Making seismology accessible to the public in Nepal: an earthquake location tutorial for education purposes

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ABSTRACT

Earthquakes become a hot topic for discussion in Nepali communities when a big local event happens. Beyond the seismic monitoring and research, efforts to improve the population's preparedness or to reduce earthquake related risks are limited, and there is a gap between scientific community and society. To establish the missing link between seismology and citizens we have initiated an educational approach called Seismology at School in Nepal and a total of 30 low-cost seismometers have been installed in schools. The program is engaging the public on earthquake related activities and found to be effective in raising the awareness levels of children, promoting broader earthquake learning in the community, thus improving the adaptive capacities and preparedness for future earthquakes. The aim of this work is to present a simple tutorial of earthquake location mainly for Nepali citizens and school teachers. We describe procedures for computing an earthquake epicenter using an open and user-friendly software, Seisgram2K. This tutorial helps the public to have first-order information on earthquakes, by allowing to locate epicenters, which will increase the frequency of earthquake discussion in the community. Open seismic data and the earthquake location tutorial helps to inspire the next generation to study Earth sciences, which is very important and required for earthquake prone countries, like Nepal.

Keywords: Citizen seismology; Earthquake location; Seisgram2K; Nepal; Education

INTRODUCTION

Nepal lies on the convergent plate boundary between the Indian and Eurasian plates. The plate collision created the Himalayan mountain range which extends over a distance of ca. 2,500 km between its two syntaxes, Nanga Parbat in the West and Namche Barwa in the East. Below surface this is the most seismically active zone on any continental plate (e.g., Bilham et al., 1997; Lavé and Avouac, 2001; Zheng et al., 2017). The region has experienced major devastating earthquakes throughout its human and geological history and claimed thousands of lives and caused significant damage. The most damaging natural disaster to hit Nepal since 1934 was the 2015 Gorkha earthquake, which killed nearly 9,000 people and injured approximately 22,000 others (MoHA, 2017), although these numbers are well below those of likely scenarios expected from seismic hazard analysis.

Earthquakes become a hot topic for discussion in Nepali newspaper and media when a big event happens in Nepal. A governmental institution established for seismic monitoring in Nepal is the National Earthquake Monitoring and Research Centre (NEMRC, previously called National Seismological Centre NSC), under Department of Mines and Geology (DMG), Ministry of Industry, Commerce and Supplies, located in Kathmandu. The NEMRC is responsible for seismic monitoring in Nepal and publishes a catalogue of ML ≥ 4 events that have occurred within and around the country. NEMRC/DMG uses not only the local earthquakes but also some regional and teleseismic earthquakes and prepares catalogue for research purposes. In addition, NEMRC/DMG shares location data regularly with international institutes such as the International Seismological Centre (ISC), the United States Geological Survey (USGS), and the European-Mediterranean Seismological Centre (EMSC), and the ISC uses phase arrival picks from NEMRC to locate the events that occurred in and around Nepal. Similarly, selected earthquake records are made available to the responsible institutes in Nepal for the purpose of establishing and improving building codes. At the same time, NEMRC/DMG data have been used for geophysical studies (e.g., Adhikari et al., 2015) and shared within some institutions who helped for the network installation; however, these data are not easily available to the public.

The National Society for Earthquake Technology (NSET) works in the field of earthquake risk mitigation in collaboration with different international organizations and has been operating for over twenty years in Nepal. The seismic safety improvement project for public schools, seismic disaster risk management initiatives, and retrofitting of buildings affected by the Gorkha earthquake are some major contributions to the community by NSET. However, NSET's activities are typically focused on Kathmandu or in a particular district in the interseismic period and they do not operate any seismic stations.

The Himalayas have been at the forefront of geophysical studies for a long time and several temporary seismic experiments were deployed in Nepal in the past two decades with denser station coverage but these studies were performed mainly by foreign scientists. Three main experiments are: (1) the Himalayan Nepal Tibet Seismic Experiment (HIMNT) experiment (Schulte-Pelkum et al., 2005) in East Nepal and southern Tibet, (2) the Lithospheric Scale Dynamics of Active Mountain Building along the Himalayan-Tibetan Collision Zone (Hi-CLIMB) experiment along an 800-km long profile across Central Nepal and central Tibet (Hetényi et al., 2007; Nábelek et al., 2009), both of which succeeded to image the subsurface in the corresponding area as well as local seismicity; (3) the Himalaya Karnali Network (HiK-NET) experiment was performed to study the seismicity in Western Nepal (Hoste-Colomer et al., 2018) and the structure of the crust has also been studied using the same data (Subedi et al., 2018).

Geophysically imaging the structure of the orogen including the geometry of the Main Himalayan Thrust (MHT) at depth is very important to establish quantitative models of seismic hazard (e.g., Stevens et al., 2018). Locating the seismicity during the inter- and the post-seismic periods (e.g., Bollinger et al., 2007; Adhikari et al., 2015; Diehl et al., 2017; Hoste-Colomer et al., 2018) is equally essential to understand the mechanical behavior and dynamics of the orogenic wedge. Other than above mentioned studies, numerous important findings in the geoscience domain are documented (e.g., Dal Zilio et al., 2021). Nevertheless, state-of-the-art geoscience knowledge reaches only a tiny fraction of the local population. Also, the local population has almost no information about these recent findings.

Beyond research and earthquake monitoring, efforts to improve the population's preparedness or to reduce earthquake related risks are limited. The main problem is that earthquakes and related topics are not taught in high school; therefore, the population lacks reliable information about the earthquake process and what practical steps to follow. It is a desperate situation to have insufficient earthquake information in the official curriculum in such a highly earthquake prone country. Therefore, the majority of the population has either a religious perception or no clear idea about what causes earthquakes and what is the best behavior and practice to protect themselves. However, the majority of these religious beliefs about earthquakes and their causes do not fit the modern seismological picture (Subedi and Hetényi, 2021). In addition, earthquake communication strategies in case of a big earthquake are not well established in the community. For example, in the 2015 Gorkha earthquake, loss of life was noted when children ran into buildings from outside during the shaking, to hide under the bed, due to misunderstanding of the earthquake risk (Parajuli, 2020).

To establish the missing link between seismology and citizens we have initiated an educational approach: Seismology at School in Nepal. The program established an educational network with the close involvement of 30 schools, each hosting a low-cost seismometer (RaspberryShake type) which created the Nepal School Seismology Network. Seismometers installed in each school are recording local, regional, and distant earthquakes and the project is also supporting both teaching and awareness objectives (Subedi et al., 2020a). In parallel, we have been involved in different educational activities at each school by teaching earthquake related topics in classrooms and offering training to teachers. It is found that educational activities implemented in schools effectively raise the awareness levels of children, promoting broader social learning in the community, thus improving the adaptive capacities and preparedness for future earthquakes (Subedi et al., 2020b).

As the next step, we think it is beneficial to engage the public in earthquake related activities. Therefore, we not only make seismic data recorded by NSSN stations freely available to everyone, but also guide teachers and anyone else to use this data for different purposes, including locating local earthquakes. By making seismic data and the present tutorial on earthquake location accessible to the public, we hope to inspire the next generation to study Earth sciences, which is very important and required for earthquake prone countries, like Nepal.

CITIZEN SEISMOLOGY FOR EARTHQUAKE RISK REDUCTION

Earthquake risk reduction strategies aim to anticipate and reduce the casualties, damage, and economic loss caused by earthquakes. The involvement of people from outside professional organizations in the gathering or analysis of seismic data, so-called Citizen Seismology, has now become popular and is part of an important trend in the scientific community for various purposes. Citizen seismology is a good candidate for earthquake risk reduction and it holds huge promise in advancing scientific knowledge within the communities. Citizen seismology can raise earthquake awareness, to provide early warning of earthquakes, to collect citizen responses for a given earthquake for emergency responses, improve earthquake detection capacity, reduce anxiety by offering timely information and services to eyewitnesses, and to contribute to seismic risk reduction (Bossu et al., 2011; Bossu et al., 2018). The idea of citizen seismology has been tested and validated in Nepal for people affected by the Gorkha earthquake sequences in 2015 using the LastQuake smartphone application (Bossu et al., 2015). From 2016, a low-cost solution, Raspberry Shake seismometers are available for non-scientists, and the sensor is making citizen seismology relatively easily accessible and feasible. This is a plug-and-play solution and is already adapted to engage citizens in seismology and to reduce seismic risk by increasing earthquake awareness in many countries, for example, United Kingdom (Denton et al., 2018), Haiti (Calais et al., 2020), Spain (Diaz et al., 2020), the Arctic region (Jeddi et al., 2020). Recently, citizens from around the world collected their Raspberry Shake data along with professional seismometers to evaluate the environmental noise reduction by the COVID-19 lockdown (Lecocq et al., 2020).

CURRENT PUBLIC ENGAGEMENT

Citizens are hardly engaged on earthquake related activities in Nepal at all. Earthquakes become a hot topic for discussion in Nepali newspaper and media when a big event happens in Nepal, as in 2015. The government of Nepal has declared a National Earthquake Safety Day, on the day of the 1934 earthquake. Each year for over 20 years, on the second day of Nepali month Magh (January 15 or 16), National Earthquake Safety Day is commemorated in the country to lay emphasis on disaster preparedness and readiness. The safety day is specially celebrated in the Kathmandu valley by organizing seminars, rallies and awareness gatherings. These activities are mainly organized by governmental authorities in co-operation with (inter)national organizations where the public is encouraged to participate. Earthquake related news can be seen in newspapers and media once there is a local earthquake of ML≥ 4.0 announced by NEMRC. Engaging in discussions about earthquakes and participating in earthquake related activities is very unlikely for students in high school and universities. Motivated students can attempt to get involved individually but this is not an effective solution for engaging citizens on earthquake science.

LOCATING AN EARTHQUAKE BY THE PUBLIC TO ENGAGE CITIZEN IN SEISMOLOGY

In most cases, citizens are interested to find out the epicenter and magnitude of the earthquake. Seismic sensors measure ground velocity or acceleration depending on what types of sensors are being used. It is only possible to locate the epicenter of an earthquake using seismic records recorded by several sensors. An earthquake location provides information about the locality of potential damage (Lomax et al., 2009).

Locating an earthquake by non-scientist could play a role to engage citizens in seismology. It will increase people's earthquake understanding level and help to make seismology more familiar in the community. Earthquake location is a major step in most of seismological studies and it gives the information about the origin time, location, magnitude, and depth of the earthquake. In modern seismology, a seismic monitoring center uses high quality three component seismometers and sophisticated computer algorithms for earthquake location which give highly accurate locations. This work presents a simple and easy to use tool to the public to determine their own simple earthquake location solution. The tutorial we describe here will give only the epicenter (latitude and longitude) of an earthquake with an uncertainty (picking, velocities, depth) that is reasonable for educational purposes. The location of an earthquake is the information people typically ask after an earthquake is felt in Nepal.

TUTORIAL FOR EARTHQUAKE LOCATION USING NEPAL SCHOOL SEISMOLOGY NETWORK DATA

Terminology

Hypocenter: The location of an earthquake expressed in latitude, longitude and depth.

Epicenter: The location of the earthquake hypocenter projected to the surface of the Earth (latitude, longitude only, no depth information).

Magnitude: It is the quantity measuring the size of an earthquake in terms of the energy released. It is a single number for each earthquake. There are a number of different ways to calculate the magnitude of an earthquake, including the Richter scale.

Intensity: The level of shaking and damage at a given place of observation. In general, the farther this place is from the earthquake location, the lower is the Intensity.

Seismic waves: Seismic waves are generated due to the release of energy at the earthquakes' hypocenter and move in all directions traveling through the body of the Earth (body waves). There are two types of body waves. Primary waves (P-waves) are faster and the first to arrive. P-waves are longitudinal waves: particle motion is along the direction of propagation of the wave. Secondary waves (S-waves) are transverse waves: particle motion is perpendicular to the direction of propagation of the wave. S-waves arrive after P-waves. The body waves interact with the surface rock layers of the Earth and generate a new set of waves called surface waves. These waves move along the surface of the Earth. These waves are low-frequency waves and can be seen last on the seismograph, after P and S waves.

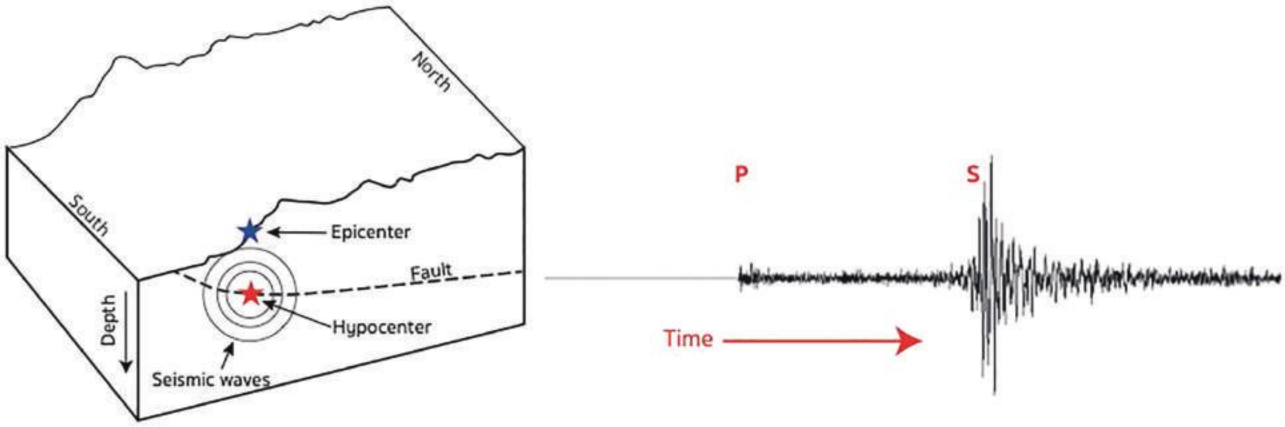

Fig. 1: Pictorial representation of some basic terminology used here. Schematic illustration of earthquake's epicenter and hypocenter (Left). Example of earthquake recorded with P and S body waves clearly seen (Right).

Educational seismic network in Nepal

The Nepal School Seismology Network (NSSN) covers mostly the Gandaki and Lumbini provinces of Nepal. As of March 2021, a total of 30 stations have been installed in different schools across Central Nepal (Fig. 2). Table 1 shows the detailed information of NSSN stations including school's name hosting a given sensor (1st column), school address (2nd column), identification number of the sensor (3rd column), geographical location of the sensor (4th, 5th and 6th columns). The seventh column refers available channels at this station (used to retrieve data) and the gain, conversion factor between digital records and ground motion is presented in 8th column (not needed to locate earthquakes).

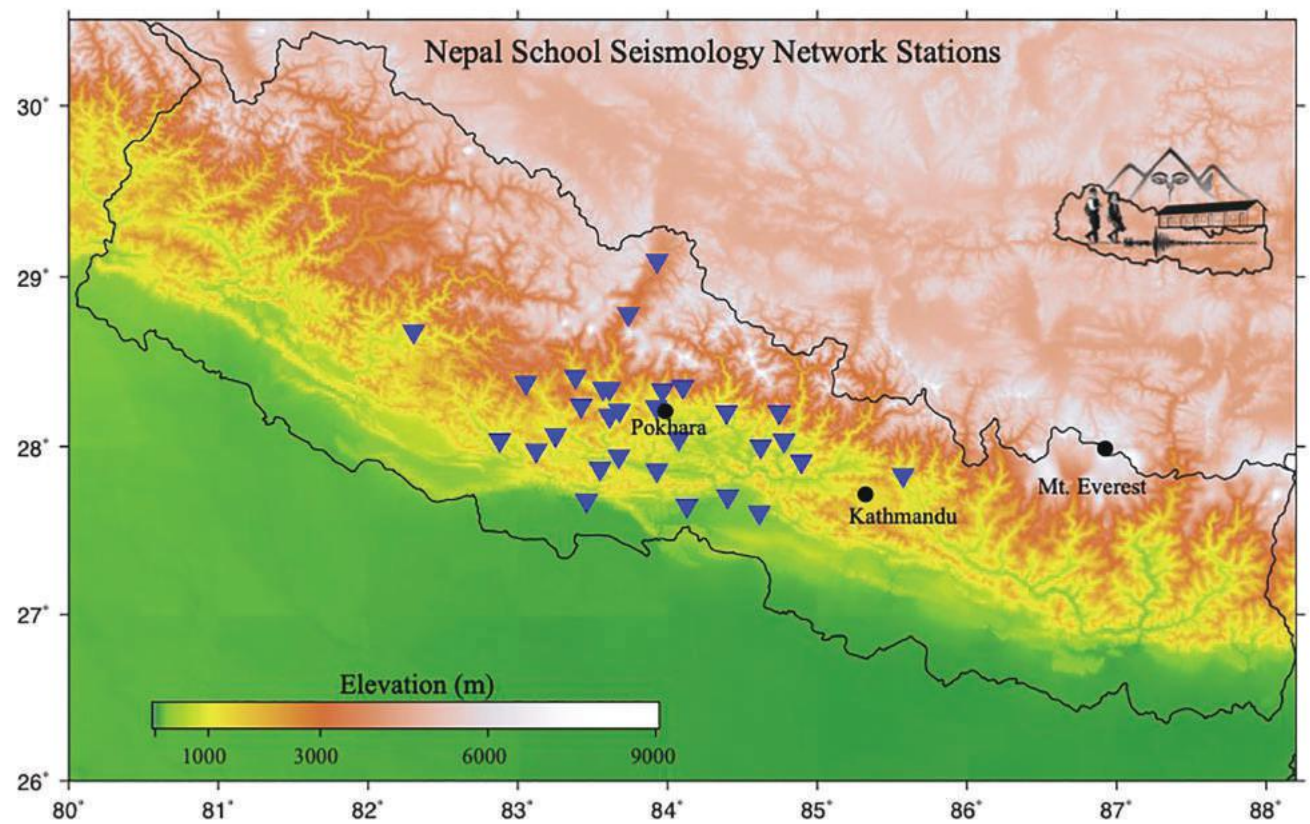

Fig. 2: Nepal School Seismology Network map (as of May 8, 2021), with blue triangles showing the location of each site.

Table 1: Detailed information of Nepal School Seismology Network stations. See text for the explanation of columns.

School's Name	School Address	Station ID	Longitude (ºE)	Latitude (ºN)	Elevation (m)	Station Channel	Gain (counts/ m/s)
Ekata Secondary	Galkot, Baglung	R023E	83.422	28.242	1320	SHZ	469087000
Shanta Secondary	Pokhara, Kaski	R0CEA	83.925	28.234	787	EHZ	381407000
Panchamuni Secondary	Shuklagandaki, Tanahun	R0F23	84.075	28.048	516	EHZ	381407000
Balkalyan Secondary	Besishahar, Lamjung	S8618	84.394	28.204	747	EHZ	381407000
Bal Mindir Secondary	Gorkha Bazar, Gorkha	RA5AB	84.623	28.001	1121	SHZ	469087000
Bhanu Bhakta School	Galyang, Syangja	RC951	83.675	27.942	722	EHZ	381407000
Parbat Gurukul Academy	Kusma, Parbat	R732B	83.679	28.215	847	EHZ	381407000
Gram Prakash Secondary	Jaljala, Parbat	RD7E6	83.612	28.342	1790	EHZ	381407000
New Horizon Secondary	Jaljala, Parbat	R7173	83.570	28.344	865	EHZ	381407000
Janapriya Secondary	Malika, Myagdi	RBB7B	83.385	28.414	1136	EHZ	381407000
Janahit Secondary	Jomsom, Mustang	RE93F	83.738	28.784	2728	EHZ	381407000
Shree Prabha Secondary	Nishikhola, Baglung	R038D	83.054	28.378	1429	EHZ	381407000
Siddha Baba Secondary	Tamghas, Gulmi	S2D97	83.252	28.068	1537	EHZ	381407000
Padma Public Secondary	Tansen, Palpa	R2AE2	83.549	27.870	1352	EHZ	381407000
Arghakhchi Secondary	Sandhikharka, Arghakhanchi	R43A3	83.122	27.978	971	EHZ	381407000
Mahindra Secondary	Airawati, Pyuthan	RCCCC	82.879	28.039	668	EHZ	381407000
Horizon Secondary	Butwan, Rupandehi	RD14A	83.460	27.680	156	EHZ	381407000
Shiva Secondary	Kawasoti, Nawalparasi	R51F6	84.130	27.649	189	EHZ	381407000
Janak Secondary	Gaindakot, Nawalparasi	R6EC4	84.402	27.704	174	EHZ	381407000
Birendra Secondary	Birendranagar, Chitwan	R8C46	84.614	27.608	204	EHZ	381407000
Himalaya Secondary	Barpak-Sulikot, Gorkha	S8086	84.746	28.204	1885	EHZ	381407000
Machhapuchre Secondary	Sardikhola, Kaski	R8328	83.966	28.333	1225	EHZ	381407000
Upper Mustang school	Lomanthang, Mustang	R1AA8	83.930	29.095	3588	EHZ	399650000
Baljyoti Secondary	Sani-Bheri, West Rukum	RFCB2	82.303	28.679	811	EHZ	399650000
Janabikash secondary	Rampur, Palpa	RA922	83.929	27.859	383	EHZ	399650000
Sanskrit Secondary	Bhimsen, Gorkha	RD184	84.778	28.036	888	EHZ	381407000
Nilkantha Secondary	Nilkantha, Dhading	R2109	84.895	27.912	593	EHZ, ENZ, ENN, ENE	399650000
Annapurna Secondary	Annapurna, Kaski	R9299	84.102	28.355	1908	EHZ, ENZ, ENN, ENE	399650000
Shanti Secondary	Jaimuni, Baglung	R0BD5	83.613	28.181	785	EHZ, EHN, EHE	360000000
Indreshwori Secondary	Melamchi, Sindhupalchok	R3B1E	85.575	27.830	885	EHZ	399650000

To see how the seismometer would perform for microseismic activities, we have installed a RaspberryShake 1-dimension (RS1D) in Switzerland, which is relatively quiet and we are able to record relatively small earthquakes (ML ≤ 1.0) earthquakes at surprisingly large (50 km) distances, while typical felt (ML ≥ 2.5) events are detected up to ca. 300 km distance (Subedi et al., 2020a). In Nepal, information on micro earthquakes (ML < 4) is not publicly accessible. Nevertheless, all reported local earthquakes of this size and larger are clearly recorded, and also some regional events of ML 4 beyond 1’000 km distance have been detected (Subedi et al., 2020a).

Some of the events recorded by our network are felt by the people involved in our school seismology program, who were naturally interested to learn more. It is very instructive to produce instrumental intensity maps that shows measured intensity values at stations across the NSSN. We produce such maps routinely for felt events in the study area, and represent shaking as instrumental intensity converted from peak ground velocity (which in our sensors is recorded on the vertical component following the scale of Worden et al. (2012). The instrumental intensity map for the event causing one of the largest intensities so far, an ML 5.3 earthquake inside the network is presented in Figure 3. In general, the instrumental intensity map representing measured shaking is critical to estimate the damage after an earthquake and to prepare an emergency response and rescue; in the frame of our educational seismology project, it shows all schools together and demonstrates the connection within the community of schools.

Tutorial

In the following text, we describe the steps needed to locate the epicenter of a given earthquake using the data from Nepal School Seismology Network stations. We expect users to have a computer with Windows operating system (the procedure below was tested on Windows 10 and MacOS Sierra). The tutorial consists of four steps summarized below:

1. **Software installation.** Prepare an environment and install necessary software (Seisgram2K and Google Earth).

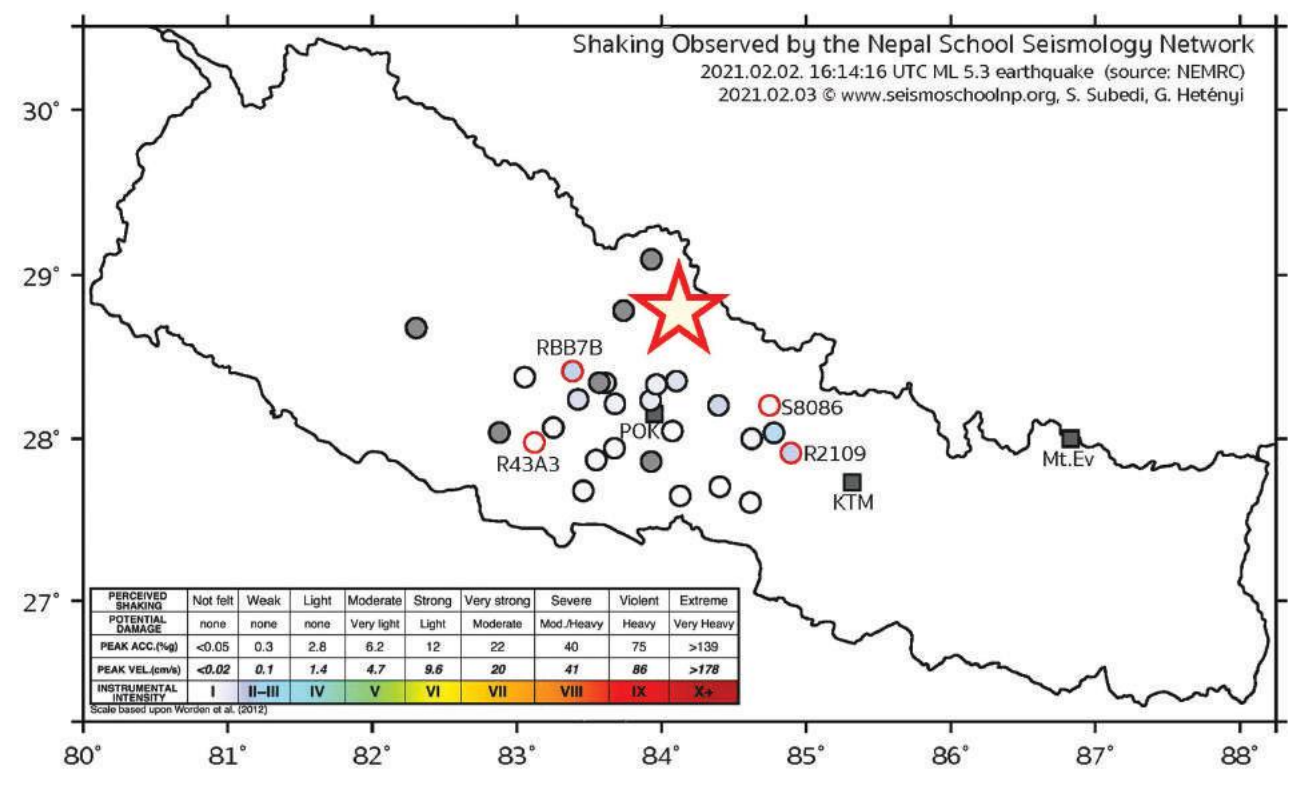

Fig. 3: Observed instrumental intensity map from the 2021 February 2 ML 5.3 Manang earthquake. The observed peak ground velocity on the vertical component (PGVV) data at NSSN stations are plotted in circles and are color-coded according to their value based on Worden et al. (2012) as shown in the legend (similar as Subedi et al., 2020a). The maximum instrumental intensity observed is II-III. Here we note that the abovementioned intensity classes are likely to differ from those in Worden et al. (2012) because we lacked the horizontal component data, and derivation of intensity scale based on our data is future work. Red contour in circles is used for earthquake location purpose later, where Station ID is also shown. Gray color means no data for the event from that station (either no internet or no power supply). The capital city of Nepal, Kathmandu is denoted by KTM, the highest point of the Earth, Mount Everest is denoted by Mt.Ev, and the capital city Pokhara of the Gandaki province is denoted by POK (gray squares).

2. **Waveform download.** Download earthquake seismograms using RaspberryShake server.
3. **Seismogram reading and phase picking.** Read seismograms and pick P and S phases to compute the earthquake distances from a station.
4. **Epicenter plotting.** Plot distances information obtained (step 3) on Google Earth (http://earth.google.com) and find the epicenter.

Step 1: Software installation

There are several freely available software for calculating the location of an earthquake. We prefer to use Seisgram2k software (Lomax, 2008), a useful tool for earthquake location purposes. In addition, we require to install Google Earth to plot the epicenter on a map.

Seisgram2k installation

All details about the software along with some sample data can be found on the official webpage http://alomax.free.fr/seisgram. Download and install SeisGram2K by following steps as described below:

1. You must have Java to run the Seisgram2K on your computer. Download Java for your operating system from the link https://www.java.com/en/.
2. Create the installation directories (for example Desktop/Seismology) and download the SeisGram2K program files. There are two different Seisgram2K versions and the newer school version of Seisgram2K has a simpler menu system and we prefer to work with the school version. To download the software file, click the link: http://alomax.free.fr/seisgram/beta/SeisGram2K80_SCHOOL.jar.
3. Download starts automatically. Move the downloaded file to your newly created Seismology directory.

Google Earth installation:

1. Click the link below and download Google Earth on your computer.

   https://www.google.com/earth/download/gep/agree.html?hl=en-GB
2. Click on "Agree and Download"
3. Open the downloaded file.
4. Follow instructions to install Google Earth on your device.

Step 2: Waveform download

There are several ways to download data recorded by the Raspberry Shake seismometer installed in your school. We recommend using easy and straightforward method to download data using the Raspberry shake FDSN server.

1. Go to the Raspberry Shake server link:
   https://fdsnws.raspberryshakedata.com/fdsnws/dataselect/1/builder
2. Visit the National Earthquake Monitoring and Research Center's webpage to see a list of earthquakes (ML ≥ 4) that occurred in and around Nepal: http://www.seismonepal.gov.np/. For regional events, you should refer United States Geological Survey or European-Mediterranean Seismological Centre webpages. Note that you need to specify the A.D. date and UTC time to download earthquake data. In this example, we show the steps for the event that occurred on 2nd of February 2021 at 16:14 UTC according to the NEMRC. You can create a separate directory for this and each other event so that you are able to use the downloaded waveforms later as well.
3. Define start time and end time to download the required data. Time must be in YYYY-MM-DDTHH:mm:ss format where YYYY is the year, MM is the month, DD is the day, HH is the hour, mm is the minute and ss is the second. For example,

   Start time: 2021-02-02T16:14:00 (earthquake start time from NEMRC webpage)

   End time: 2021-02-02T16:19:00 (5 min window)
4. Select the station name, channel, and location that you want. In our case, we are using Raspberry Shake seismometers, so, Network = AM, Station = StationID*, Location = 00, Channel = StationChannel*, where choose StationID* and StationChannel* from Table 1. In this tutorial, data from 4 stations are downloaded: S8086, R2109, R43A3, and RBB7B. We start with S8086 and channel EHZ (Fig.3, Table 1).
5. Click the URL that is composed of your input data which appears at the bottom of the page to download the data (Fig. 4, bottom link). A file called 'query' should be downloading to your computer's regular download folder.

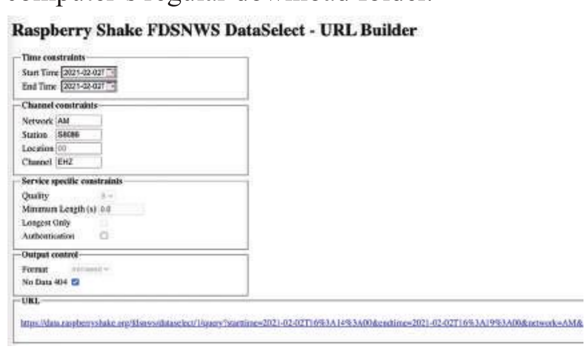

Fig. 4: Illustration for downloading data using the Raspberry Shake FDSN server.

6. Rename 'query' to 'S8086.EHZ.mseed' and move it to the Desktop/Seismology/Event folder.
7. Similarly, repeat steps 4, 5, and 6 to download waveforms from at least another two stations, otherwise the epicenter estimate is not possible.

Step 3: Seismogram reading and Phase picking

Seisgram2K can be used for reading and plotting seismograms, and for picking the arrival of P and S waves (called 'phases'). Picking the arrival time of phases is the base for computing the correct location for a given earthquake.

1. Now, open Seisgram2K with java application. The image below is the basic display of seisgram2K (Fig. 5).

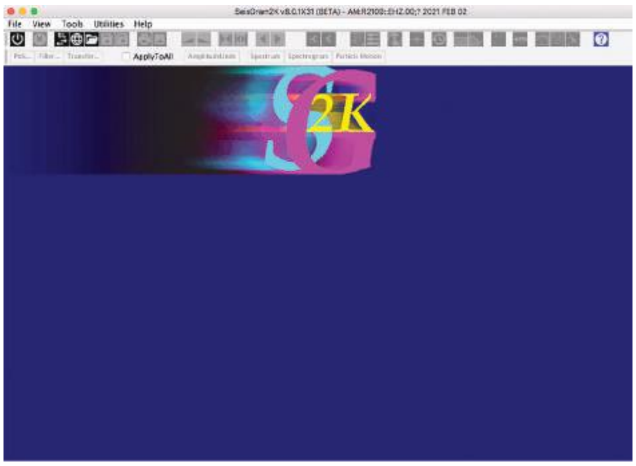

Fig. 5: Seisgram2K display screen.

2. Open seismograms by clicking, File > Open file. > click your seismograms file > Open > Open (see Fig. 6).

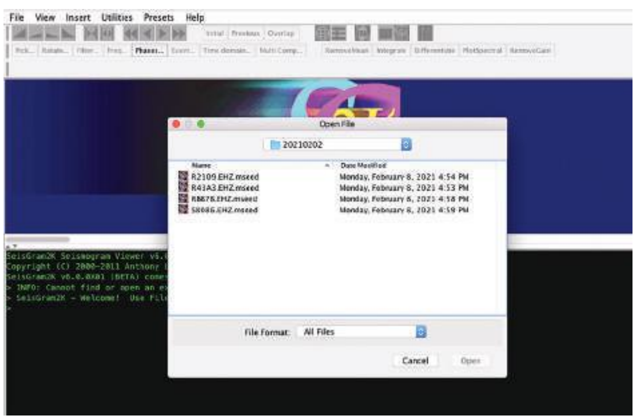

Fig. 6: Illustration for reading seismograms in Seisgram2K.

Now you see a seismogram displayed by Seisgram2K. You have to visually verify that this seismometer has detected the event, i.e. that P and S waves can be recognized.

3. The school version of Seisgram2K automatically chooses the filter type and the number of poles in the filter. Apply a filter in the 0.7 to 8.0 Hz frequency band by following steps 1 to 4 highlighted in red (Fig. 7). Some of the options appear only if you clicked the previous one.

Fig. 7: Illustration for filtering data.

4. Remember how the waves travel in the ground. The first wave that is recorded by the seismometer is the P wave (the fastest wave). The following wave is the S wave which usually has greater amplitude than P wave, and the last wave is surface wave which has lowest velocity . For this exercise, we only use the P and S waves which are sufficient to locate epicenter of an earthquake.

5. To pick phases in Seisgram2K, click the "Pick" tool, then select the wave which you think as a P wave or S wave. Click "Pick" > Click "P" (from the dropdown menu) >> choose the P phase arrival time on the screen and click with the mouse, and click "P". Play around zooming in and out by rolling your mouse for precise picking (Fig. 8).

Fig. 8: P phase picking illustration.

Similarly, click "S" in the drop-down menu, zoom and pick the S-phase, and click "S" (Fig. 9).

Fig. 9: S phase picking illustration.

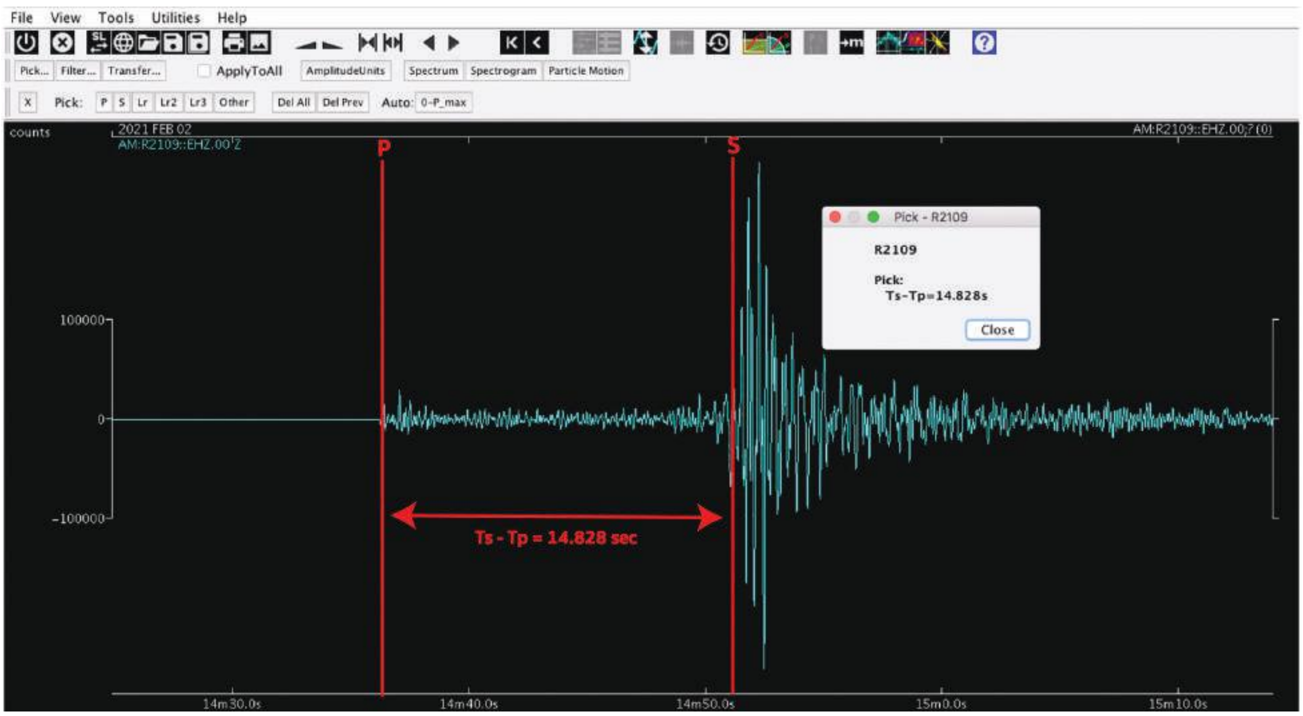

Fig. 10: Computing time difference between P and S phases.

6. Once you picked the P and S phases, the time difference between the P and S phases (Ts-Tp) appears in a Popup along with station name (Fig. 10). Then, using the formula below, you can estimate the earthquake distance from this station by inserting the (Ts-Tp) value in the following equation (Havskov, 2012):

$$distance = (Ts - Tp)\frac{Vp \times Vs}{(Vp - Vs)}$$

where Vp = 6.1 km/s and Vs = 3.5 km/s, the thickness-weighted harmonic mean of two-layer velocity model (Pandey et al., 1995).

Hence, distance (km) = (Ts-Tp) ×8.2 km/s

For the average conditions of the crust, Lay and Wallace (1995) use distance = (Ts-Tp) × 8.0 km/s, with an average Vp = 5.9 km/s. In our case, distance = (Ts-Tp) × 8.2 is close to this, and any deviations from this due to varying ray geometries is considered to be part of the uncertainty of the earthquake location.

For station R2109, distance = 14.828 × 8.2 = 122 km

The earthquake on 2021-02-02T16:14:00 was 122 km far from the station R2109, Dhadingbesi.

Similarly, you can compute **(Ts-Tp)** for other stations. Here we presented the final result from the other three stations as follows.

For station R43A3, distance = 16.13 × 8.2 = 132 km

The earthquake on 2021-02-02T16:14:00 was 132 km far from the station R43A3, Arghakhanchi.

For station RBB7B, distance = 10.00 × 8.2 = 82 km

The earthquake on 2021-02-02T16:14:00 was 82 km far from the station RBB7B, Darwang Myagdi.

For station S8086, distance = 11.38 × 8.2 = 93 km

The earthquake on 2021-02-02T16:14:00 was 93 km far from the station S8086, Barpak Gorkha.

Table 2: Summarized table for P and S phase arrival times and the distance of the earthquake from given station.

Station Name	Ts-Tp [sec]	distance = **(Ts-Tp)** ×8.2 [km]
R2109	14.80	122
R43A3	16.13	132
RBB7B	10.00	82
S8086	11.38	93

We suggest you compute the epicenter using at least three stations (Fig. 11). It would be easy for picking if you choose relatively less noisy stations. In our experiences, R8C46, R6EC4, R51F6, and RD14A are noisy stations compared to others as these sensors are installed either in big cities or nearby highways.

Step 4: Epicenter plotting

When you calculate the distance of the earthquake from at least three stations then you can locate the epicenter of that earthquake. For estimating the location of the earthquake, you need to plot the circle (radius of the circle equals the computed distance of the earthquake from the station).

1. Open Google Earth in your computer.
2. Click "Add Placemark" from the top panel 2nd left option, to add each of the selected stations in the interface and using latitude and longitude from Table 1 and click "OK" to save it (Fig. 12). (You can also add all stations and save them for later.)
3. Click on the "Ruler" icon from the top menu and click "Circle" and select "Kilometers" for radius. Put the origin at S8086 (Barpak) and draw a circle of a radius of 93 km and save it (Fig. 13).
4. Similarly, put the origin at R2109 (Dhading Beshi) and draw a circle of a radius of 122 km, and save it.
5. Similarly, put the origin at R43A3 (Arghakhanchi) and draw a circle of a radius of 132 km, and save it.

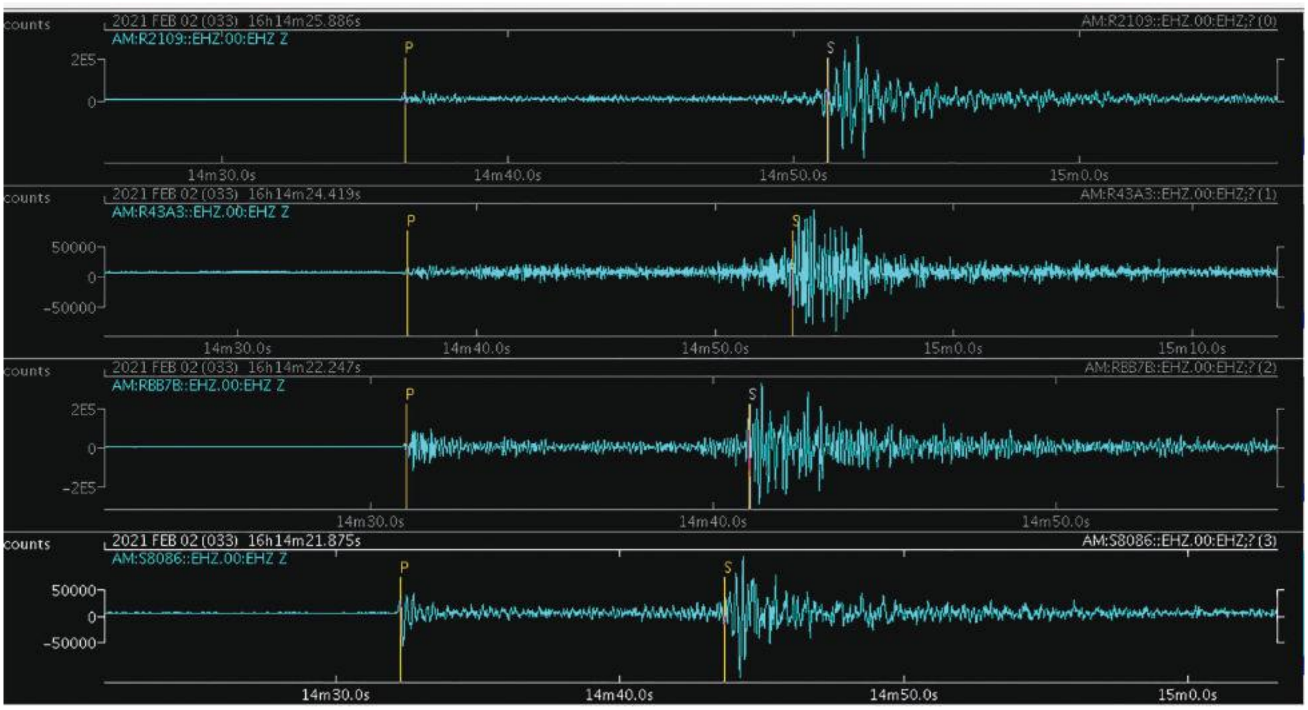

Fig. 11: Plotting four seismograms simultaneously in Seismogram2K.

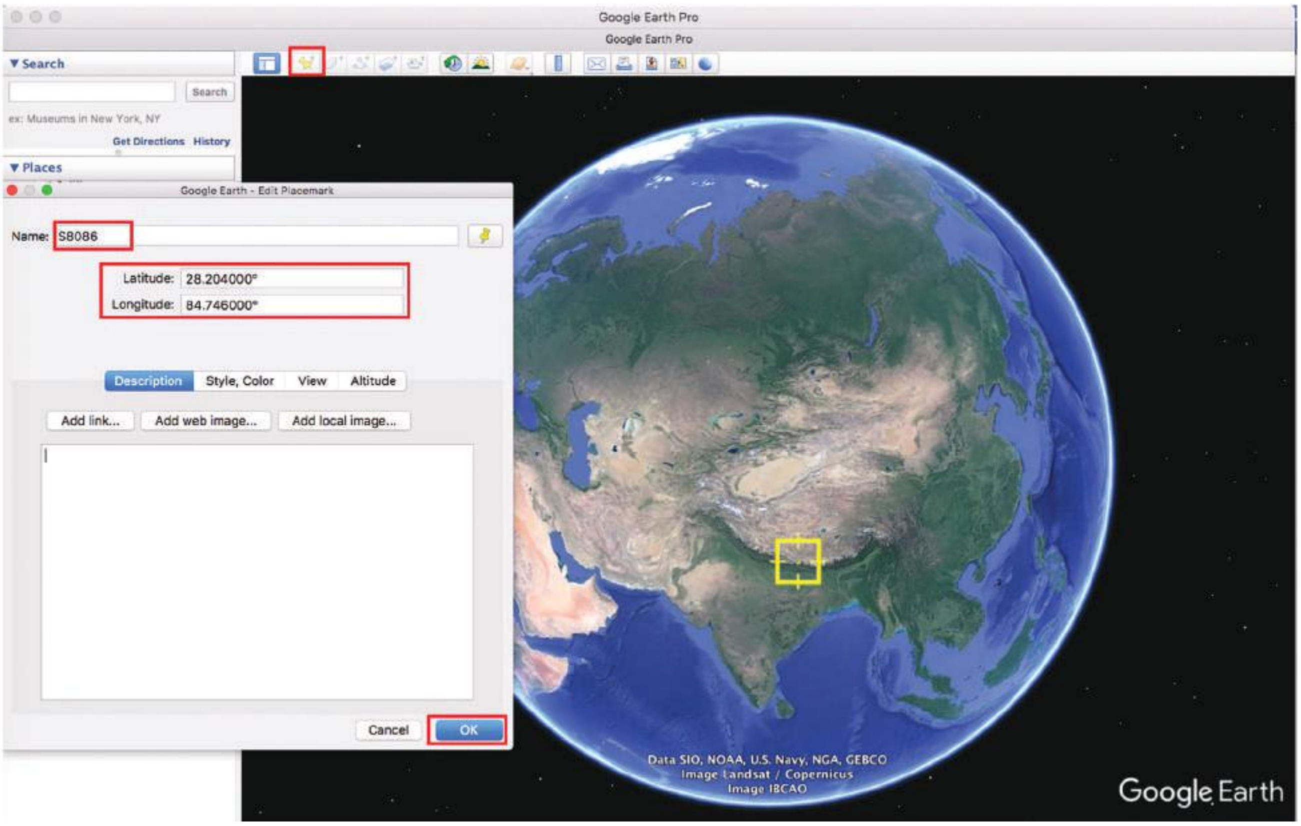

Fig. 12: Adding station information on Google Earth.

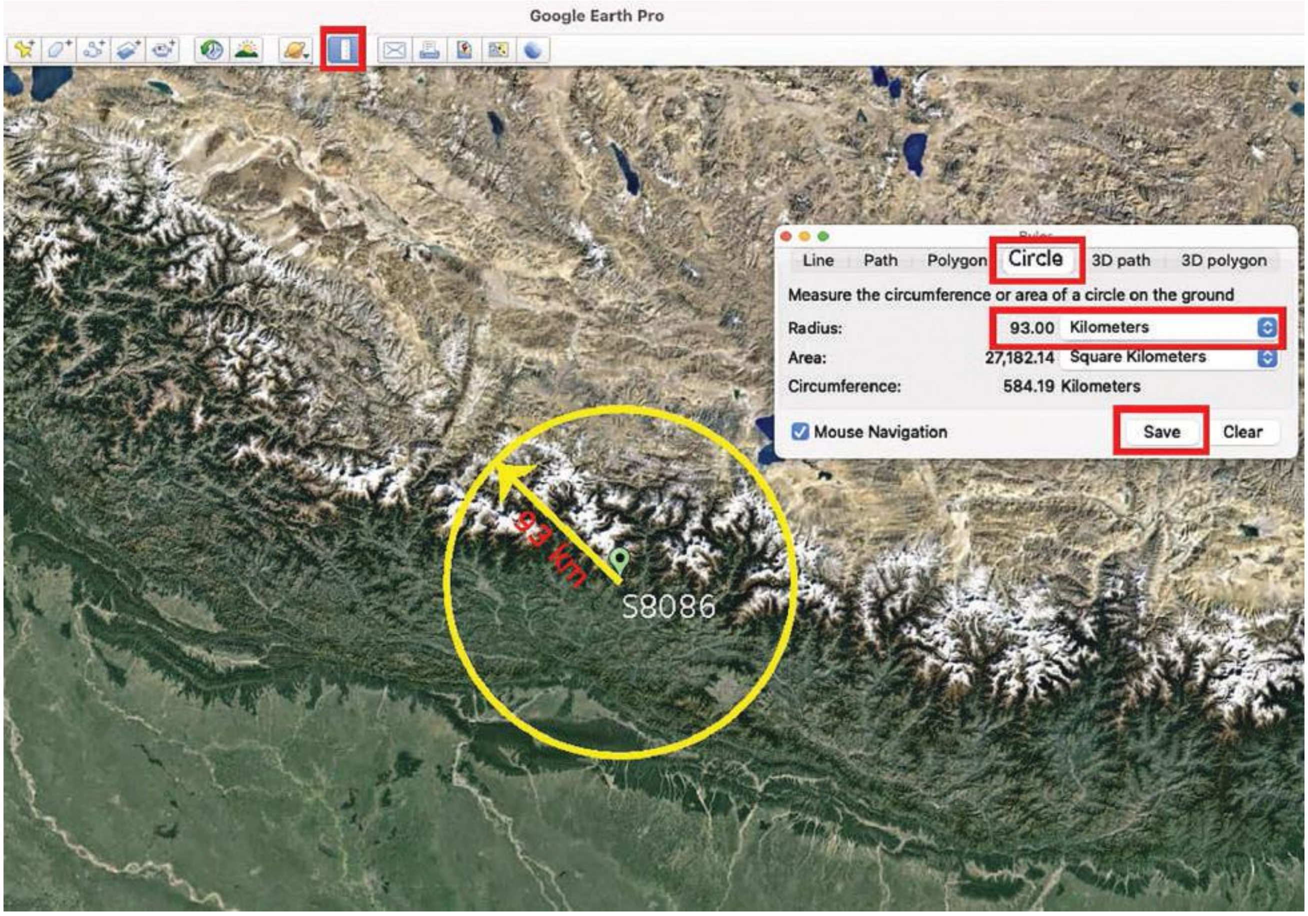

Fig. 13: Plotting a circle on Google Earth (radius = earthquake distance).

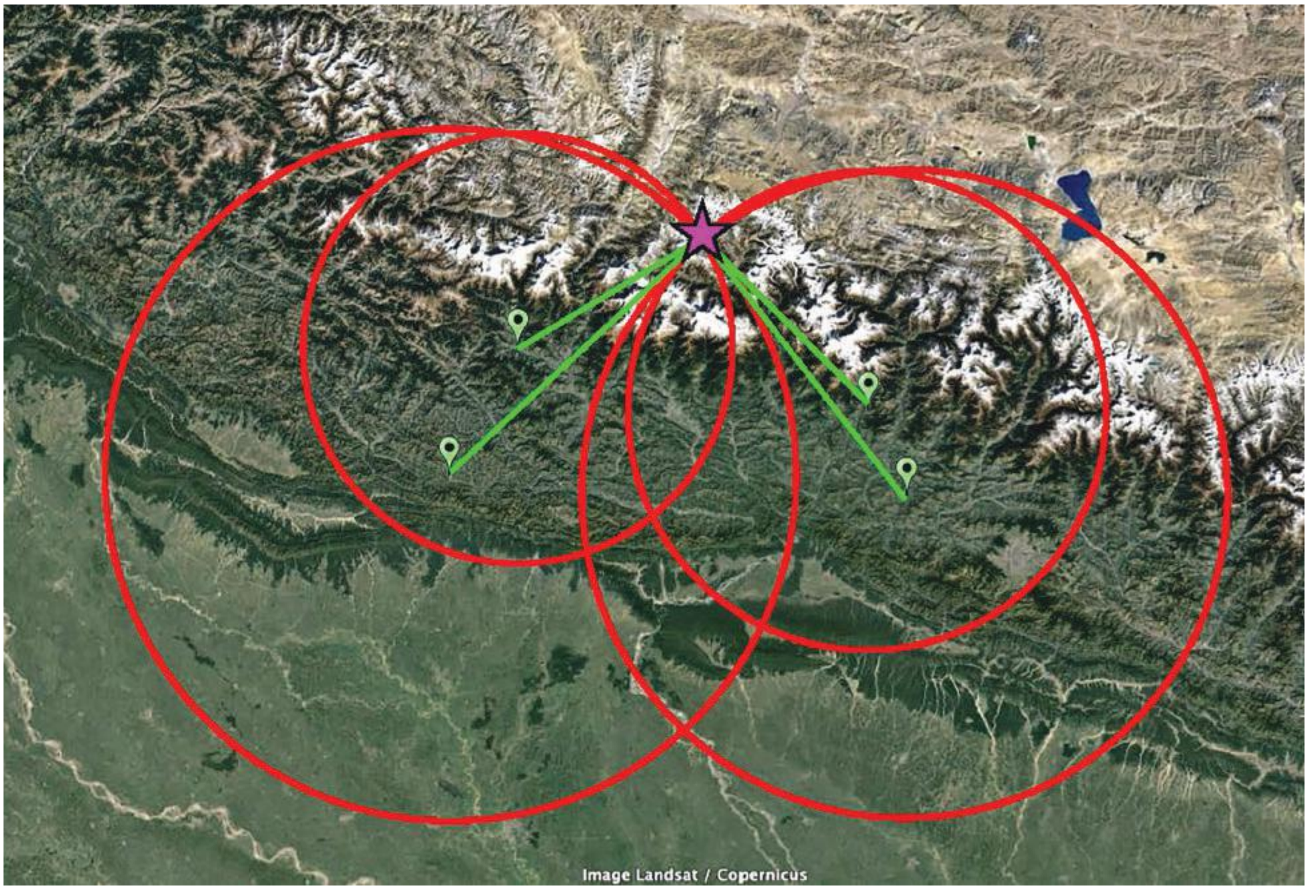

Fig. 14: Locating epicenter of an earthquake using four stations.

6. Once again, put the origin at RBB7B (Myagdi) and draw a circle of a radius of 82 km, and save it.

7. Then, ideally, you will find a point where all four circles intersect, this is the epicenter of the earthquake (Fig. 14). The earthquake epicenter you computed may differ from the published epicenter because of the uncertainty on the arrival time while picking P and S phases, because of not considering the exact depth of an earthquake, and also due to the simplified average velocity consideration. It can also happen that the circles you drew do not exactly cross each other at a single point. However, these are minor problems at the scale of this exercise, and the general goal of this tutorial of locating the approximate region of an earthquake can be well achieved.

DISCUSSION AND CONCLUSIONS

This tutorial can be used to locate all earthquakes that occurred in Nepal. Waveforms from sufficient number of NSSN stations to determine a location are available from April 2019. For those earthquakes, felt locally but not published in the NEMRC catalog users should still try to locate by downloading waveforms recorded in the given time by seismometer installed in the given region. Just for reminder, Raspberry Shake seismometer needs couple of minutes for forwarding data to the server via internet. Ideally, the tutorial works for all NSSN stations, but no data is available if the station is offline at the specified time. Picking of P and S phases is tricky and is not easy especially for the noisy stations. Applying different frequency bands for example 0.8-2.0, 0.8-5.0, 0.8-3.0, etc. for waveform filter could be helpful to pick correct P and S phases and it is recommended. If anyone prefers to use the normal version of Seisgram (http://alomax.free.fr/seisgram/ver70/java/SeisGram2K70.jar), an additional step is needed for removing the waveform mean, and more options for data filter are available. At the same time, the school version of Seisgram removes the mean automatically and chooses a 2-pole Butterworth filter.

The earthquake epicenter we computed here is based on the circles drawn from each station, and each circle could have ± 0.5 sec time uncertainty at most, which gives up to 15 km uncertainty for each circle. In the given example above, our estimated earthquake epicenter is at ca. 2 km far from the NEMRC/DMG location, which is very good and probably made possible due to the impulsive arrival of waves. However, the epicenter uncertainty depends on the P and S phases picking accuracy, the approximated velocity model, and the true depth of the event as well.

The aim of this work is to present a simple tutorial of earthquake location mainly for Nepali citizens and school teachers. This helps the public to have first-order information on earthquakes, by allowing to locate epicenters, which will increase the frequency of earthquake discussion in the community. In addition, locating earthquake epicenters is helpful for high-school students and university students to develop their knowledge and possibly a carrier in Seismology or Earth Sciences. Finally, we also believe it is a good practice to engage the public on earthquake related discussions, so that citizens become more motivated to create earthquake safer communities.

FURTHER READING SUGGESTIONS

http://seismoschoolnp.org/wp-content/uploads/2019/04/Talk3_PDenton_Waves.pdf

http://seismoschoolnp.org/wp-content/uploads/2021/01/denton_presentation.pdf

http://ds.iris.edu/data/vocab.htm

http://seismoschoolnp.org/wp-content/uploads/2019/04/IndiaAsiaCollision_fast.mp4?_=1

http://edumed.unice.fr/fr/contents/news/tools-lab/EduCarte

https://en.wikipedia.org/wiki/Seismic_wave

https://edu.raspberryshake.org/

https://www.iris.edu/hq/inclass/software-web-app/jamaseis

https://www.iris.edu/hq/inclass/fact-sheet/vocabulary_for_earthquakerelated_topics

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AUTHOR'S CONTRIBUTION

P. Denton provided the idea and the procedure described here. S. Subedi did the manuscript preparation, figures tables, and calculation and verified by P. Denton, K. Michailos, G. Hetényi. All authors discussed the results and contributed to the final manuscript.

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