COORDINATING COMMITTEE FOR GEOSCIENCE PROGRAMMES IN EAST AND SOUTHEAST ASIA (CCOP)

54th CCOP Annual Session
28 October – 1 November 2018
Busan, Republic of Korea

Member Country Report of SINGAPORE

Submitted by

Kerry Sieh, Earth Observatory of Singapore

(For Agenda Item 3)

COORDINATING COMMITTEE FOR GEOSCIENCE PROGRAMMES IN EAST AND SOUTHEAST ASIA (CCOP)
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ANNUAL MEMBER COUNTRY REPORT

Country:	SINGAPORE	Period:	1 July 2017 – 30 June 2018

1. OUTREACH

The notes in italic below each heading apply to all similar headings in all the following strategic goals. If you have nothing to report under a particular heading please write "Nothing to Report".

1.1. Summary

Through its Community Engagement Office, the Earth Observatory of Singapore expands outreach and builds identity within and beyond the scientific community, strengthening existing partnerships and forging new ones through communication and collaboration.

The Office has been actively communicating science through various channels. One of these is through the institutional blog, where research findings and commentaries are publicised. Over the past year, the team worked with students from Nanyang Technological University's Wee Kim Wee School of Communications and Information and the Asian School of the Environment on blog posts highlighting the work of EOS researchers and exploring topics related to Earth science. The introduction of short videos featuring EOS research and the stories behind them is another way the Community Engagement Office shares the work of the Observatory's scientists with a broader audience.

Partnerships are integral to the Office's outreach plans. The team worked with colleagues from France and Indonesia to promote the second Marine Investigation of the Rupture Anatomy of the Great 2012 Earthquake (MIRAGE) expedition through a widely-publicised outreach event in Jakarta, Indonesia. Other activities the Community Engagement Office is involved in include participating in annual conferences, exhibitions, and panel discussions. On-site tours are another way of introducing the Observatory to visiting scientists and dignitaries. This year, guests included His Excellency Mr Marc Abensour, Ambassador of France to Singapore, Professor Subra Suresh, President of Nanyang Technological University, and researchers from Haifa University and the Darwin Volcanic Ash Advisory Centre.

In the coming year, the Community Engagement Office plans to increase visibility, expanding communication and outreach across the scientific community and deepening relationships with local and global partners.

1.2. Annual Review of Individual Technical Activities

Completed activities:

- **Phuket Pilot and School Project**: More than 2,000 children from 20 schools attended earthquake and tsunami safety sessions designed and developed by EOS' Applied Projects Group with the support of DPM Phuket, DDPM RC18, Le Meridien Beach Resort Phuket and DDPM Training Academy. Students learned about tsunami and earthquake risks and how to stay safe in the event of earthquakes and tsunamis. Some students and government officials, including the Governor of Phuket, experienced the effects of a simulated magnitude-7.0 earthquake in the DDPM's Earthquake Simulator Truck, that was mobilised and driven from the north of Thailand to Phuket in support of the school training project. It was the first time the earthquake simulation truck found its way to Phuket. The success of the training project has resulted in new budgets and plans that have been put in place to expand this initiative to other schools in Phuket and expand the outreach to more and a new cohort of students.

Ongoing activities:

- **The Digital Inventory Response Asset Tracking Project (Phuket Pilot):** This project aims to develop a simple and cost-effective real time, cloud based digital platform, that tracks all available critical disaster response assets in Phuket. Such a digital response inventory and asset-tracking database would capture, catalogue and track response equipment from government and non-government agencies in Phuket.

  The local disaster management agency in Phuket currently operates with an inventory excel lists of disaster response equipment under control of the government. It is currently not clear, whether this equipment is operational or under maintenance. For non-stationary assets, it is not clear where these assets are at any point in time. Furthermore, response assets from hospitals and other first responder organisations and / or the private sector (in particular, from hotels) are not captured.

  We seek to create an integrated inventory of all critical response assets on Phuket Island and develop a real-time asset-tracking platform that is available to Phuket's Incident Command Center (ICC) and other stakeholders. Digital asset tracking and inventory software exist, and we are currently assessing how to best utilise software solutions using GPS and RFID technology.

  Disaster response agencies can benefit greatly by a real-time asset-tracking platform, which will enable them to stay updated on the available disaster response equipment at their disposal and by being able to track the real-time movement of this equipment during a disaster event. Having such a system in place will exponentially increase operational efficiency of the disaster response apparatus thus allowing it to reach out to a larger portion of the affected population.

  Three organizations have agreed to join as pilot organisations:
  1) Kusoldtham Foundation
  2) Vachira Hospital (public hospital)
  3) Nakhon Phuket Municipality (Tessaban Nakhon Phuket)

1.3. Proposed Future Activities

Future activities:

- **Science Centre Singapore Exhibition Redesign:** EOS and SCS are planning the review and redesign of the five-year-old "Earth – Our Untamed Planet" exhibition, currently on the floor at the SCS. Over the past five-years, the exhibition has served the Singapore primary and secondary schools as a teaching tool within the framework of their earth sciences unit within the geography curriculum. Additionally, it is a very popular exhibition with the SCS general public and tourist audience. A key priority with the redesign is to expand the knowledge of earth sciences and geohazards research within Southeast Asia and meet the educational needs of Singapore's geography teachers and students.

  Through a complete review of the existing exhibition, the SCS and EOS will reimagine and develop a revised concept and redesign for the exhibition. Concepts to explore include geohazard phenomena and how different events are connected (earthquakes and tsunamis, volcanoes and earthquakes), scale and historical timelines, mapping to understand the past, new technologies to help see into the future. SCS will work with the Exploratorium, through an established MOU, to manage the building of the exhibits with EOS staff and faculty acting as project facilitators, scientific directors and content advisors. Project kicks off in the fall of 2018 with an opening date of fall 2020.

- **PERFORM; Interactive Crisis Awareness and Management Games:** EOS is launching a new series of educational games for students, age 11 – 18 years of age. Working with the Science Centre Singapore (SCS), EOS will launch a new program for visiting field trip students in early 2018. Focusing on Typhoons and Volcanoes, a series of workshop games for up to 30 students, will be incorporated into a 2-hour earth sciences field trip program at SCS. Students will visit the *Earth; Untamed Planet* exhibit currently at SCS and will extend their learning experience through the new one-hour games workshop. The workshop takes students through the before, during and after events of a Typhoon and Volcano, requiring them to make quick, smart, life or death decisions on how best to manage the challenges facing their communities. SCS educational staff will be trained to implement and lead these games, in early 2018 and roll out the extended field trip program in the spring of 2018.

1.4. Assistance Offered to CCOP/Other Member Countries in Support of Future Activities

The EOS collaborates on geohazard research projects with colleagues in government and universities throughout much of Southeast Asia, including Myanmar, Lao PDR, Thailand, Vietnam, Indonesia, Malaysia, and Bangladesh.

Programme Contact Person:

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2. COOPERATION AND PARTNERSHIP

(Activities for enhancing networking and effective collaboration)

2.1. Summary

The Earth Observatory of Singapore (EOS), through advancement initiatives, worked to provide financial investment, strengthen strategic alliances, and promote institutional priorities. Through meaningful discourse with individuals, foundations, corporations, and other constituents, EOS fostered mutually beneficial relationships.

This year EOS created an advancement infrastructure that includes a CRM system, multimedia collateral, and strategic protocols, all designed to enhance collaboration and networking. In addition, a grants administration unit was added to provide support for EOS researchers and allow for the integration of additional partnerships.

2.2. Annual Review of Individual Technical Activities

- **Collaboration and partnership with corporate donors and sponsors on geoscience projects to further knowledge of geohazards in southeast Asia and the region:** The AXA Research Fund supports the following projects:
    - Seismic behavior of the Xiaojiang Fault, southwestern China, and its implication for seismic hazard (research led by Research Fellow Shi Xuhua)
    - Probabilistic assessment of multiple coastal flooding hazards in the South China Sea under changing climate (research led by Research Fellow Li Linlin)
    - Living with Natural Disaster (research led by Professor Isaac Kerlow)

- Last year, the Dr Stephen Riady GeoScience Scholarship provided funding for students pursuing a post-graduate degree at EOS. This scholarship provided funds for post-graduates to conduct independent research.
- EOS was involved in a project towards an inclusive urban reconstruction policy development process in Nepal. The project aims to pursue a qualitative approach to generate reflections, learning, and concrete planning activities to practical problems during establishment of Nepal's urban reconstruction policy among the various involved stakeholders. This project was supported by The International Institute for Environment & Development (IIED).
- The SCOR Southeast Asian Hazard Research Fund supported the field, analytical, conference, and publication components of EOS post-doctoral and student research projects to coastal and volcanic ash hazards.
- The Arcadia and the Oxford Centre for Islamic Studies at the University of Oxford collaborated with EOS on a Maldivian cultural heritage project.

- Equitable disaster recovery through mapping and integration of social-vulnerability into post-disaster impact assessments in Nepal. The main objective of the project is to create a new methodology that will rapidly and accurately assess post-disaster damage in Nepal. This project is supported by World Bank Group.

2.3. Proposed Future Activities

Corporate partnership and collaboration:

The Earth Observatory of Singapore will continue to seek to collaboration and support with strategic partners in order to further advance efforts related to geohazard research and education.

2.4. Assistance Required from CCOP in Support of Future Activities

Corporate partnership and collaboration:

The Earth Observatory of Singapore would be interested in any programs or network opportunities that CCOP can provide in order to promote and facilitate collaboration.

2.5. Assistance Offered to CCOP/Other Member Countries in Support of Future Activities

The Earth Observatory of Singapore offers CCOP and its partners, expertise and a platform to launch alliances in the interest of geohazard science. EOS welcomes outreach from CCOP to spark dialogue and initiatives.

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Corporate partnership and collaboration:

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3. KNOWLEDGE ENHANCEMENT AND SHARING

Activities for enhancing capabilities with area of focus - geo-hazards prediction and mitigation, environmental geology, water resources integrated management, energy and mineral resources sustainable development and geo-information.

3.1. Annual Review of Individual Technical Activities

New activities:

- **Analysis of data recorded by the TREMBLE (Temporary REceivers for Monitoring BangLadesh Earthquakes) network:** Commenced analysis of two years of data collected from the network of 28 seismometers (the TREMBLE network) installed across the eastern side of Bangladesh in 2016. The installed equipment consists of 6 broadband seismometers and 22 short-period seismometers, supported by data recorders. The team will ultimately integrate the data that we gather with other geological information in order to develop a more complete understanding of the tectonic framework of the system, linking it to the seismicity, sedimentation, and monsoon in the region.

Completed activities:

- **Uttarakhand project:** The Himalayan state of Uttarakhand is vulnerable to earthquake risk due to its location on the major tectonic belt and lies in Zone V of the seismic zonation map of India. This region has witnessed several significant earthquakes in the past. It is important to estimate the recurrence intervals of major earthquakes in this part to understand earthquake risk to the state. EOS developed earthquake hazard parameters for the state of Uttarakhand. These earthquake hazard parameters have been used to develop a risk assessment for the state.

  Specifically, the objectives for this project were to provide the active fault source model for Uttarakhand, India, that form inputs into the probabilistic seismic hazard assessment, and also to provide the Geo-referenced fault database for Uttarakhand, India with associated attributes based on existing information (including activity level, depth and traces, representative slip behaviour, any recurrence information). The project was executed in collaboration with the Danish Hydrological Institute, Wadia Institute of Himalayan Geology, Indian Institute of Technology, Kanpur and the Inter-university Accelerator Center, Delhi.

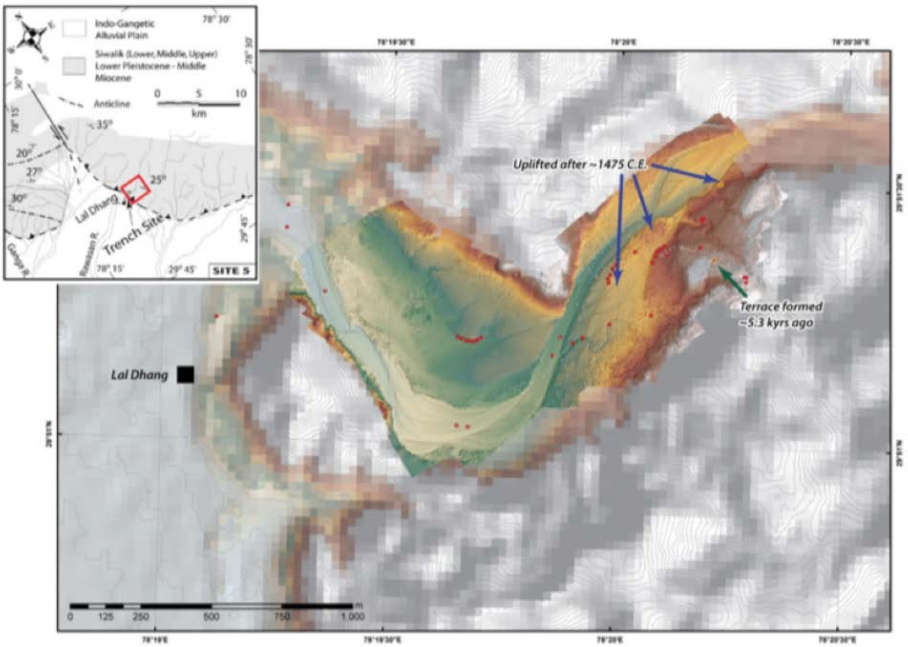


Figure 6 0.1 m-resolution Digital Terrain Model generated from drone photographs at Lal Dhang, showing uplifted fluvial terraces along either side of river. Colour code from light-green to white shows increasing elevation. Location map (top left) is from Kumar et al. (2006).

Through this project our researchers were permitted to fly a drone in a protected area for the study, and a DEM was created from the aerial imagery collected (Source: Wang Yu)

- **Historical cyclones in the Philippines:** Student researchers at EOS coastal lab recently completed studies of overwash deposits in the central Philippines associated with Typhoon Haiyan in 2013 and an un-named typhoon in 1897. The inland extent and sedimentary characteristics of the deposits suggests that the storm surge was likely similar to Typhoon Haiyan in 2013 though with a smaller magnitude. On the open coast of Hernani the geological record also suggests that several previous typhoons have struck that coast within the last 1000 years.

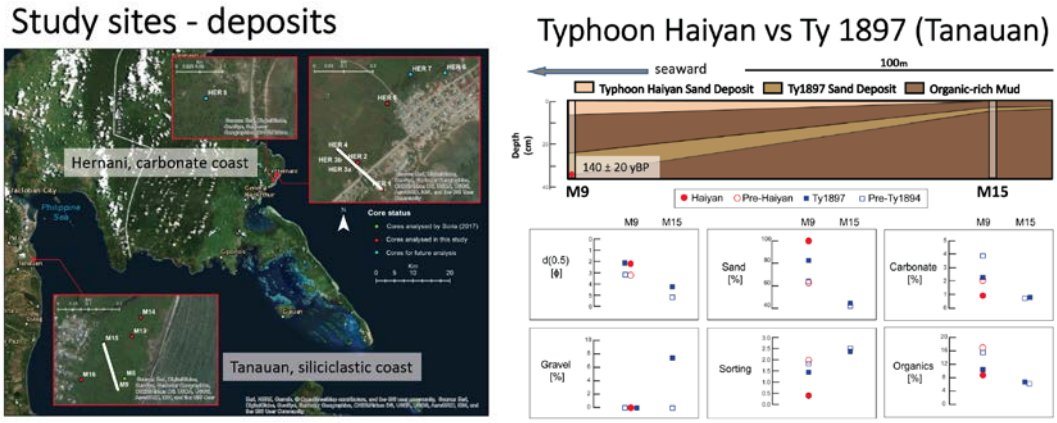


Fig. X. a) Sediment cores taken Tanauan, a siliciclastic coast, in the Leyte Gulf region, Philippines, show coarser sand layers below the sands deposited by Typhoon Haiyan that likely record the inundation of Ty 1897 (Tan, 2018, unpublished).

- <u>Water resources integrated management</u>
  Isotopic studies of tropical cyclone rainfall: The water chemistry of typhoon rainfall in Manila, Philippines differs from that of non-typhoon rainfall and may provide a valuable indicator of past typhoon frequency in Asia. Stable water isotopes can be used to study fractionation processes of typhoons, as such processes leave distinct isotopic signatures in storm-related precipitation. We recently analyzed stable isotope compositions of 186 daily precipitation samples collected in Manila, Philippines from March 2014 to October 2015 and found that daily precipitation samples with the lowest observed isotope values correspond to the passage of TCs. A clear example of extreme δ18O depletion in precipitation resulting from TCs is Typhoon Rammasun, which passed Manila on July 15, 2014. Rainfall samples collected throughout the study period have an average δ18O isotopic value is -5.25‰ while Rammasun has a δ18O value of -13.84‰.

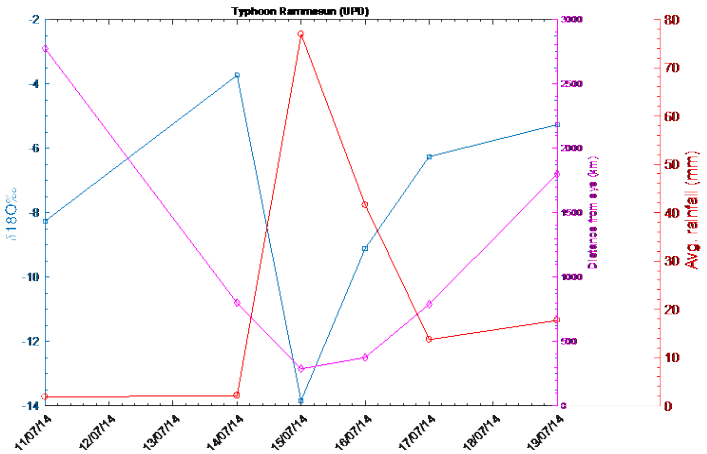


Figure X – Plot of rainfall δ18O isotope values, rainfall amount and distance from Rammasun to University Philippines Diliman sampling site against time during the passage of Typhoon Rammasun in July 2014.

Ongoing activities:

- Geo-hazards prediction and mitigation
  Advances in South China Sea Tsunami modelling: EOS coastal lab continues to work on improving Probabilistic Tsunami Hazard Assessments (PTHA) in the South China Sea as benchmarks for others studies in the region. Recent work built on the teams recent heterogenous slip model PTHA and incorporated sea level rise (SLR). Using Macau as an example the work showed that coastal cities considered 'tsunami safe' move rapidly toward increasing vulnerability when SLR is considered. In this case, we demonstrated that 0.5m of SLR more than double the tsunami hazard in Macau.

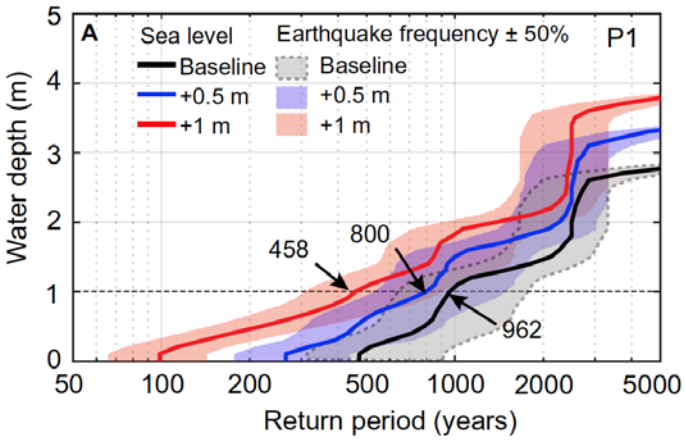
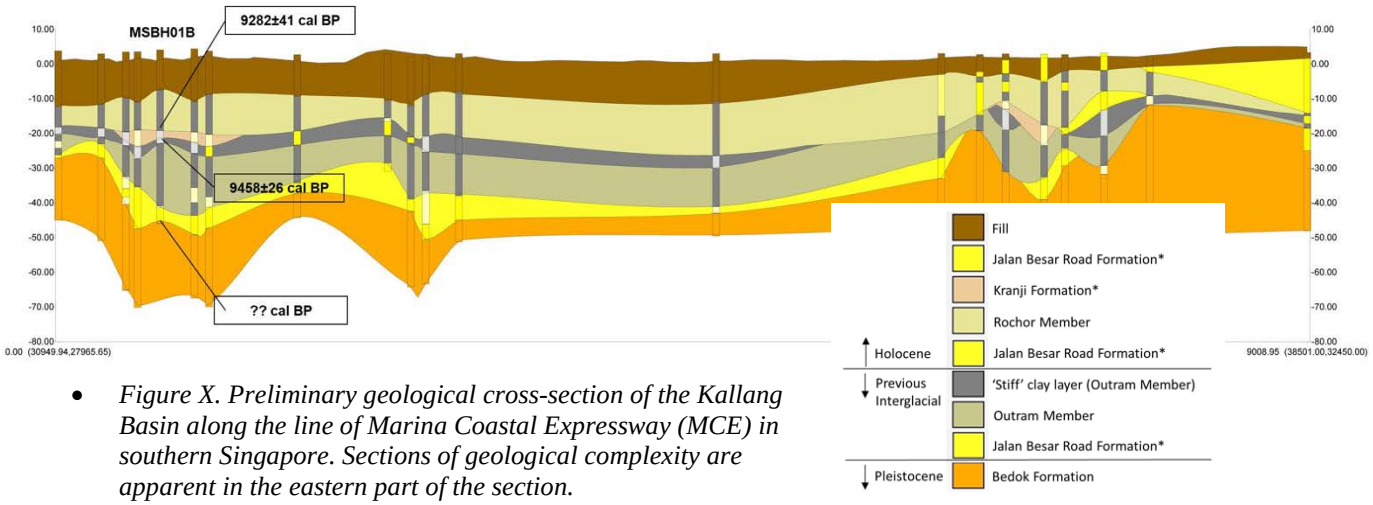


Figure - Hazard curves at the Inner Harbour location of Macau southern China. The colours represent different sea-level conditions. Black, blue, and red solid lines show hazard curves for current sea level, 0.5-m SLR, and 1-m SLR, respectively. (Li et al., Science Advances. 2018)

- Environmental geology
  3D Geological models for the Quaternary Geology of southern Singapore: EOS researchers have produced a new geological model for the downtown area of Singapore a terrane known as the Kallang Basin. The model used more than 4000 boreholes from site investigations that were condensed to 150 judged to be meet the desires for highest quality and spatial spread. The work is guiding a re-evaluation of the Holocene (last 10000 years) stratigraphy and will aid in developing a stronger understanding of the subsurface of Singapore city. New work now concentrates on refining the age structure of the sequence and investigating the 3D geology of the basin.



- *Figure X. Preliminary geological cross-section of the Kallang Basin along the line of Marina Coastal Expressway (MCE) in southern Singapore. Sections of geological complexity are apparent in the eastern part of the section.*

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Historical Cyclones, Isotopic studies, Tsunami Modeling and 3D Geological Models
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4. DATA AND INFORMATION

4.1. Summary

The Centre for Geohazard Observations manages all major field geophysical, geodetic, geochemical, and geospatial instruments and networks conducted by the Earth Observatory of Singapore (EOS) throughout Asia. It oversees the Observatory's data centre, where acquired instrumental data are pre-processed, archived, and disseminated to the scientific community, and works closely with governments and research agencies across the globe.

The Centre achieved two major targets this year, setting up a 30-station permanent broadband seismic network in Myanmar and carrying out airborne LIDAR surveys in Nepal and Myanmar.

Data gathered from the 30 new seismic stations—which include low-noise underground vaulted sensors and automated telemetry—is streamed in real-time to a central server in Nay Pyi Taw, and then relayed to the Observatory. Carried out in collaboration with Myanmar's Department of Meteorology and Hydrology and the Myanmar Earthquake Committee in Yangon, the project took more than 18 months to complete.

These 30 new stations, added to the existing five USGS sites, form the backbone of the Myanmar Seismological Network. In addition to installing these seismic stations, the team also added nine new permanent GPS stations to the existing eight operating in Myanmar, further enhancing the network's capabilities.

The airborne LIDAR studies mapped geomorphological signatures of past earthquakes along the Himalayan frontal thrust in Nepal and the Sagaing Fault in Myanmar. Using data collected from an area of 2,100 square kilometres, the team produced a digital-terrain model with decimetre-level resolution.

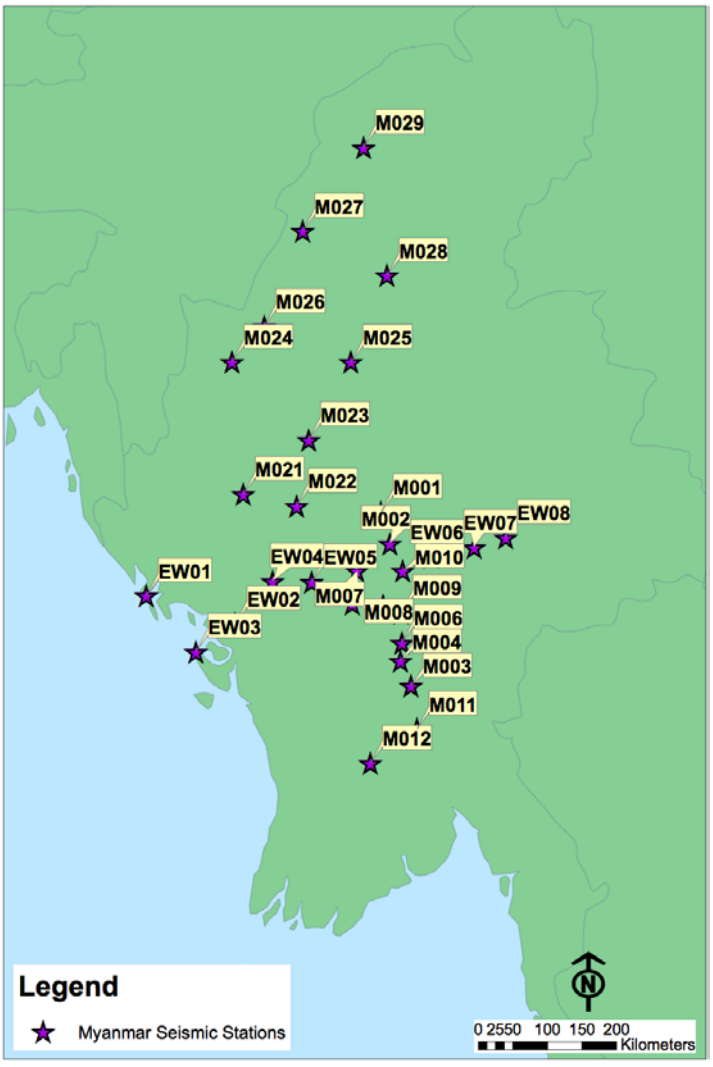
In 2017, the Technical office continued its work of maintaining seismic and GPS networks in the Mayon volcano in the Philippines, as well as at the Gede, Salak, and Marapi volcanoes in Indonesia, where the team installed a new infrasound network array.

4.2. Annual Review of Individual Technical Activities

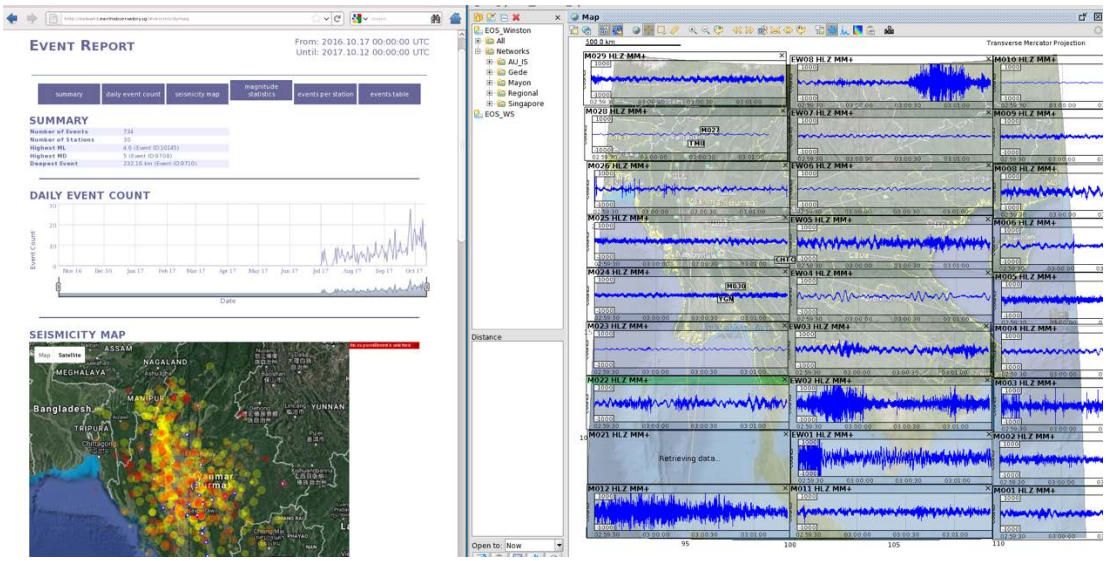
Completed activities:

- **Installation of the Myanmar Seismic Network:** The installation of the final station of the Myanmar Seismic Network was completed in July 2017, and was done so in collaboration with the . The network comprises 30 broadband seismometers scattered throughout the country from the northernmost Kachin state, all the way to the Tenasserim Division in the south. The seismometers measure ground motion, and detect the presence of seismic waves generated by earthquakes. The data collected by the seismometers is transferred by 3G telemetry to servers in Singapore and Nay Pyi Taw, Myanmar.

  As it is being transmitted in real time, the data is initially processed using a free software, which continuously assesses whether any earthquakes are occurring. Whenever the software detects the presence of an earthquake above magnitude-1.5, it locates the earthquake's precise coordinates and magnitude, and plots it as a data point on a centralised map, before sending out an automatic email notification with all the relevant information. the data provided by the MSN will eventually be open-access, and thereby available to people in all countries.



The Myanmar Seismic Network consists of 30 broadband seismic stations scattered throughout the country (Source: Centre for Geohazard Observations, EOS)



The seismic data is transferred real time by 3G telemetry to servers in Singapore and Nay Pyi Taw, Myanmar (Source: EOS)

New activities:

- **EOS' acceptance and contribution as a Data Analysis Node by Sentinel Asia:** EOS will contribute to the Sentinel Asia community by applying synthetic aperture radar (SAR) interferometry technologies to gather data that will be useful for disaster management. Besides SAR interferograms, EOS will also be contributing to Sentinel Asia by producing Damage Proxy Maps (DPM), which can be used to identify areas of possible damage to built infrastructure. EOS will also be providing Sentinel Asia with Flood Proxy Maps (FPM). These maps can be produced by estimating the change in amplitude of the SAR signal. In the presence of water, the SAR signal will reflect off the water's surface in the direction away from the satellite, resulting in a darker image pixel compared to areas with no water.

  The Sentinel Asia membership demonstrates EOS' determination and active involvement in disaster management through international cooperation, and strengthens the connection between EOS and other space technology agencies in the Asia-Pacific region.

Ongoing activities:

- **WOVOdat:** WOVOdat is a comprehensive global database established by the World Organization of Volcano Observatories (WOVO), which has a membership of ~70 observatories), and is hosted by EOS. It collects information on volcanic unrest, such as instrumentally and visually recorded changes in seismicity, ground deformation, gas emission, and other parameters from their normal baselines. WOVOdat contains now about 40% of worldwide unrest data, covering 105 volcanoes with more than 910 unrest episodes.

A robust online-interface has been created to efficiently explore and use the database. The WOVOdat team has started to develop statistical analysis to estimate the likelihood that an unrest will lead to eruption using probabilistic event tree analysis. Some of the tools have already been adopted by observatories.

- **Infrasound Monitoring for Atmospheric Studies:** Violent volcanic eruptions, common especially in Southeast Asia, pose an ongoing serious threat to aviation and local communities. However, the physical conditions at the eruptive vent are difficult to estimate. In order to tackle this problem, satellite imagery and infrasound can rapidly provide information about strong eruptions of volcanoes not closely monitored by on-site instruments. For example, the recent infrasonic array at Singapore, installed to support the coverage of the International Monitoring System, allows identification of nearby erupting volcanoes based on the characteristics of the recorded signal. But, due to its location close to the equator, seasonal changes in the wind velocity structure of the atmosphere strongly affect its potential to detect small volcanic eruptions at certain azimuths. To overcome this limit, infrasound could be augmented with satellite data. Yet, with the high average cloud cover in Southeast Asia, there are also challenges to identify weak volcanic plumes using satellite-based monitoring techniques. In this chapter, we aim to examine the relative strengths and weaknesses of the two technologies to better understand the possibility to improve overall detection capability by combining infrasound with satellite imagery.

4.2. Proposed Future Activities

- **Myanmar Seismic Network:** The data acquired by the Network will be processed by EOS researchers.

- **Sentinel Asia:** EOS' collaboration with NASA's Jet Propulsion Laboratory (JPL) will eventually allow the production of SAR interferograms, Damage Proxy Maps, and Flood Proxy Maps to become fully automatic. Together, EOS and JPL will work to develop an ARIA (Advanced Rapid Imaging and Analysis) system.

- **WOVOdat:** The WOVOdat team hopes to explore the use of volcano analogues, continue with data population with a focus in Latin America, and establish WOVOdat as a platform and reference tool for observatories during volcanic crises.

- **Volcanic Eruption; Location and Characterization using Infrasound:** Pressure waves in the atmosphere with a frequency below human hearing (~20Hz) are known as infrasound. Infrasound can be generated by a wide range of natural and anthropogenic sources, including volcanic eruptions. These waves can travel thousands of kilometers from their source, making them an excellent candidate for regional hazards monitoring. Prior work has focused on accurately assessing the detection capability of the regional infrasound network in the ASEAN region. Signal detection and atmospheric attenuation modeling will be combined into an automated eruption detection system, which has the potential to improve the monitoring of volcanic activity in Southeast Asia.

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