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Ground Motion in Future Accelerators
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Ground vibration at the site of ESRF and comparison with some other places

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Background

Ground vibrations measurement was **simultaneously** carried out at the sites :

- **ESRF**
- **SuperACO** *in the south of Paris*
- **Orme des Merisiers** *(for **SOLEIL** project) near SuperACO*

during 8-11 **October 1996**

the initial **purpose** of this investigation :

- measurement of the ground vibration at the site of Orme des Merisiers
- comparison with the sites of ESRF and SuperACO.

Outline

- **Measurement instruments, set-up and procedure**
- **Analyses and results in the frequency range (1-100 Hz)**
  - *Temporal signal analyses and results*
  - *Spectral analyses and results*
  - *Study of high level events*
- **Analyses and results in the low frequency range (0.05-1 Hz)**
  - *Temporal signal analyses and results*
  - *Spectral analyses and results*
  - *Correlation between the 3 sites*

Instruments & set-up

at each site, installed :

- **data acquisition system** *(RefTek 72A-06 or 72A-07, 6 channels, 16 or 24 bits)*
- **long period seismometer** *(Guralp CMG-3ESP : 3D, 0.03-50Hz)*
- **1 Hz geophone** *(Mark Products L4C : vertical)*

additionally

- **1 spectrum analyser** *(HP35670, 4 channels, 80 db)* + **4 geophones** *(L4C vertical + horizontal)*

for special study (homogeneous, 3D)

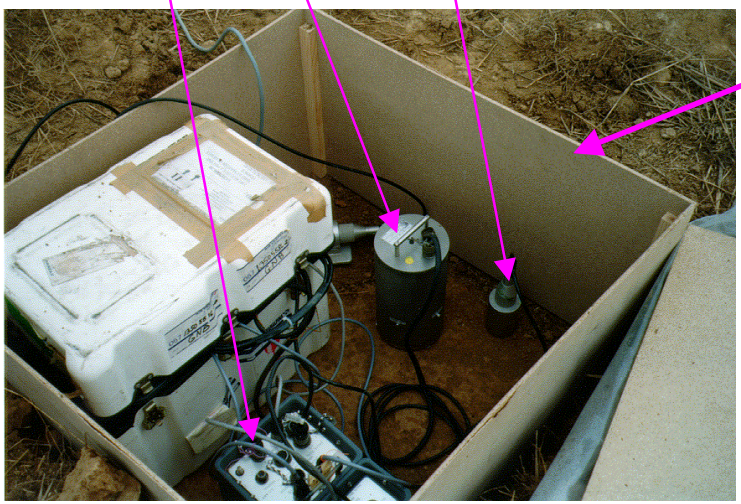
all materials were just placed on the floor within about 1 m^2 surface area.

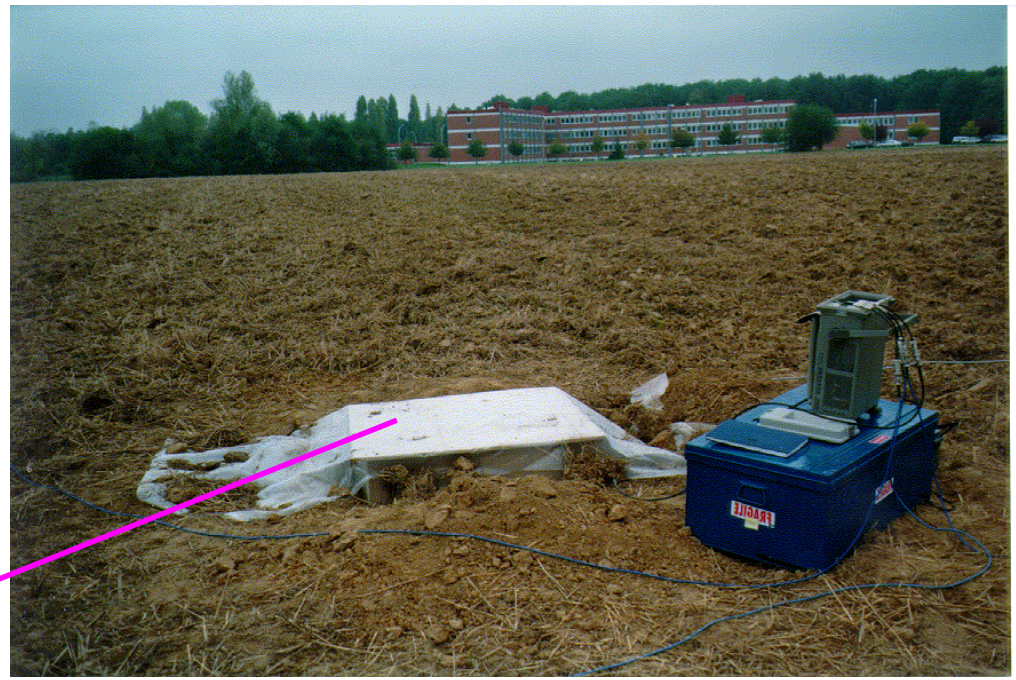
Instruments & set-up

Data acquisition system
(Reftek 72A-07)

Seismometer
(Guralp CMG-3ESP)

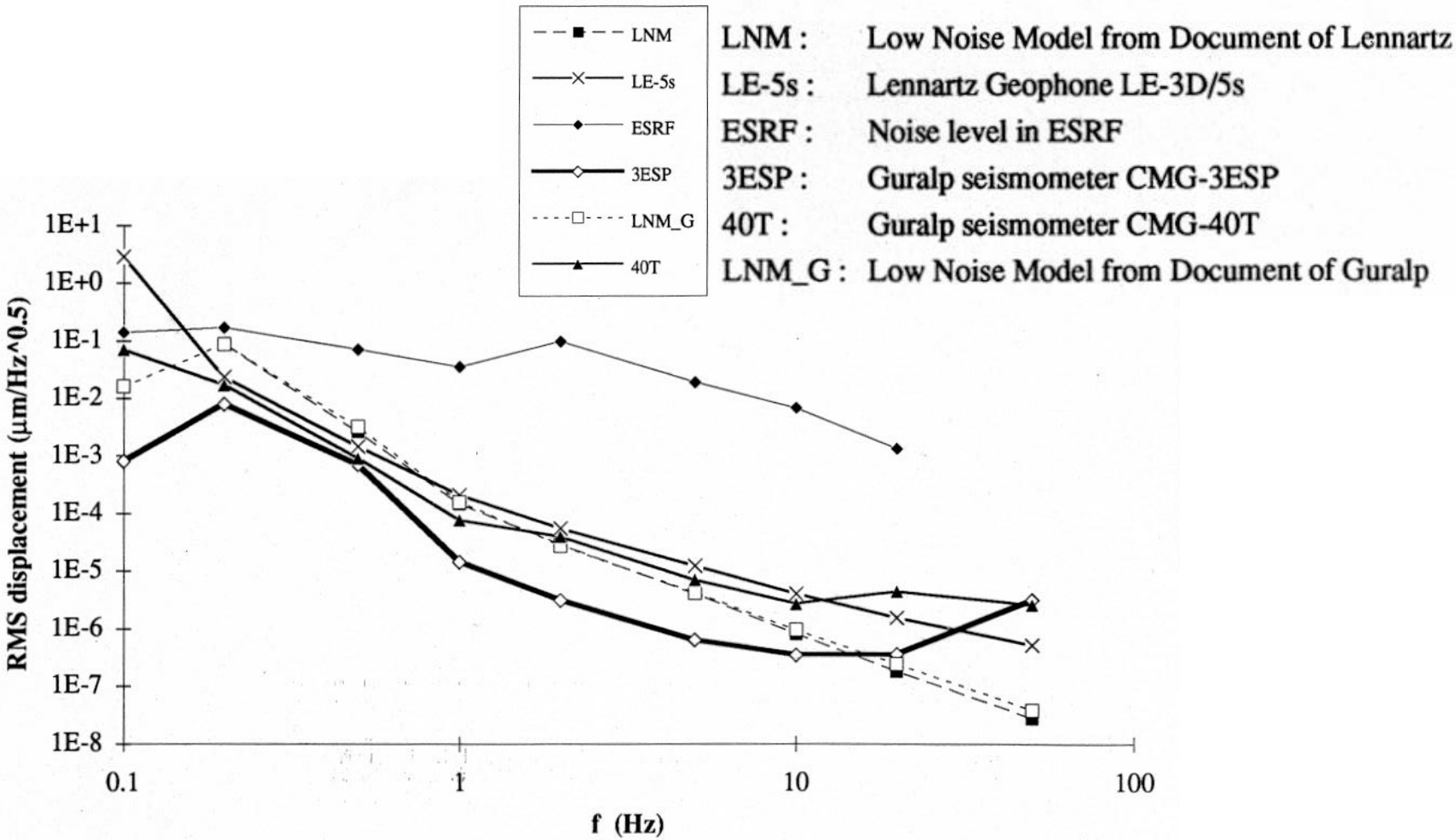
Geophone
(Mark Products L4C)





at L'Orme des Merisiers

Instruments & set-up - *seismometer study (1992)*



Measurement procedure

considerations for defining the measurement procedure :

- collect maximum amount of data
- hard disk capacity 500 Mb for data storage
- a reasonable number of files for the convenience of data processing

synchronisation accuracy < 1 second for periodical measurements at the three sites

two types of measurements :

- i) with the vertical 1 Hz geophone, (sampling rate 250 pts/s)

  1.5 minutes measure + 3 minutes break + 1.5 minutes measure + 3 minutes break +...
- ii) with the long period seismometer, (sampling rate 125 pts/s)

  15 minutes measure + 90 minutes break + 15 minutes measure + 90 minutes break +...

these measurements (data acquisition) covered at least a period of 60 hours (from 8-Oct-1996, 6pm to11-Oct-1996, 8am) in the three sites.

General data processing procedure

Time domain	(**SAC** : **S**eismic **A**nalysis **C**ode, *LLNL*)	for (0.05-1Hz)
	(**MatLab**, *The Math Works Inc*)	for (1-100Hz)
Frequency domain	(**MatLab**)	

2 frequency ranges :

— intermediate : 1-100 Hz

— low : 0.05-1 Hz

Quantity of data and formats

collected DATA during more than 60 hours of measurements from the 3 sites :

	format	**quantity**	**for use**
	compressed	250 Mb	raw data stored in the acquisition system
order of	.segy	500 Mb	visualisation and simple analysis with **PQL**
conversion	.sac	500 Mb	Dpp and Drms calculation with **SAC**
	.mat	1 Gb	advanced analyses with **Matlab**

total number of files :

from 1 Hz geophones L4C :	2700
from seismometers CMG-3ESP :	312

all these files were visualised

(1-100 Hz) - *temporal signal analyses / data processing*

- **instrument correction**
- **time integration**
- **high pass filtering**
- **peak-to-peak (or RMS) displacement calculation**

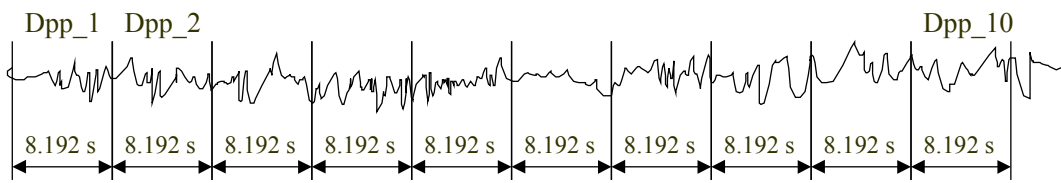
— peak-to-peak displacement

$$Dpp=max(D_{max\_}i-D_{min\_}i)_{i=1,2,...10}$$

— RMS displacement

$$Drms=max(Drms\_i)_{i=1,2,...10}$$

each file of 90 seconds was divided into 10 windows of 8.192 seconds (2048 pts):

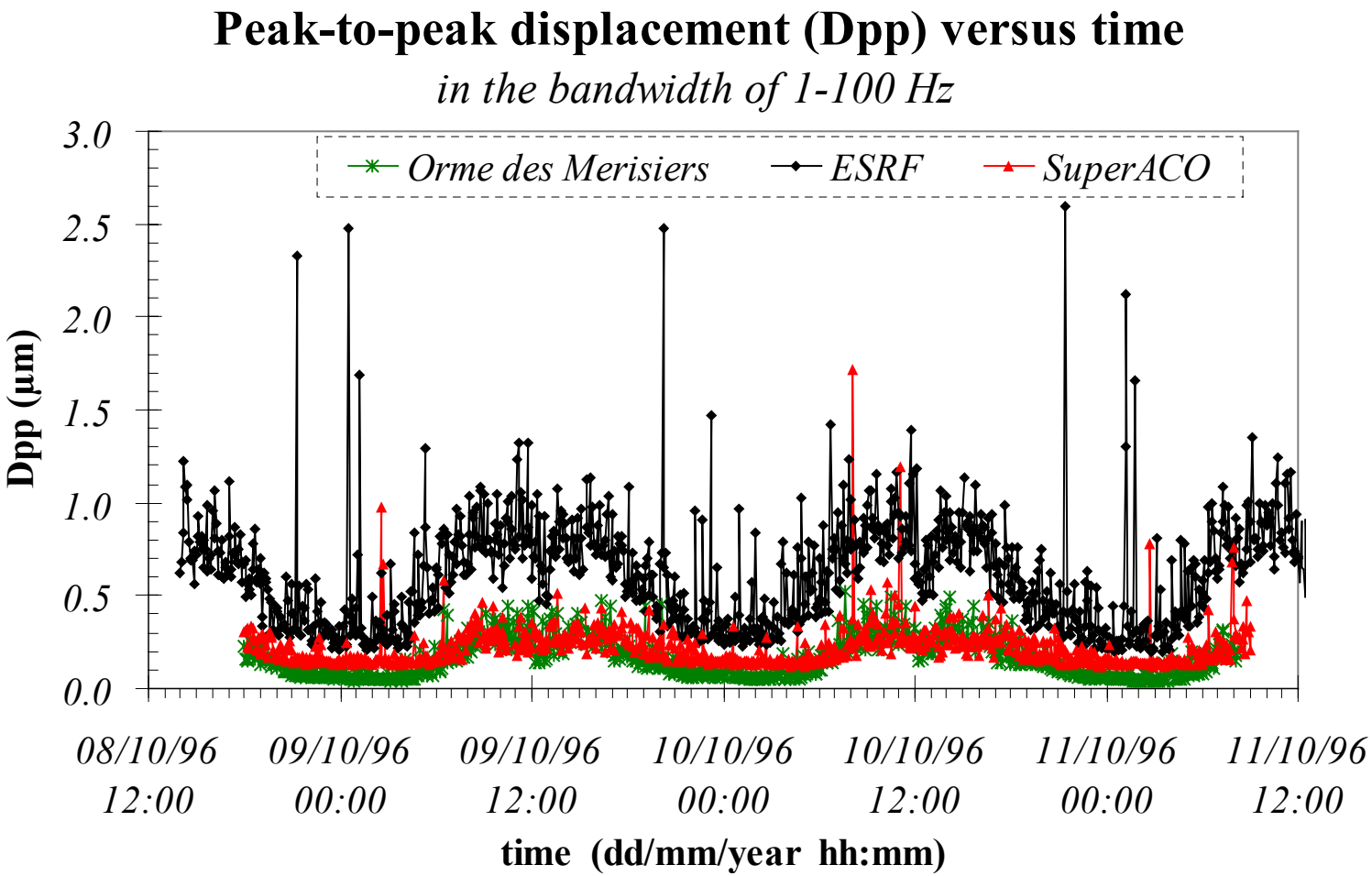


Dpp(t)

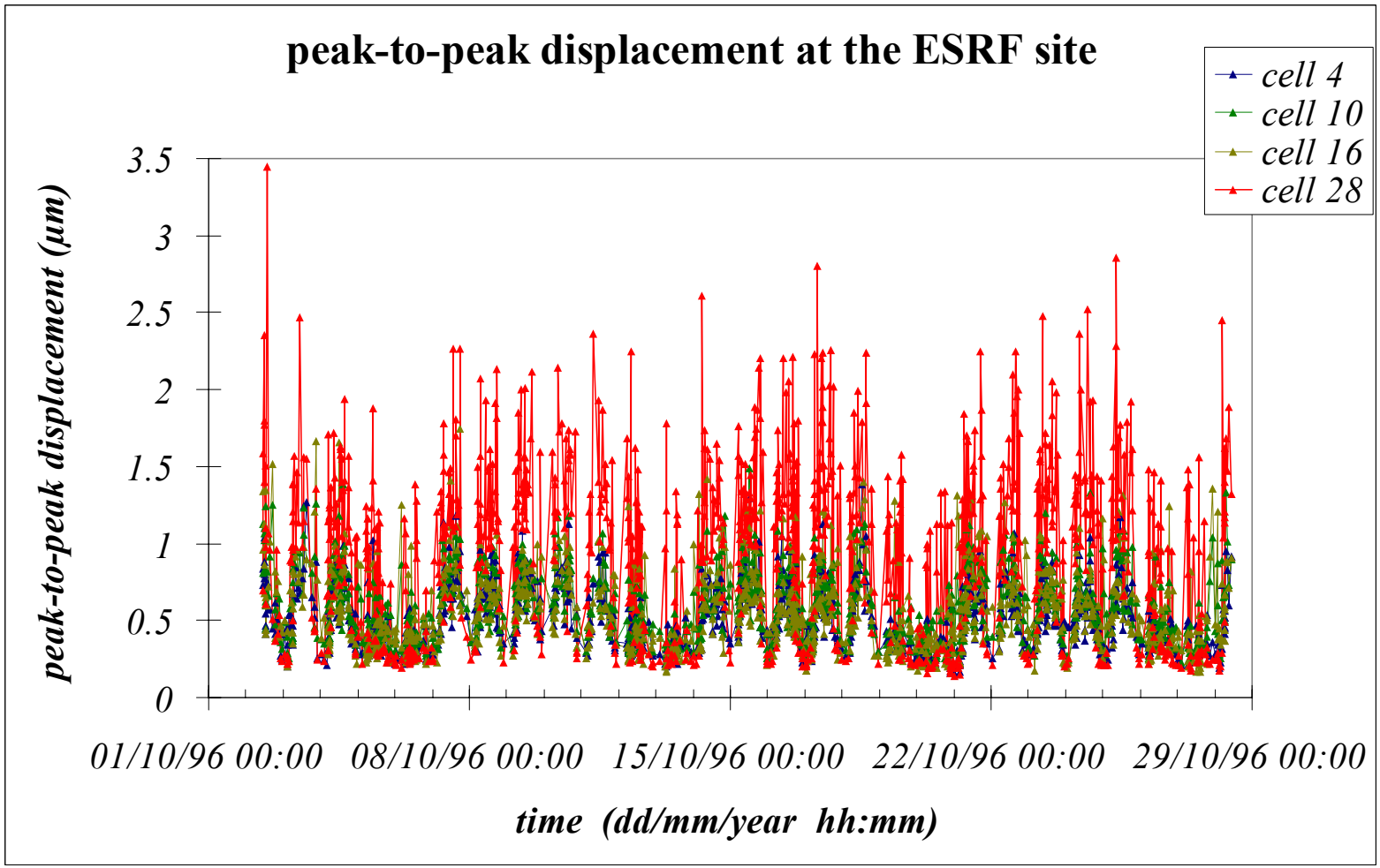
Drms(t)

t : beginning time of the file

(1-100 Hz) - *temporal results*



(1-100 Hz) - *temporal results*



Summary of results - in the frequency range (1-100 Hz)

- **The vibrations level varies clearly with time.**

- **Typical values** are summarised as below :

	ESRF	Orme des Merisiers	SuperACO
Dpp during day	0.9 µm	0.4 µm	0.4 µm
Dpp during night	0.4 µm	0.08 µm	0.16 µm
Drms during day	0.15 µm	0.04 µm	0.04 µm
Drms during night	0.08 µm	0.01 µm	0.02 µm
high level events	yes, up to 3 µm	no	yes, up to 2 µm

(1-100 Hz) - *Spectral analyses*

- **Instrument correction**
- **Spectral displacement calculation**
  - —integration of measured velocity in time domain
  - —FFT, displacement spectrum
  - —averaged velocity spectrum
- **some parameters used for spectra averaging**
  - —window length of FFT : 16.384 s
  - —windows overlap : 14 s
  - —number of spectra used for average : 31

Different form of spectral results and units

v_FT Fourier Transform of velocity over a window length of T (unit : $\mu m/s/Hz$)

v_sp real spectrum of velocity (output of spectrum analyzer) (unit : $\mu m/s$)

$$v\_sp = \frac{2}{T} v\_FT$$

PSD_v velocity Power Spectrum Density (unit : $(\mu m/s)^2/Hz$)

$$PSD\_v = \frac{T}{2} v\_sp^2 = \frac{2}{T} v\_FT^2$$

d_sp real spectrum of displacement (unit : μm)

$$d\_sp = \frac{v\_sp}{j2\pi f}$$

PSD_d displacement Power Spectrum Density (unit : $\mu m^2/Hz$)

$$PSD\_d = \frac{T}{2} d\_sp^2$$

PSD_d^0.5 root squared displacement Power Spectrum Density (unit : $\mu m/\sqrt{Hz}$)

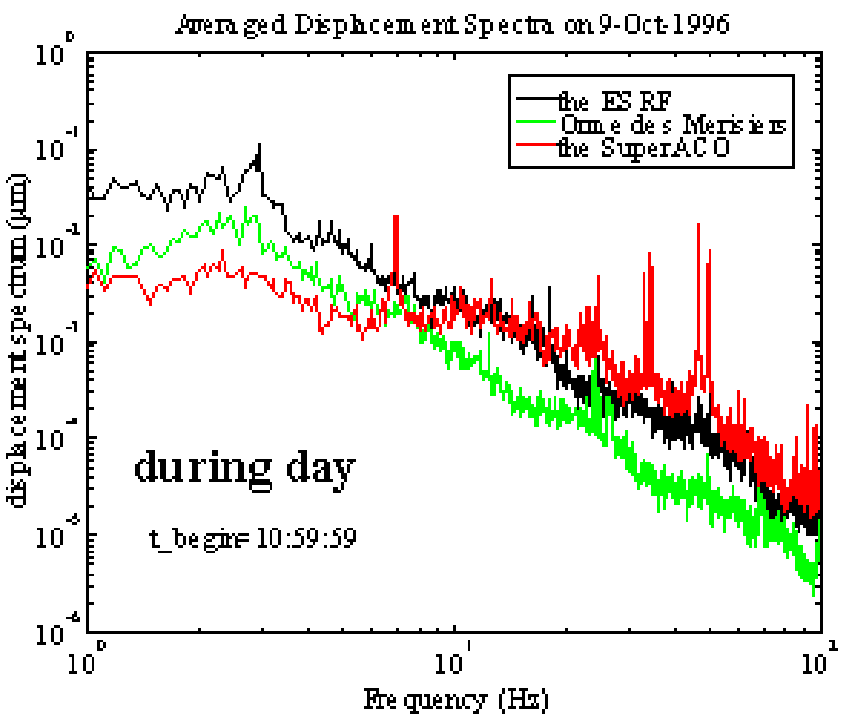
PSD_d^0.5= $\sqrt{PSD\_d} = \sqrt{\frac{T}{2}} d\_sp$

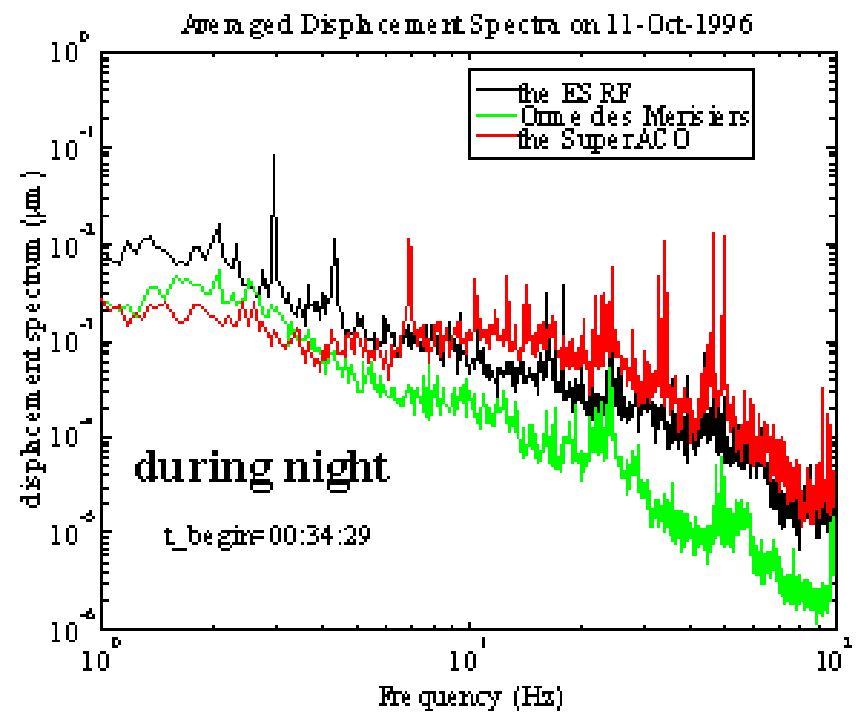
The integral of PSD_d over frequency leads to rms displacement :

$$Drms = \sqrt{\int_0^\infty (PSD\_d) df} = \sqrt{\sum (PSD\_d)/T} = \sqrt{\sum d\_sp^2 / 2}$$

(1-100 Hz) - *Spectral results*

examples of spectral displacements at the 3 sites



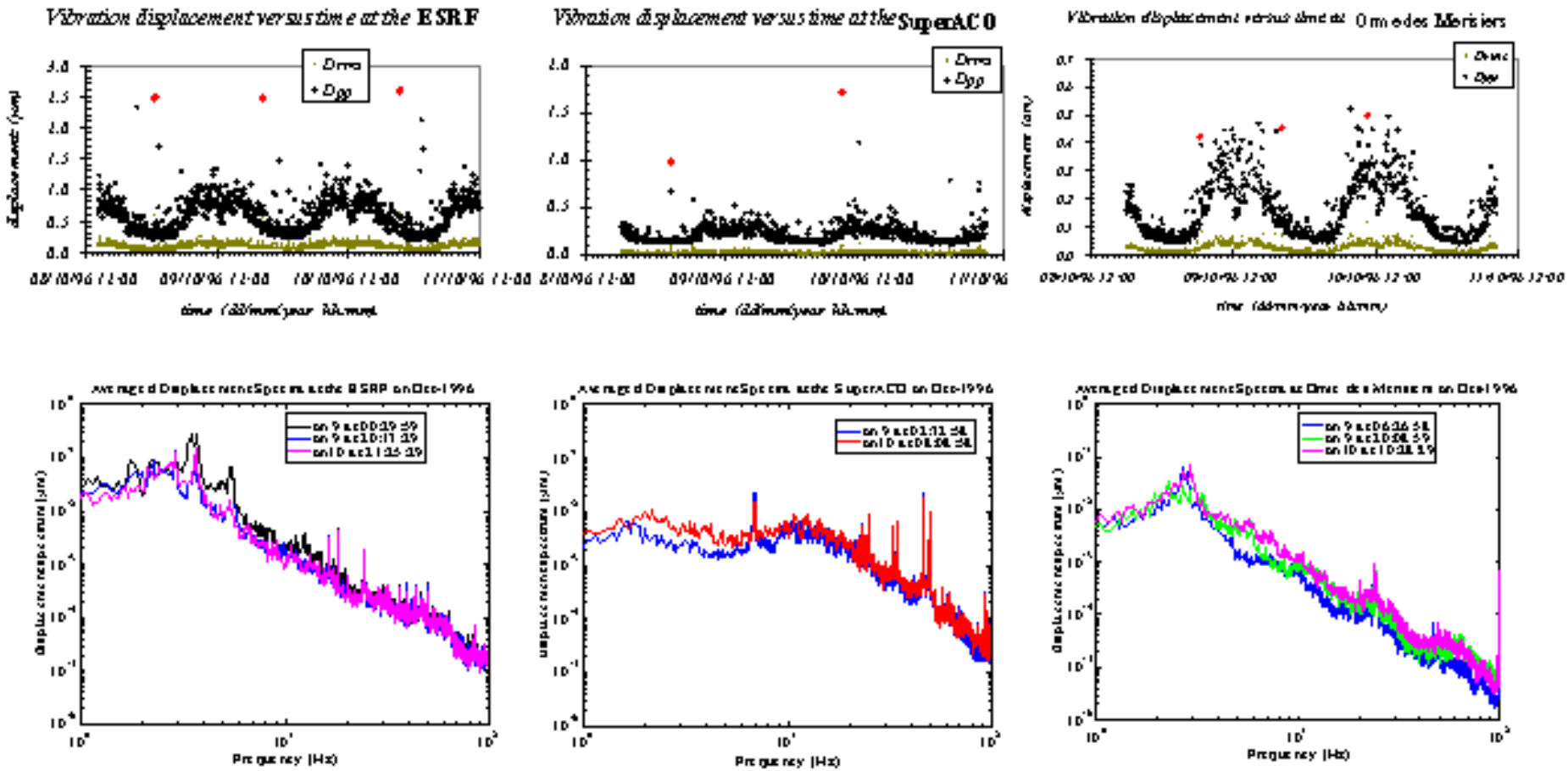


(1-100 Hz) - *Spectral results*

principal peak frequencies (Hz) :

ESRF	**2,92,**	16.4							
Orme des Merisiers	*12.2,*	*24.3,*	*49.3,*	*100*					
SuperACO	**6.9**,	*12.7,*	*24.8,*	33.1,	34.2,	46.0,	*48.5*,	92.8,	*100*

(1-100 Hz) - *some high level events*



(0.05-1 Hz) - *Analyses Procedure*

Temporal signal analyses *(SAC)*

—band pass filtering *: f_high=0.05 Hz, f_low=1 Hz*

—FFT *: velocity spectrum, window length = 128 seconds, over 7 windows (900s)*

—Integration in the spectral domain *: displacement spectrum (dividing by $\omega=2\pi f$)*

—IFFT *: temporal displacement*

—Dpp and Drms calculation : similar as in the frequency range (1-100 Hz)

$$\mathrm{Dpp}=\max(D_{max\_}i-D_{min\_}i)_{i=1,2,\ldots 7}$$

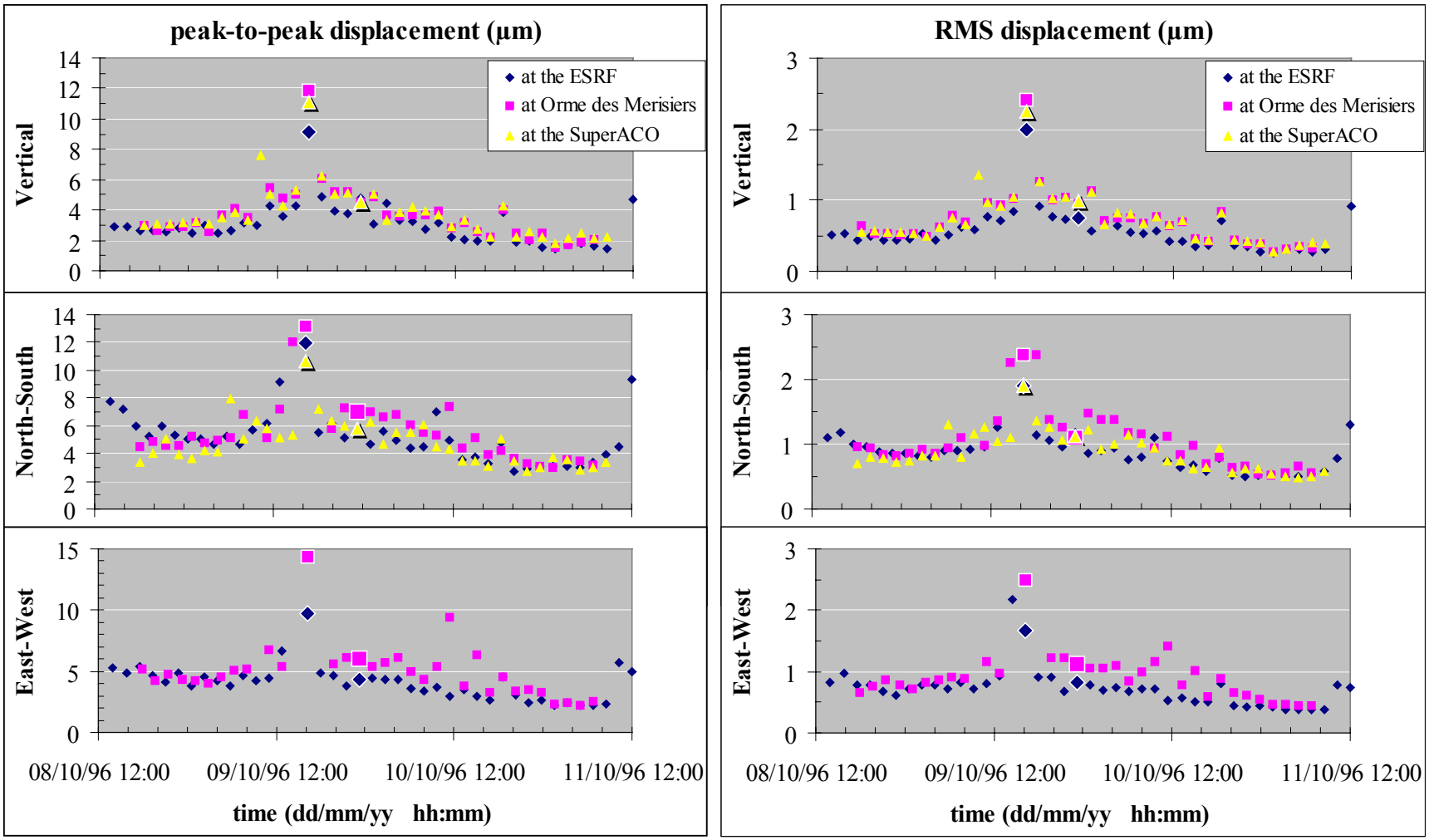
$$\mathrm{Drms}=\max(Drms\_i)_{i=1,2,\ldots 7}$$

Spectral analyses

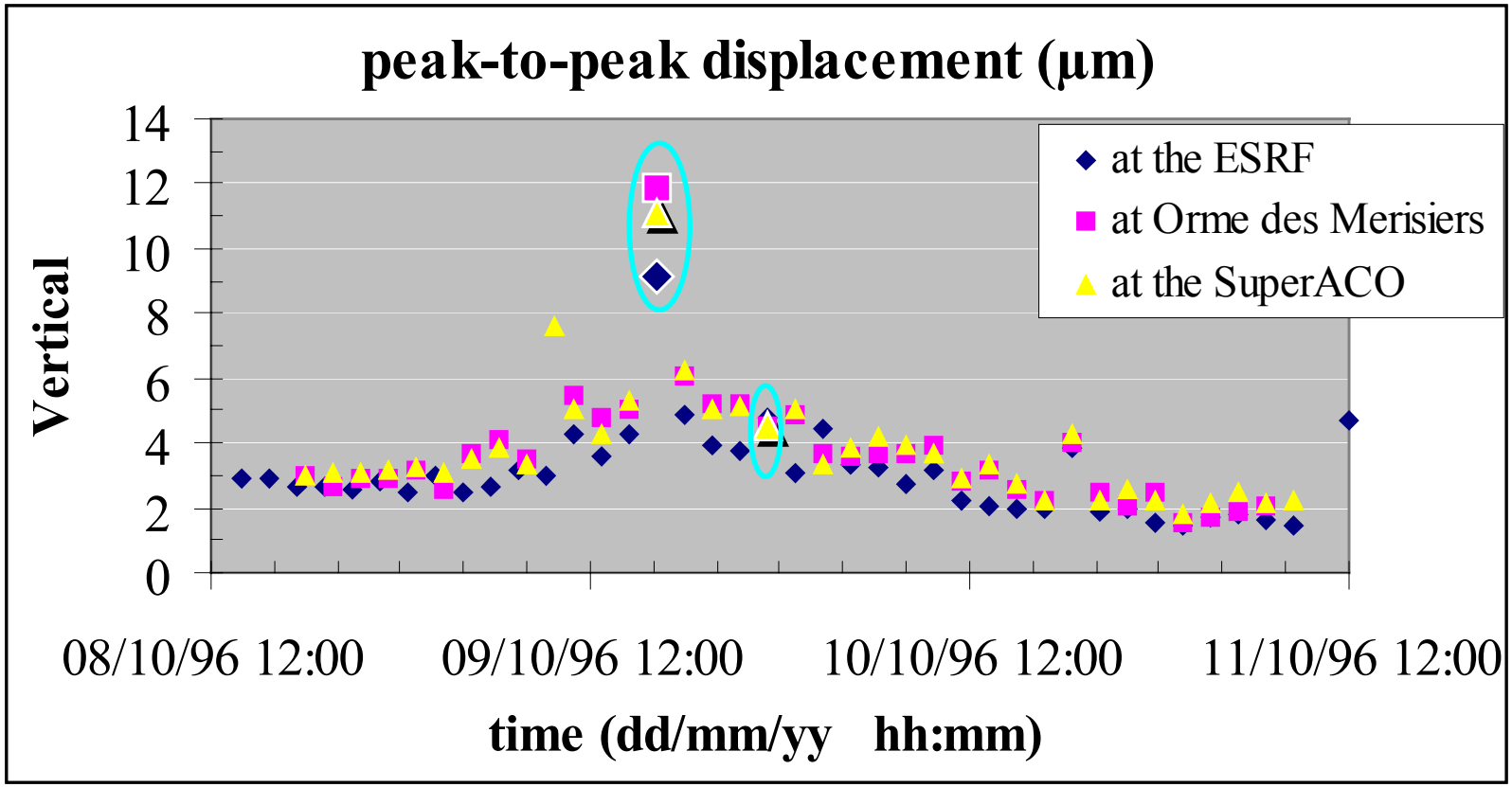
FFT ⟶ velocity spectrum ⟶ averaged velocity spectrum ⟶ **displacement spectrum**

window length of FFT :	**131.072 s**
windows overlap :	**120 s**
number of spectra used for average :	**69**

(0.05-1 Hz) - *temporal results / Dpp*

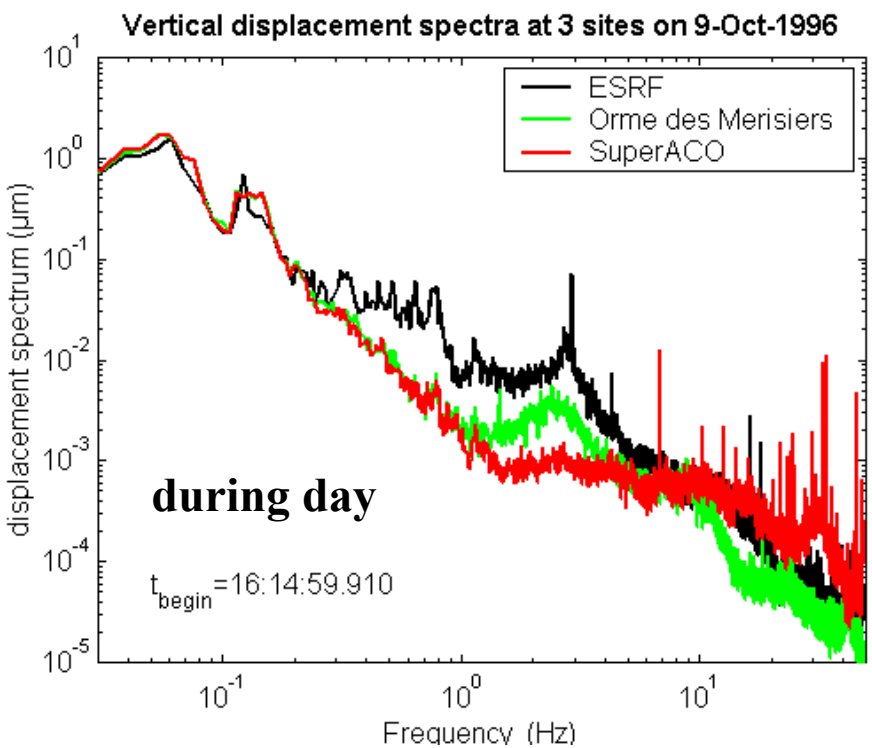


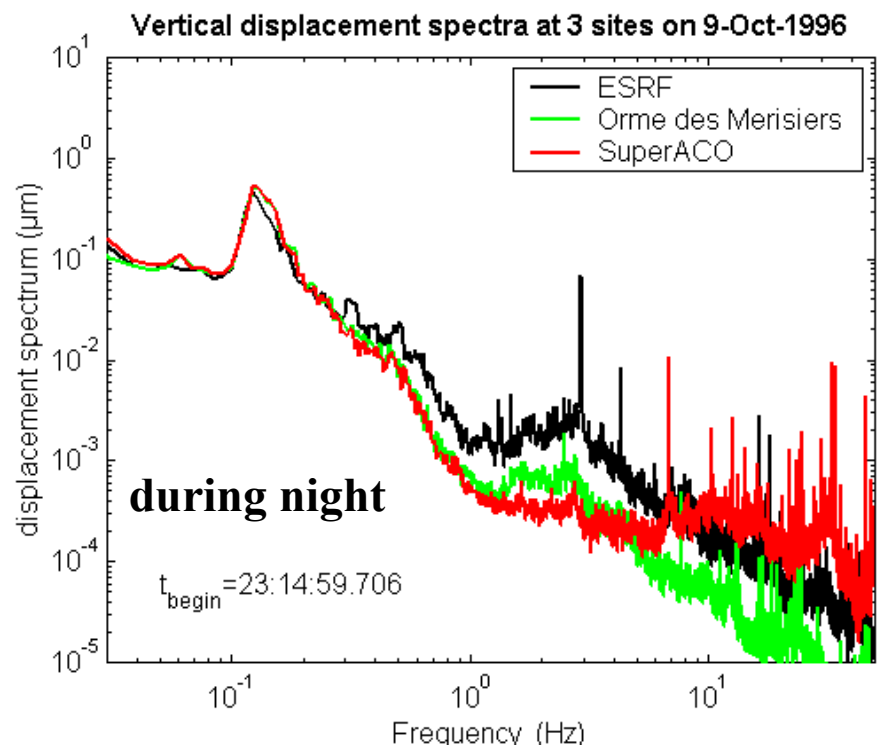
(0.05-1 Hz) - *temporal results / Dpp*



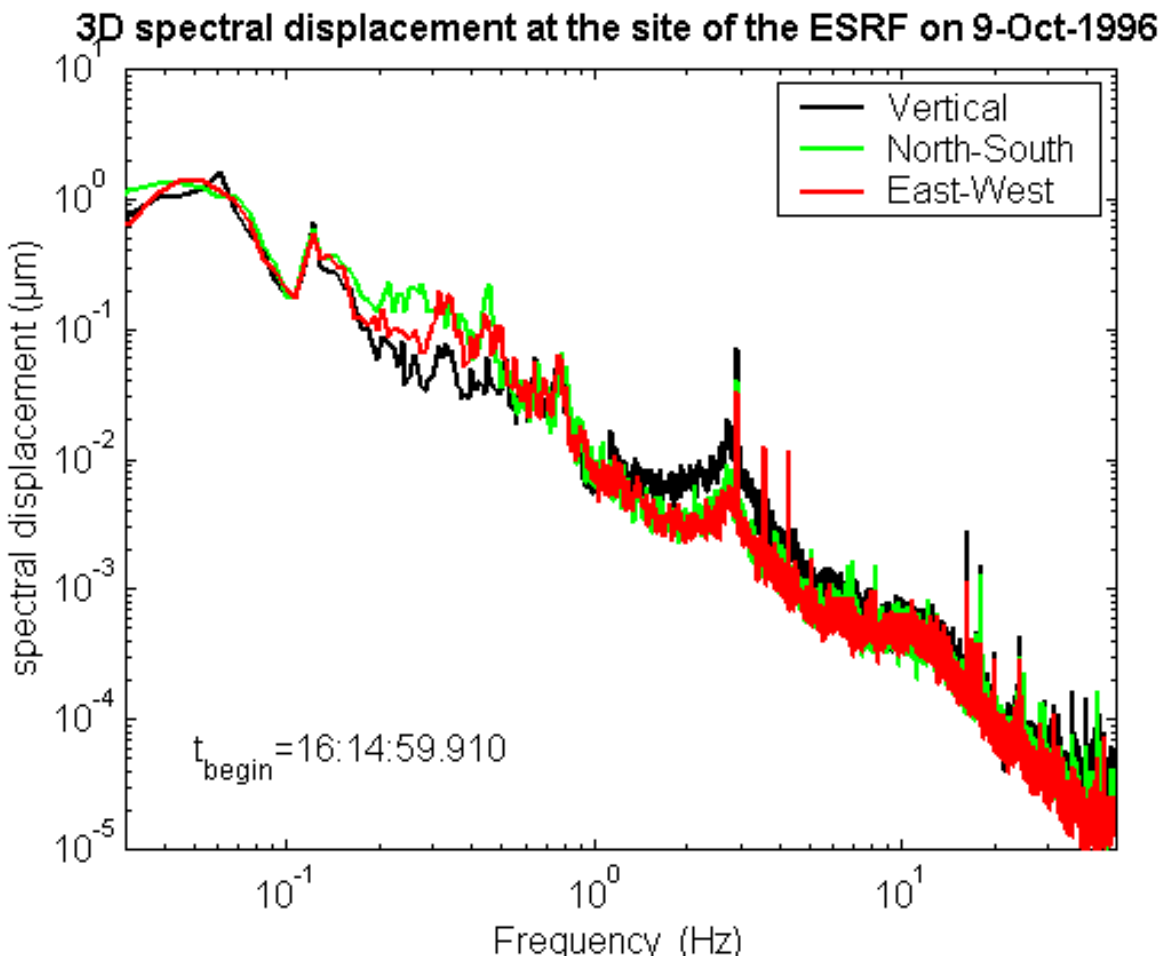
(0.05-50 Hz) - *displacement spectra at the 3 sites*

vertical spectral displacements *at the 3 sites*

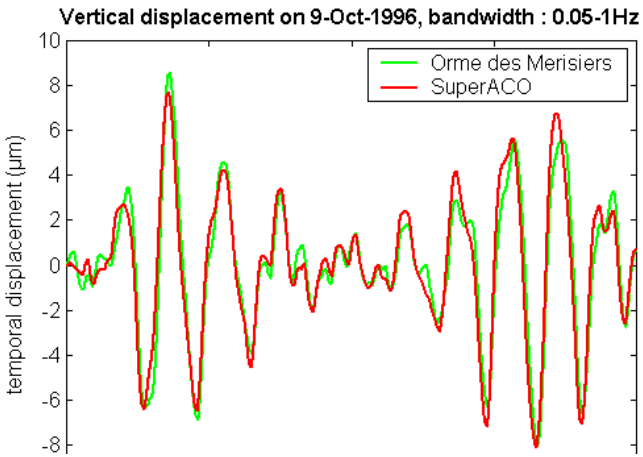


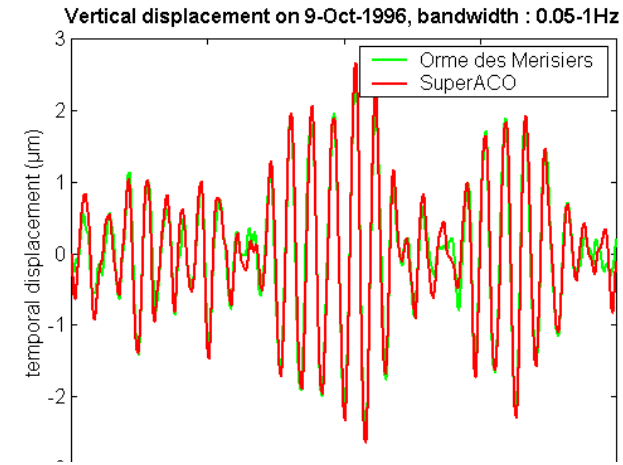


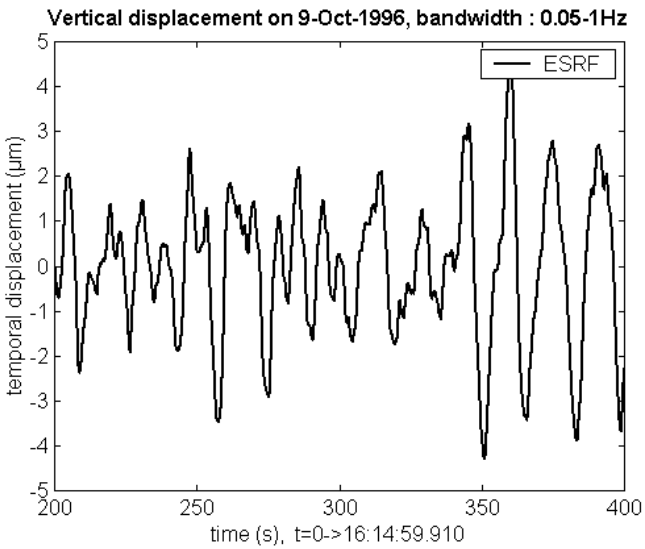
(0.05-50 Hz) - *3D displacement spectra at the site of ESRF*



(0.05-1 Hz) - *temporal results / vertical displacements*

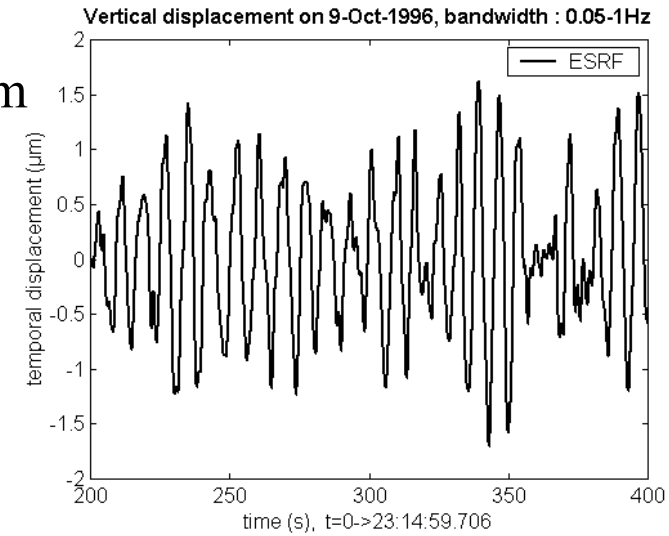




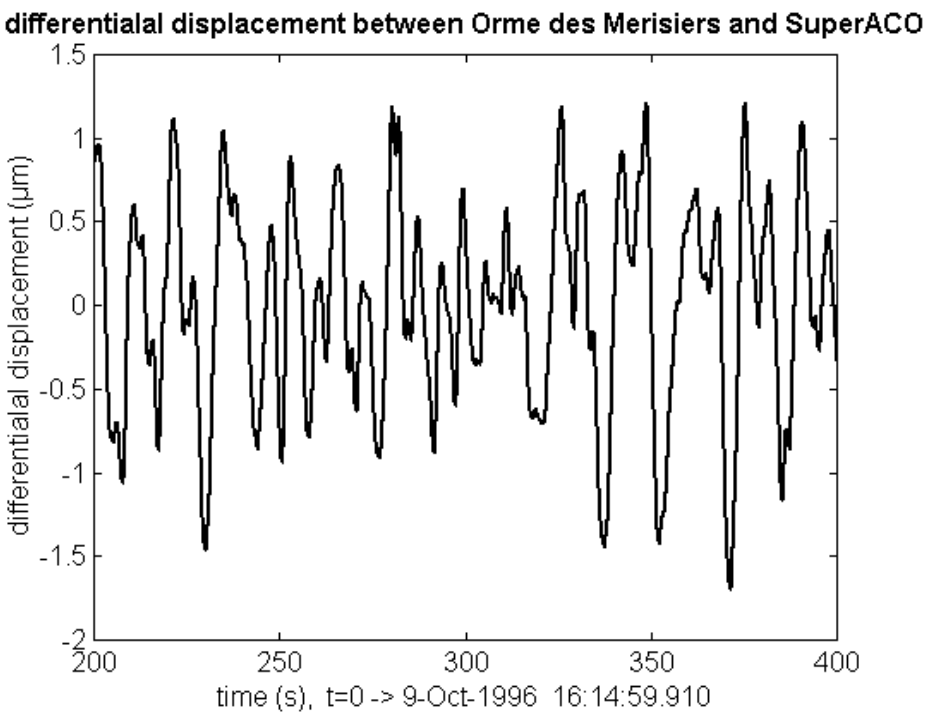


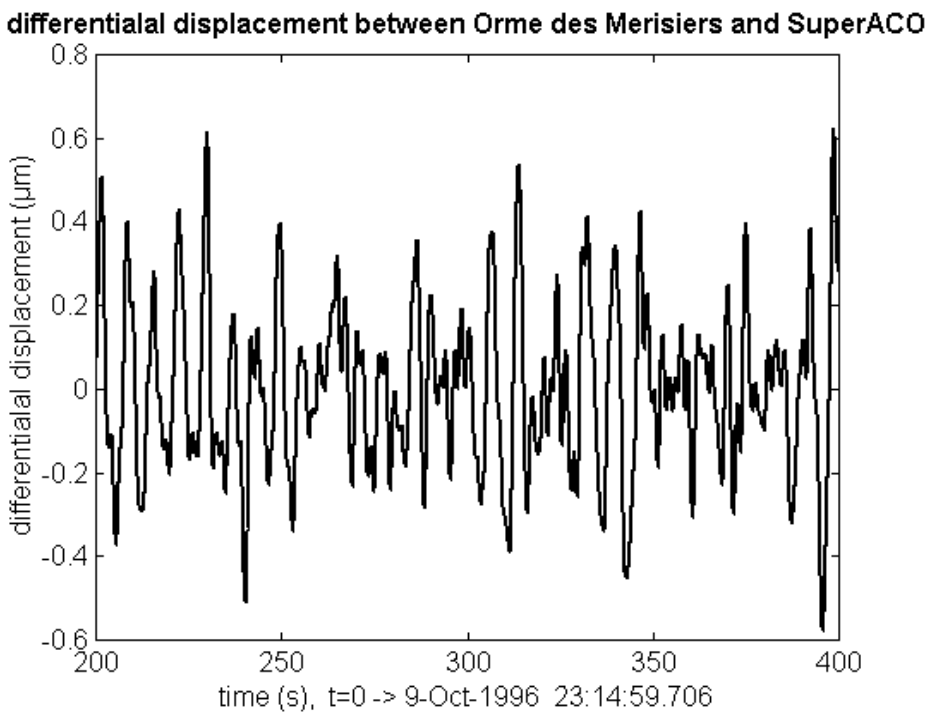
$d_{2\text{sites in Paris}}$=3 km

$d_{\text{Paris-Grenoble}}$=480 km



(0.05-1 Hz) - *differential vertical displacements*



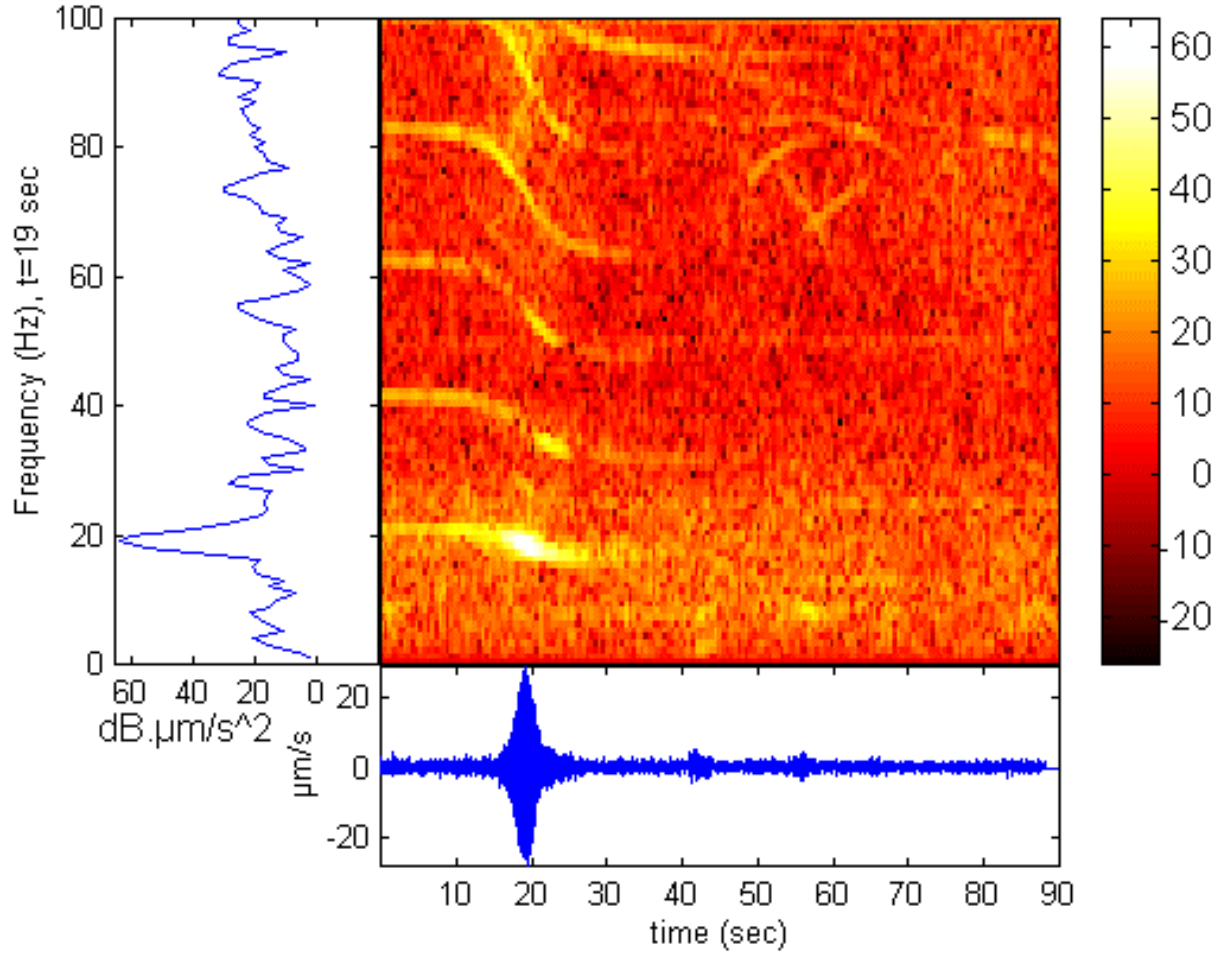


Concluding remarks

- **time dependence** of ground vibration
- in the frequency range of 1-100 Hz, **dpp(t) varies as quasi sin(2πt/T)** with a period of T=24 hours
- there is a quite **good space correlation** of the vibration in the frequency range of 0.05-1 Hz

Influences of helicopters flying over the site

Spectrogram *of vertical acceleration (dB.µm/s^2)*



Doppler Effects :

$$\frac{\Delta f}{f} = \frac{V_{helico} * \cos\theta}{(V_s - V_{helico} * \cos\theta)}$$

V_s : sound speed

$\Delta f/f \sim 1/8$

→ V_{helico} **~40 m/s**

~144 km/h