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Time evolution of broadband seismic noise during the French pilot experiment OFM/SISMOBS

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Abstract. During the French pilot experiment OFM/SISMOBS (April 22 – May 20, 1992) in the Atlantic Ocean, two sets of Guralp CMG-3 broadband seismometers were successfully installed and recovered. The first set, OFP (Observatoire Fond de Puits: Borehole Observatory), was installed inside the DSDP borehole 396B at 296m below the seafloor and the second one, OFM (Observatoire Fond de Mer: Ocean Bottom Observatory), on the sea bottom close to the hole at a depth of 4450 m. A first analysis showed that the broadband seismic noise (5 sps) on the seafloor had the same magnitude as compared with the long period seismic noise (1 sps) recorded at SSB, a continental station of the GEOSCOPE network. The noise recorded in the borehole was disappointedly high. The seismic data obtained during the experiment have been reanalyzed and it is shown that the seismic noise in the borehole is decreasing significantly with time whereas the instrument on the seafloor displays normal variations. A long term experiment (at least one month) is necessary to assess the final noise in the borehole.

Introduction

In examining the global coverage of the Earth by seismic stations, most of them are located in the Northern hemisphere on continents. There are almost no seismic instruments on the surface corresponding to the oceans, that is 2/3 of the surface of the Earth. All the tomographic models derived by the broadband seismic network have a limited lateral resolution due to the nonuniform spatial coverage. Therefore, different workshops [*ION*, 1995; *JOI/IRIS*, 1995] recommended the installation of permanent geophysical oceanic observatories. However, the installation of such observatories represents a formidable technological challenge if we want to maintain scientific sensors, supply power and retrieve data for long periods of time. Before attaining that goal, pilot experiments are necessary to unravel the different technical problems involved by such an ambitious project.

In that context, the French OFM/SISMOBS pilot experiment was firstly designed to demonstrate the feasibility of installing, operating and recovering broadband seismometers on the seafloor and in a borehole. The experiment took place in the North Atlantic Ocean at 23°N, 43.3°W, at the location of the DSDP borehole 396B [*Montagner et al.*, 1994a; *Montagner et al.*, 1994b]. Two CMG3 3-component seismometers were installed at that site. The first one, OFM, was installed in the sediments on the seafloor in a re-entry cone of an aborted hole and the other one, OFP, was installed in the borehole. The installation was described in *Montagner et al.* [1994a]. Three scenarios were planned concerning the installation of the OFP seismometer in the borehole. The first one was that the installation would not have been changed if the verticality of the devices by its own weight (100 kg.) was correct enough, the second scenario consisted in filling the hole with small glass balls (diameter of 4mm) up to the top of the instrument and the last one consisted in filling the hole with sediments and thus probably lose the seismometers. The first scenario was chosen, given the good conditions of the installation, the tiltmeters did not move very much and the masses were centered twice during the experiment. It has been chosen not to lose the instrument since it was a temporary experiment. The filling with glass balls was not necessary because the coupling by the weight of the instrument turned out to be good. The cable was not clamped to the borehole but was left loose. Unfortunately, the horizontal components of OFP did not work. Those of OFM were rather noisy [*Montagner et al.*, 1994b]. The output signals were digitized with a 16-bit digitizer with a flat velocity response of the seismometers between 0.0027 and 5 Hz and a resolution of about 10^{-9} m/s. *Rodgers* [1992] gives a good description of the CMG3 seismometer. The preliminary scientific results presented by *Montagner et al.* [1994b] show that OFM displays a noise level much smaller at low frequencies on the vertical component than OFP. But, as we will see later, the noise level of OFP decreases with time.

A similar experiment was also carried out by Japanese colleagues. The Japanese experiment [*Suyehiro et al.*, 1992; *Kanazawa et al.*, 1992], which started in Fall 1989, installed a broadband seismometer (DC – 30 Hz) in an ODP borehole in the Japan sea. The device was lowered in the borehole to a depth of 715 m below the seafloor with a water depth of 2807 m. The seafloor recording unit was recovered 8 months after the installation but not the seismometer in the borehole. Only a few local events and one teleseismic event were recorded before the event detector failed. It appeared that the signal-to-noise ratios of local earthquakes recorded by the borehole seismometer were much higher than those recorded by an ocean bottom seismometer (OBS). The background

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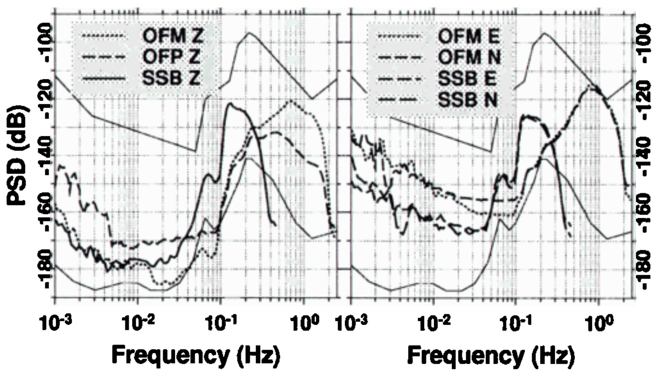

Figure 1. Comparison between noise levels (dB of $m^2/s^4/Hz$ referred to 1 $m^2/s^4/Hz$) calculated at OFM, OFP and SSB on day 130, 12h - 16h. OFM Z has a lower noise level than OFP Z at frequencies lower than 0.1 Hz. In the microseismic band, SSB displays a noise level higher than OFM or OFP. At high frequencies (greater than 0.3 Hz), the oceanic stations are noisier than the continental station. The horizontal components of OFM are noisier than those of SSB by about 5 to 10 dB at frequencies lower than 0.05 Hz but are quieter in the frequency range 0.05 – 0.3 Hz. The upper and lower curves represent respectively the high and the low noise model of *Peterson* [1993].

seismic noise level depends very much on the ocean where the OBSs are installed, the lowest noise levels are observed in the Atlantic ocean during calm weather periods [*Webb et al.*, 1992; *Blackman et al.*, 1995]. In this paper, we confirm the previous findings of *Montagner et al.* [1994b] but in addition investigate the time variation of seismic noise in the borehole and on the seafloor. In both cases, results obtained during these two experiments clearly demonstrate that such observatories should be installed permanently in the future.

Background Seismic Noise

We studied the broadband seismic noise in the frequency range 0.001 – 2.5 Hz simultaneously on the seafloor (OFM) and downhole (OFP) during the experiment and it is compared with the long period seismic noise in the frequency range 0.001 – 0.5 Hz recorded at the continental station SSB. The long period data of SSB are the only continuous data available recorded at that station during the OFM/SISMOBS experiment.

Figure 1 shows an example of comparison between the power spectral densities of the noise recorded at OFM and OFP, two oceanic stations and at SSB (day 130, 1992, 12h – 16h). A time window of four hours has been used to calculate the spectrum which has been smoothed with an average moving window. We first observe that the two microseismic peaks usually located at 0.07 and 0.14 Hz on continental stations are less excited on both oceanic stations. This confirms the previous findings [*Montagner et al.*, 1994b]. These peaks were explained by *Wiechert* [1904] and *Longuet-Higgins* [1950] to be the waves striking the coast for the smaller peak and the standing ocean waves for the main peak. The noise of SSB is decreasing sharply at frequencies greater than 0.14 Hz while on OFM and OFP, the noise is still important. With these oceanic stations, the frequency range with a noise level lower than -170 dB has increased. Noise level lower than -170 dB is observed up to 0.1 Hz on OFM/OFP but up to only 0.035 Hz on SSB. The horizontal components of OFM are noisier than the verti-

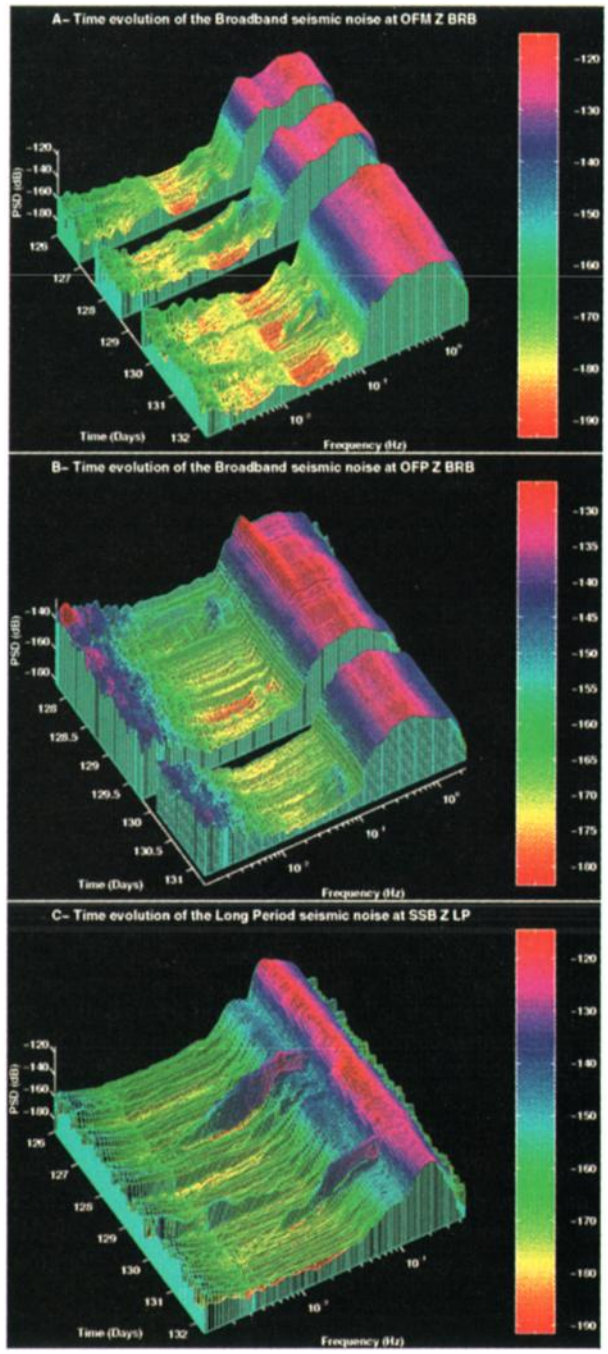

Figure 2. These three spectrograms show the seismic noise level function of time and frequency at the two stations OFM (A) and OFP (B) for the broadband vertical components (5 sps) and SSB (C) for the long period vertical component (1 sps). OFM displays a noise level lower than OFP at frequencies lower than about 0.1 Hz. Four earthquakes are visible on the OFM spectrogram at frequencies lower than 0.1 Hz. Each spectrum is calculated using a time window of four hours shifted every hour and plotted at the start time of the window. Each spectrum are then smoothed with an average moving window. All the spectra are stacked adjacently to produce the spectrograms.

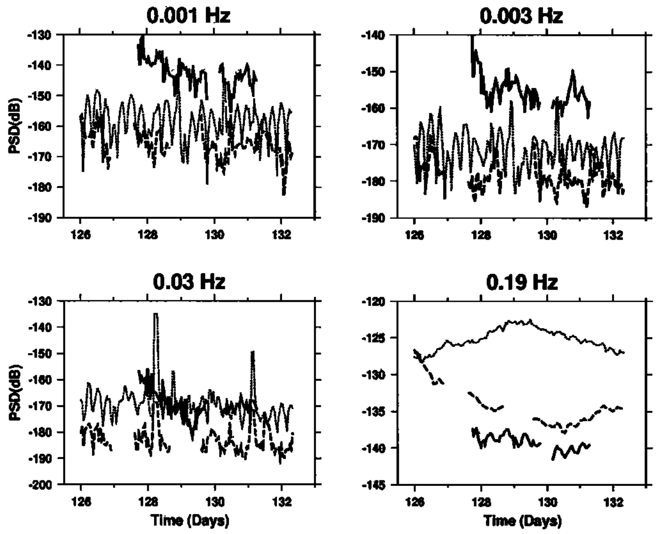

Figure 3. Time evolution of the power spectral density of the noise recorded at OFM (dashed), OFP (solid) and SSB (dotted) at four different frequencies (0.001 Hz, 0.003 Hz, 0.03 Hz and 0.19 Hz). Each curve corresponds to a cross-section of either figure 2A, figure 2B or figure 2C for a given frequency showing the decrease of the noise level of OFP and OFM.

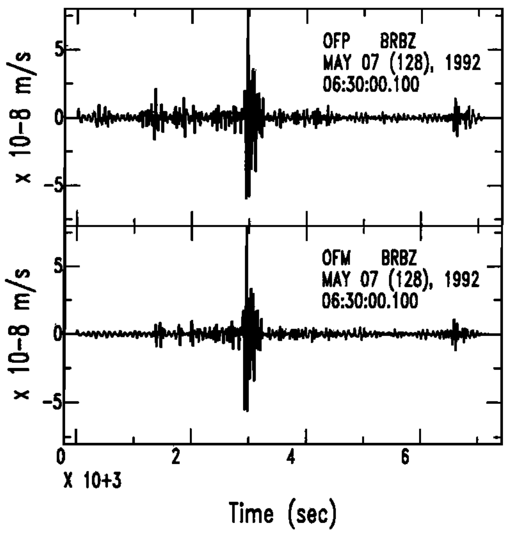

Figure 4. Seismograms of the Hokkaido earthquake (05/07/92 - 06h23' - mb = 5.8) recorded on the vertical component of the OFM and OFP stations. The seismograms are filtered between 0.01 and 0.03 Hz. R1 and R2 represent the two first Rayleigh wavetrains.

cal components and than those of SSB. The seafloor instruments were tilting while sinking into the sediments and since the horizontal components are more sensitive to the tilt than the vertical component, the noise is higher on OFM E and N. In the frequency range 0.1 – 0.25 Hz, OFM and OFP have roughly the same noise level. At frequencies higher than 0.25 Hz, OFM has a noise level larger than OFP which, in turn, has a noise level larger than SSB. At frequencies lower than 0.1 Hz, OFP becomes much noisier (~ -170 dB) than OFM (~ -180 dB). The noise level at the station SSB is roughly the same as OFM at frequencies lower than 0.04 Hz. In order to gain insight on this behaviour, we investigate the change with time of seismic noise level.

Figure 2 shows the spectrograms (noise level as a function of time and frequency) of the broadband vertical components of OFM and OFP and the long period vertical component of SSB. Each spectrum is calculated with a time window of four hours shifted every hour and is smoothed with an average moving window. All the spectra are plotted as a function of time. The missing data correspond to the time when the masses of the seismometers were recentered. Indeed, the instruments were continuously sinking into the sediments and thus the mass position was drifting. On the three spectrograms, we observe the two biggest earthquakes that occurred during the experiment. The first one occurred in Hokkaido (05/07/92 at 6h23', mb = 5.8) and the second one, in Tadzhikistan (05/10/92 at 4h04', mb = 5.6). Two smaller earthquakes are also visible during day 126 at OFM (figure 2A) but not at OFP (figure 2B) (because of a too large noise level) and SSB (figure 2C) (too far from the sources). The general form of the noise spectra seems to be constant with time for OFM as well as for SSB, while, for OFP, the noise level tends to decrease with time. A peak around 0.01 Hz can be observed on the OFM spectrogram (figure 2A) but still remains unexplained.

Figure 3 shows the time evolution of the noise level at OFM and OFP at four different frequencies (0.001 Hz, 0.003 Hz, 0.03 Hz and 0.19 Hz). Each curve corresponds to a cross-section of either figure 2A, 2B or 2C for a given frequency. At these four frequencies, OFP is clearly decreasing with time while the noise level of OFM has slightly decreased (at 0.001, 0.003 and 0.03 Hz) between the beginning and the end of the experiment. The noise at SSB seems to be stable with time. Particularly, at 0.03 Hz, the noise level of OFP seems to stabilize around -170 dB, a noise level still higher than at OFM. The peaks at day 128 around 06h and at day 131 around 04h correspond respectively to the Hokkaido earthquake and the Tadzhikistan earthquake. At 0.19 Hz, OFM displays a noise level decreasing from about -127 dB to -135 dB, higher than OFP by about 3 to 4 dB. The noise level of SSB is much higher than the two oceanic stations, between -128 dB and -123 dB. Unfortunately, the experiment did not last long enough to verify if the noise level of OFP could decrease more or even become lower than on OFM.

Conclusion

These first results are very encouraging since they demonstrate that ocean bottom seismometers can provide valuable information on earthquakes and Earth structure. Figure 4 shows the seismograms of the Hokkaido earthquake recorded on the vertical component of OFM and OFP. A bandpass filter (10 – 30 mHz) has been applied. We can observe the Rayleigh wavetrains R_1 and R_2. We showed that the noise level recorded on the ocean floor by the vertical component of OFM is very low. Fortunately, all the conditions for such low noise level were fulfilled during the experiment. Meteorological conditions were favourable, the ocean was calm, there was no wind. By the end of the experiment, the OFM station was half-buried into soft sediments. On the other hand, our results look slightly disappointing for the OFP seismometers, which do not display smaller noise level than OFM except at frequencies greater than 0.1 Hz but has a noise level decreasing with time. The OFP vertical seismometer was probably perturbed by some hydrothermal circulation. Indeed, during the installation of the OFP device, an ascending water flow induced by the temperature gradient was observed coming out of the borehole. The cable used to download OFP was left loose. Such a waterflow can act directly on the OFP seismometers or it can perturb the cable connecting the downhole devices to the logging shuttle NADIA located on the seafloor and, therefore, it may increase the noise level. This suggests that, in order to avoid water circulation, boreholes should be filled with sand or small glass balls, or capped in future experiments. This will prevent the water from fluctuating inside the hole and will maintain the cable immobile. It seems also easy to remove the sensors from such a borehole [*Holcomb et al.,* 1995]. Therefore, there is a need for a new pilot experiment in a borehole for several months of duration in order to assess the final noise level of the borehole seismometers.

The challenge in the future will be the installation of ocean bottom observatories, their maintenance, the recovery and transmission of the recorded data and the supply of enough power for several years. In addition to the seismometers, these observatories will be composed of tiltmeters, gravimeters, magnetometers, etc. We observed good correlations between seismic data and atmospheric pressure variations at the station SSB and were able to remove this pressure effect from seismic signals [*Beauduin et al.,* 1996]. Oceanic pressure fluctuations on the seafloor may also perturb the seismometers. Therefore, the installation of microbarometers is recommended for further oceanic experiments in order to quantify the perturbation of the pressure variations on the seismometers.

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