New Tools for Terrain Gravimetry
NEWTON-g
Project number: 801221

Deliverable 3.2

Plan for the deployment

Lead beneficiary: Koninklijk Nederlands Meteorologisch Instituut (KNMI)
Dissemination level: Public
Version: Final

NEWTON-g has received funding from the EC's Horizon 2020 programme, under the FETOPEN-2016/2017 call (Grant Agreement No 801221)

DOCUMENT INFORMATION

Grant Agreement Number	801221
Acronym	NEWTON-g
Start date of the project	1 June 2018
Project duration (months)	48
Deliverable number	D3.2
Deliverable Title	Plan for the deployment
Due date of deliverable	31 July 2019
Actual submission date	20 September 2019
Lead Beneficiary	Koninklijk Nederlands Meteorologisch Instituut
Type	R: Document, report
Dissemination level	PU - Public
Work Package	WP3 – On-field application

Version	**Date**	**Author**	**Comments**
v.0	21/07/2019	M. Koymans, E. de Zeeuw - van Dalfsen	Creation
v.1	09/09/2019	D. Carbone	1st Revision and integration
v.2	15/09/2019	E. Rivalta, G. Hammond, J. Lautier-Gaud	2nd Revision
Final	19/09/2019	M. Koymans, D. Carbone	Validation

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

WP3 of NEWTON-g deals with planning the installation of the gravity imager at Mount Etna. The gravity imager consists of a network of microelectromechanical (MEMS) relative gravity sensors, anchored to an absolute quantum gravimeter (AQG). The present document describes the state-of-the-art, including achieved developments, challenges mitigated, and steps taken towards the successful field deployment of the gravity imager in the summer of 2020.

The effort described here will continue after submission of this document, until the field deployment is completed.

2. INTRODUCTION

In the framework this document, the following conventions are adopted:

MEMS sensor indicates only the sensing part of the relative gravity device.

MEMS station is used to indicate the sensor housing, auxiliary sensors, data link, power supply system, and any additional element required for a functional deployment of a single MEMS sensor in the network.

MEMS pixel of the gravity imager indicates a single complete installation, comprising a MEMS sensor plus station.

It is critical for the success of the project that the AQG and MEMS pixels are installed near the summit zone of Mt. Etna, despite the more complex logistical issues this poses, concerning the deployment of the gravity imager. Indeed, models developed by the GFZ team indicate that mass changes beneath the summit crater zone, at depths within 2km below sea level, can be best detected if the network nodes are within a few kilometers from the summit area of the volcano. The road crossing the summit area of Mt. Etna runs in a half circle around the active craters (Fig. 2) and can be accessed by all-terrain (authorized) vehicles during summer. To facilitate the deployment of the gravity imager, the MEMS pixels will be placed at close distance from this road that, indeed, allows a suitable configuration of the MEMS network, especially in the uppermost part of the volcano.

In the following sections we discuss the main solutions that have been identified so far for the deployment of NEWTON-g's gravity imager at Etna and the challenges that still lie ahead.

3. TIMELINE

The expected timeline towards the field deployment (summer 2020) is illustrated in Figure 1. The activities that are being carried out and will be carried out in the coming months are, in order of priority:

- defining the optimal geographical distribution of the MEMS pixels, allowing the highest detection power and taking into account the main field constraints;
- running out-of-the-lab experiments and field tests on Etna, using a prototype MEMS station (excluding the MEMS sensor) to verify the performance of the different components (e.g. auxiliary sensors, motherboard, data transmission system, power system) under specific field conditions;

- defining details of the set up for the AQG at the chosen installation site (PDN), taking into account all the constraints imposed by the characteristics of the instrument (e.g. power requirements);
- purchase and assembly of the MEMS stations including all required hardware and software components;
- running field tests on a prototype MEMS station including the MEMS sensor;
- deploying the gravity imager at Mt. Etna.

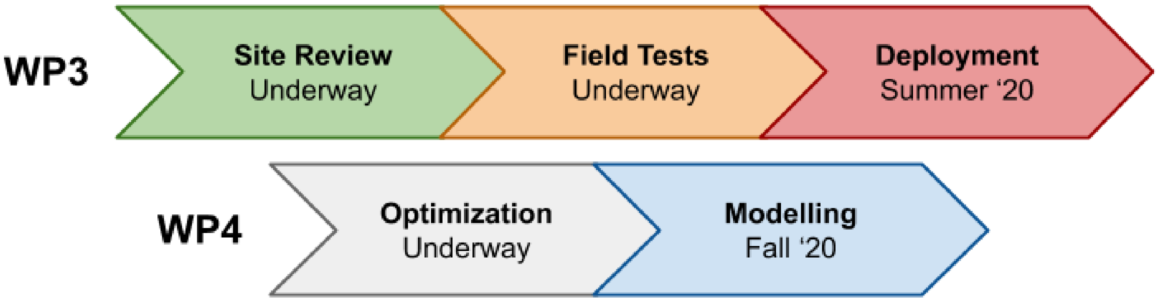

Figure 1 - Timelines for activities under work packages 3 and 4. The results obtained from the optimization modelling in WP4 will guide the field deployment. Information from the field (WP3) will be used to constrain the model optimization in an iterative, circular approach that converges towards a suitable MEMS pixel configuration.

4. GRAVITY IMAGER CONFIGURATION

The GFZ team has developed a numerical algorithm to discover the theoretically optimal configuration of the MEMS pixels in the gravity imager. A network configuration can be considered as “optimal” when it allows the most accurate estimation of the characteristics of a causative bulk mass source. The optimization problem has been addressed by combining concepts from geodetic network design and genetic algorithm analysis. The main constraints in the optimization procedure are:

- MEMS pixels within 200m of the main roads;
- deployment of MEMS pixels is not allowed in areas difficult to access.

The availability of high-quality data from the superconducting gravimeters in the monitoring network of INGV-OE is considered in the calculation. Preliminary network optimization results were presented in D2.1 (Gravity imager design review) and in the framework of an oral communication at the EGU General Assembly 2019 (Nikkhoo et al., 2019). More detailed information will be published in a peer reviewed journal (Nikkhoo et al., in prep.). The details of this approach are outside the scope of this document. For more details on the algorithm we refer the reader to Part B of the first Technical Report of NEWTON-g (section 4.2.2).

The position of the MEMS pixels is selected by the algorithm to provide a configuration that can optimally resolve gravity changes caused by mass sources at depths down to 2 km b.s.l. It is also assumed in the calculation that the AQG is installed at PDN (Fig. 2); however, the feasibility of installing the AQG at this site still needs to be assessed, due to logistic issues. If it will not be possible to deploy the AQG at the preferred site, an

alternative MEMS configuration will be probably selected by the algorithm. Furthermore, some of the sites included in the optimal configuration selected by the algorithm could present characteristics not well suited for the installation of a MEMS pixel (absence of firm base rock at close distance, poor or absent cellular coverage for data transmission, etc.). Hence, an iterative approach must be followed. The numerical algorithm defines a preliminary optimal configuration that is checked against real field conditions. The new information from the field is fed back to the numerical algorithm as further constraints. The new run of the optimization procedure will possibly converge towards a slightly different configuration with respect to the previous run.
By iteratively combining theoretical results from the optimization procedure and information from the field, the final configuration of the MEMS pixel in the gravity imager will be determined.

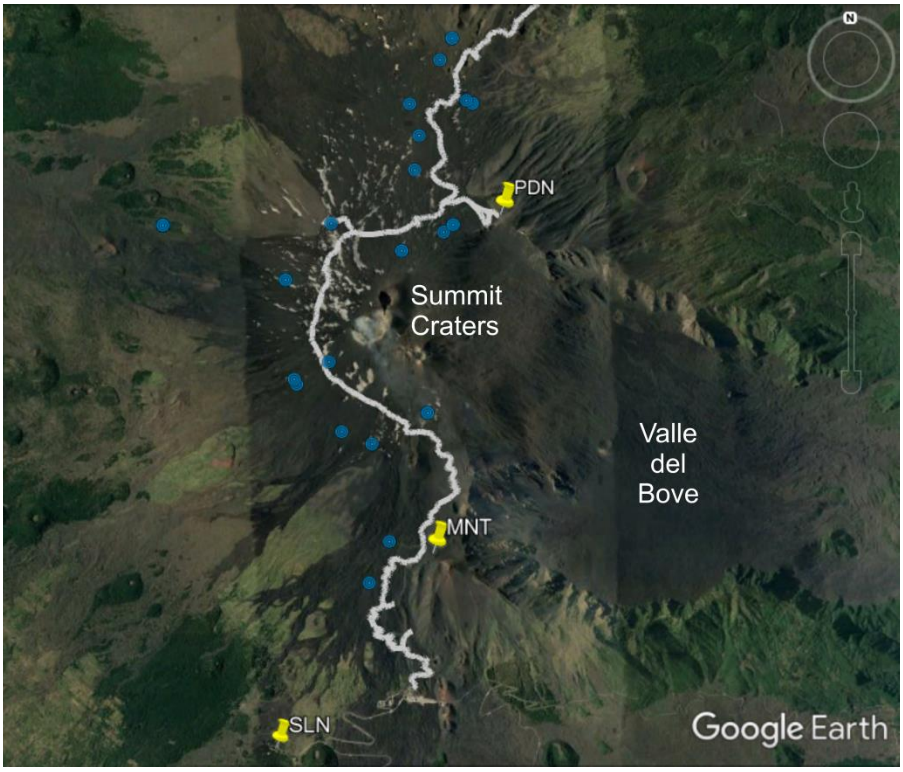

Figure 2 – Preliminary optimal configuration of MEMS pixels (in blue) selected by the numerical algorithm of the GFZ team. In some cases, the algorithm clusters different sensors in a single site, to locally enhance the signal-to-noise ratio. Positions of sites equipped with iGrav SG meters (SLN and MNT) are shown in the map, as well as the position of the Pizzi Deneri Observatory (PDN). The grey trace is the road crossing the summit crater zone of Etna. Aerial photograph taken from Google Earth.

5. MEMS STATION DESIGN

The acquisition system of the MEMS stations will be based on the Raspberry Pi 3 (Model B+), that was chosen because of its flexibility, low power consumption and limited cost. Each station will be powered through a 65Ah battery (12V DC), charged by a 100W solar panel. A 12-to-8V DC-DC converter is required to power the MEMS sensor (5-8V input). Each MEMS sensor draws less than 625mA (technical Report - Part B; section 2.2.2) of current, that the chosen battery can supply continuously for several days, during long no-sunshine intervals.

Thermal isolation of the MEMS sensor is a clear challenge that needs to be faced. Indeed, a single mK (millikelvin) change in temperature would alter the MEMS spring constant and induce an apparent gravity change of 25-50 μGal (Middlemiss et al., 2016; NEWTON-g technical report Part B; section 2.2.2). The MEMS sensor itself is isolated through a three-layer precise thermal control system. At each MEMS station the MEMS sensor will be also protected by a polystyrene housing, aimed at reducing the amplitude of daily and annual temperature fluctuations.

The MEMS sensor head will be installed on a layer of consolidated concrete poured on stable bedrock, in order to prevent vibrations (e.g. wind) of the protecting housing to be coupled to the sensor. The MEMS station will be placed in a separate weather-proof case, containing all the required electronics (e.g. battery, data-link, additional sensors), that will be installed next to the MEMS sensor. The sensor will be connected to the station with IP66 verified cable and connectors. Data will be transmitted over the cellular network through a 4G router and will be collected by INGV-OE at the base station.

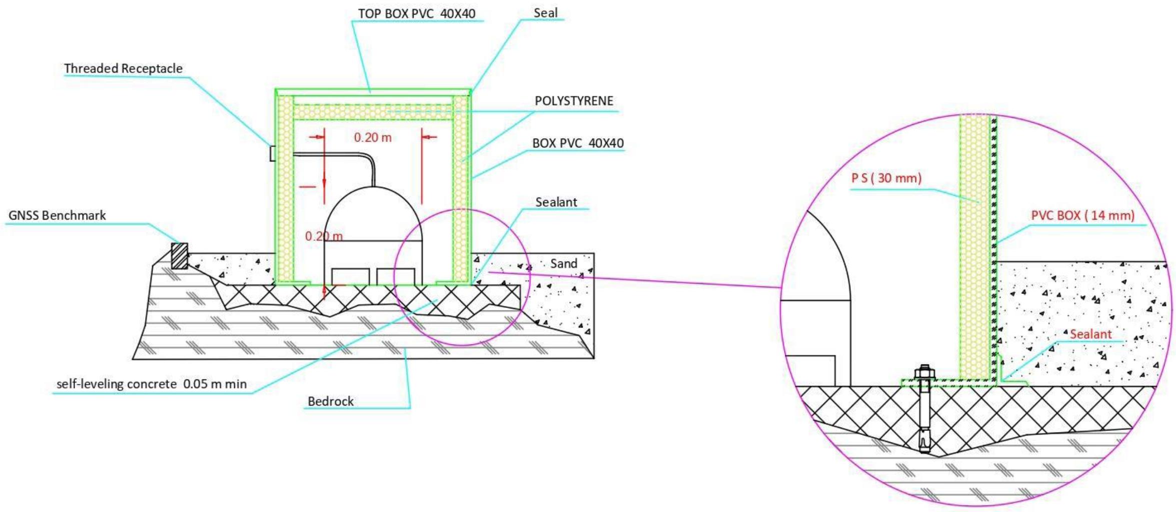

Figure 3 - Preliminary design of the housing protecting the MEMS sensors. The sensor is anchored on self-leveling concrete in direct contact with stable bedrock. A weatherproof cable will connect the sensor to the adjacent MEMS station.

5.1 MEMS Station auxiliary sensors

Besides hosting the sensor that measures changes in the gravity field, each station will be equipped with a set of auxiliary sensors that record environmental parameters (e.g. ambient temperature, barometric pressure, soil moisture). The data from these sensors will be used to distinguish volcano-related from other gravity changes (e.g., due to atmospheric pressure changes or to changes in the underground water mass). Furthermore, battery voltage, load current of the power system and cpu temperature of the raspberry module will be continuously recorded at a lower rate to control the state-of-health (SoH) of the MEMS station.

5.2 MEMS transport

Great care must be paid during transport of the MEMS gravimeters, as the spring flexures can break when subjected to excessive strain. For safe transport, the MEMS mass must be locked in place, which can be facilitated by transporting the device upside down. However, this approach only holds the proof mass down by gravity, and rough handling may be harmful to the instruments. Once the MEMS are sealed the flexures can no longer be observed and damage to a sensor will only become apparent after the data is reviewed. Whether the instruments can survive transport by car on the rough slopes of Mt. Etna needs to be reviewed diligently. MEMS devices were tested up to a shock load of 45g by UNIGLA and instrument transport should not exceed this threshold. Alternatively, the instruments can be carried up the volcano on foot and/or making use of the existing cable car.

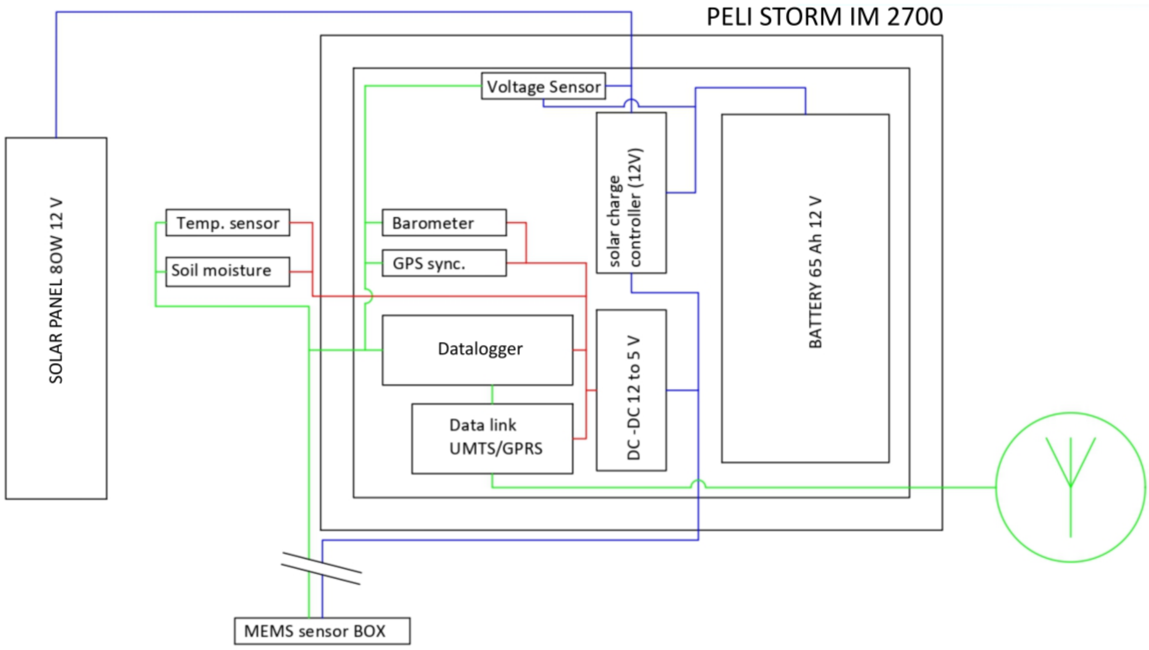

Figure 4 - Schematic electronic layout of the MEMS station. The blue and red line represents a 12 and 5-8V lines respectively. The green line represents the grounding line. The datalogger (motherboard) is a Raspberry Pi.

5.3 Sensor-to-station interface

When the MEMS sensor is delivered by UNIGLA, the interfacing with the MEMS station will be carried out together by KNMI and INGV-OE. A generic serial cable (e.g. RS232 or a generic N-pin connector) will be used to link the sensor to the raspberry module. A hardware controller will be added to interface the sensor with the station and some additional software will need to be written to read out the gravity signal and auxiliary state-of-health channels (e.g. temperature) from the sensor.

5.4 Fieldwork on Etna to check installation sites

In June 2019 a team of partner representatives from GFZ, KNMI, and INGV took a field trip to Mt Etna, to assess the feasibility of the MEMS sites selected by the optimization algorithm (blue dots in Figure 5). Some of the sites identified by the algorithm are unsuitable for installation of MEMS pixels, since either they are characterized by steep slopes, or present unstable unconsolidated ground (e.g., ash and scoriaceous lava-flows - see Figure 6), or are outside of cellular coverage.

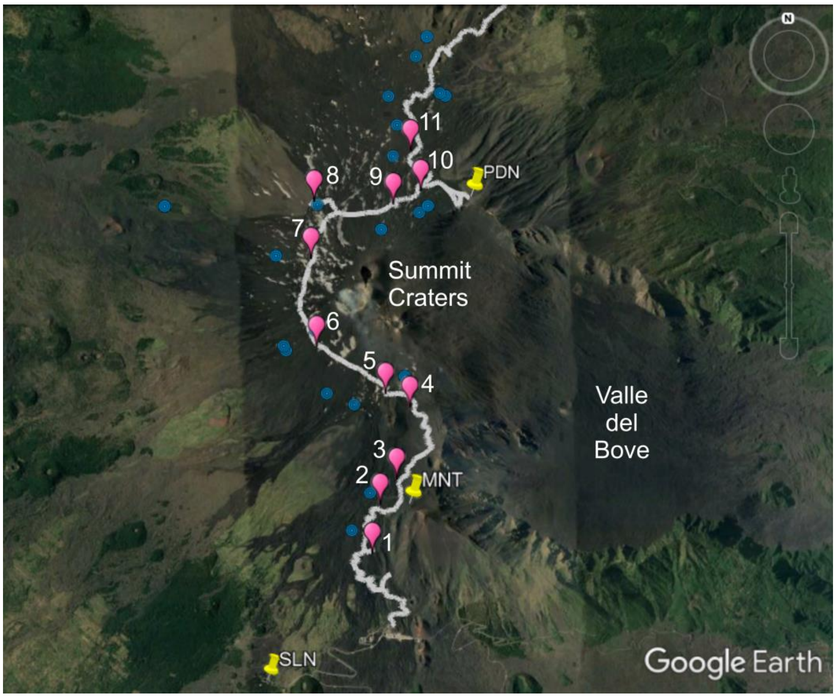

Figure 5 - Preliminary optimal configuration of MEMS pixels (in blue) selected by the numerical algorithm of the GFZ team and sites identified as suitable for the installation of MEMS pixels during the field trip in June 2019 (purple symbols). Yellow pins mark the site where the two iGravs at higher elevations are installed (SLN and MNT) and the position of the Pizzi Deneri Observatory (PDN). Aerial photograph taken from Google Earth.

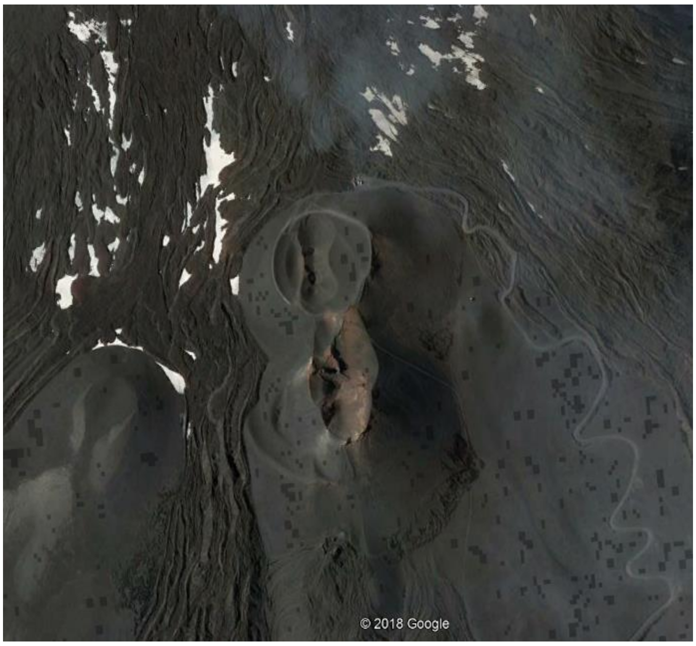

Figure 6 - Aerial image showing a zone in the upper southern slope of Etna that is almost entirely covered by ash and scoriaceous lava flows. Image taken from Google Earth.

During the field trip in June, sites suitable for MEMS pixels installation and as close as possible to those selected by the optimization algorithm were identified (purple pins in Figure 5). As stated in section 4, this new information has been fed back into the numerical algorithm to obtain an updated configuration of the gravity imager. We expect that this iterative feedback between theory and field information will continue until the deployment of the gravity imager in the summer of 2020.

5.5 Preliminary outdoor and field tests run by the INGV-OE team

5.5.1 Auxiliary devices and sensors

Preliminary tests have been accomplished, and are ongoing at the time of this writing, aimed to check the performances of the different parts of the MEMS station.

Figure 7 – Setup of the test station installed in the facilities of INGV-OE between 6 and 21 August (see text for details). The solar panel on top of the orange case, containing most components of the station, are shown.

Between 6 and 21 August 2019 an outdoor test was carried out at the facilities of INGV-OE in Catania, with the twofold aim of (i) checking the power consumption of data acquisition and data transmission systems and (ii) testing the performances of different components and auxiliary sensors in the MEMS station. In particular, a waterproof case was installed in the roof terrace of the INGV-OE facilities (Fig. 7) containing:

- a raspberry pi 3 b+ module;
- a cellular modem;
- a battery (12V - 65Ah);
- a solar charge controller.

Auxiliary sensors were used to measure:

- ambient temperature inside and outside the case;
- humidity inside the case;
- atmospheric pressure outside the case;

- battery voltage;
- load current of the power system.

The CPU temperature of the raspberry module was also recorded in the data stream. A 100 W solar panel was used to charge the battery. It also protected the case from direct solar radiation (Fig. 7). During the whole 14-day interval, data from the auxiliary sensors were transmitted over the Internet, at regular intervals, by the cellular module. As shown in Fig. 8, the current absorbed by the load was about 0.25A during the whole test interval. This value, corresponding to about 3W (0.25A at 12.5 - 13.5V), can thus be considered as the standard current absorption of the acquisition and transmission systems of the MEMS station.

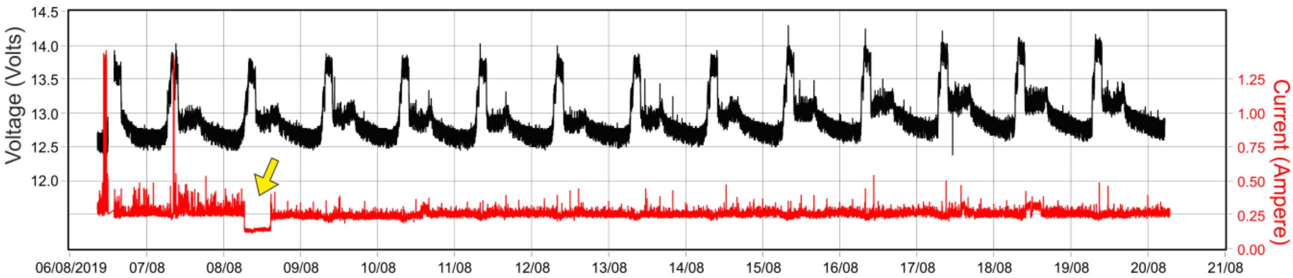

Figure 8 – Battery voltage (black curve) and current absorbed by the load (red curve), measured during the 14-day test period at INGV-OE. The lower value of absorbed current during 8 August (yellow arrow) occurs because the cellular modem was temporally removed to perform cellular coverage tests on Etna. The amount of the decrease indicates that the cellular modem takes about half of the whole current absorbed by data acquisition and data transmission systems.

External ambient temperature was very high during the interval of the outdoor test at INGV-OE (up to 45°C, see Fig. 9), implying extreme working conditions inside the waterproof case (temperature up to 50°C). In spite of that (the CPU temperature of the raspberry module exceeded 70°C on different occasions; see Fig. 9), all the devices inside the case worked properly.

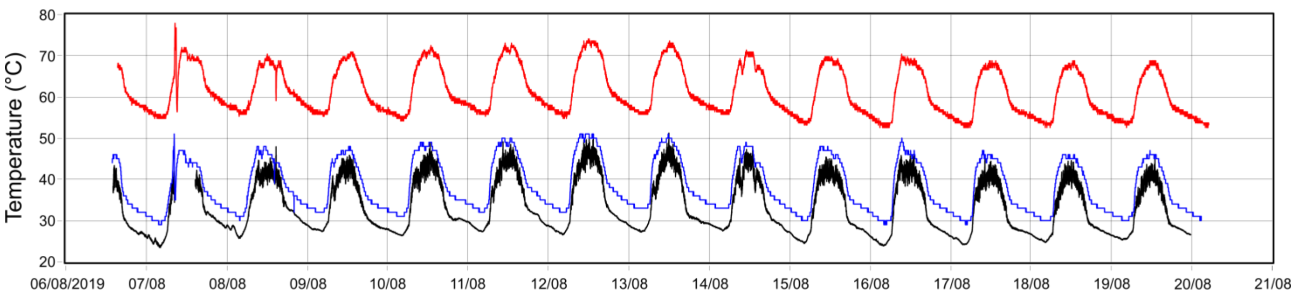

Figure 9 – Ambient temperature outside (black) and inside (blue) the waterproof case and CPU temperature of the Raspberry module (red), measured during the 14-day test at INGV-OE.

On 22 August, the same prototype MEMS station was moved to Etna and installed on the southern slope of the volcano, at an elevation of about 2300m (point 1 in Fig. 5). In this case, a LaCoste & Romberg D gravimeter, equipped with Aliod 100 linear electronic (beam nulling) feedback system, has been employed in substitution of the MEMS gravimeter (prototype unavailable at the time of the test installation). The Aliod 100 features a RS-232C Serial Port with continuous data output, that has been streamed directly to the Raspberry Pi. Data output includes gravity, X and Y levels, internal meter temperature, tension to the meter. The L&R gravimeter draws about 10W, hence, about twice the power needed by the MEMS device (~5W; see D2.1). This must be taken into account when considering the power balance during the field test of the MEMS station. Weather conditions were unfavorable during the first days after installation on Etna. Frequent cloudy conditions prevented the solar panel from properly recharging the battery. This caused a drop in the battery voltage during the first 3 days after installation (Fig. 10).

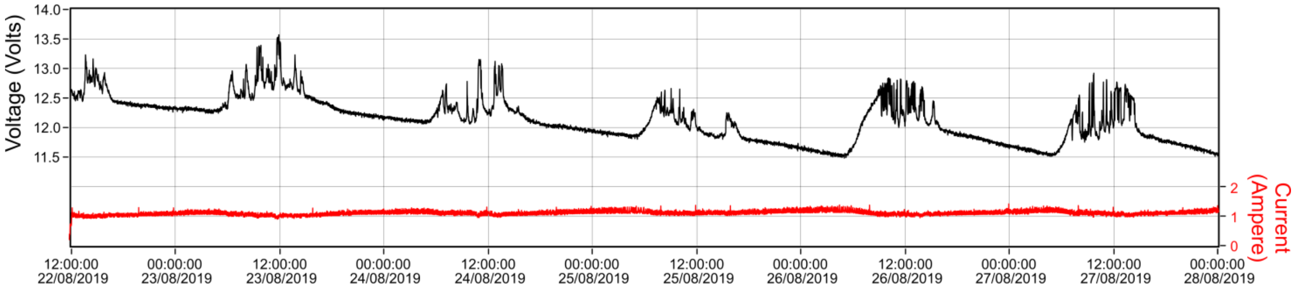

Figure 10 – Battery voltage (black curve) and current absorbed by the load (red curve), measured during the first 5 days of the test at Etna.

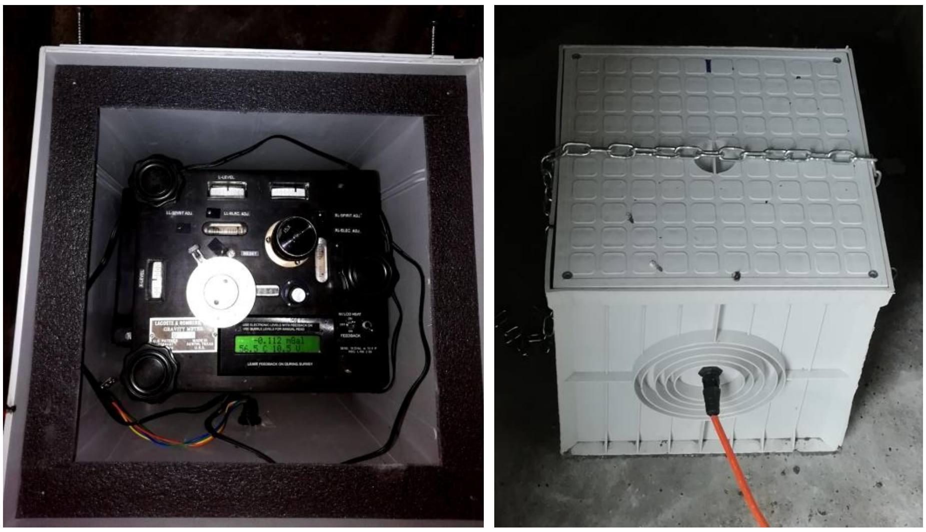

Figure 11 – Left: L&R gravimeter inside the protective plastic box at the test installation site on Etna. Ambient temperature and atmospheric pressure sensors are visible on the left, inside the box (edge of the multicolor wire). Right: the protective plastic box is screwed onto the concrete base and sealed with silicon; it is closed with a lead firmly screwed onto sealing ribbon (visible as a black frame in the left panel).

However, the value of the battery voltage remained within an acceptable range. Future developments of this test (ongoing at the time of the present writing) will provide useful indications on the reliability of the chosen power system, taking into account the above difference in power taken by the gravimeter used for the test and the MEMS device. Fig. 10 also shows the current absorbed by the load.

The L&R gravimeter was installed inside a plastic box, screwed onto a concrete base (Fig. 11). Ambient temperature and atmospheric pressure are measured inside the box hosting the gravimeter. The latter does not feature any thermal insulation. It will be added at a later stage, to better evaluate its performance. Temperatures (i) inside the gravimeter box, (ii) inside the electronic case and (iii) raspberry CPU temperature are shown in Fig. 12. Daily changes inside the plastic box and case exceed 5°C.

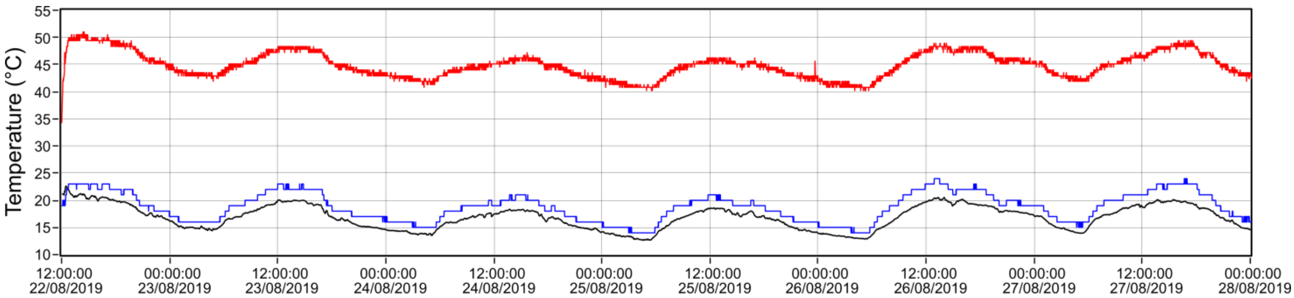

Figure 12 – Ambient temperature inside the plastic box hosting the gravimeter (black), inside the waterproof case (blue) and CPU temperature of the raspberry module (red), measured during the first 5 days of the test at Etna.

Fig. 13 shows the gravity signal from the L&R device, during the first 6 days after its installation on Etna. Interestingly, there is an increase in the higher frequency noise during daylight hours (roughly, between 9:00 and 18:00). This could be induced by the movement of the cableway, which is at a minimum distance of about 300m from the installation site.

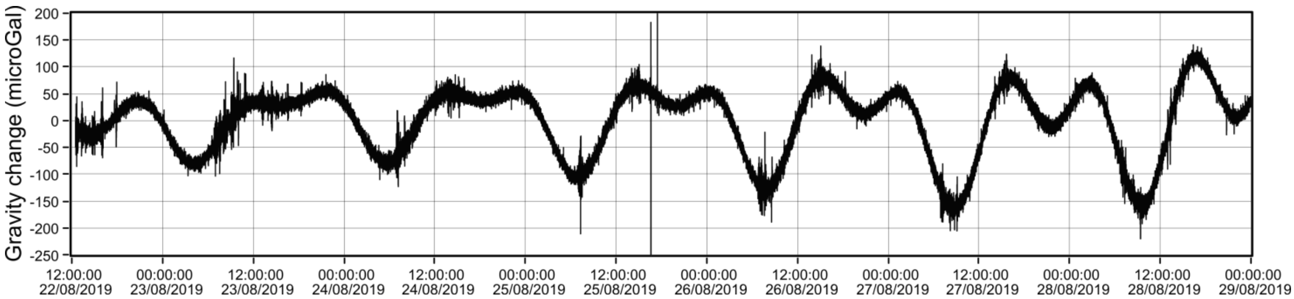

Figure 13 – Earth tides observed by the L&R gravimeter in the test station on Etna, between 22 and 28 August 2019.

5.5.2 Field infrastructure

As reported at the beginning of section 3 and in Part B of the first Technical Report of NEWTON-g (section 3.2.2.1), the field infrastructure of each MEMS station will include (i) a thin layer of self-leveling concrete, to ensure suitable coupling of the sensor to the base rock and (ii) a PVC box, hosting the MEMS gravimeter, that will be anchored on the flat and level concrete base. The bottom of the PVC box will be partly removed to place the MEMS device directly on the concrete and also to avoid that shocks and vibrations of the external housing are transmitted to the sensor.

Figure 14 – Left: concrete base on Etna at 2900m elevation. The summit active craters are visible in the background. Right: gravity measurements are performed with a L&R gravimeter on the concrete base at 2600m elevation.

To check the reliability of this design for the field infrastructure of the MEMS devices during deployment at Etna, field tests were performed during the summer of 2019. In particular, two prototype concrete bases were built at two test sites (Fig. 14), at elevations of about 2600 and 2900m (points 3 and 5 in Fig. 5). Gravity measurements were made on top of both concrete bases using the Scintrex CG-6 gravimeter and a L&R gravimeter equipped with Aliod 100 feedback system. These measurements were intended to verify whether the concrete layer provides suitable coupling to the base rock. Gravity measurements were also carried out through the Scintrex CG-6 at other candidate sites for the installation of MEMS stations, to check the stability and suitability of the base rock.

Figure 15 – Left: on a check performed 28 days after its installation, the interior of the bottomless PVC box, installed on Etna at 2600m elevation, was dry, proving the reliability of the adopted sealing solutions. Right: the box at 2600m elevation is covered with ash and stones to make it less visible and to provide further protection against environmental factors.

At the lower elevation site, a bottomless PVC box was also anchored to the concrete base, to gain further insight on the possibilities of the infrastructure design. In particular, tests have been run to check whether the adopted sealing solutions actually make the PVC box waterproof. Preliminary results are encouraging: the interior of the box was perfectly dry 28 days after its installation (Fig. 15), despite the occurrence of a rain events.

5.5.3 Cellular coverage

As reported in D2.1, our first choice for transmitting data produced by the gravity imager, from the acquisition sites in the field to the collection point, is through the cellular network. The advantage of this approach is that it allows direct data transfer from any point in the array, provided that there is sufficient cellular coverage.

On two occasions in August 2019, the INGV team checked the cellular phone coverage in the summit zone of Etna, using a 4G router and SIM cards from three different carriers (TIM, Vodafone and Wind). These checks were performed in sites (i) as close as possible to the positions defined by the GFZ team on the grounds network optimization results (see D4.1 and Part B of the first Technical Report of NEWTON-g, section 4.2.2) and (ii) offering suitable conditions for the installation of MEMS stations.

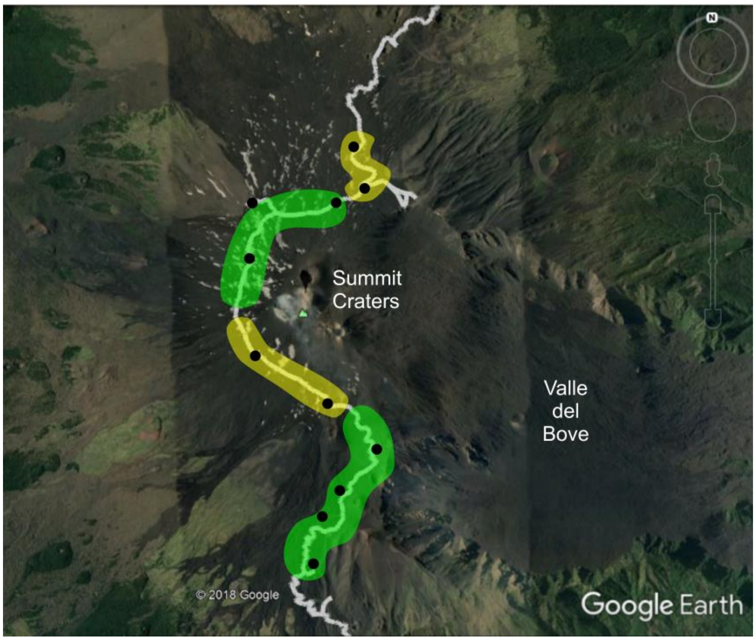

Figure 16 – Cellular phone coverage along the summit road of Etna. The green color indicates areas with good coverage. The yellow color indicates areas with poor or no coverage. Black dots indicate the sites where the checks were performed

In general, there is good cellular coverage (marked in green in Fig. 16) around the southern branch of the summit road, at elevations between about 2300 and 2800m (mostly, TIM network). Good cellular coverage was also found along the part of the road that goes around the summit craters, immediately N and NW of them (Fig. 16), at elevations between about 3050 and 2900m (Vodafone and TIM carriers). Conversely, areas with poor or no cellular coverage (marked in yellow in Fig. 16) are located SW of the summit craters and in the northernmost part of the checked zone (elevations between

2650 and 2800m). Further tests will be accomplished in the areas with poor cellular coverage, to understand whether data transmission is possible from selected sites, using a directive antenna.

6. DEPLOYMENT OF THE ABSOLUTE QUANTUM GRAVIMETER

The deployment of the AQG is still under review. The consortium has considered four sites that have advantages and disadvantages from both the scientific and logistical perspective (see D2.1 and Table 2).

Site (elevation m)	Advantages	Disadvantages
PDN (2800)	Very close to summit Space for deployment	No infrastructure (power) Access in winter complicated
MTN (2600)	Close to summit Existing infrastructure	Space limitations High summer temperatures
Cable Car (2500)	Close to summit Existing infrastructure	Noise Reluctant collaboration of owner
SLN (1730)	Existing infrastructure	Far from summit

Table 2 - Summary of possible deployment locations of the AQG and its advantages and disadvantages.

The first-choice installation site is the Pizzi Deneri Volcanological Observatory (PDN; Fig. 2), which is the closest to the summit craters. In the semi-underground basement of the observatory there is space enough to install the AQG. The biggest challenge to tackle is the relatively large power consumption of the AQG, as there is no mains electricity at PDN. In the following section, we discuss the possible solutions.

6.1 Possible power sources at PDN

The expected power consumption of the AQG is about 500W. Here we review the possible alternative solutions, in terms of cost, practicality, and effectiveness.

- Fuel Cells + Solar Power is an effective but expensive solution.
- Portable Power Generator + Solar Power is an effective and affordable solution.
- Solar Power alone is ineffective because of the low yield and unreliable yield.
- Wind Power is ineffective because of excessive wind speeds and unreliable yield.

All deployments must include a large stack of batteries (exceeding 500Ah) that will store the generated power and supply power to the AQG. Power is never drawn directly from the source. Additional electronics (e.g. charge controllers) required or case-specific circuitry are not yet considered. The AQG runs on 24V DC (or 220V AC) and uses 500W of power (between 300 - 400W at lower temperatures). The AQG draws roughly 20A and a 500Ah-rated battery stack would power the AGQ for 1 day. A balance between cost and power storage needs is to be found.

6.1.1 Option 1: Fuel Cells & Solar Panels

A hybrid solution with solar panels and methane fuel cells has been considered for continuously powering the AQG. However, the fuel cells that would be needed to power the AQG are very expensive to purchase and operate; the total cost exceeds 150k€ over the duration of the deployment. Quotes for the cells were requested by INGV and KNMI from different suppliers. The supplier recommends 2-3 units of type EFOY PRO 12000 Duo that can each supply 500W and have a connector for two 60L methane tanks. The cost of the fuel cell is 20k€ per unit and the methane tanks cost 350€ each. Six methane tanks can autonomously power the AQG for roughly 30 days depending on the monthly solar yield (see Figure 17). This yields a yearly cost of roughly 25k€ for the methane fuel. The cumulative cost of this solution is considered above the budget.

6.1.2 Option 2: portable power generator & solar panels

Another possibility for powering the AQG at PDN is a hybrid system with a portable power generator and solar panels. The stack of batteries would be charged by a combination of solar cells (rated at ~100W per square meter at full efficiency) and a supplementary diesel generator (2kW). The precise configuration of the electronics is currently under review and the consortium will consult some companies with proved experience in this type of deployment to assist in the design of the hybrid solar and fuel power system. As an example, a possible setup is shown in Figure 18.

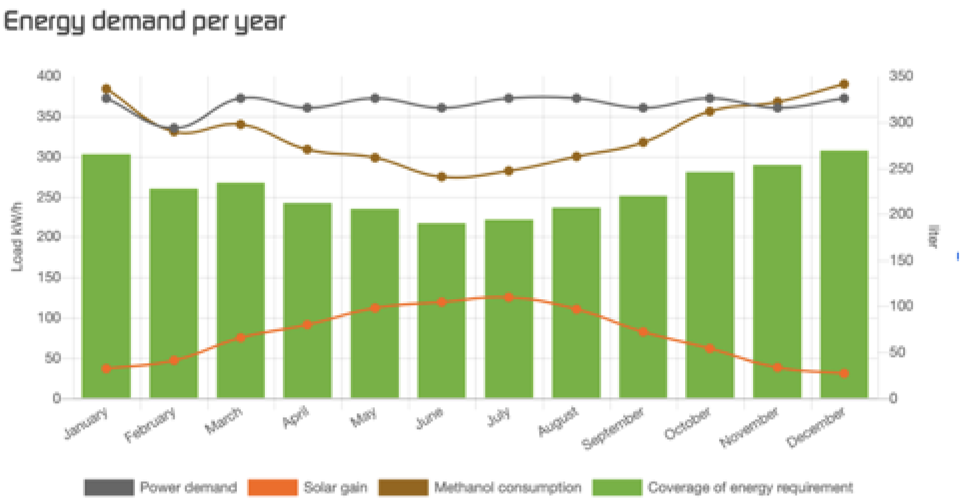

Figure 17 - Power demand (grey line) and the expected gain from 600W solar panels (orange) and methane fuel cells (green bars). The monthly methanol consumption is illustrated by the brown line. Created using the EFOY Calculator (https://www.efoy-pro.com/en/service/energy-calculator/).

Portable power generators (diesel) use roughly 3 kWh per liter. A fuel tank of 1000L is feasible and would provide 3000 kWh = 6000 hours of 0.5kW power, hence 250 days of continuous operation, assuming that no power comes from the solar panels. At 1.5EUR per L of diesel this would come out to 6 EUR per day of operation (excluding fuel transport and additional costs).

6.1.3 Option 3: Solar panels

Solar panels are only effective for a few hours during the day and may be ineffective due to clouds and ash cover. In winter snow may completely cover the panels surface. Because solar power is very unreliable on its own, it is not a good candidate for sole use, especially since the AQG should operate continuously. However, solar power can contribute to other power installations.

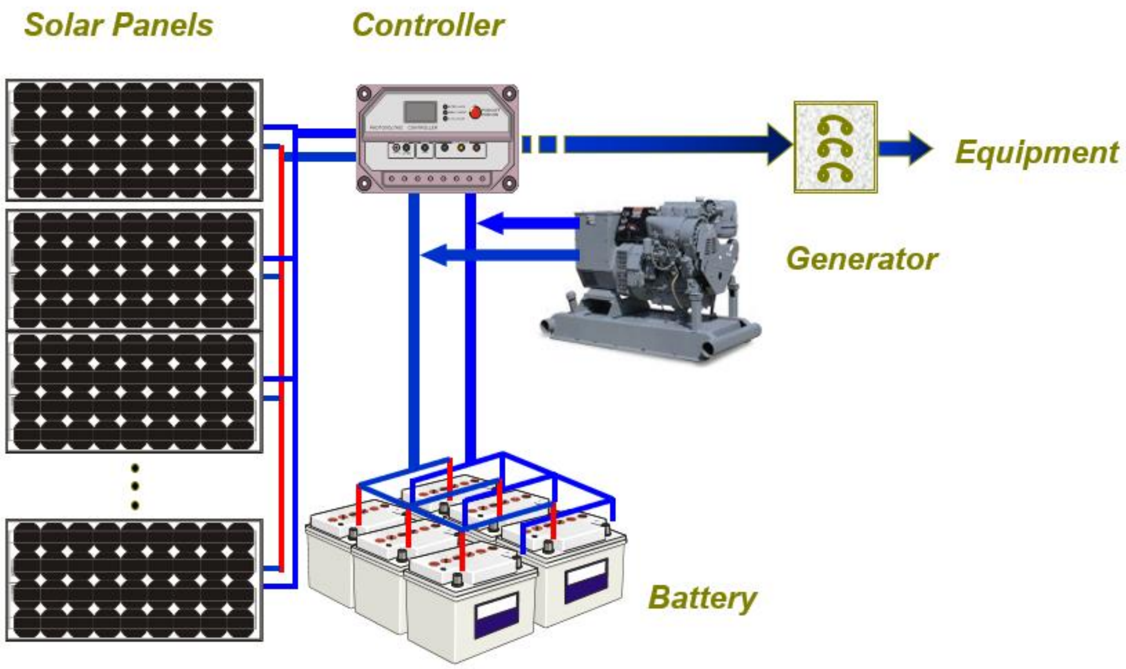

Figure 18 - Example set up of hybrid portable power generator and solar power system. The solar panels are connected in parallel and run through a charge controller that prevents the batteries from overcharging. Image copyright by IOV-ASIA.

6.1.4 Option 4: Wind power

Wind speeds on Mt. Etna can be extreme and a wind turbine is not considered a good candidate as it could easily get damaged. Furthermore, using only natural power sources can be unreliable and the AQG should operate continuously.

7. CONCLUDING REMARKS

During the last months of 2019 a focus will be placed on identifying MEMS locations and on finalizing the design of the typical MEMS station. This includes both hardware and software components. Outdoor and field test will be carried out on a complete MEMS station to verify the conditions required for successful deployment.

Before the end of 2019 a decision will be made for the final deployment location of the AQG, in order to prepare the installation site.

Once a single MEMS sensor is delivered (end of 2019 / beginning of 2020), it will be tested in the field with the prototype MEMS station. If the tests are considered successful, all required components will be bought and the needed number of MEMS stations will be assembled in time for the deployment during the summer of 2020.