The Malta Seismic Network:
From earthquake monitoring to seismic imaging of groundwater

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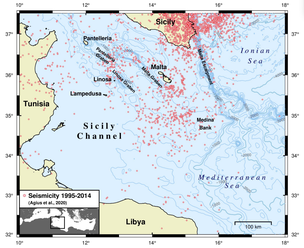
ABSTRACT

Following the setting up of the Malta Seismic Network, new opportunities for research arise which go beyond the conventional monitoring of local and regional earthquakes. The new data is used to carry out site response studies as well as high-resolution sub-surface studies such as velocity profiles and groundwater imaging of the aquifers below. These studies have significant importance for Malta, particularly because it is a small island country 15 km wide by 30 km long in the centre of the Mediterranean Sea (about 100 km south of Sicily, Italy). The network operated by the Seismic Monitoring and Research Group at the University of Malta is being exploited to maximize its full potential aiding the local Department of Civil Protection with earthquake monitoring and tsunami modelling and now the Energy and Water Agency with groundwater monitoring.

We present the recent developments of the seismic network, examples of local earthquake recordings, earthquake catalogue and site response studies. In addition, we present SIGMA (Seismic Imaging of Groundwater for Maltese Aquifers), a new project aimed at imaging the spatial and temporal characteristics of aquifers across Malta – a first to cover a whole country that is completely surrounded by sea. The data set is derived from a combination of 13 stations, including those of the Malta Seismic Network and other temporary instruments spanning across the whole archipelago. We use auto/cross-correlation of noise recorded on the stations to extract information about the subsurface and track temporal and spatial changes in water content at different scales. These changes are compared to in situ borehole readings and meteorological parameters.

1. Malta seismicity

The Sicily Channel, situated on the leading edge of the African plate as it collides with Europe, presents a range of interesting and complex tectonic processes that have developed in response to various regional stress fields. The Maltese islands lie approximately 100 km to the south of Sicily, and are known to have been affected by a number of earthquakes in the Channel, with some of these events estimated to be very close to the islands (Galea, 2007). Yet, in the absence of nearby seismic instruments, an accurate evaluation and mapping of small magnitude seismicity, and, hence, the identification of unmapped active faults in the region, remains a challenge. This situation is partially addressed through the deployment of more seismic stations on the Maltese archipelago as part of the **Malta Seismic Network (MSN)**.



► ***Seismicity around Malta and in the Sicily Channel.*** *Pink dots: Seismicity between 1995-2014, compiled from regional catalogues and high-quality single-station locations (Agius, 2020). Magnitudes range between 2.0-4.9. Contours: Bathymetry at 250 m intervals.*

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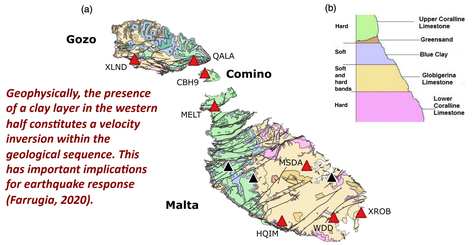
2. Stations of the MSN

The MSN comprises eight broadband 3-component stations distributed over an area of 315 km^2. Station WDD, installed in 1995 as part of MedNet, was the only operating station until 2014. All sensors, with the exception of WDD and HQIM, are Trillium (120PA or Compact) connected to Centaur digitizers (Nanometrics). WDD has an STS-2 sensor and Quanterra data logger. Station HQIM instrument is GeoTiny which incorporates sensor and digitizer but has near-broadband characteristics. The stations are located on different geological settings. The Maltese islands are composed of a layered sequence of Tertiary limestones and clays. The western half of the archipelago conserves the whole lithostratigraphic sequence, whereas the eastern half conserves only up to the Globigerina Limestone. Five of the stations are installed on bedrock (Globigerina or Lower Coralline Limestone) while three stations are located on Upper Coralline Limestone, which is underlain by a thick clay layer.

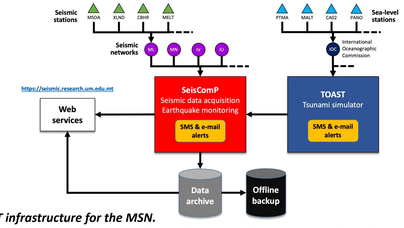


Geophysically, the presence of a clay layer in the western half constitutes a velocity inversion within the geological sequence. This has important implications for earthquake response (Farrugia, 2020).

▲ ***Station and geology map.*** *(a) Outcrop geology of the Maltese islands and major onshore faults (Oil Exploration Directorate, 1993). (b) The stratigraphic layers with corresponding colours. Red triangles: the station locations of the Malta Seismic Network. Black triangles: Planned station locations.*

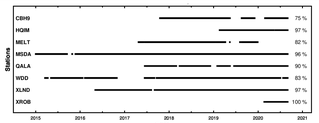
3. IT infrastructure

The MSN stations transmit continuously to a central server using the SeisComP3-SeedLink protocol. SeisComP3 also receives data from 600+ stations located in the Mediterranean and around the globe. Another server hosts the Tsunami Observation and Simulation Terminal (TOAST), which is integrated with SeisComP3, and acquires sea-level data from stations in the Mediterranean. It performs rapid tsunami simulations when triggered. Wave heights and travel times at points of interest are used in tsunami alert decision support systems.

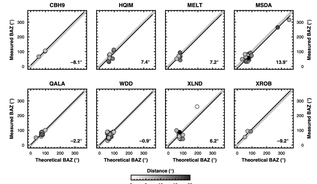


▲ ***IT infrastructure for the MSN.*** *Four dedicated servers run SeisComP, TOAST, website services, and the data archive. SeisComP and TOAST retrieve real-time data from seismic and sea-level stations (triangles) through the corresponding networks (circles).*

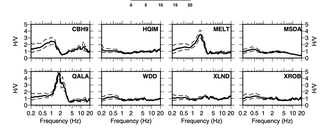
4. Quality control



◄ ***Waveform data completeness.*** *Black bars: Daily data availability of the vertical component for each station. Percentages: Data completeness stored in the archive.*

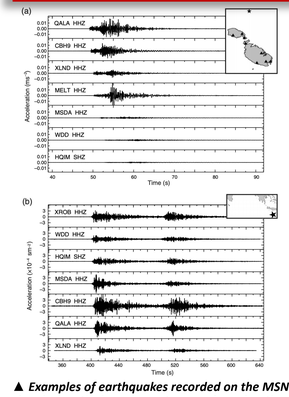


◄ ***Station orientation analysis.*** *Circles: Measured station-earthquake back azimuth (BAZ) compared with the theoretical BAZ. The thick grey line: Expected 1-to-1 relationship. Black line: Average difference in degrees. Filled shade of each circle represents the earthquake distance in degrees from the station. Earthquakes with magnitude >4.5, <40 km depth and distance <20° from the stations were selected from the ISC catalogue.*



◄ ***Horizontal-to-vertical spectral ratios (HVSR) computed from 24 hr recordings of ambient seismic noise.*** *Solid black curves: Mean of the spectral ratios over all time windows. Dashed lines represent the mean ±1 standard deviation.* ***Note presence of H/V peaks for stations CBH9, MELT and QALA, which are located on Upper Coralline Limestone (UCL) underlain by Blue Clay (BC)***

5. Earthquake examples

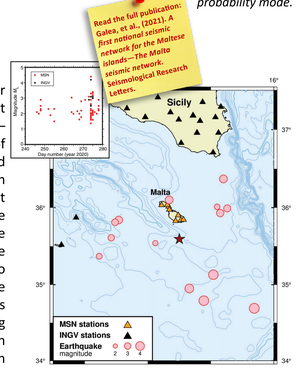


▲ ***Examples of earthquakes recorded on the MSN showing vertical component, ground acceleration, corrected for instrument response.*** *(a) 8 October 2019 M3.7 north coast of Gozo event; (b) 2 May 2020 M5.4 near Crete event. Insets: Location of the earthquakes with respect to the MSN.* ***NOTE: Strong amplitude contrasts due to underlying geology.***

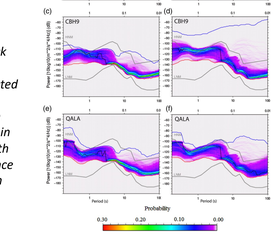
Seismicity close to the islands are better located thanks to MSN such as the recent swarm that occurred through September–October 2020, around 20 km south of Malta (right figure). The improved detection and location capability in such cases provides new and important insights into the seismic behaviour of the intricate fault systems governing the tectonics of the Sicily Channel. The enhanced network leads to unprecedented possibilities to observe and monitor in more detail the numerous faults crossing the islands and continuing offshore. These faults have generally been presumed to be inactive; An increase in station density will make a significant difference in the detection and location of microearthquakes lying within the network or close to shore, considerably lowering the threshold of detectability.

FUNDING OF MSN

Funding for stations was provided by Interreg Italia-Malta projects (SIMIT and SIMIT-THARSY, Codes B1-2.19/11 and C1-3.2-57) and by Transport Malta.



▲ ***Location of earthquake epicentres using the MSN (orange triangles) and available arrivals from regional stations (black triangles) between July 2019–October 2020.*** *Magnitudes range between 2.5–4.5. Red star: Largest event of the earthquake swarm that took place during September and October 2020. Inset: Magnitude–time progression of the earthquake swarm. Red dots: MSN locations; black dots: INGV bulletin listings.*



▲ ***Noise spectra of 3 MSN stations represented as power spectral density probability density functions (summer vs winter).*** *a, c, e: Data for July 2018 (summer) b, d, f: Data for January 2018 (winter). Gray curves: Low-noise model (LNM), high-noise model (HNM) (Peterson, 1980). Blue/red curves: Maximum/minimum. Black curve: Highest probability mode.*

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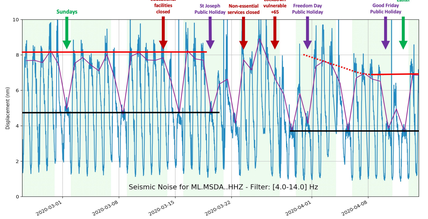
tm Transport Malta

Impact of COVID social restrictions on ambient seismic noise

Decrease in daily ambient seismic noise in Malta due to the COVID19 social restrictions.

The figure shows the level of background seismic noise recorded at the seismic station MSDA. The daily variation in noise level between night and day can be observed, and the sharp reductions in daytime noise are evident on Sundays and public holidays. These peaks dropped even further by about 20–25% when the public was urged to stay indoors.

Software provided by Thomas Lecocq (Lecocq, 2021).

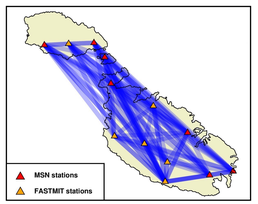


SIGMA

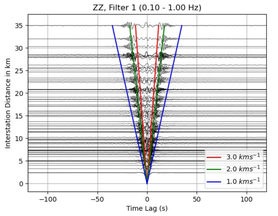
Seismic Imaging of Groundwater for Maltese Aquifers

THE ENERGY & WATER AGENCY
MINISTRY FOR ENERGY AND WATER MANAGEMENT

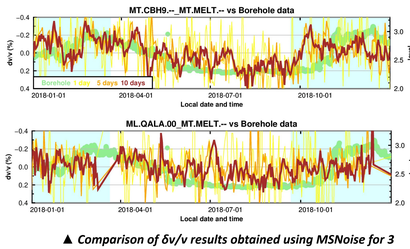
SIGMA is a geophysical and hydrological investigation on groundwater. Ambient seismic noise recorded on the Malta Seismic Network can provide information on the shallow seismic wave velocity structure beneath the network, which in turn is influenced by the water content and distribution. Changes in the water content, for example, the replenishing and depletion of aquifers due to seasonal effects or anthropogenic intervention, will result in changes in the velocity structure. This will be measured in an automated manner, complementing on-site, single-measurement borehole data. The combination of pairs of stations from the network provides an extensive coverage on a national scale.



▲ ***Coverage from pairs of seismic stations across Malta.*** *Red triangles: Stations from the permanent Malta Seismic Network. Orange triangles: Temporary network FASTMIT (2017-2018). Blue lines: Potential coverage.*



▲ ***Cross-correlation functions sorted by interstation distance.*** *Correlations are determined using MSNoise (Lecocq, 2014). Colour-coded lines: Reference travel times.*



▲ ***Comparison of δv/v results obtained using MSNoise for 3 different moving-window stacks.*** *Light blue background shade marks the Autumn-Winter season. Colour coded lines: Different moving window-stacks 1, 5 and 10 days. Large green dots: Borehole data.*

FUNDING OF SIGMA

Project SIGMA is financed by the Energy and Water Agency under the National Strategy for Research and Innovation in Energy and Water (2021-2030).