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Mitigation of the effect of changes of atmospheric pressure on gravity detectors: preliminary results obtained with microphones at the Sos Enattos mine

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Low-frequency changes of atmospheric pressure contribute to the measurement noise of gravity detectors. On one hand, changes of frequency around 0.05 Hz and below cause tilt of the ground and the instrument placed on it. On the other hand, infrasound waves propagating in the atmosphere change the density of air, and hence cause changes in the gravitational field. These result in undesired movements of the test-masses of gravitational-wave (GW) detectors. One strategy to mitigate the effects of changes of atmospheric pressure on gravity detectors is to put them under the ground. In this study, recent results of infrasound measurements performed at the Sos Enattos mine (Lula, Nuoro Province, Sardinia, Italy) are presented. A designated area near the mine is one of the candidate sites for the Einstein Telescope, a proposed third-generation GW detector that is currently in the preparatory phase. Infrasound is monitored at three levels underground, as well as on the surface. The infrasound background noise 111 meters below the surface, and its relationship with other noise sources were investigated, too.

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1. Introduction

Towards low frequencies, the measurement range of ground-based interferometric gravitational-wave (GW) detectors are limited by the seismic vibrations of Earth [1]. Seismic vibrations are more pronounced on the surface than below the surface. Therefore, by installing new detectors at least a hundred meters below the surface, the measuring range is expected to be extended below 10 Hz. The Einstein Telescope is a proposed third-generation GW detector planned to be built at one of three candidate sites [1]. Nowadays, the Einstein Telescope Collaboration is working on the characterization of the candidate sites, partly in order to predict the measurement noise of the future detectors [2]. Pressure waves traveling in the atmosphere are expected to contribute to the gravity gradient noise (Newtonian noise) of GW detectors below 10 Hz [3]. Changes of the atmospheric pressure with frequencies below 0.05 Hz can cause tilt of the ground. This should be considered during the designing of the active seismic control of the instruments [4]. Preliminary results of the measurements performed with acoustic and infrasound sensors at Sos Enattos mine, close to the Sardinian candidate site of ET are presented in this article.

2. Measurements performed with microphones at Sos Enattos mine

Sos Enattos is a mine that is no longer in exploitation [2] [5]. Four measurements sites were established at the complex. One of them is at the surface (SOE0), and three others are below the surface: SOE1 at -84 m, SOE2 at -111 m and SOE3 at -160 m. At each site, seismometers and geophones are detecting the seismic vibrations, while microphones are detecting audible and infrasonic vibrations of the air [5]. At the surface, a weather station is measuring the wind speed, the atmospheric pressure, etc. All the passages of the mine are connected to the outside world through an open channel above the main entrance on the surface and vertical shafts at the end of the passages.

At the surface, the microphones are not well protected against the wind, so the pressure changes around them generated by air flow should be considered as wind noise. At SOE1 and SOE3, GRAS 47AC and AstroCeNT (Fig. 1) [5] microphones were installed in closed cavities made of foam panels. Their data were collected by Nanometrics Centaur 32-bit data loggers, the sampling rate was set to 1 kHz. At SOE2, a cabin was built by separating a small part of the mine with a wall made of plastic foam and plate covering. Next to a system of GRAS 47AC and Centaur data loggers, a custom-made infrasound microphone (ISM 1802) made by ATOMKI (Hungary) connected to an EarthData EDR-209 digitizer were placed. The system of ATOMKI collected data from 23d Nov. 03:00:00 to 25th Nov. 08:59:59 in 2022, while all the other microphones are operating till now (Nov. 2023). The measurement data were downloaded from the Einstein Telescope repository [6].

Figure 1: The microphones installed at Sos Enattos.

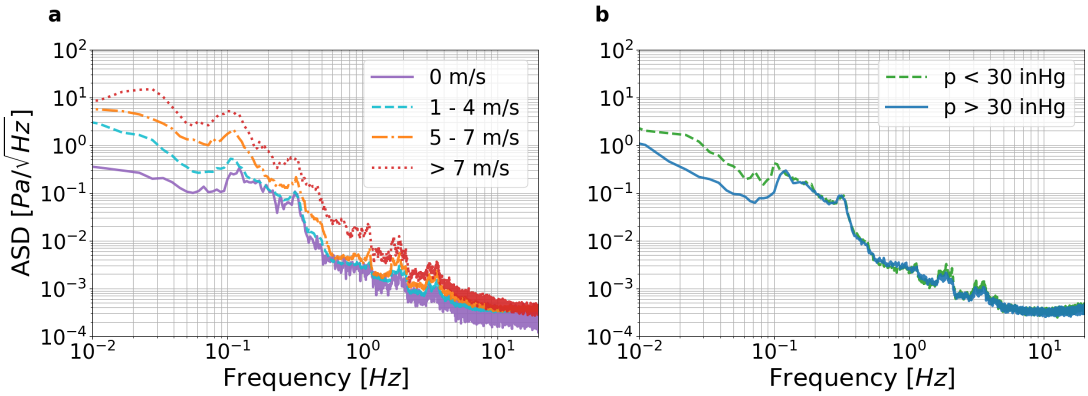

Figure 2: a) The effect of wind on ASD median curves corresponding to different wind speed intervals, measured by the ISM 1802 microphone of ATOMKI at the SOE2 station 111 m below the ground. b) The effect of the atmospheric pressure on ASD median curves measured by ISM 1802 at SOE2 during windless periods. Colours indicate the high and low atmospheric pressure intervals.

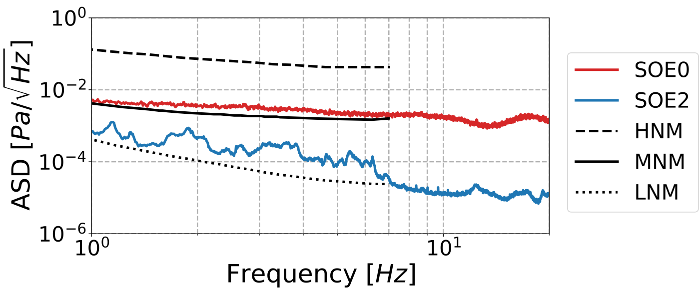

Figure 3: Median ASD curves measured by the GRAS 47AC microphones on the surface at the SOE0 station (red line) and at the SOE2 station (blue line), corresponding to windless periods. Black curves show the Bowman models [7].

Data were processed with spectral methods. Amplitude spectral density(ASD) values were calculated from 120 seconds of data, and were statistically analysed. The median ASD curves were chosen to represent the ambient noise at the different sites of the mine. Bowman's noise models representing the ambient infrasound noise on the surface of the Earth were used as a reference [7]. Since only ISM 1802 is able to measure infrasound down to 0.01 Hz, it was chosen in this study to investigate the effect of the wind at the low frequencies at the SOE2 station. Wind speed data were provided by the weather station in every thirty minutes. The data measured by a microphone in the 120 s long period after recording the time stamp from the weather station were taken for calculating the relevant ASD values. The obtained ASD values were categorized according to the corresponding wind speed intervals: 0 m/s (windless), 1-4 m/s, 5-7 m/s, and above 7 m/s. The median ASD curves of the different categories in Fig. 2 a) show that the wind on the surface affects the noise at the SOE2 stations, at each frequencies below 20 Hz. (However, the ASD values above 5 Hz are close to the self-noise limit of ISM 1802.) In order to give an estimation on the level of mitigation of infrasound at SOE2 compared to the surface, only the data segments corresponding to windless periods were considered.

The GRAS 47AC microphones have lower self-noise than ISM 1802, but their measurement range is above 1 Hz. By using their data, estimation of representative ASD curves of the surface and of SOE2 is possible for the 1-20 Hz frequency range. Fig. 3 shows the two representative ASD curves together with the Bowman models' curves. At the surface, the representative values below

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7 Hz are slightly larger than the values of Bowman's Median Noise Model (MNM), and follow the trend of it. Above 7 Hz, no specific structure can be observed on the curve, except a slight decrease followed by a slight increase above 10 Hz. The representative ASD curve of SOE2 shows different behaviour: below 7 Hz, the values are above Bowman's Low Noise Model (LNM), and the curve shows several peaks, which is expected to be caused by the resonances originated of the structure of the mine. Between 7 Hz and 12 Hz, the curve becomes smoother, but peaks are present at certain frequencies. At larger frequencies, a specific structure emerges. The ASD curves corresponding to windless time periods and calculated from the data measured by ISM 1802 can be grouped into categories according to the atmospheric pressure data of the weather station at the surface. Two categories were chosen: $p<30$ inHg and $p>30$ inHg. Fig. 2 b) indicates that atmospheric pressure above 30 inHg causes significant increase of the ASD values below 0.2 Hz.

3. Conclusions

The ASD curves of the microphones operating at the site 111 meters below the ground in Sos Enattos mine show that the wind on the surface has a significant effect on the spectra. After excluding the windy time periods, the representative ASD curves of the surface and the underground site indicate that the infrasound background noise can be significantly decreased by going under the ground, but the shape of the passages of the mine introduce resonances. Resonances are not expected to be present in the future ET infrastructure. Moreover, the mine is not separated from the surface, so higher damping of the noise can be expected at ET's underground cavities. During windless periods, the effect of the changes of the atmospheric pressure could be detected at the frequencies below 0.2 at the underground site.

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