Early Detection of Earthquakes in Southeast Asia with IoT Big Data Seismology and Geodesy Synergy

Session 2:

ICT for Environment Protection and Disaster Prevention

Contents

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Requested Amount

- Year 1 (2021) = USD 40,000 (12-month)
- Year 2 (2022) = USD 39,000 (12-month)
- Total = **USD 79,000**

Proposed Duration and Starting Dates

- Proposed Duration: 24 months (2 years)
- Starting Date: July 2021
- End Date: Jun 2023

Project Summary

- Overview
- Intellectual Merit
- Broader Impacts

Overview

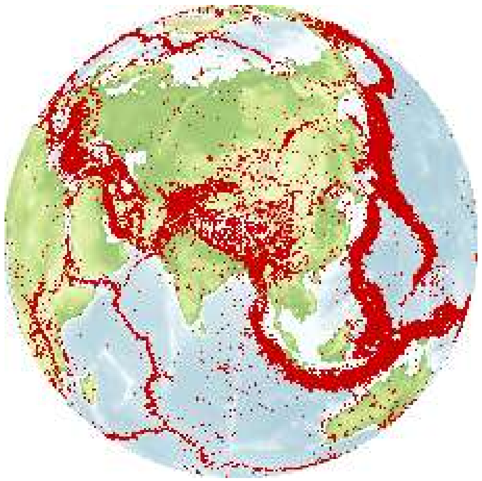


Figure 1: The Earth showing the distribution of earthquakes (dots) covering a period of ***50 years***. Most of the earthquakes clearly occur along the plate boundaries (Source: *BGR)*

- Philippines is one of the most earthquake prone countries in the world (Figure 1)
- Every year, bigger than > 6 magnitude of earthquakes are recorded in Philippines [1]
- They are many of smaller magnitude earthquakes that went under the radar (not detected or ignored)
- Recent research show that smaller earthquakes can be the pre-cursor of upcoming greater earthquakes [2]
- Advanced IoT of seismic sensor networks and big data signal processing can be performed to accurately predict and warn the population regarding on the bigger earthquakes based on the smaller events
- To validate the claims and to further improve accuracy the monitoring data will be cross referenced with geodesy monitoring data (ground truth) and other existing monitoring stations [3] [4]

Intellectual Merit

- IoT sensor networks data can provide more comprehensive representation of the earthquakes event that would be otherwise gone unnoticed by detecting seismic waves (underground) and infrasonic waves (overground)
- Big data time-frequency analysis can provide more robust and reliable earthquake detection due to the multi-component and non-stationary nature of the earthquake events especially for small earthquakes with noisy environments (as in towns)
- Comparison with geodesy data will provide reference or “ground truth” for the validation of the detected minor/smaller earthquakes event

Broader Impacts

- Accurate and timely early warning system can provide the population ample time to prepare and avoid casualty especially in heavily populated area
- Enable reliable and robust modelling of earthquakes in specific location/region/country (e.g. Philippines) for future planning and intervention in mitigating major catastrophe (e.g. tsunami) based on comprehensive characterization of earthquake events (small and big)
- Smaller and cheaper seismic sensor networks run by citizens and smaller organizations can complement big and expensive seismic sensors run by the government agencies [5]

Project Proposal Details

- Introduction
- Targets
- Methods
- Implementation and Proposed Locations
- Budget Explanation
- Facilities, Equipment and other Resources
- References

Introduction

- Philippines and East Malaysia locations in the region of “Ring of Fire” make it prone to earthquakes (see Figure 2)
- Earthquakes follow power-law relation, smaller events occur more often than larger
  - Every 174 seconds (495 earthquakes every day) the ground in Southern California trembles as Earth’s tectonic plates shudder past one another [2]
- Recently there are two discoveries being made regarding the nature of earthquakes that are relevant to their early detection.
  - Firstly, the big earthquake is normally preceded by several smaller earthquakes [2].
  - Secondly, earthquake occurrences have been found to be not a random event but correlated with solar activity [6]
- Early detection can help warn and predict of the big earthquakes events that can potentially disrupt people lives.
  - Help timely evacuation and pre-emptive action for reducing the casualty and loss of properties
- This project uses advanced IoT sensor networks and Big Data time-frequency analysis
  - IoT with sensors for detecting underground seismic waves and overground infrasound waves
  - Big data analysis with time-frequency essential for detecting smaller earthquakes [7]

Tectonic Setting of South East Asia

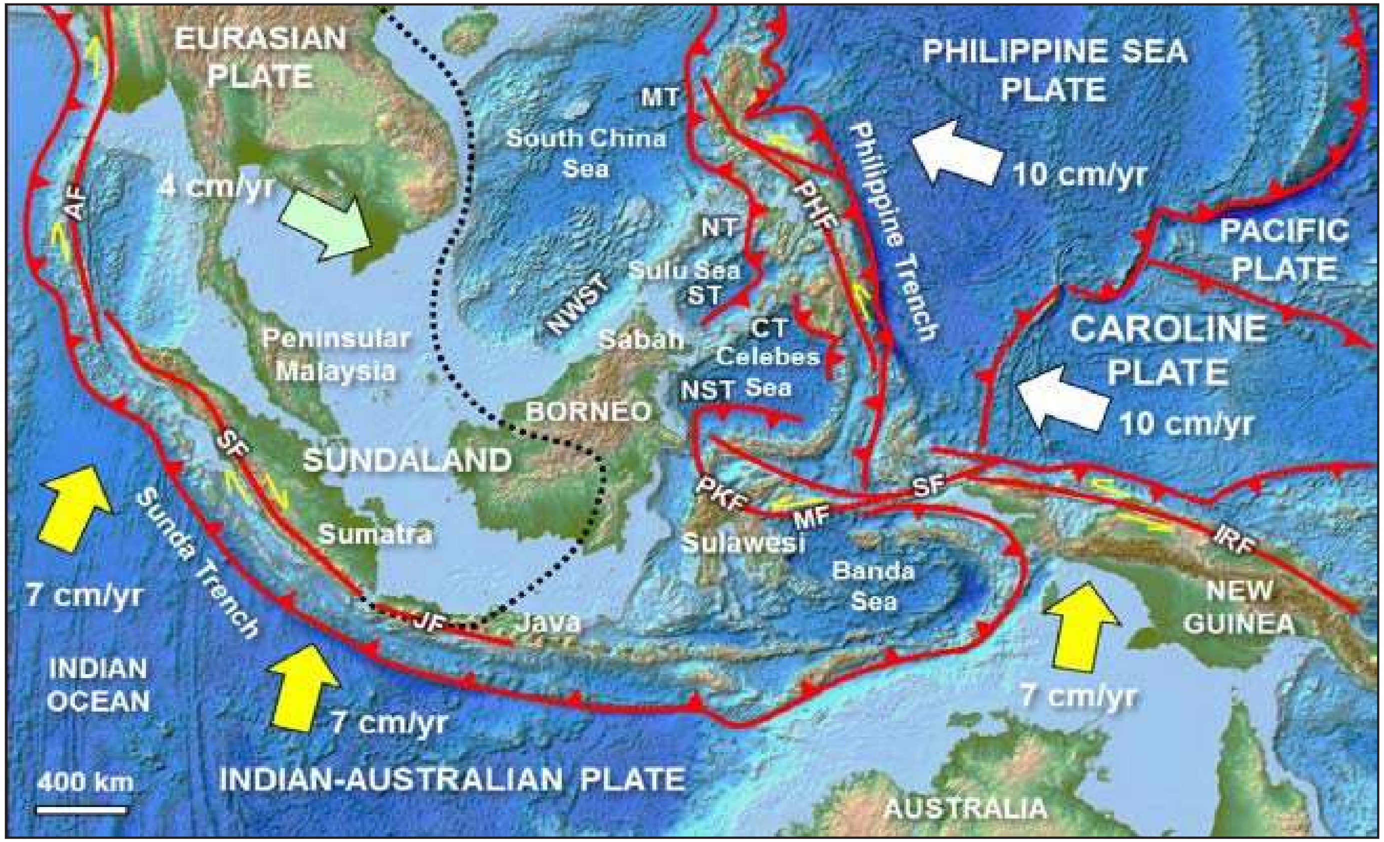
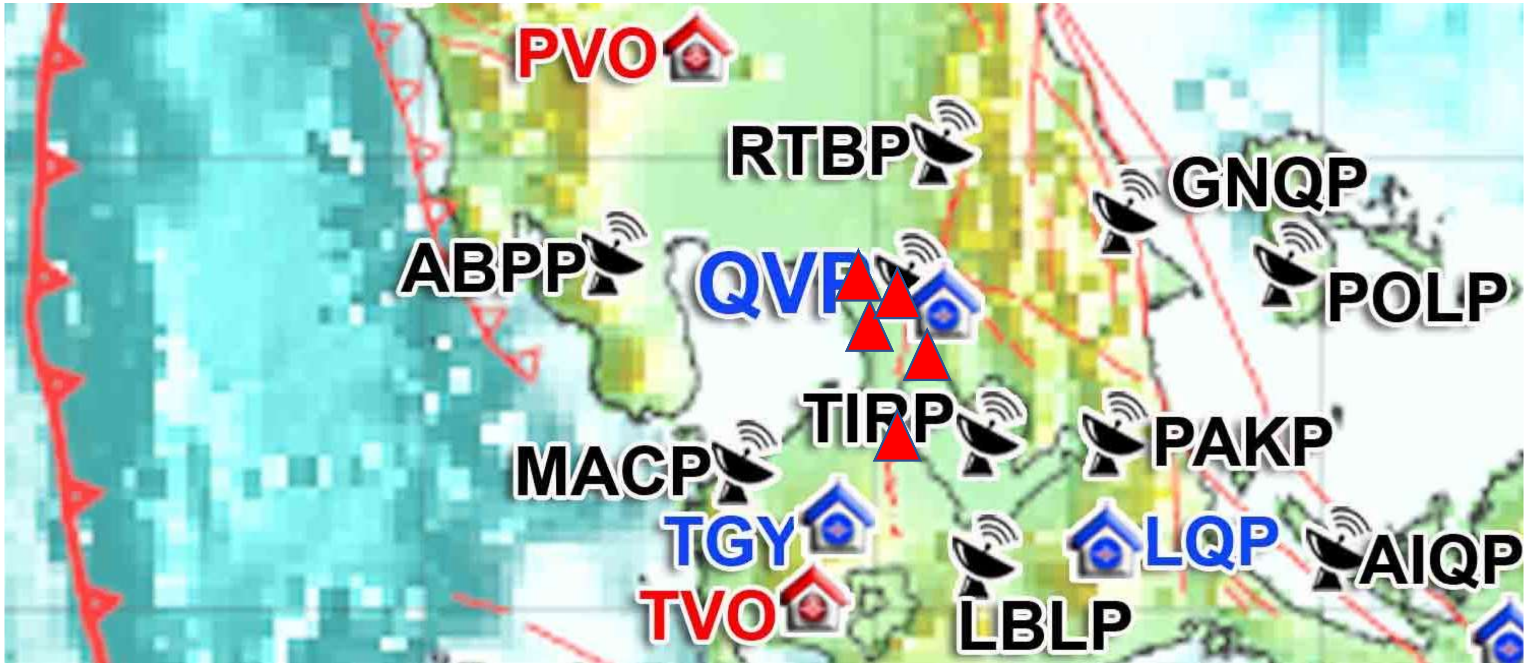


Figure 2: Tectonic setting of South East Asia showing major plate movements. The Philippine-Caroline-West Pacific Plate moving relatively faster towards the west. MT: Manila Trench, NT: Negros Trench, ST: Sulu Trench, CT: Cotabato Trench, NST: North Sulawesi Trench, NWST: NW Sabah Trough, PHF: Philippine Fault, PKF: Palu-Koro Fault, MF: Matano Fault, SF: Sorong Fault, IRF: Irian Fault, AF: Andaman Fault, SF: Sumatra Fault, JF: Java Fault [8].

Targets

- Three target clusters for early detection of earthquakes and monitoring
  - Metro Manila (Northern Philippines)
  - Davao City (Southern Philippines)
  - Sabah (East Malaysia)
    - Kota Kinabalu
    - Ranau

Targets
(Metro Manila, Northern Philippines)



Satellite telemetered monitoring seismic stations (unmanned)

Staff controlled seismic stations (manned)

Volcano observatory and stations

New sensors locations

Figure 3: Proposed sensors location in Metro Manila cluster together with existing seismic monitoring stations [10]

Targets
(Davao City, Southern Philippines)

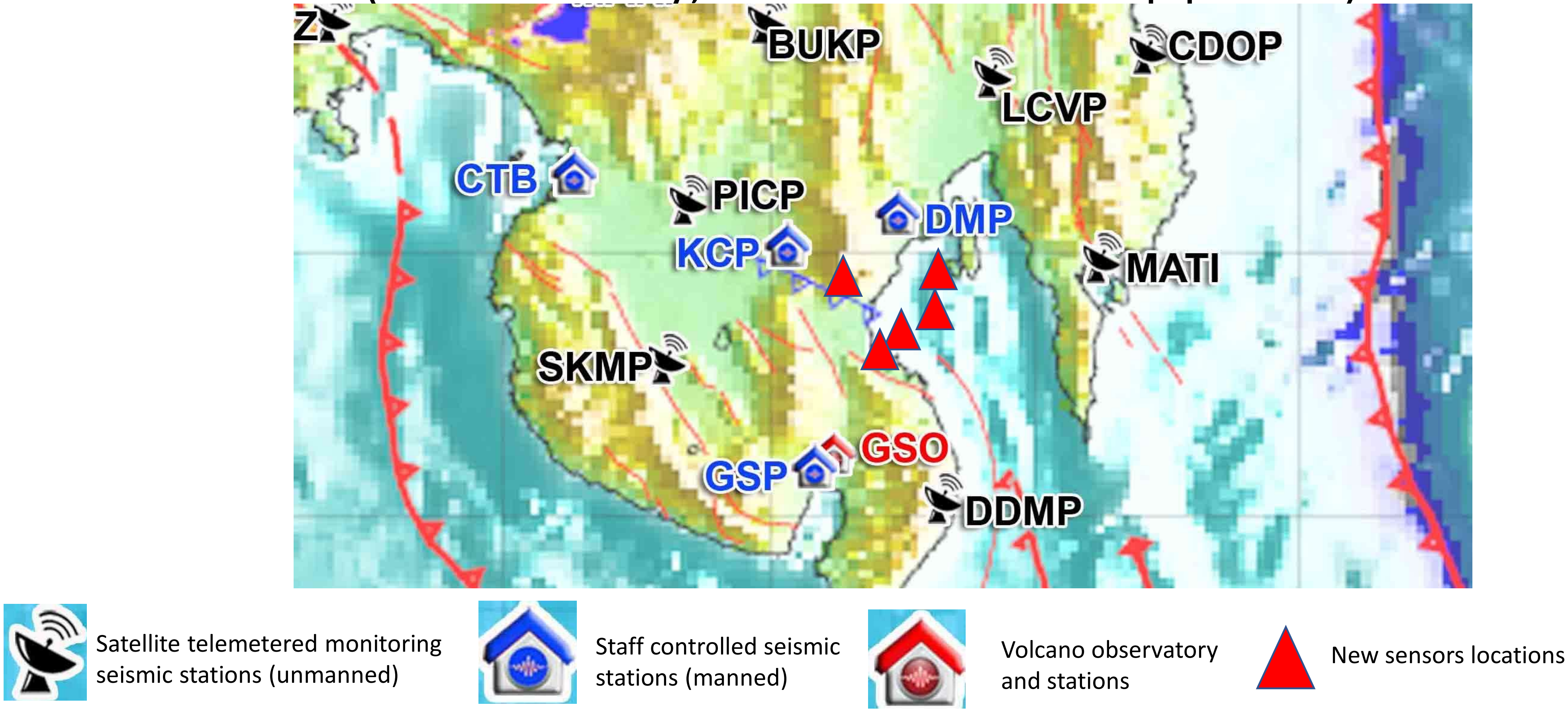


Figure 4: Proposed sensors location in Davao City cluster together with existing seismic monitoring stations [10]

Targets
(Sabah, East Malaysia)

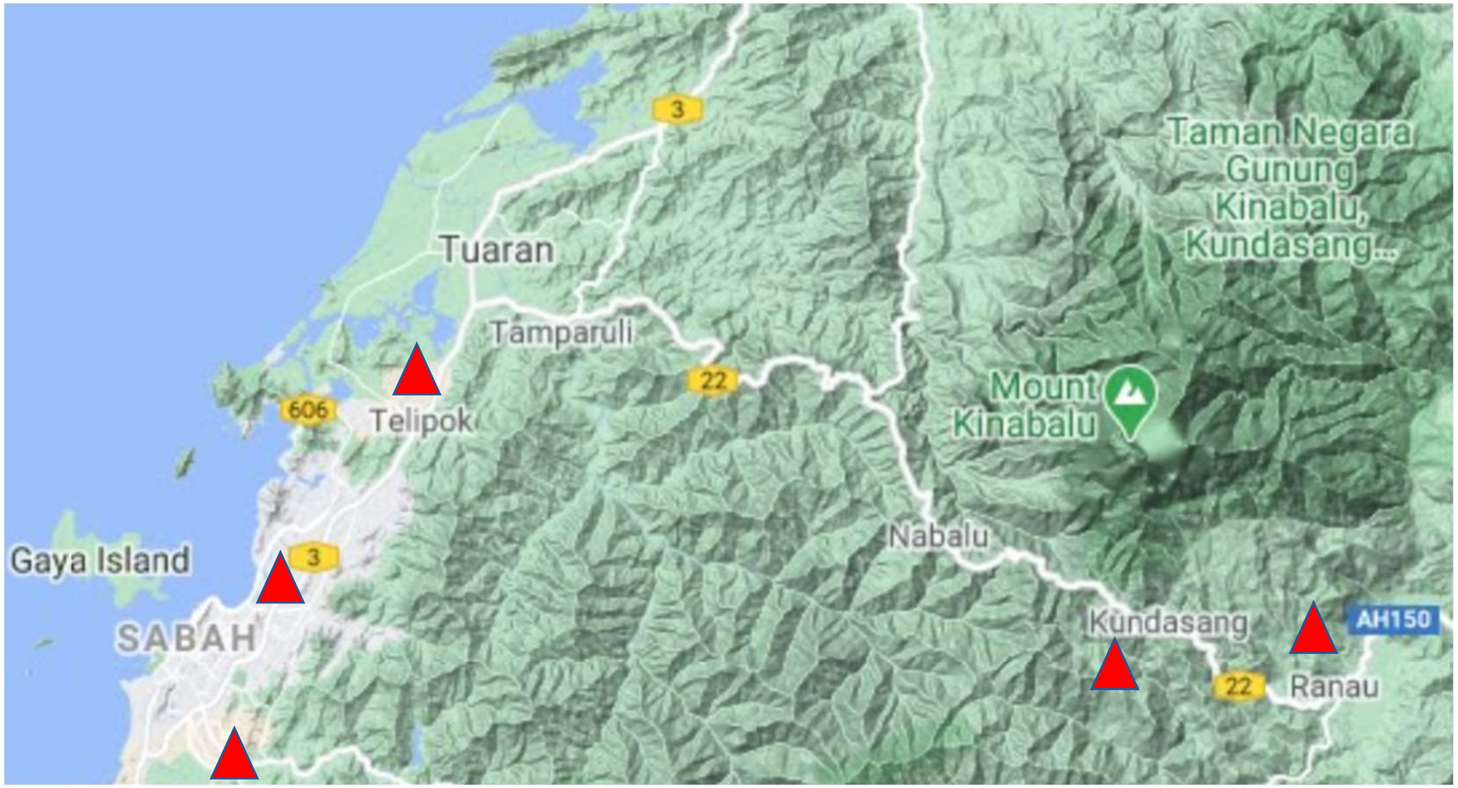
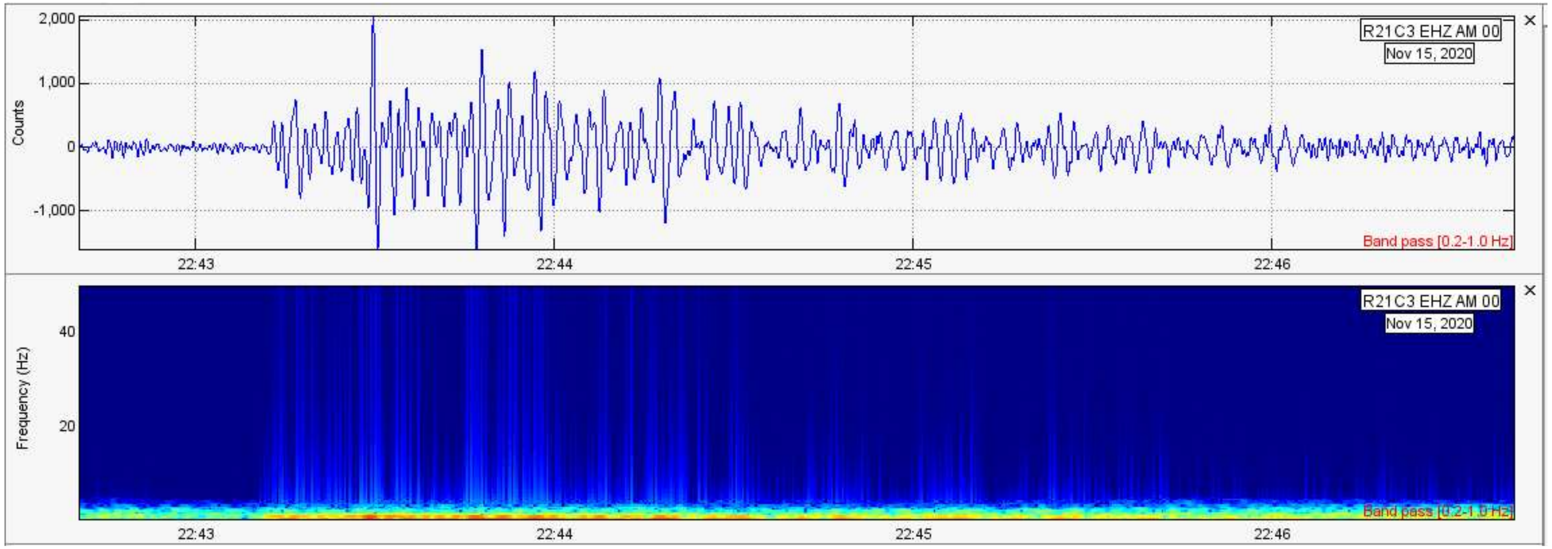


Figure 5: Proposed sensors location in Sabah cluster [11]

Methods

- At sensor layer all sensors are synchronized with Network Time Protocol (NTP) and GPS locations
  - Analog seismic and infrasonic waves are acquired by respective sensors and transform into digital signals
  - The digital data signals are send over network with to the NoSQL database
- The data processing layer provide data pre-processing, processing and analytics
  - The one dimensional (1-D) digital of signal of seismic and infrasonic waves are decomposed into two dimensional (2-D) time-frequency representation
  - Normalization process is performed on the time-frequency earthquake seismic and infrasonic signal
  - Linear time-frequency analysis is performed to denoise the signal in time-frequency domain [7]
  - Non-linear time-frequency analysis is used to calculate the energy concentration of the earthquake data for classification based on the thresholds [10]
- At application layer analysed data are presented to web server
  - Data is massaged and send to the experts, normal users and alert messages according to their respective format requirements based on their representation and graphics
- For system level architecture please refer to Figure 5

Methods



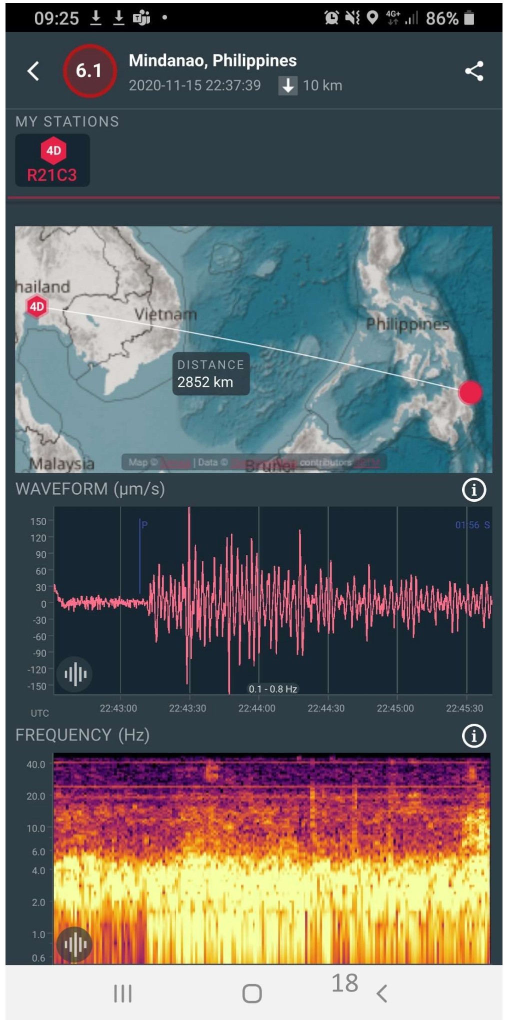


Figure 6: Seismic waves and the equivalent time-frequency representation for Mindanao Philippines earthquakes on 15th Nov 2020 taken by Raspberry Shake sensor, for more pictures check Appendix [12]

Time-frequency Seismic Data Denoising

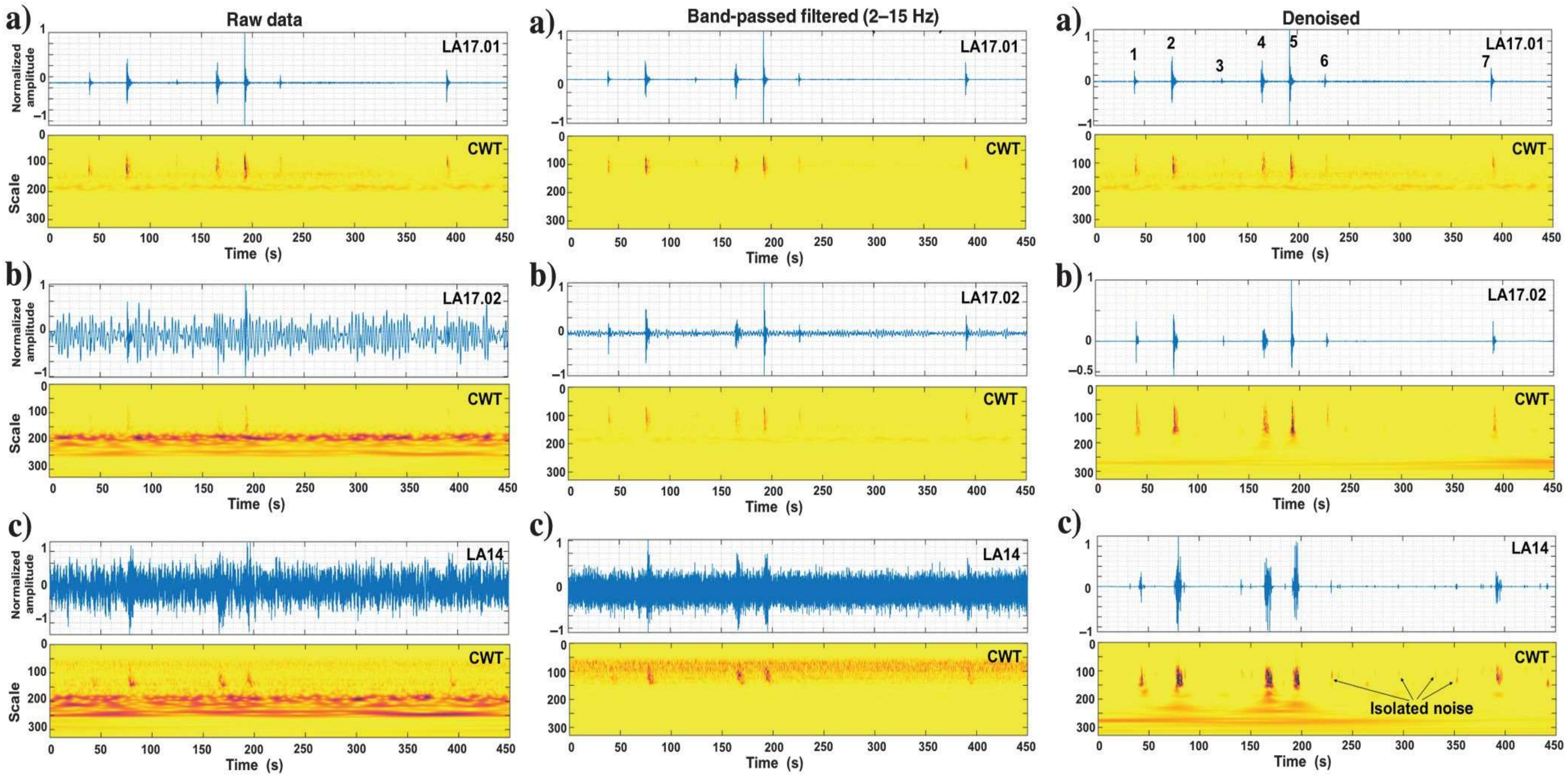


Figure 4: The 7.5 min long vertical seismograms passively recorded in 1 November 2013 at Bayou Corne, Louisiana, US
(a) 2 Hz geophone at the bottom of a borehole (approximately 287 m deep)
(b) Broadband sensor (Trillium-compact) the top of the same borehole (approximately 190 m deep)
(c) Broadband sensor (Trillium-compact) at the surface (1 km southeast of borehole) [7]

Implementation Proposal

- Front-end sensor with IoT capability
  - Two types of sensor for raw data acquisition and transmission
    - Seismic waves sensors (under ground activities)
    - Infrasonic waves sensors (above ground activities)
- Back-end processing with big data and time-frequency analysis
- User interfaces
  - Alert Messages
  - Normal user interface
  - Specialist or Metrologist
    - PHIVOLCS-DOST (Philippines)
    - myGEMPA (Malaysia)

Earthquake Early Detection System Architecture

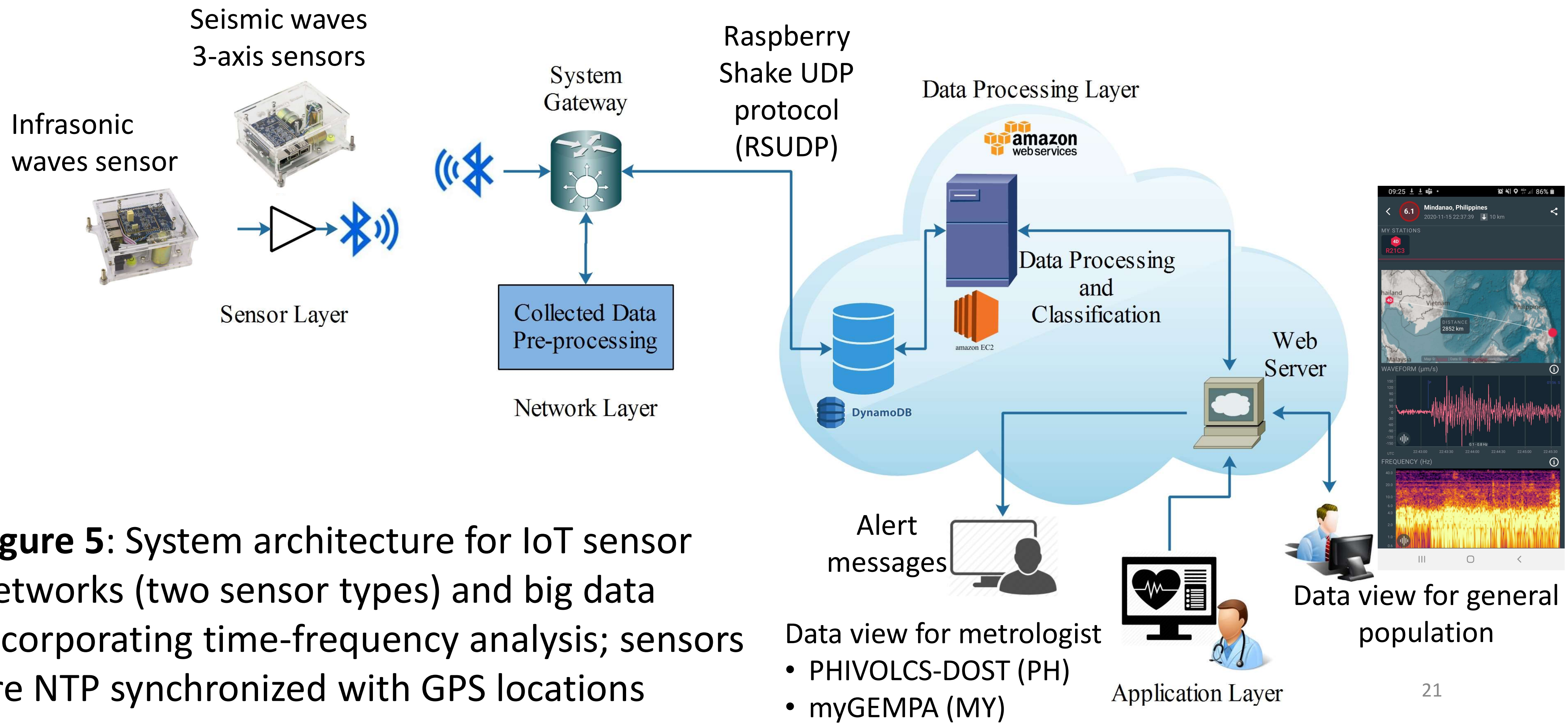


Figure 5: System architecture for IoT sensor networks (two sensor types) and big data incorporating time-frequency analysis; sensors are NTP synchronized with GPS locations

Seismic and Infrasonic Waves Sensors

Raspberry Shake 3D
3-axis Geophone
(North-South or N-S)
(East-West or E-W)
Z-components

Raspberry Shake and Boom
Infrasound sensor
Geophone – vertical

Raspberry Shake IP67 Enclosure
for water and dust protection

Do Low-Cost Seismographs Perform Well Enough for Your Network? [13]

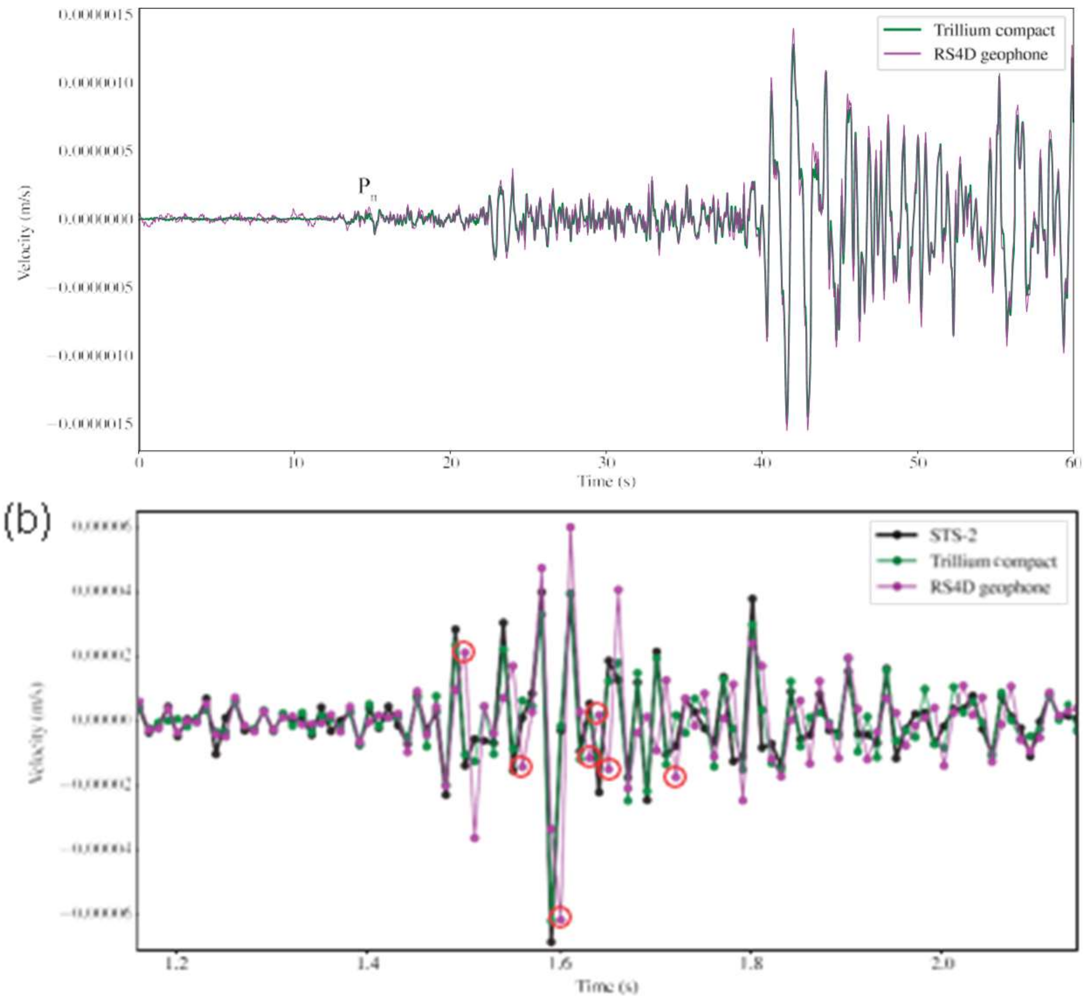


Figure 6: (a) The ***P-wave*** arrivals of a regional (7.4°) Mw 4.6 event in Oklahoma recorded at Albuquerque Seismological Laboratory (ASL) on a collocated OSOP RS-4D and Nanometrics Trillium Compact. The first phase arrival (Pn) is labeled for reference.

(b) The ***S-wave*** arrival of an MD 1.7 local event recorded on three collocated seismometers in the surface vault of ASL. The Streckeisen STS-2 and Trillium Compact were recording on a Q330 digitizer with timing accurate to $\ll$ 1 ms (Kromer, 2006). Red circles indicate samples from the RS-4D that appear to have a one sample (10 ms) lag compared to the other instruments.

IoT Sensor Networks Locations Proposal

- Three main clusters of sensor networks deployment
  - ***Metro Manila*** (Northern Philippines)
  - ***Davao City*** (Southern Philippines)
  - ***Sabah*** (East Malaysia)
    - Kota Kinabalu
    - Ranau
- Each cluster has five (5) sub-locations and overall fifteen (15) strategic sub-locations are proposed for installation and deployment of the sensor networks
- Each location has two type of sensors (2 units) for comprehensive earthquakes data acquisition and monitoring with overall thirty (30) units of sensors
  - seismic waves sensor (raspberry shake 3D) – 15 units
  - Infrasonic waves sensor (raspberry shake & boom) – 15 units

Metro Manila, Philippines (10 units sensor nodes)

Institution Name	Location	Seismic Sensor RS3D	Seismic Sensor Shake & Boom
De La Salle University Manila	Malate, Metro Manila	1 unit	1 unit
Manila Science High School	Ermita, Metro Manila	1 unit	1 unit
Muntinlupa National High School	Muntinlupa, Metro Manila	1 unit	1 unit
Taguig Science High School	Taguig, Metro Manila	1 unit	1 unit
Florentino Torres High School	Tondo, Metro Manila	1 unit	1 unit

Table 1: Sensor nodes placement for Metro Manila cluster (10 units)

Davao City, Philippines
(10 units sensor nodes)

Institution Name	Location	Seismic Sensor RS3D	Seismic Sensor Shake & Boom
De La Salle University Davao	Talomo, Davao City	1 unit	1 unit
Davao Central High School	Poblacion District, Davao City	1 unit	1 unit
Francisco Bangoy National High School	Buhangin, Davao City	1 unit	1 unit
Crossing Bayabas National High School	Toril, Davao City	1 unit	1 unit
Calinan National High School	Calinan, Davao City	1 unit	1 unit

Table 2: Sensor nodes units placement for Davao City cluster (10 units)

Kota Kinabalu and Ranau (10 units sensor nodes)

Institution Name	Location	Seismic Sensor RS3D	Seismic Sensor Shake & Boom
Polytechnic Kota Kinabalu	Telipok, Kota Kinabalu	1 unit	1 unit
Tebobon Secondary School	Inanam, Kota Kinabalu	1 unit	1 unit
Bahang National Secondary School	Penampang, Kota Kinabalu	1 unit	1 unit
Kundasang Secondary School	Kundasang, Ranau	1 unit	1 unit
Lohan Secondary School	Lohan, Ranau	1 unit	1 unit

Table 3: Sensor nodes placement for Sabah cluster (10 units)

Budget Details
(2 years project)

Items	Description	Quantity	Unit Cost (USD)	Total Cost (USD)
Seismic sensor (RS3D)	Raspberry Shake with Geophone 3 -axis	15	USD 1,300	19,500
Seismic sensor (RS Shake & Boom)	Raspberry Shake with Infrasound sensor Geophone – vertical	15	USD 900	13,500
Data plan (4G)	Internet data connection	15 data modems	USD 25 per month per node (for 2 years)	9000
Workshops (3 times)	Travel, accommodation and seminar rooms	Kota Kinabalu, MY Metro Manila, PH Davao City, PH	USD 8000 for 20 pax (3 times)	24,000
Engineering works	System engineering services	3 months	USD 3,000 per month	9,000
Cloud services	Server hosting and bandwidth connection	2 years	USD 4,000 per year	4,000
Overall Cost				**79,000**

Table 4: Project Budget Details

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[2] Zachary E. Ross et. al, Pervasive Foreshock Activity Across Southern California, Geophysical Research Letters, 2019

[3] Giuliano Francesco Panza, et. al, How Geodesy Can Contribute to The Understanding And Prediction Of Earthquakes, 2017

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[7] S. Mostafa Mousavi and Charles A. Langston, Automatic noise-removal/signal-removal based on general cross-validation thresholding in synchrosqueezed domain and its application on earthquake data

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[9] Ahmed Faeq Hussein, ***Shaiful Jahari Hashim****, Ahmad Fazli Abdul Aziz, Fakhrul Zaman Rokhani and Wan Azizun Wan Adnan, Performance Evaluation of Time-Frequency Distributions for ECG Signal Analysis, 2018

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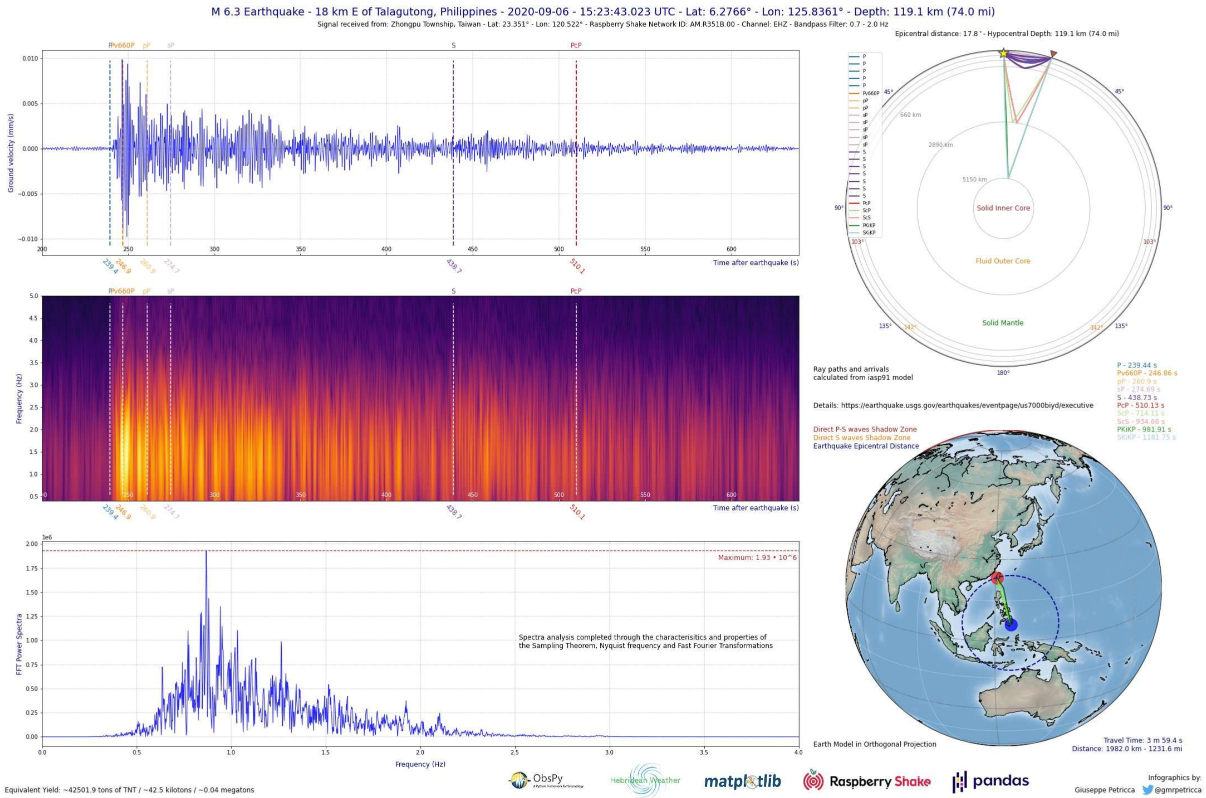
[13] Robert E. Anthony, Adam T. Ringler, David C. Wilson, and Emily Wolin, Do Low-Cost Seismographs Perform Well Enough for Your Network? An Overview of Laboratory Tests and Field Observations of the OSOP Raspberry Shake 4D, (US Geological Survey - USGS)

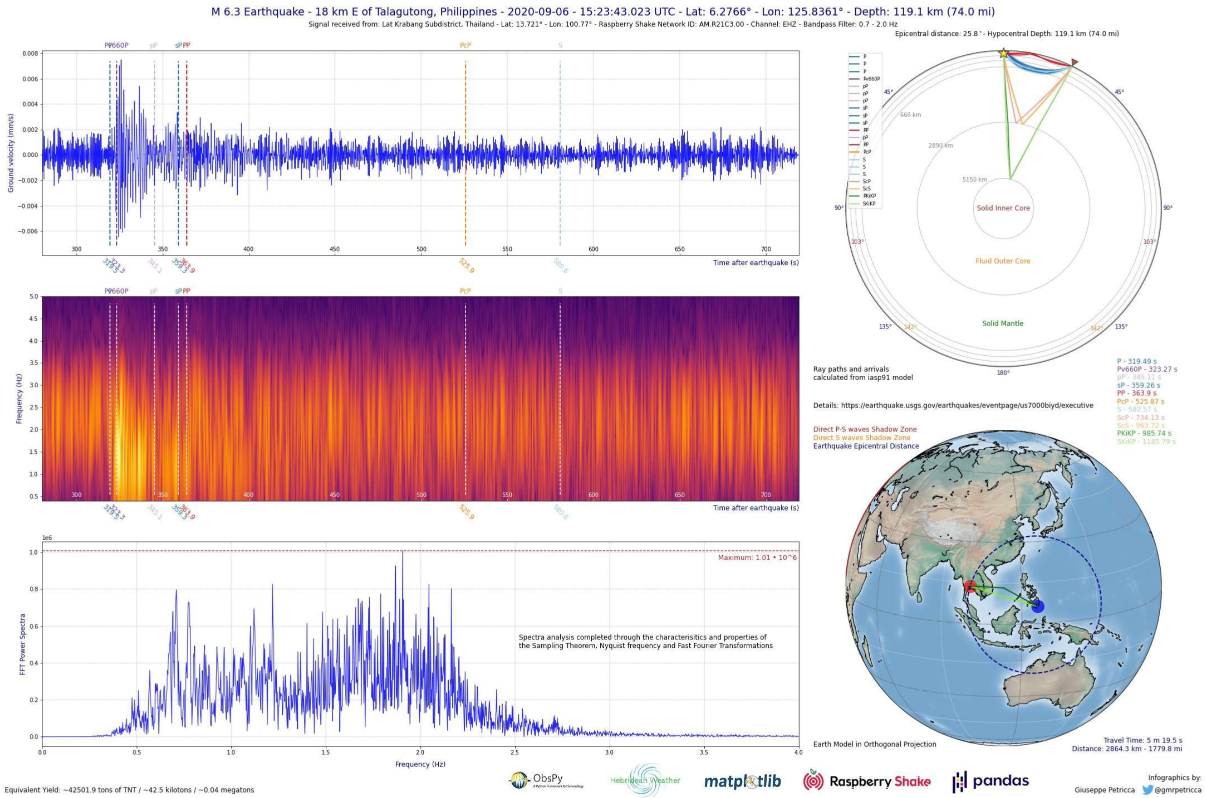
[14] Giuseppe Petricca @gmrpetricca, Twitter, Philippines earthquake detected by various RaspberryShake seismometer units all over the world

Appendix

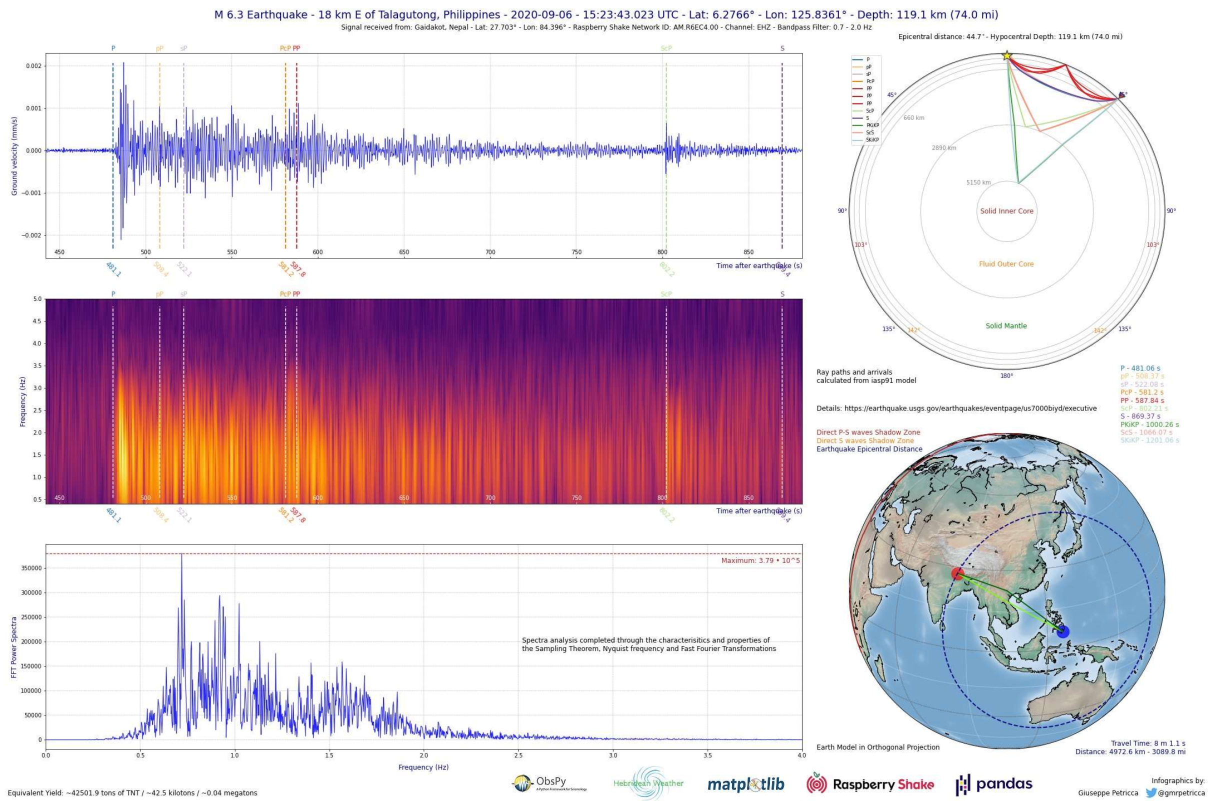
Philippines earthquake detected by various RaspberryShake seismometer units all from Taiwan [14]



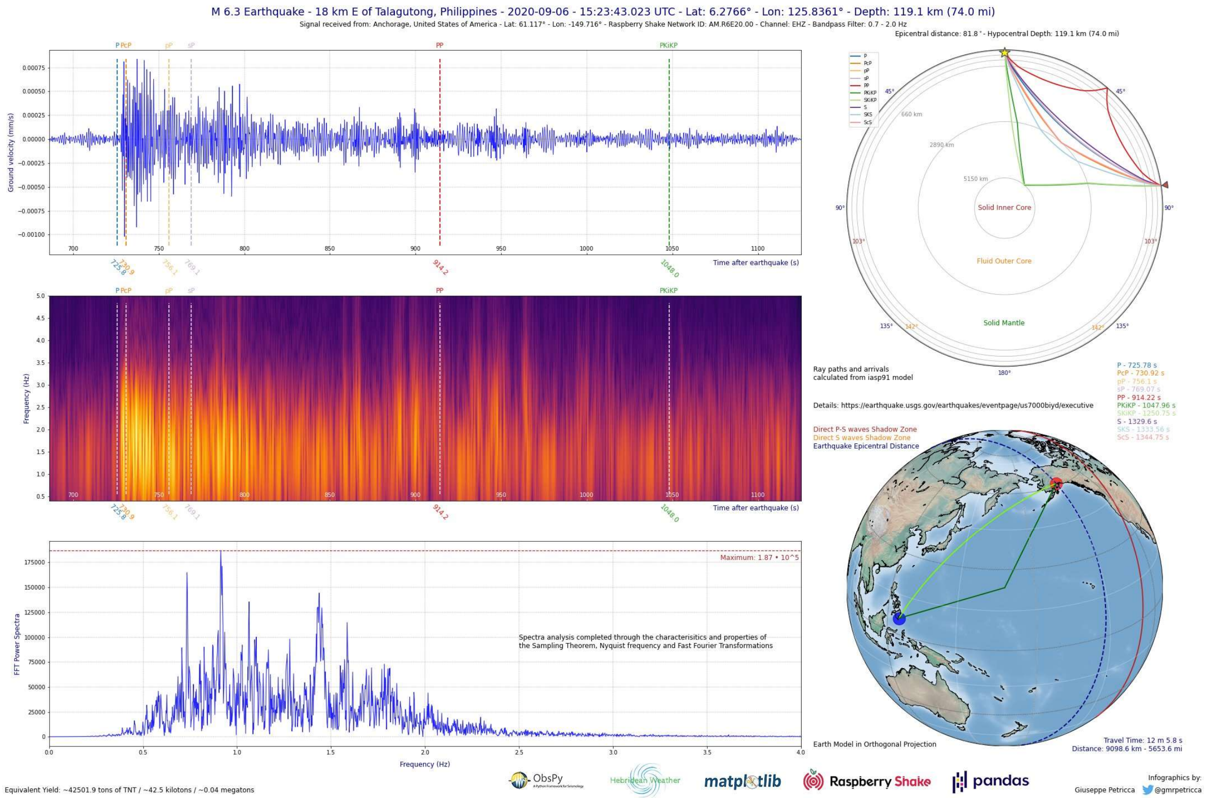
Philippines earthquake detected by various RaspberryShake seismometer units all from Thailand [14]



Philippines earthquake detected by various RaspberryShake seismometer units all from Nepal [14]



Philippines earthquake detected by various RaspberryShake seismometer units all from US [14]



Time-Frequency Distributions (Bi-linear) [9]

For bilinear-TFDs, Cohen, generalized most of the TFDs into a single class, with a kernel function being the only distinction between each distribution, this called quadratic

$$W_z^Q(t,f) \;=\; \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} z(u+\frac{\tau}{2})z^*(u-\frac{\tau}{2})\phi(\nu,\tau)e^{i2\pi(\nu t-f\tau-\nu u)}dud\tau d\nu$$

Where

$z(\;)$	time signal to be analyzed
$z^*(\;)$	Complex conjugate
$t\,,\,f$	time , frequency
ν,τ	frequency lag , time lag
$\phi(\nu,\tau)$	kernel defining a particular distribution

$\phi(\nu,\tau)=1$ Wigner-Ville

$\phi(\nu,\tau)=e^{-\frac{\nu^2\tau^2}{\sigma}}$ Choi-Williams

$\phi(\nu,\tau)=\mathrm{sinc}(a\nu\tau)=\frac{\sin(\pi a\nu\tau)}{\pi a\nu\tau}$ Born-Jordan

$\phi(\nu,\tau)=\frac{J_1(2\pi a\nu\tau)}{\pi a\nu\tau}$ Bessel

RSUDP:

Tool for receiving and interacting with data casts from Raspberry Shake personal seismographs and Raspberry Boom pressure transducer instruments.

Features	Description
Alarm	An earthquake/sudden motion alert trigger, complete with a bandpass filter and stream deconvolution capabilities
AlertSound	A thread that plays a MP3 audio file in the event of an alarm
Plot	A live-plotting routine to display data as it arrives on the port, with an option to save plots some time after an alarm
Tweeter	A thread that broadcasts a Twitter message when the alarm module is triggered, and optionally can tweet saved plots from the plot module
Telegrammer	A thread similar to the Tweeter module that sends a Telegram message when an alarm is triggered, which can also broadcast saved images
Writer	A simple miniSEED writer
Forward	Forward a data cast to another IP/port destination
RSAM	Computes RSAM (Real-time Seismic AMplitude) and either prints or forwards it to an IP/port destination
Custom	Run custom code when an ALARM message is received
Print	A debugging tool to output raw data to the command line

Data sheet of geophone 4.5Hz (Typical)

Type	EG-4.5-II
Natural Frequency (Hz)	4.5±10%
Coil resistance(Ω)	375±5%
Damping	0.6±5%
Open circuit intrinsic voltage sensitivity (v/m/s)	28.8 v/m/s ±5%
Harmonic distortion (%)	≦0.2%
Typical Spurious Frequency (Hz)	≧150Hz
Moving Mass (g)	11.3g
Typical case to coil motion p-p (mm)	4mm
Allowable Tilt	≦20º
Operating Temperature Range (℃)	-40℃ TO +100℃
Height (mm)	36mm
Diameter (mm)	25.4mm
Weight (g)	86g
Warranty Period	3years