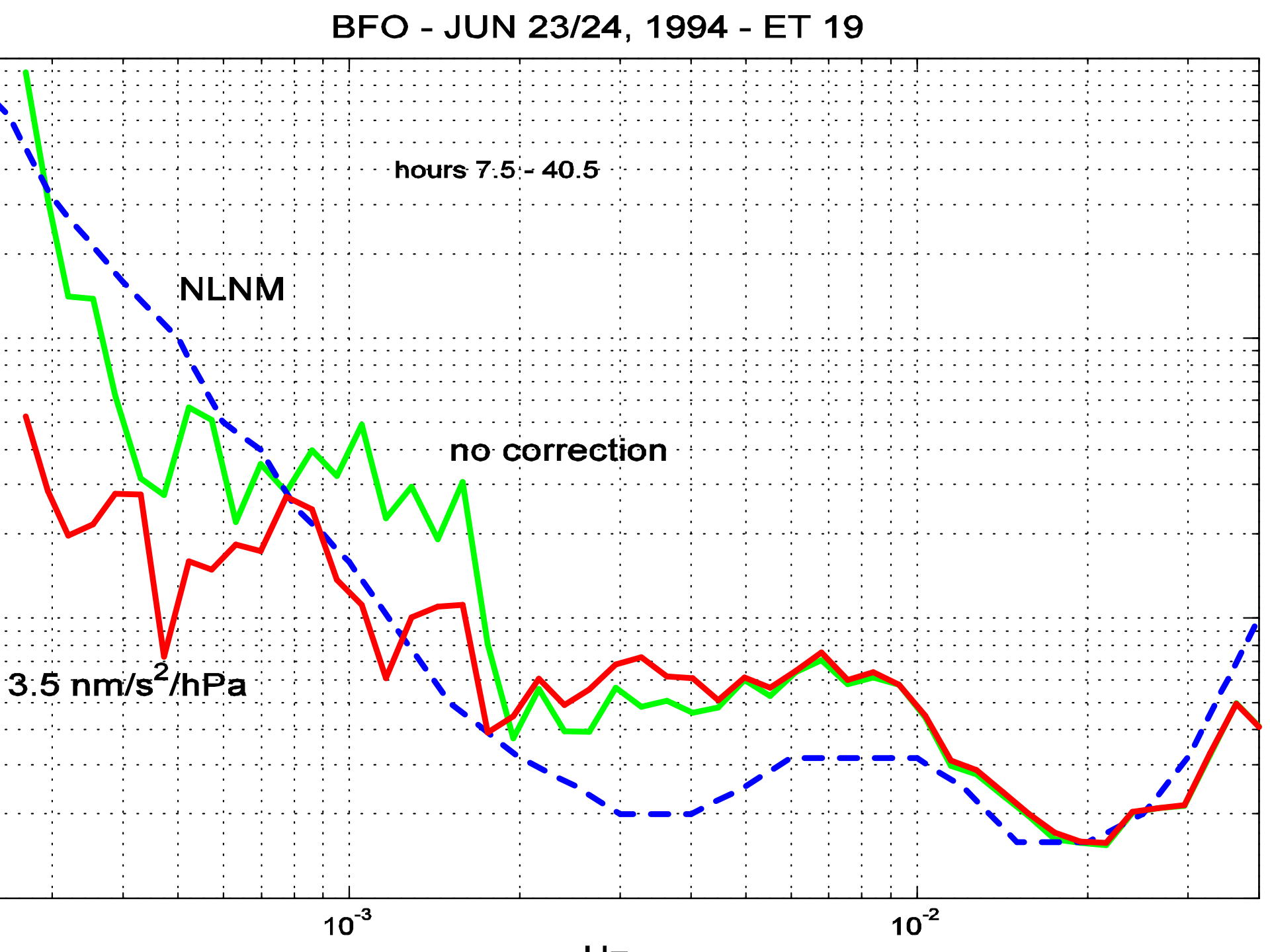
##########

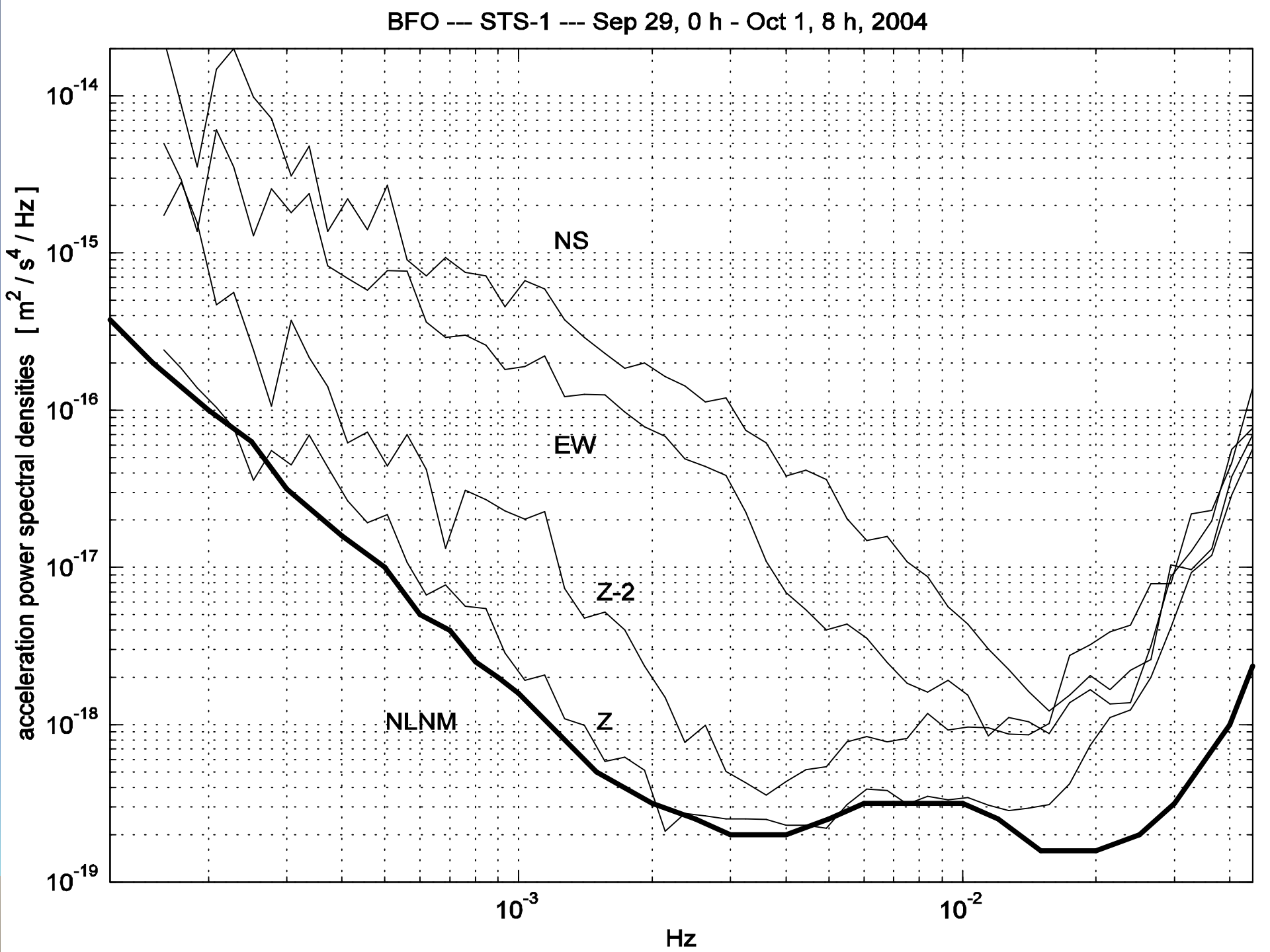
On reduction of long-period horizontal seismic noise using local barometric pressure
W. Zürn, J. Exß, H. Steffen, C. Kroner, T. Jahr, and
M. Westerhaus
Geophys. J. Int. (2007), **171**, 780 – 796

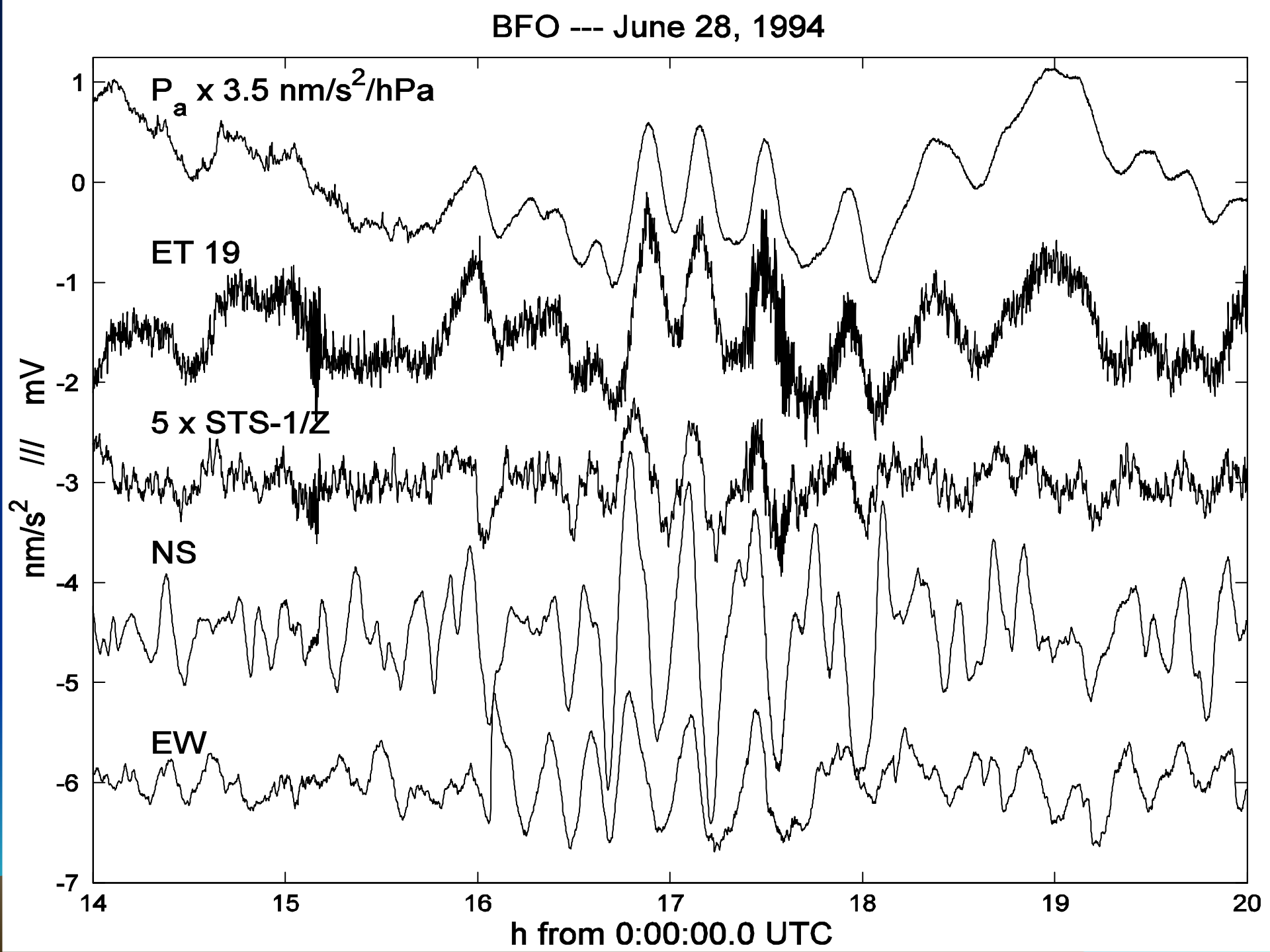
##########

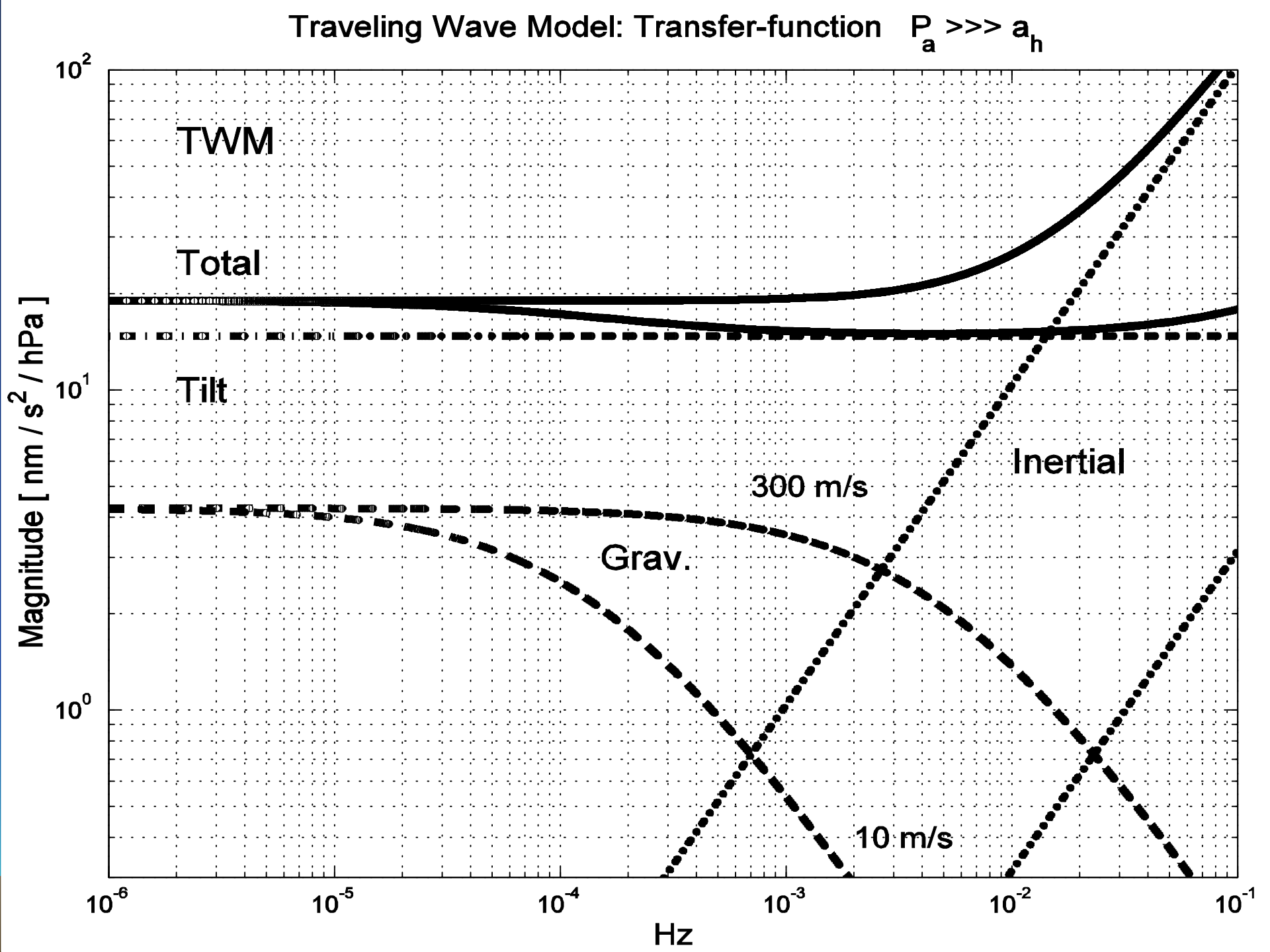
Clear evidence for the sign-reversal of the pressure admittance to gravity near 3 mHz
W. Zürn and B. Meurers
J. Geodynamics (2009), 48, 371 - 377

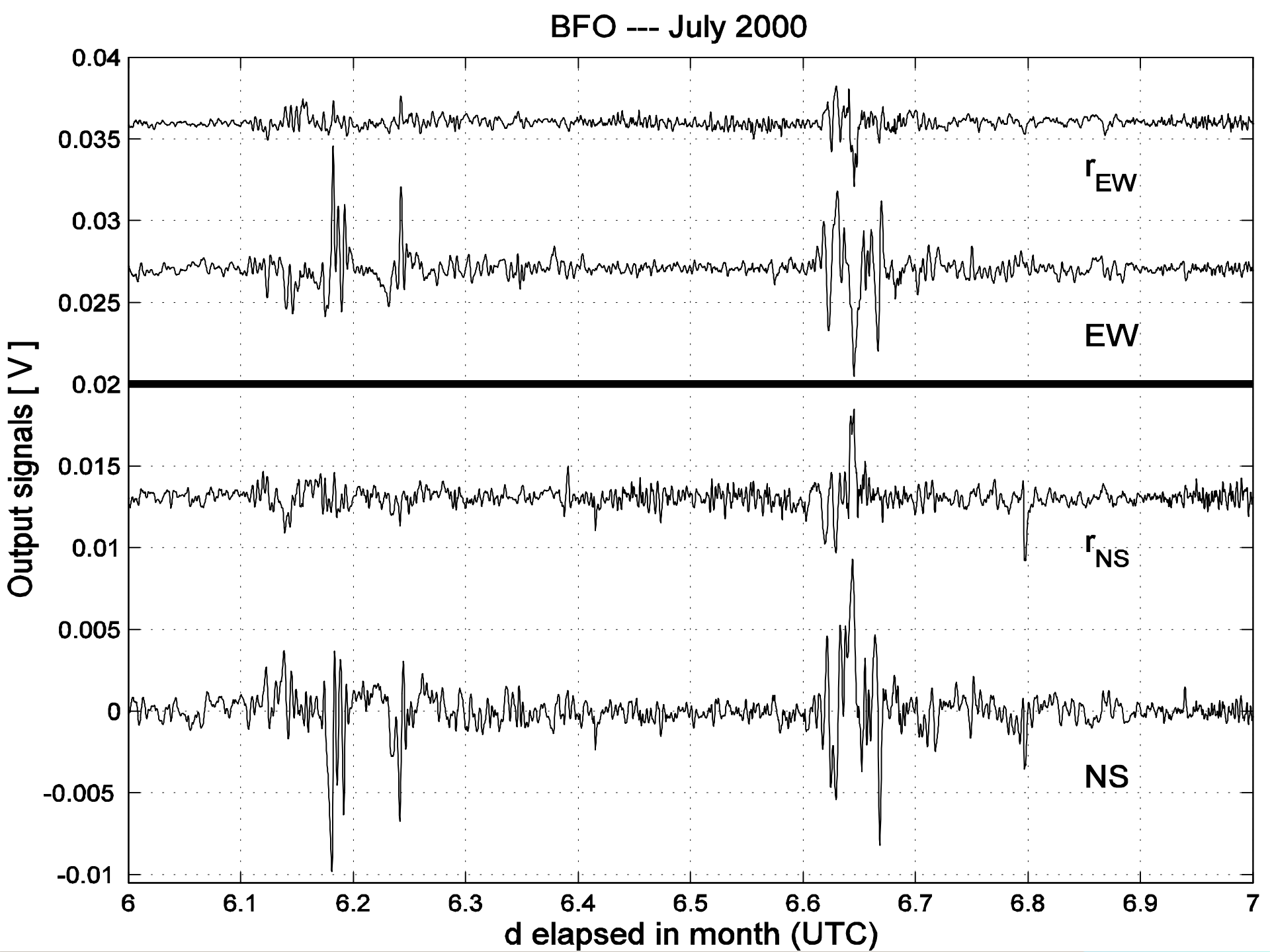

964
963
962
961
942
941
940
939
990
989
988
987
983
982
981
980
Air pressure
AKH (UBA)
Hermannskogel (UBA)
SG
18:30
19:00
19:30
20:00
20:30

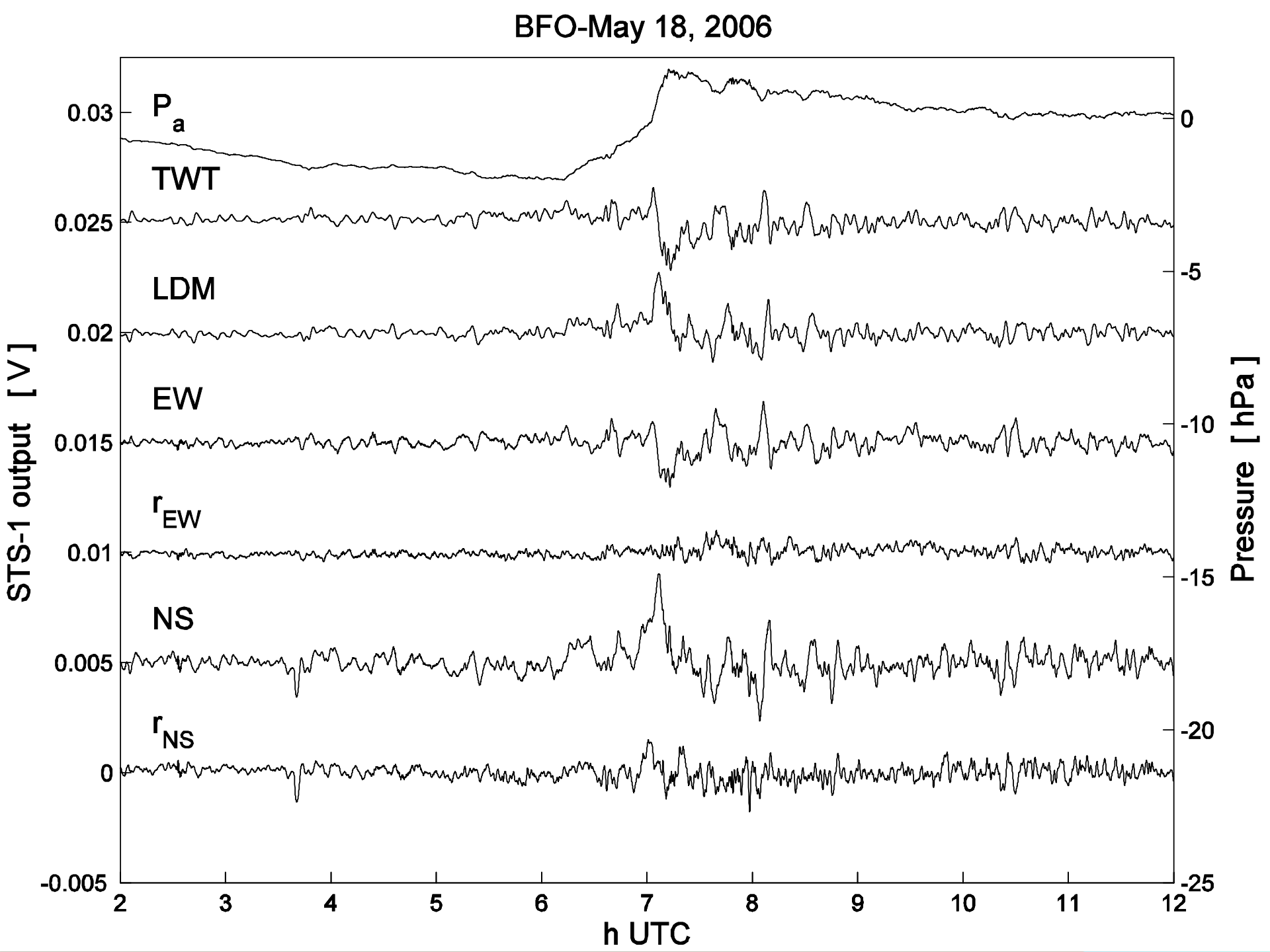

BFO - JUN 23/24, 1994 - ET 19
hours 7.5 - 40.5
NLNM
no correction
3.5 nm/s2/hPa
10-3
10-2

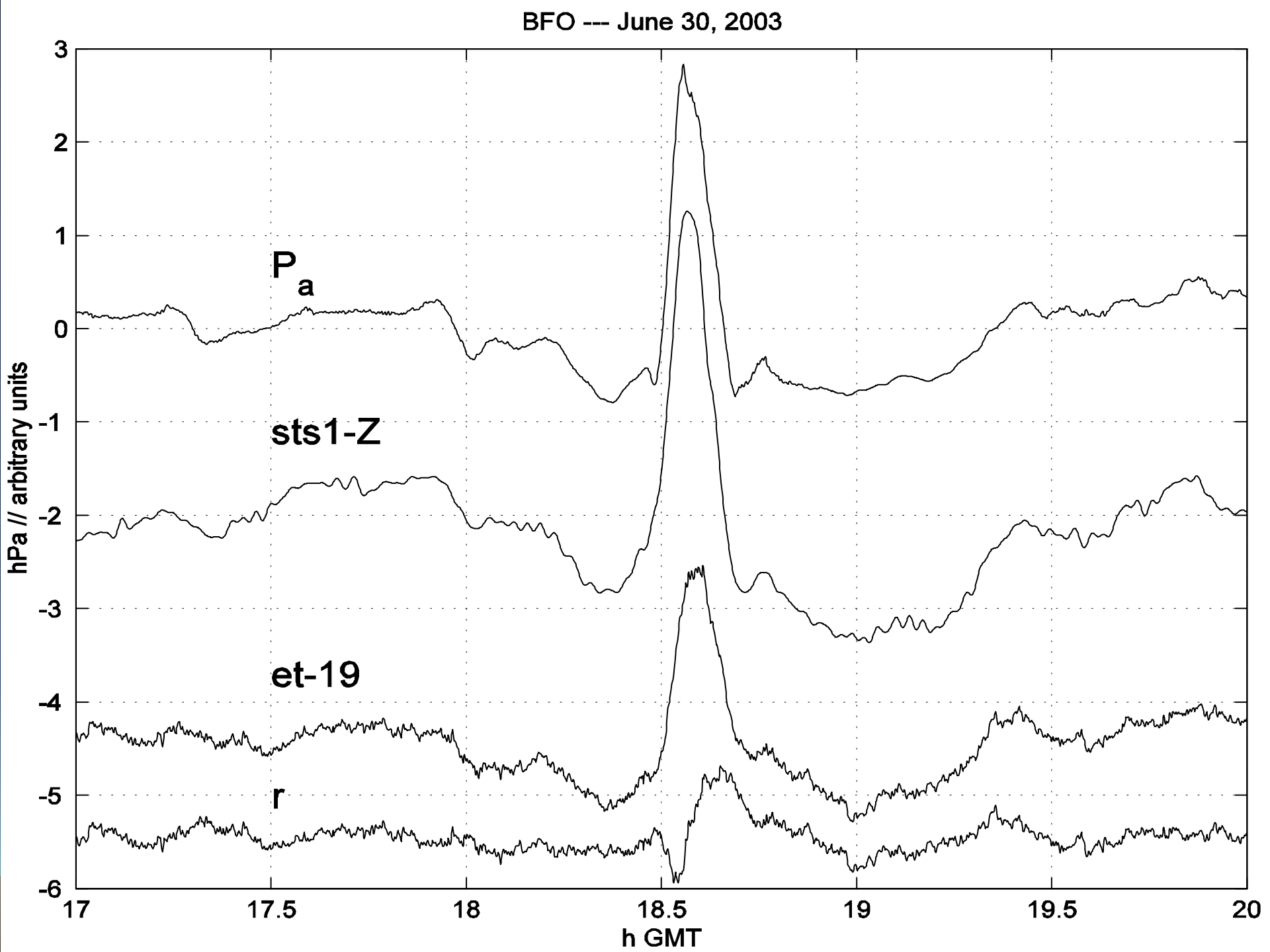

BFO --- STS-1 --- Sep 29, 0 h - Oct 1, 8 h, 2004
acceleration power spectral densities [m2 / s4 / Hz]
10-14
10-15
10-16
10-17
10-18
10-19
NS
EW
Z-2
Z
NLNM
10-3
10-2
Hz

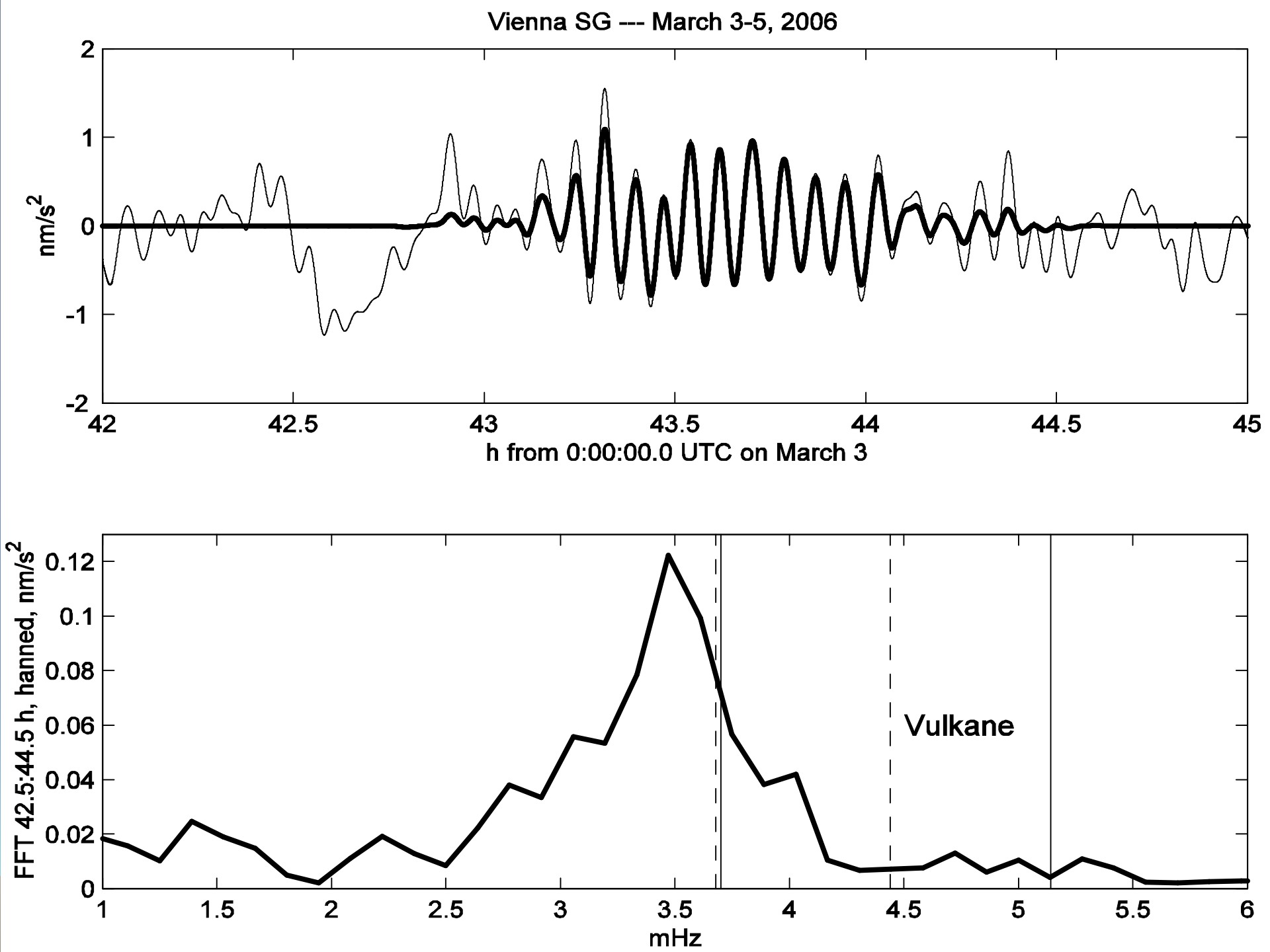

BFO --- June 28, 1994
P a x 3.5 nm/s2/hPa
ET 19
5 x STS-1/Z
NS
EW
nm/s2 /// mV
1
0
-1
-2
-3
-4
-5
-6
-7
14
15
16
17
18
19
20
h from 0:00:00.0 UTC


Traveling Wave Model: Transfer-function P_a >>> a_h
TWM
Total
Tilt
Inertial
300 m/s
Grav.
10 m/s
Magnitude [nm / s^2 / hPa]
Hz
10^2
10^1
10^0
10^-6
10^-5
10^-4
10^-3
10^-2
10^-1


BFO --- July 2000
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
Output signals [V]
r EW
EW
r NS
NS
6
6.1
6.2
6.3
6.4
6.5
6.6
6.7
6.8
6.9
7
d elapsed in month (UTC)


BFO-May 18, 2006
P a
TWT
LDM
EW
r EW
NS
r NS
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
0
-5
-10
-15
-20
-25
2
3
4
5
6
7
8
9
10
11
12
h UTC
STS-1 output [V]
Pressure [hPa]


BFO --- June 30, 2003
3
2
1
0
-1
-2
-3
-4
-5
-6
hPa // arbitrary units
P a
sts1-Z
et-19
r
17
17.5
18
18.5
19
19.5
20
h GMT


Vienna SG --- March 3-5, 2006
nm/s2
h from 0:00:00.0 UTC on March 3
FFT 42.5:44.5 h, hanned, nm/s2
mHz
Vulkane

Models for vertical seismic noise from local atmospheric pressure

Acceleration of sensor mass due to

1. Newtonian attraction
2. Free air effect } due to vertical loading
3. Inertial effect }

Model IBPM: laterally homogeneous atmosphere over 1 elastic layer on rigid halfspace

$$\frac{\Delta g}{\Delta p} = -\frac{2\pi G}{g_0} + \frac{D}{\lambda + 2\mu}\left(\omega^2 + \left|\frac{\delta g}{\delta z}\right|\right)$$

G - Gravitational constant; g_0 - surface gravitational acceleration;
D - Layer thickness; λ, μ - Lamé constants of elastic layer;
ω - angular frequency; $\left|\frac{\delta g}{\delta z}\right|$ - vertical gravity gradient

Model AGW: Traveling acoustic-gravity (Lamb-) wave over elastic halfspace

$$\frac{\Delta g}{\Delta p} = -\frac{2\pi G}{g_0}\cdot\frac{1}{1+\frac{\omega c^2}{c_h \cdot g_0}} + \frac{1}{2\mu}\cdot\frac{\lambda+2\mu}{\lambda+\mu}\cdot\frac{c_h}{\omega}\left(\omega^2 + \left|\frac{\delta g}{\delta z}\right|\right)$$

c - sound velocity (333 m/s); c_h - horizontal phase velocity

Models for horizontal noise from local barometric pressure

Local deformation model (LDM)

homogeneous atmosphere over elastic halfspace
with complicated topography and cavities

$$\delta a(x,y,z,t) = C(x,y,z)\,\delta p(t)$$

Traveling wave model (TWM)

isothermal atmosphere above elastic halfspace

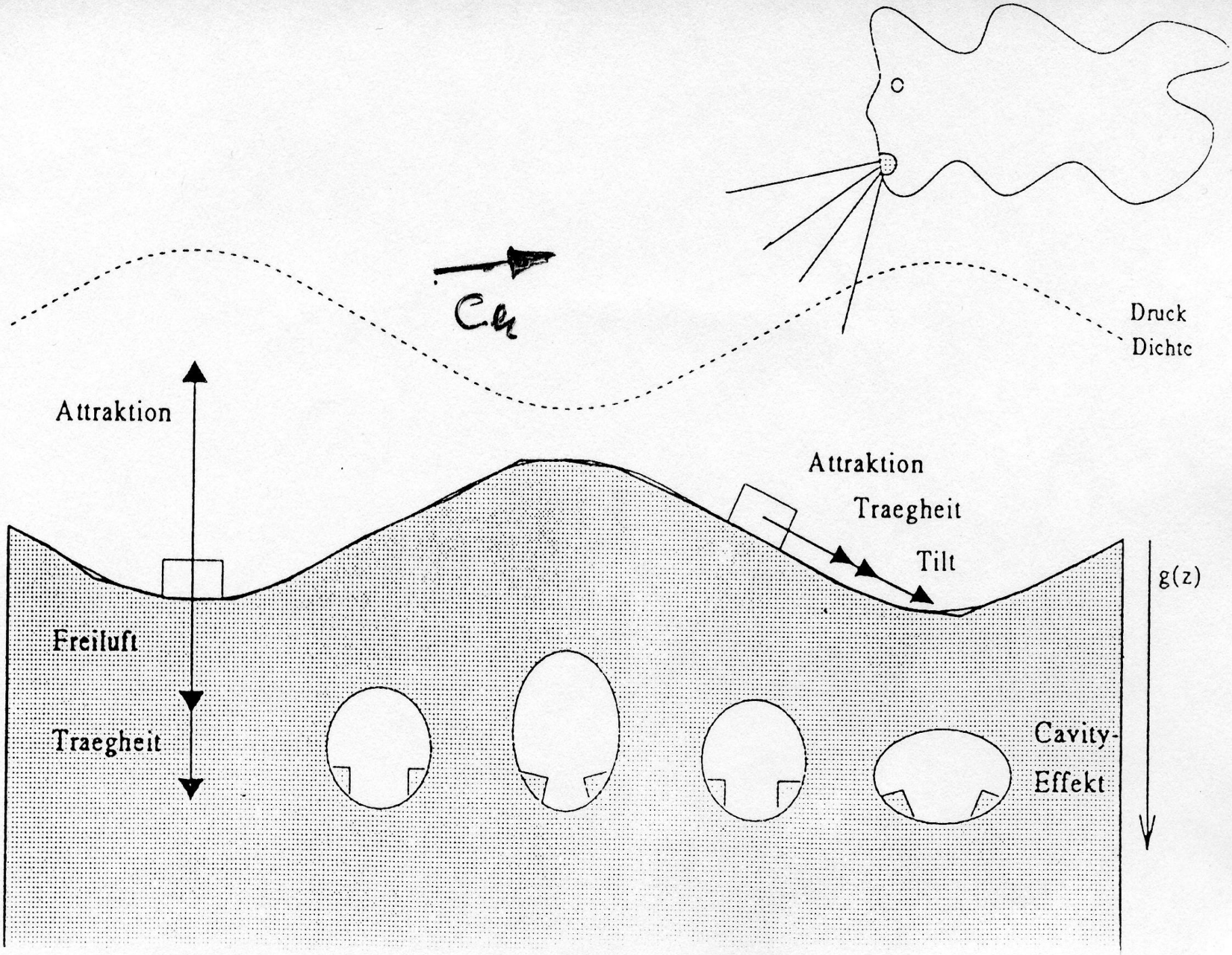
$$\delta a_N = i2\pi\, G/g_0\; 1/(1+\omega c^2/(c_h g_0))\;\delta p$$

$$\delta a_T = i\, g_0/(2\mu)\;(\lambda+2\mu)/(\lambda+\mu)\;\delta p(t)$$

$$\delta a_I = i\,\omega c_h/(2\mu)\;\mu/(\lambda+\mu)\;\delta p(t)$$

with $\delta p(t) = p_0 \exp(i\omega(x/c_h - t))$

50
40
30
20
10
0
-10
-20
-30
-40
-50
-10
0
10
20
30
40
50


Druck
Dichte
Attraktion
Attraktion
Traegheit
Tilt
g(z)
Freiluft
Traegheit
Cavity-
Effekt

- Hum detection with STS-2 at BFO:

  (Widmer-Schnidrig, BSSA, 2003)