GI-2012-14: Authors answers to referee #2

Authors answers in red, Quotes from revised manuscript in blue, Referee comments in black

The comments and questions raised by referee #2 have been carefully considered and have helped us improving the manuscript:

[...] Without precluding the publication of this manuscript, some points need to be improved, clarified or described with more details:

1) The introduction: In the present form the introduction is focused essentially on the rock weathering related to permafrost and not so much on the systems used in the past. So the progress allowed by their new system does not appear clearly. Previous works should be cited with more detail for showing clearly how the proposed new system covers a field that was not before. In particular, many previous works related to high frequency monitoring of rock masses used systems that need a careful housing to be protected from environmental conditions (e.g. Amitrano et at 2011, Amitrano et al 2012, Senfaute et al 2009; Guglielmi et al 2010, Cheong et al 2011). The systems that works with autonomous energy supply (photovoltaic with battery) and resist to outside conditions are actually restricted to low frequency monitoring, i.e. in the range of seismology monitoring (e.g. Helmstetter and Garambois, 2010; Gaffet et al, 2010; Amitrano et al, 2007; Levy et al, 2010; Gomberg et al, 2011; Lacroix and Helmstetter, 2011; Walter al, 2012). Other systems have previously used waveguide for ensuring an efficient AE monitoring (e.g. Cheong et al, 2011, Dixon et al 2003). I suggest the author enlarge the scope of their introduction to show more clearly that the new system they developed associates features that was not associated before, i.e high frequency monitoring, autonomy for energy supply, resistance to hard conditions and use of a waveguide to be closer to AE sources. This would help the reader to see how important is the progress done by this system.

The references given by referee #1 have been used to improve the introduction and to show the originality of the AE system that we have developed. This was achieved by adding the following paragraphs to the introduction:

[...] AE monitoring techniques have been used in earlier studies to understand the evolution of different gravitational instabilities such as large rockslides (Lacroix and Helmstetter, 2011; Helmstetter and Garambois, 2010; Gaffet et al., 2010), rock wall (Levy et al., 2011) and rock slope instabilities (Cheon et al., 2011), or mudslides (Amitrano et al., 2007; Walter et al., 2012). Most of these studies have used geophones or accelerometers instead of AE sensors. The principle of such measurements, more often referred to as microseismic monitoring, is similar to AE monitoring, although it concerns a lower frequency band, typically extending from 1 Hz to a few hundred Hz. The reason for this is that natural slopes are generally large (hundreds of meters) and include discontinuities. Under such conditions AEs generated within the unstable slope/wall are strongly attenuated and may not be detected if the sensor is too far away from the source. In this study, we focus on near-surface mechanisms (up to 1 m depth) that progressively damage rock, such as freezing and thermal gradients. In order to achieve this, the monitoring system should be suitable to detect early stages of damage, i.e. AE generated by sources of small (typically millimeter) sizes. As we focus on progressive damage mechanisms that occur in the near-surface, the spatial detection range of AE monitoring (on the order of a meter) is sufficient. The feasibility of using AE monitoring for this purpose was assessed by carrying out a pilot study which yielded promising results (Amitrano et al., 2012).

Current commercial AE platforms in this frequency range are typically based on hardwired centralized data collection of weight and power requirements that are too large for our application. Previous studies that have monitored AE in outdoor conditions have been restricted to short time periods, during which the monitoring system was carefuly protected from the changing environemental conditions in a nearby heated building for example (Cheon et al., 2011; Amitrano et al., 2012, 2010). Recently, a few wireless AE platforms, based on cell-phone communication, have been created to perform structural moni- toring of concrete or steel structures such as bridges (Ledeczi et al., 2009; Grosse et al., 2008). To date, none of the existing AE systems allow *long term monitoring under harsh outdoor conditions with autonomous power supply. Our application brings a number of new challenging requirements that motivate the development of a new AE acquisition system. [...]*

2) The tests done in the laboratory are interesting but they need to be more detailed. What are the amplitude, energy, rise time, duration frequency of the signals used for testing the system. Could the author plot the signal used for doing these tests. Moreover, if I understood well, the signals used do not replicate the full range of amplitude energy and temporal distribution as they are of constant amplitude. So it is difficult to extrapolate these results for having an idea of the reliability of the system when it monitors natural signals. Testing the full natural range of these parameters is probably difficult but at least the authors should discuss this point and if possible do some tests with signals of various sizes. Questions rises from the temperature dependence of some AE parameters: Could the authors provide some physical explanation? Is it related to the coupling? How is done the coupling?

The characteristics of the signal used to evaluate the performance of the AE-node have been added to the revised manuscript. Additionally, figure 1 (below) shows the full test signal. As mentioned by referee #2, the same signal was used throughout the experiment. We agree that experimenting with a wide range of signal characteristics would be required to get a full understanding of the temperature sensitivity of the measurements. However, our 'idealized' experiment already gives a first order idea of this temperature sensitivity. Another essential point is that the precision of the measured parameters is (almost) not affected by temperature. These aspects are now discussed in more details in the revised manuscript.

The temperature sensitivity most likely results from the analog signal processing part of the AE-node, which behavior is sensitive to temperature. As mentioned in the manuscript, the preamplifier was showed to contribute to most of the temperature sensitivity. Our experiment cannot be affected by coupling problems because the AE-node was not connected to a transducer. Instead, it was directly stimulated by an electronic waveform generator. The waveform generator was kept outside the climatic chamber, at constant temperature, so that the waveform sent to the AE-node remained similar during the whole test. These details are mentioned in the manuscript:

[...] As the experimental conditions shall be reproducible, the AE-node was stim- ulated by a synthetic test waveform electrically transmitted by means of a waveform generator (i.e. no piezoelectric transducer were used during this experiment). The test waveform simulates an AE event consisting of three frequency components at 35, 50 and 60 kHz, with the 50 kHz oscillation being the dominant frequency component. This characteristics, further detailed in Table 2, match well the average waveform that has been captured during the preliminary experiments (Amitrano et al., 2012). [...]
[...]While temperature variations had no influence on data processing performances, they did affect the analog signal processing and thus the accuracy of the parameter values (Fig. 3 and Table 2). The event amplitude increases with temperature while the length and count number decrease. The most affected parameter is energy due to its quadratic nature. The rise time, on the other hand, is not sensitive at all to temperature. The precision of all measured parameters does not appear to be affected by temperature, since the standard deviation of the measured parameters, for a fixed temperature, remains small (≤ 2%, Table 2). The significant sensitivity of most AE parameters to temperature should to be accounted for during data analysis. Further tests showed that this temperature sensitivity was mostly induced by the external pre-amplifier of the AE-node. The results presented on Fig. 3 can be used to establish simple correction functions for the temperature dependance of AE parameters. The temperature recorded inside the AE-node by the TinyNode184, assumed to be representative of that of the whole AE-node, can be used to perform the correction. However, in order to gain a full understanding of the temperature sensitivity of measured parameters, further tests considering a wide range of waveform characteristics would be useful. [...]

Table 2 - Characteristics of the synthetic AE signal used to evaluate the AE-node performance, mean and standard deviation (Std Dev) of parameter values detected by the AE-node at -20°C and +40°C.

		Measured at -20°C		Measured at +40°C	
param.	Characteristics	Mean	St. Dev	Mean	St. Dev
Length (us)	2532	2619 (+3.4%)	49.6 (2.0%)	2458 (-2.9%)	21.2 (0.8%)
Rise time (us)	436	436 (+0.0%)	0.8 (0.2%)	436 (+0.0%)	1.0 (0.2%)
Amplitude (mV)	1402	1332 (-5.0%)	8.6 (0.6%)	1410 (+0.5%)	12.6 (0.9%)
Count	73	76 (+4.1%)	1.3 (1.8%)	70 (-4.1%)	0.8 (0.9%)
Energy	9.31E+02	1010 (+8.5%)	1.8 (0.2%)	771.1 (-17.0%)	5.6 (0.6%)

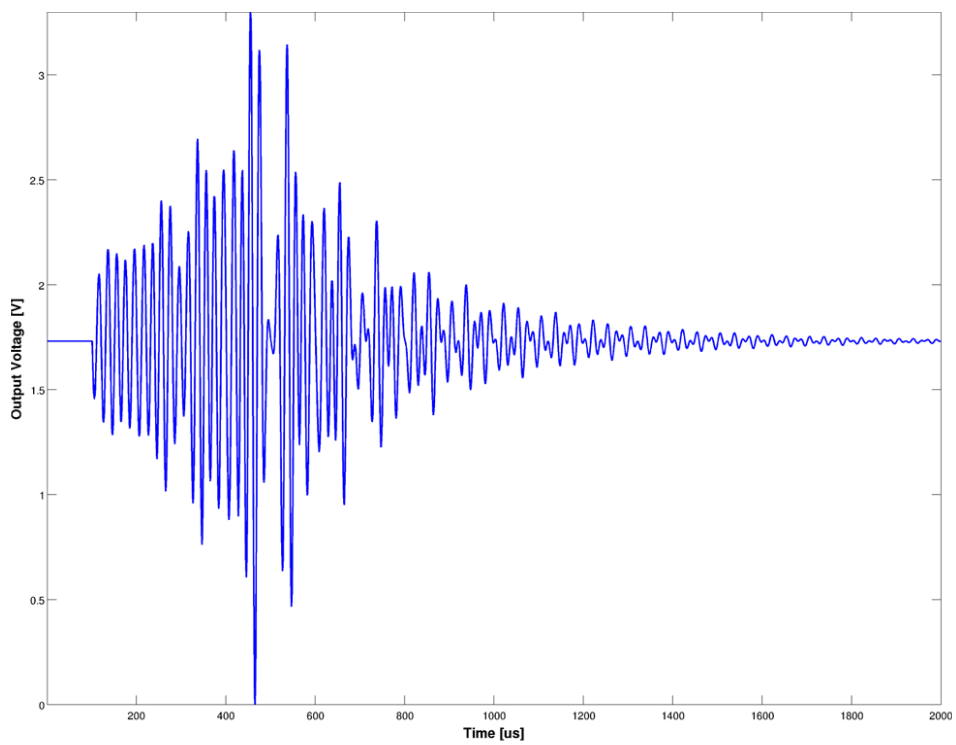

Figure 1 - Test signal generated by the waveform generator to evaluate the AE-node performance (section 3.2 of the manuscript). Remarks: the y-axis does not compare directly with the amplitude measured by the AE-node. During the experiment a posttrigger time of 800 µs was used.

As a side remark, we have also performed a similar test with a manufactured AE system from Physical Acoustics: the temperature sensitivity on the AE parameters measured was comparable or larger than that of the AE-node.

3) The results shown here are promising but they are presented in very partial manner restricted only to the AE activity. For example one could be interested in knowing what is the range of signal amplitude or energy that are recorded by the system in natural conditions, what is the maximum rate of event recorded... Even if the scope of the paper is the system and not the

detailed description of the results, these information could be interesting for estimating the efficiency of the system. Consequently I recommend this manuscript for publication after adressing the minor modification I suggested.

The range of signal amplitudes measured by the AE-nodes in the field is now specified in the revised manuscript. The maximal event rate measured is also mentioned. While providing more details on the result would indeed be interesting, we believe it is not in the scope of the present paper. The authors are currently working on another paper that will provide a thorough analysis of the results acquired in the field with the system described in the present manuscript.

[...]Measurements obtained between September 2011 and February 2012 are summarized on Figs. 9, 10 and 11, respectively giving the rock temperature, the AE-node performance, and a sample of the capacitance measurements. During this period, 107 AE events have been detected by both channels of M1, with maximum rates reaching 50 events per second on a single channel. This corresponds to the maximal rate of events that the AE-node can measure.[...]
[...]The maximal amplitude of AE events ranged from 35 dB (corresponding to the threshold) to 83 dB. In comparison, the absolute maximal amplitude that the system can detect is 93dB. [...]