EOS

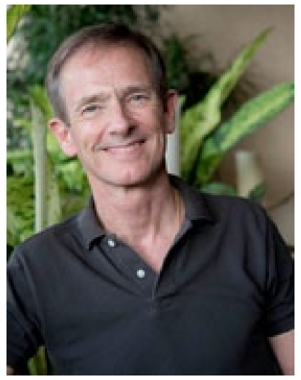
The Earth Observatory of Singapore

The Year at EOS

Earth Observatory of Singapore

Young woman working in the fields near Bardibas, Nepal.

Director's Message



Prof. Kerry Sieh
Director

The fundamental goal of the Earth Observatory is to understand how our planet works, and use that knowledge to help individuals and societies live and prosper in a sustainable way. This is in line with Singapore's four principal goals for its program of Research Centres of Excellence, begun over seven years ago. Looking over our accomplishments in this year's annual report I am pleased to see that the country's first big effort in the Earth Sciences is achieving these objectives.

We continue to attract and support top-quality researchers from Singapore and all over the globe. We have been able to build a scientific infrastructure, ranging from geochemical laboratories and computational facilities here on campus to geophysical networks with our colleagues in neighboring countries. We have become a regional and global nexus for geohazards research in Southeast Asia, and we seek to be an enduring magnet for retention of research talent for decades to come.

We are accomplishing excellent and impactful research with global impact and relevance to Singapore. The past year saw the publication of papers that will have important impacts in our research arenas. Alongside with our curiosity-driven research, our Applied Projects Group, formerly the Sustainability Group, is moving closer to meeting the immediate research needs of regional governments, businesses and communities.

We made great progress this past year in meeting our mandate to nurture Singapore's own young talent. Throughout 2013, EOS staff took the lead in conceiving of NTU's new Asian School of the Environment. We now offer a new major in Environmental Earth Systems Science and a minor in Environmental Sustainability.

We have developed strong research collaborations in the region and abroad. Just as important, we are raising the awareness of geohazards in our classrooms and in the regional public arena. And we are building durable bridges with our Southeast Asian neighbors through research, training, and collaboration.

Ancient Tsunami Records

Charles Rubin, Kerry Sieh and Patrick Daly

EOS scientists are actively exploring for new records of ancient tsunami events in Aceh Province, Indonesia. The team recently discovered a cave near the beach that is protected from the waves and stands over a meter above the tide. Digging into the cavern floor, the scientists discovered perfectly preserved layers of sandy sediments left behind from tsunamis over the past 8000 years. The discovery of such well-preserved tsunami records has the potential to increase our understanding of natural hazards in West Sumatra.

Radiocarbon analysis of charcoal fragments and shells suggest the interval between tsunamis is on average every 400 years. But variable recurrence intervals hint that events may occur in flurries of closely-timed ruptures.. Thus far, evidence of tsunami events has been found, including the devastating 2004 Indian Ocean tsunami event that claimed the lives of nearly 250,000 people.

The EOS team is in the process of using this data to fine-tune the timeline of earthquakes and tsunamis in the region. However, this evidence is still insufficient to predict with absolute certainty when the next tsunami will take place. The insights gained from this discovery will help communities along Aceh's coast to better prepare for such disasters.

EOS scientists discovered a hidden cave close to a beach in Aceh Province.

Kerry Sieh explains the different rock layers that have been deposited over several millenia.

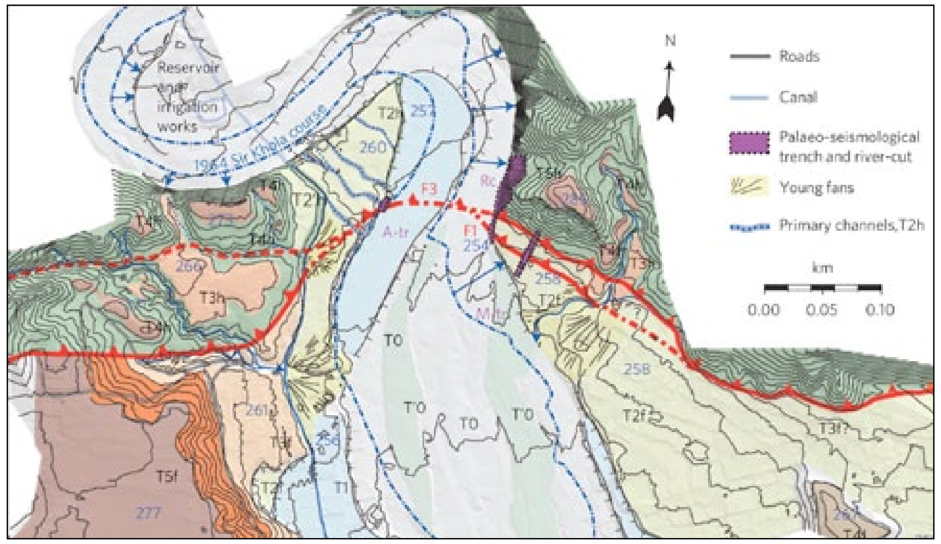
Above: Charles Rubin (R) and Kerry Sieh (L) examine sediment deposits under the glow of fluorescent lights.

Above: Beautiful trench wall reveals tsunami events and fracturing from ground shaking. The 2004 tsunami sand sits atop multiple ancient tsunamis.

Top left: The scientists discuss the relations between layers of tsunami sand and organic bat guano. Counterclockwise, L to R: Kerry Sieh, Charles Rubin, Patrick Daly, Jedrzej Majewski, and Ben Horton.

Top of page: Charles Rubin (L) and Kerry Sieh (R) take measurements along the coastline south of Banda Aceh.

Paul Tapponnier searches for charcoal samples to be used in radiocarbon dating. Charcoal is sampled where active faults occur.



Top of page: An aerial view of the Himalayan Front with the Sir Khola and Jangha rivers cutting across the vast Gangetic plain. Photographing represents a powerful way to gather evidence that can be used to find indicators of active faulting.

Map: The team mapped the active faults and geomorphology of the Sir Khola outlet on a high-resolution topographic image. Map from Sapkota et al., 2013.

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Opposite page, top: The amount and size of charcoal specimen given to the processing laboratory is crucial in ensuring accurate radiocarbon dating.

Nepal Surface Rupture

Paul Tapponnier

The last earthquake to occur in the Himalayas was the MW~8.2 Bihar-Nepal earthquake in 1934, one of the most devastating quakes Nepal and India had experienced. Paul Tapponnier's team ruled out an 80-year-old consensus when they found a surface rupture at the thrust's fault and proved that the latest great Himalayan faults were not "blind."

With a preliminary record of seven great earthquakes in the last 4,500 years, the team found out that two had ruptured the surface. Through morphological and paleoseismological studies along the active Main Frontal Thrust, they uncovered traces of the 1934 quake's surface rupture in the Sir Khola and adjacent valleys. They also discovered that the AD 1255 earthquake that had devastated Kathmandu also broke the surface at the same place, providing the first return time of 680 years of such catastrophic earthquakes.

Research fellows extracting charcoal specimens in a 1.5-meter trench.

Explosivity of Merapi

Fidel Costa

Mount Merapi spews sulphuric gases due to seismic activity. This type of event might take place for weeks at a time.

Fidel Costa (second from left) explains volcanic phenomena during the teachers' field seminar at Mount Merapi, Indonesia.

Merapi is one of the most explosive volcanoes in Southeast Asia and the world. In 2010 the volcano produced its largest and most explosive eruption in over a century. Even as it remains one of the most hazardous volcanoes in the world, little is known about Merapi and the processes that control the timing and size of its eruptions. Fidel Costa and his team have embarked on a study of the explosive eruptions of Merapi, hoping to unravel these processes with the early monitoring signals before the eruption.

Through geochemical and mineralogical studies, Fidel Costa's team was able to determine that the cause of the eruption was the fast ascent of a voluminous, bubble-rich, hot liquid from over 30 kilometers under the volcano.

The clues to what could have triggered the eruption are locked in the structure of the crystals found in volcanic rocks. The patterns of elements found in these crystals are good indicators of the volcanic processes because crystals are shaped by changes in gas composition and temperature, similar to how tree rings record changes in climate and environment.

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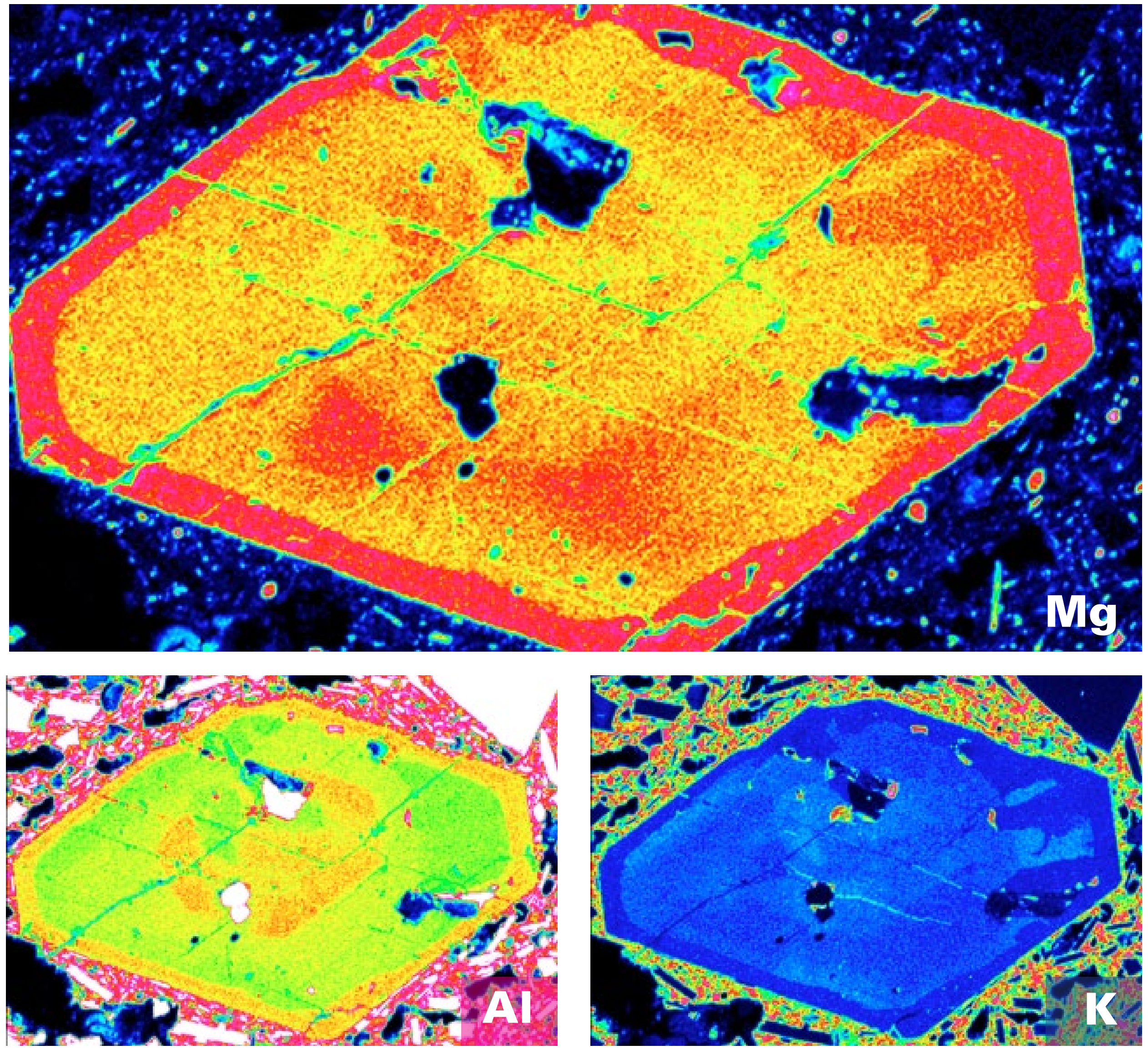


Top of page: View of Merapi on a windy day just before it is hidden by clouds.

The research conducted by the forensic Volcano Petrology team involves analysing Merapi's volcanic rocks. This aids in understanding the processes that take place inside magma chambers during eruptions. The team is one step closer to unraveling the cause of explosive eruptions. Viewed through an electron microscope this amphibole crystal shows areas with varying concentrations of magnesium (top, yellow), aluminum (green) and potassium (blue).

Typhoon Haiyan

Adam Switzer

Scientists take auger cores to discover the thickness and extent of the sand eroded mostly from the beach and deposited inland by the storm surge in Tanauan, Leyte.

Scientists measure maximum flood heights in Tacloban City based on survivors accounts. Coastal lab scientists investigate the geological record of storms and tsunamis in Southeast Asia.

In November 2013, super typhoon Haiyan struck central Philippines, leaving a trail of damage in its wake. The Coastal Lab team, headed by Adam Switzer, conducted storm surge reconnaissance in the vicinity of San Pedro Bay and in the coastal city of Tacloban–the worst-hit city in the country. They also interviewed eyewitnesses and analyzed video recordings. The scientists also paired their surveys with other analyses in order to characterize Super typhoon Haiyan's inundation.

Using digitized local bathymetric charts and *Delft3D Flow* software, they generated a model that simulated surge heights on the open coast and within San Pedro Bay and compared it with a 1897 typhoon—dubbed Ty 1897 by EOS scientists— of similar magnitude. Storm surge heights from Ty 1897 ranged from four to seven meters, devastating cities as it crossed the Philippines in a similar path. The team found out that Haiyan, with surge heights of five to seven meters, was unprecedented in San Pedro Bay but comparable to Ty 1897 on the open Pacific coast. Together with its 1897 predecessor, Haiyan teaches lessons on disaster awareness, response, and mitigation; all issues relevant to sustainable societies.

Top of page: Survivors recount their personal experience of the storm surge while PhD student Lea Acierto Soria listens. The accounts of the survivors on the timing and depth of flooding are valuable in reconstructing and validating storm surge models. Tacloban City, Leyte November 2013.

Ships washed ashore by the 7 meter storm surge in Anibong village, just north of downtown Tacloban. Two months after the event, stilt houses were rebuilt seaward of the stranded ships.

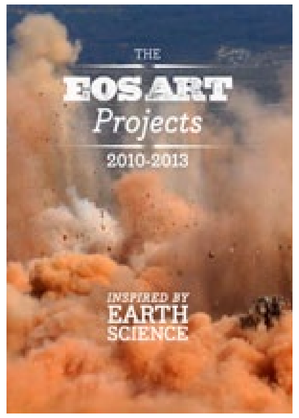
Scientists measure reef boulders transported during typhoon Haiyan on a wave-cut terrace in Hernani, Samar.

RESEARCH #
82–96–97

The EOS ART Projects

Clara Balaguer, Carlos Casas, Chen Sai Hua Kuan, Isaac Kerlow, Sutthirat Supaparinya, Robert Zhao, and Zhang Xiao

Above: Coastline, by Zhang Xiao presents human life along the Chinese coast as well as some of its negative impact on the natural environment. This image presents a group of construction workers in Shandong coming into contact with the sea for the first time.



Cover of the exhibition catalog featuring a still frame from *When Need Moves the Earth*, by Sutthirat Supaparinya is a video installation of an explosion of a coal mine reflects the possible consequences of human activities on the environment.

The six projects produced between 2010 and 2013 under the art residencies at EOS are inspired by Earth science, natural hazards, and humans living in high risk areas.

These interdisciplinary projects were showcased at the Singapore Art Museum as part of the *Unearthed* exhibition, and augmented with a series of seminars for young students about the interactions of science and art.

The Possibility of Knowing, by Robert Zhao Renhui, is part of a project of images about the Indonesian cities of Padang and Banda Aceh.

Opposite page, lower right: Sound of the Earth, by Chen Sai Hua Kuan is an experimental sound installation that harnesses the power of wet soil to produce sound.

Above (L and R): Lupang by Clara Balaguer and Carlos Casas. These stills of the video installation feature a member of the Ayta tribe relocated to a new area after the Mount Pinatubo eruption.

FRACTURED
பிளவுபட்ட
PATAH
断裂

CRUSHED
HANCUR
நசுக்கப்பட்ட
压碎

is a project about the uneasy relation between Man and Nature. Multilingual signs in English, Chinese, Malay, and Tamil list some of the destructive actions typical of natural hazards.

RESEARCH #
34

Climate Research

气候

Iklim

தட்ப வெப்பம்

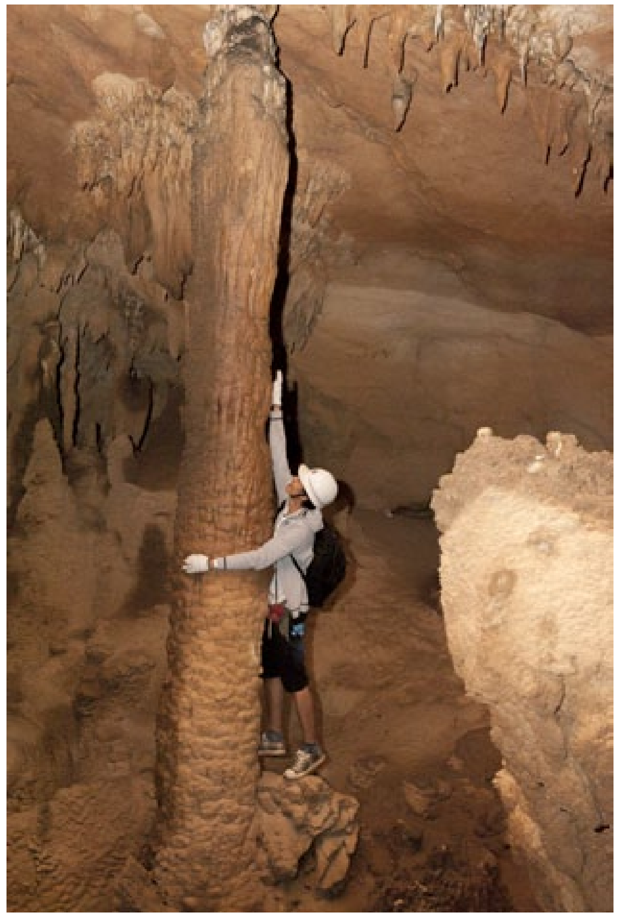
Climate research at EOS concentrates on regional climate monitoring, and the measurement and modeling of past and modern tropical climates. EOS aims to fill a gap of much-needed information on climatic forces in Southeast Asia, including the Western Pacific Warm Pool and the Indian Ocean Dipole, which will allow better prediction of regional consequences that can expected from global climate change.

Indo-Pacific Hydroclimatic Variability

Wang Xianfeng

The tropical Indo-Pacific Oceans hold the warmest ocean water in the world, and are crucial to maintaining the balance between global atmospheric water and energy in this region. Any dramatic hydroclimatic change here may threaten the livelihood of more than half of the world's population. Funded by a NRF fellowship and collaborating with colleagues from neighboring countries, the Isotope Geochemistry team is working to reconstruct the spatial and temporal pattern of rainfall change in the tropical Indo-Pacific by using cave carbonates called speleothems. High-precision uranium-thorium (U/Th) dating techniques are used to determine the ages of these speleothem samples. Stable isotope and trace metal analysis are also employed in the reconstruction of regional rainfall patterns.

The knowledge acquired can be used to understand three issues: how astronomical forcing drives the hydroclimate change in the Indo-Pacific; whether the tropical Indo-Pacific was dry during the glacial maximums; and if the monsoonal rainfall in the region has already been disrupted by the effects of human activities.



An EOS scientist reaches up to examine a speleothem in a Myanmar cave. Samples from these hidden carbonates can provide insight into historical rainfall patterns.

RESEARCH #
11–12–19–22
77–88–90

Haze from Forest Fires in Southeast Asia

Mikinori Kuwata

A peat swamp forest in Sumatra is burned to clear land for plantations. The atmospheric chemistry research team currently focuses on investigating the chemical composition and properties of aerosol particles emitted by tropical Asia's forest fires. Haze from forest fires reduces visibility and poses a hazard to air travel.

Peat swamps are a big reservoir of carbon and they are abundant in Kalimantan (Borneo) and Sumatra. Peat becomes the fuel that keeps the forest fires going—a peat layer can range from five to ten meters thick.

Maximally between 30 to 50 centimeters of peat burns up when a forest fire starts, which means that a lot of fuel is burnt within a small area. The amount of carbon accumulated in peat makes it difficult to completely extinguish forest fires once they start. In 1997, for example, during one of the most heated forest fires in Indonesia, the carbon fuel consumption of peat fire alone accounted for nearly 40% of Indonesia's fuel consumption that year.

By tracing the chemistry of particles emitted from peat burning, the team seeks to arrive at a more accurate simulation of haze in the Southeast Asia.

RESEARCH #
40

Unlocking Climate Secrets

Nathalie Goodkin

Teamwork and coordination is required when carrying out labor-intensive fieldwork. A hydraulic drill is used to extract coral samples off the coast of south Taiwan.

Nathalie Goodkin passes a sample of Porites coral to a scientist aboard the research vessel.

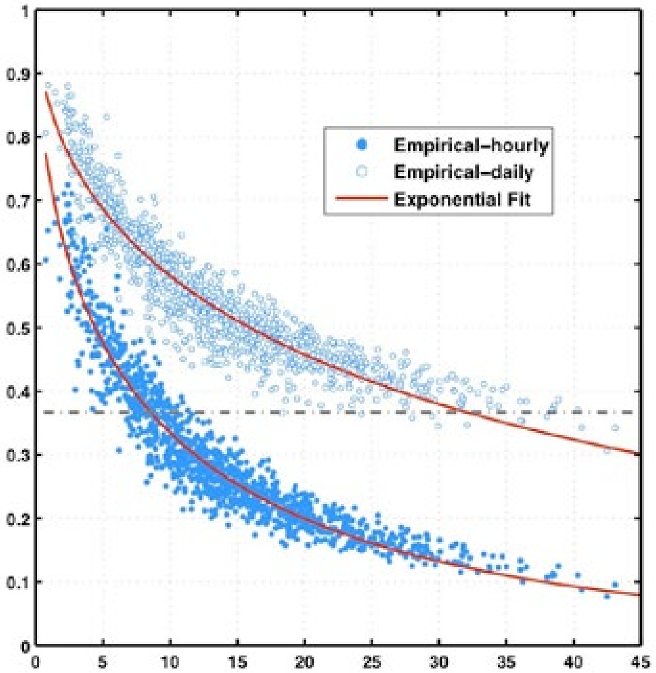
The Marine Geochemistry team traveled to Checheng, Southern Taiwan, to investigate Earth's climate history through the study of corals. This region is where the Kuroshio Current intrudes into the South China Sea. They extracted samples of the *Porites* coral species that are approximately 300 to 500 years old, as well as seawater in which these corals grow.

Because the chemical composition of corals depend on the seawater in which they grow, testing the coral samples can give an indication of the temperature and salinity of the surrounding seawater. With these results, the team is able to reconstruct global climate and weather systems throughout several centuries.

RESEARCH #
4–64–94

Singapore's Hydroclimate

Qin Xiaosheng



To understand temporal and spatial structure of rainfall in Singapore and surrounding regions for a wide range of scales, and to study their impact on urban hydrology under changing climate conditions.

The Hydroclimatology group focuses on deriving statistical relationships and forecasting smaller-scale weather details based on large-scale climate variables. The aim of the research is to develop tools and a framework to better understand local weather and climate.

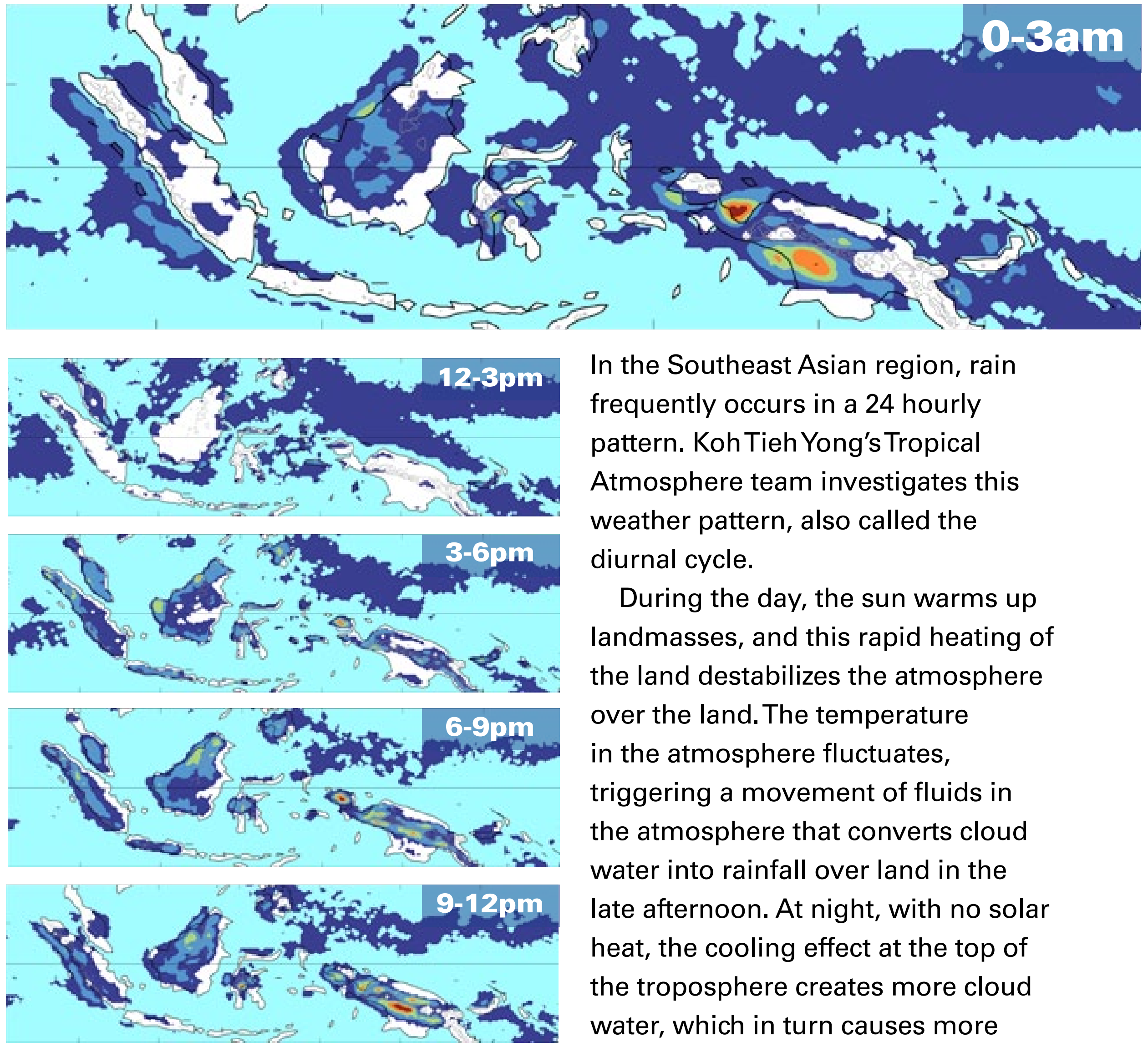
This project involves characterizing Singapore's rainfall intensity distribution and its multiscale variability by using statistics called L-moments to identify rain rates over a period of time. These ratios are then compared between probability models (theoretical three-parameter skewed distributions) to determine which best suits precipitation rates.

Besides investigating products that measure precipitation in Singapore, the scientists also characterise and model the small-scale spatial structure of local rainfall. This is crucial to both the distribution of rainfall data breakdown and its analysis from master to satellite stations. The findings yielded may facilitate other climate change studies and the assessment of flood risks in Singapore.

RESEARCH #
31–50–51
52–55

Weather and Climate Cycles in SE Asia

Koh Tieh Yong



These time simulations created for the tropical atmosphere research show 3-hour average accumulated rain samples throughout the day, in Singapore time (SGT).

In the Southeast Asian region, rain frequently occurs in a 24 hourly pattern. Koh Tieh Yong's Tropical Atmosphere team investigates this weather pattern, also called the diurnal cycle.

During the day, the sun warms up landmasses, and this rapid heating of the land destabilizes the atmosphere over the land. The temperature in the atmosphere fluctuates, triggering a movement of fluids in the atmosphere that converts cloud water into rainfall over land in the late afternoon. At night, with no solar heat, the cooling effect at the top of the troposphere creates more cloud water, which in turn causes more rainfall over open seas.

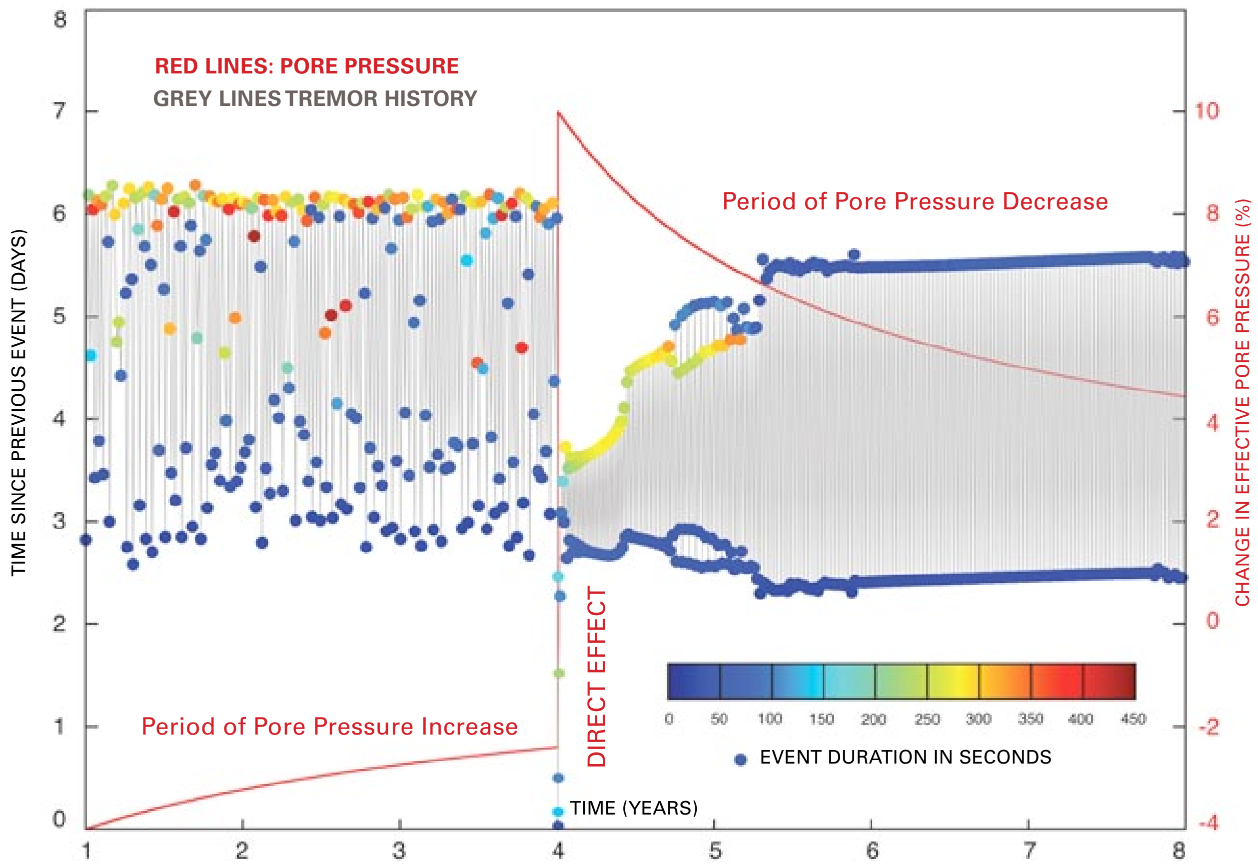
RESEARCH #
39

Tectonics Research

The broad goal in this area of EOS research is to increase fundamental knowledge of the region's tectonic and seismic behavior, as a basis for more reliable forecasting of earthquakes and tsunamis as well as actions to reduce the potential hazards.

When the Earth Ticks Like a Clock

Sylvain Barbot



A physics-based model of the earthquake cycle helps to assess the full range of seismic behavior that can be expected across a plate boundary.

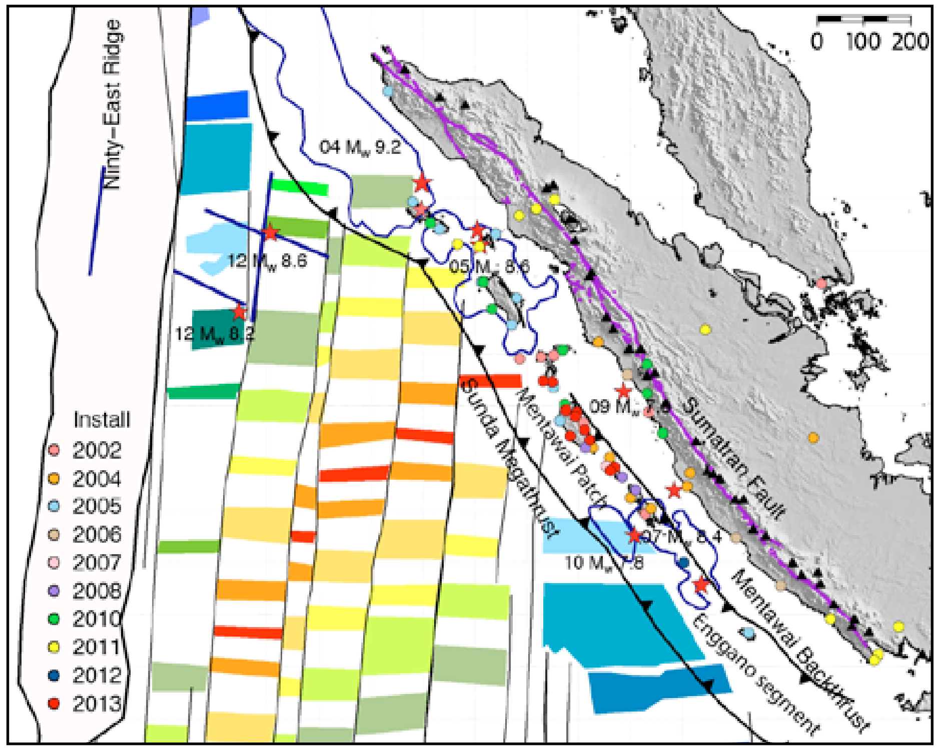
Parkfield is a small community located in Southern California, and is also situated along the San Andreas fault. The Parkfield segment of the fault has frequently experienced strong earthquakes throughout history, and this Earthquake Physics project analyzes the unusual tectonics behavior observed in this region.

Earthquakes usually occur after a fixed period. However, the seismic history at Parkfield shows a series of tremors at irregular intervals. The research team led by Sylvain Barbot developed a unique simulation model, with significant contributions from Deepa Mele Veedu, that reproduces the Parkfield tremor activity including one thousand events, and is using this model to zero in on their study of earthquake recurrence patterns.

RESEARCH #
2–9

Sumatra Geodesy Project

EMMA HILL



Combining multiple geodetic data sets helps to separate the different signals in the data, and to provide better-constrained models for earthquakes and sea-level change.

RESEARCH #
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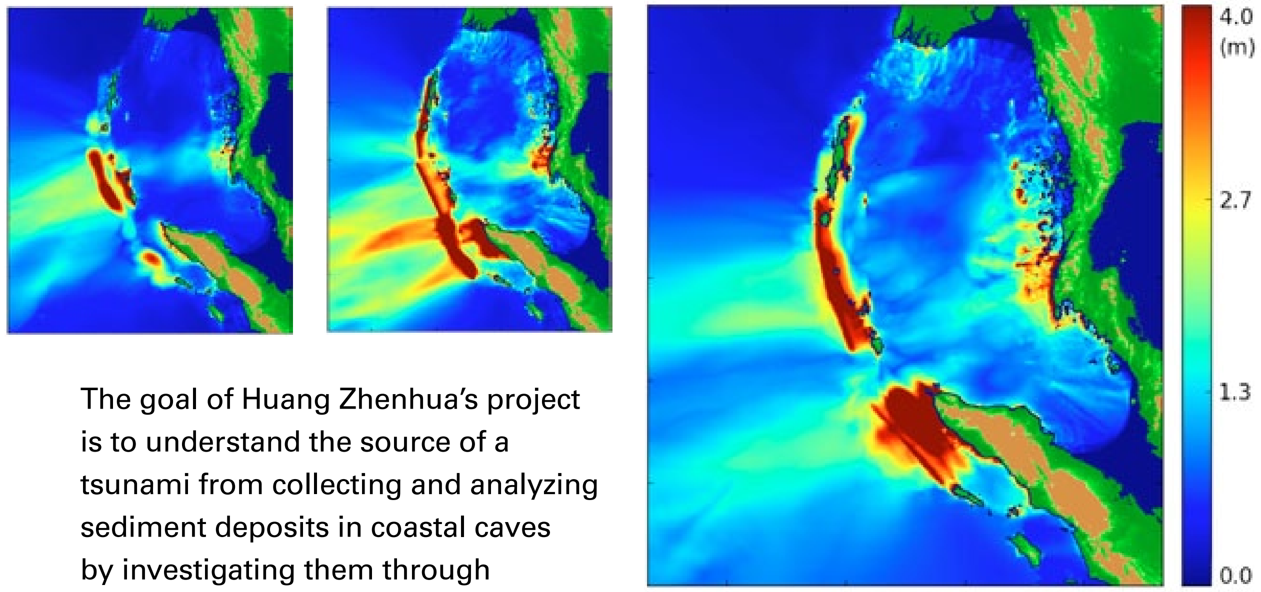
The Indonesian island of Sumatra is an area with high seismic activity. This is why EOS scientists and engineers have installed the 60-station Sumatra GPS Array (SuGAr) to monitor seismic behavior. Data obtained from GPS signals transmitted during seismic activities helps them understand the processes and hazards associated with active tectonics in the area. The Geodesy Group traces the behaviour patterns of the Mentawai seismic gap and segments of the Sunda megathrust that may potentially cause a large earthquake in the near future. The team also keeps track of slip patterns of the Great Sumatran Fault, the seismic behavior in the aftermath of large earthquakes, as well as the megathrust's potential for seismic and tsunami activity. With the GPS data, they can also calculate the possibility of an earthquake's occurrence and whether the megathrust experiences gradual plate movement. The information gathered gives scientists insight into impending earthquakes and tsunamis that may occur in the region.

Tsunami Heights and Sediment Deposits

HUANG ZHENHUA



The goal of Huang Zhenhua's project is to understand the source of a tsunami from collecting and analyzing sediment deposits in coastal caves by investigating them through laboratory experiments. Tsunami deposits are formed when tsunami waves propagate in the inland area. The features of tsunami deposits, such as spatial distribution, thickness, and grain size, are indicative of the features of tsunami waves. His research employs a combination of numerical modelling, hydraulic lab testing, as well as field observations, to investigate actual tsunami events.

Numerical experiments are then used to relate characteristics of the sediment deposition in a cave to the tsunami source. With the information derived from tsunami deposits, we can better understand the locations and nature of the source earthquakes that generate tsunami waves.

Zhenghua's team found that slip distribution, geometry of the tsunami source, bathymetry, and directivity affect the extent of near-shore tsunamis. They also discovered that the landward extent and elevation of tsunami deposits are indicative of tsunami size.

RESEARCH #
95

The Ratu River Expedition

Judith Hubbard

Top of page: Members of the team take a photo with the newly arrived six-ton seismic truck.

A close up of the mechanism that vibrates the ground to produce sound waves for visualizing the underground rock layers.

Nepal is home to the Himalayas, which continue to grow as the Indian and Eurasian plates converge. This motion occurs along the Main Frontal Thrust, a fault that has recently been identified as the cause of the highly destructive 1934 Nepal earthquake. Judith Hubbard and the structural geology team embarked on an expedition to the Ratu River - which crosses the fault and is exposed during the dry season - to find out what the fault looks like beneath the Earth's surface.

The team uses an *EnviroVibe* seismic truck, as well as a set of 264 geophones, to detect ground vibrations that pass through the subsurface. The scientists collect the data in the field, then process and analyze it in the lab to visualize the Earth's subsurface. The researches then match the seismic data to field observations, such as bedding planes or rock deposits.

Understanding the shape of the fault allows the scientists to predict how slip on the fault in an earthquakes should deform the Earth's surface, and therefore to translate the record of ground deformation into an estimate of slip in past events. Learning about the past behavior of this fault system is key to forecasting how it may behave in the future.

RESEARCH #
29–47–89

Volcano Research

எரிமலை

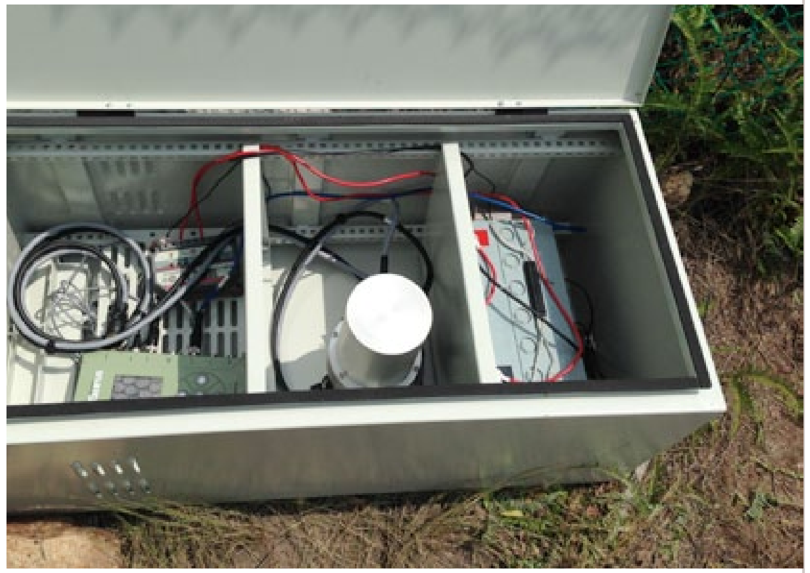
火山

Gunung Berapi

The EOS Volcano Group conducts geologic, geochemical and geophysical studies to improve understanding of volcanic activity, particularly processes related to eruptions. They aid in forecasting volcanic eruptions, assessing their environmental and societal impacts, and mitigating risk.

Monitoring of Volcanoes with Infrasound

Benoit Taisne



Benoit Taisne, standing in the middle, sets up a temporary infrasound sensor with his team at Bukit Timah Nature Reserve (L to R): Sorvigenaleon Ramos from the Technical Office, Corentin Caudron, Benoit, and Patrick Whelley.

Details of the acquisition system for one point. From left to right: digitizer and data transmission, sensor and battery. The full infrasonic array is composed of five similar setups.

Benoit Taisne's Lab Volcanoes' project aims to understand the timing, rates and other details of the magma supply for different volcanoes in order to improve forecasts of future eruptions.

Hundreds of volcanoes surround Singapore, and these volcanoes are natural sources of infrasound. This project aims to detect and classify recorded infrasound signals during a volcanic explosion. Infrasounds are atmospheric low-frequency sounds below the 20 Hz threshold of human hearing. They are generated during the explosive release of magma and gas, and can be recorded at large distances making them a robust indicator that an eruption has occurred. In Singapore, this technology is particularly interesting to detect, locate and characterize major remote volcanic eruptions. The team's first infrasound array in Singapore is set up at the MacRitchie Nature Reserve.

RESEARCH #
85

Assessing Hazards from Sumatran Volcanoes

Caroline Bouvet

Among the 130-odd volcanoes in Sumatra, Indonesia, only a few have been studied by geologists. What makes investigating these volcanoes important is their close proximity to the 47 million inhabitants of the Indonesian island. Caroline Bouvet's research assesses both active and potentially active volcanoes, their morphologies, and eruptive activities—identifying those with a high potential to erupt frequently and explosively—in order to understand unrest signals and forecast eruptions. This is accomplished by employing methods that involve examining the sediment strata of volcanoes, their shapes and forms, as well as focused studies of their locations. Insight into the characteristics and recurrence of a volcano's eruption can be gained by referencing the history of eruptions. These methods can address the eruptive activity of Sumatra as a whole, initiating investigation of key locations.

Sumatran volcanoes and population density. Studying Sumatra's volcanic activity and accessing eruption hazards in order to set recovery plans in motion.

RESEARCH #
14

Art+Media Research

Isaac Kerlow

The Art+Media Group explores innovative methods for communicating Earth science to a wide audience. This group is also focused on raising the level of community engagement and regional preparedness that can ultimately lead to safer and more sustainable societies. The interdisciplinary projects developed and produced by this team involve research in the areas of storytelling, interactive media, film and animation.

Earth Girl 2: Preparing for the Tsunami is an interactive casual strategy game about making strategic decisions that can directly increase the survival rate in coastal communities during earthquake and tsunami scenarios. Earth Girl is the host and guide, and the player is the protagonist.

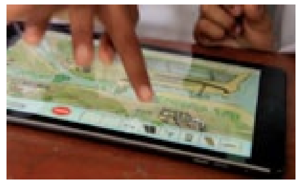
The game was developed by an interdisciplinary team of game artists and scientists at the Earth Observatory of Singapore. Earth Girl 2 is based on real-life situations, with an emphasis on learning preparedness and survival skills. It was inspired by the kids who live in coastal communities throughout Asia, and by the stories told by survivors of recent tsunamis.

RESEARCH #
35–36–37–38

INSPIRE
ENTERTAIN
INFORM
TRANSFORM

Players can explore each level in the iPad App, looking for weak spots that can be enhanced with selected tools. The strategies laid out by the player drive a crowd simulation interactive system.

At the market, players hear a variety of opinions about tsunamis. They must use their judgment to distinguish between fact and fiction.



Students at an elementary school in Padang, Indonesia, collaborate and learn about tsunami preparedness using the *Earth Girl 2* casual strategy game.

Monitoring Hazards

PARAMESH BANERJEE

GPS Networks

The Sumatran GPS Array, SuGAr, is a network of 60 GPS stations that spans more than a thousand kilometers along the convergent boundary between Indo-Australian and Asian tectonic plates.

SuGAr is the most extensive of all the Observatory's field-monitoring efforts, and it is maintained by the Technical Office lead by Paramesh Banerjee. Most of the stations are in Sumatra, directly above the Sunda megathrust, the giant fault that produced great earthquakes in the 2000s. The tsunami triggered by the 2004 earthquake killed about 250,000 people in India, Thailand and Sumatra.

The Myanmar-Bangladesh-Assam GPS Network comprises 22 GPS stations and it monitors the ongoing collision of two of Earth's continental plates–the Indo-Australian and Eurasian plates. This is the site where some of the Earth's greatest earthquakes have occurred over the past few centuries.

Lab Volcanoes

The Observatory's volcano-monitoring facilities enable fundamental research on volcanoes at the Mayon volcano in Luzon, Philippines, and the Gede-Salak volcano in West Java, Indonesia. The Technical Office staff maintains the equipment and the Volcano scientists lead the research projects that utilize the sensors. The Lab Volcanoes are aimed at understanding the timing, rates and other specifics of the magma supply of different volcanoes, in order to improve forecasts of future eruptions.

The Technical Office at EOS works closely with local authorities, research and educational institutions both in Singapore and overseas in its monitoring efforts. The observatory has invested in a variety of modern experimental, laboratory and monitoring instruments to gather essential data for its research projects. Field monitoring relies primarily on networks of GPS, seismic and ultrasound instruments.

Most of the SuGAr GPS stations are installed in remote locations throughout Sumatra and the Mentawai Islands, in Indonesia (see pages 46–47).

Sustainability

Andreas Schaffer

The goal of the Sustainability Group is to harness geo-science for safer livelihoods and to safeguard economic assets in the region. The group identifies the needs and strategies of international organizations and governments and develops for them customized solutions for geo-risk mitigation and sustainability.

The Sustainability Group works with government agencies and private sector organisations in the region to apply geo-hazards knowledge in projects such as infrastructure development, disaster resilience planning and climate change adaptation. Against the backdrop of a rapidly developing Southeast Asia, the Sustainability Group acts as a bridge, broker and catalyst to fulfil EOS's mission of achieving safer and more sustainable societies in and around the region.

The group also serves as a commercial transfer function for EOS – generating economic value in Singapore by providing world class market oriented geo-hazards solutions through three avenues: geo-hazard assessments and technical consultancy services; provision of technological solutions through partner organisations; and facilitation of multi-stakeholder workshops and programmes.

RESEARCH #
27–74

Education and Outreach

Susan Eriksson

EOS contributed to the development of Earth science exhibits at the Singapore Science Centre.

Top left: EOS volcanologists and educators brought teachers on a field seminar to Mount Merapi, Indonesia.

The Education and Outreach department works with internal and external media to build public's awareness in Earth science research. Some of the outreach efforts include engaging informal education, field seminars, and museum exhibits.

EOS volcanologists and educators took 27 teachers from Singapore on field seminars at the Batur and Toba volcanoes in Indonesia. These field experiences, including workshops before and after the trip, aimed to deepen the teachers' content knowledge of plate tectonics and volcanoes in Southeast Asia and their impact on people. The trips also sought to enhance teachers' skills in designing and facilitating inquiry-based learning so that secondary students may benefit from it. The teachers' evaluations were highly encouraging, with many considering this a valuable professional development. Many have incorporated this learning in their classroom teaching and shared it with their colleagues, and that their students are benefiting as a result.

Degree Programs

Charles Rubin

The Division of Earth Sciences (DES) was founded in 2011 as the academic arm of the Earth Observatory of Singapore (EOS). Renamed as the Asian School of the Environment (ASE) it first offered a PhD in Earth Sciences, and later a Bachelor of Science degree in Environmental Earth Systems Science, as well as a minor in Environmental Sustainability open to all NTU students.

The pioneer cohort of students comes from a variety of personal and academic backgrounds. These students work with professors, visiting scholars, and researchers from over 20 different countries and ten different fields.

Earth Systems students forged friendships over food as they share a laugh with researcher and faculty memberJudith Hubbard.

Students pose for a photo with Charles Rubin, Head of NTU's new Asian School of the Environment.

It was a fun-filled evening at the students' welcome barbecue as students made new friends to see them through the fresh-man year.

Research Documents

2013/2014

List of research authored by principal investigators, research fellows, staff members, and PhD students at the Earth Observatory of Singapore roughly between January 2013 and May 2014.

Principal Investigators

Sylvain Barbot: 2, 9, 49
Caroline Bouvet Maisonneuve: 14, 66
Fidel Costa: 1, 14, 23, 30, 32, 59, 63
Nathalie Goodkin: 4, 64, 94
Emma Hill: 98
Huang Zhenhua: 10, 28, 45, 46, 95
Judith Hubbard: 29, 47, 89
Isaac Kerlow: 34, 35, 36, 37, 38
Koh Tieh-Yong: 39, 48
Mikinori Kuwata: 40, 68, 75
Qin Xiaosheng: 31, 50, 51, 52, 55
Charles Rubin: 24
Kerry Sieh: 5, 91, 92, 98
Adam Switzer: 24, 25, 43, 65, 79, 80, 81, 82, 83, 96, 97
Benoit Taisne: 85
Paul Tapponnier: 44, 73
Wang Xianfeng: 11, 12, 19, 22, 77, 88, 90

Staff

Malinda Kent-Corson: 6, 33
Dorinda Ostermann: 4
Andreas Schaffer: 27, 74

Research Fellows

Annette Bolton: 3, 4, 57, 58
Chiang Hong Wei: 54, 92
Reshmi Das: 8, 17
Feng Lujia: 53, 67, 76
Christos Gouramanis: 24, 25, 43, 82, 87, 93, 96
He Shaoneng River: 69
Iwan Hermawan: 72
Jason Scott Herrin: 7, 15, 16, 30, 70, 84, 86
Dannie Hidayat: 26, 53
Li Lin Lin: 45, 46
Kenneth Macpherson: 53
Pradeep Venkata Mandapaka: 21, 55, 56
Patrick Martin: 18, 20, 60, 61, 62
Aron Meltzner: 5, 42
Jeremy Pile: 13, 97
Teo Chee Kiat: 39
Wang Yu: 91, 92
Patrick Whelley: 65
Christina Widiwijayanti: 71
Yu Fengling: 78, 82, 96, 97

PhD Students

Társilo Girona: 23
Sujata Annavarapu Murty: 41
Pham Tien Dat: 24, 43, 82
Qiu Qiang: 46
Sim Yisheng Shawn: 28
Janneli Lea Acierto Soria: 43, 82
Yang Teng Teng: 94

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***GALENA**, PbS*
Missouri, USA

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TOURMALINE
$NaFe^{2+}_3Al_6Si_6O_{18}(BO_3)_3(OH)_3OH$
Minas Gerais, Brazil

***BARITE**, $Ba(SO_4)$*
Nevada, USA
(Opposite page)

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Research Technology

Mass Spectrometer

This state-of-the-art facility supports a variety of cutting-edge research in low-temperature geochemistry, climate, and environmental change through high-precision isotope analyses, with an emphasis on isotopes of U, Th, Sr, Nd, Pb and Hg by using an inductively-coupled plasma as a highly efficient ion source. Equipped with nine Faraday cups and two ion counters for simultaneous isotope collection, it dramatically increases the overall efficiency and precision of isotopic measurements.

Laser Ablation System

Boasting a precision of 1 to 400 micrometers, this system determines trace amounts of almost any chemical element. The presence of trace elements in certain environments can provide clues about the environmental conditions that existed during their growth. Materials that are chemically analyzed at EOS with this instrument include igneous rock crystals, speleothems, corals, microfossils, fish otoliths and scales, and organic tissues.

Isotope Mass Spectrometer

This instrument measures the relative abundance of isotopes in a given sample, for example, oxygen isotopes in coral skeletons. These ratios incorporated during the organism's growth process are used as an indicator for measuring sea surface temperature and salinity through time. The data acquired may allow scientists to determine climate and other environmental conditions that were present.

Clean Room

Specially designed, this metal-free chemistry clean laboratory is used to prepare samples for mass spectrometric measurements. Equipped with a dedicated air handling unit and HEPA filters, this lab exceeds Class 1,000 conditions. Features include a main chemistry room containing five fume hoods, one horizontal laminar flow workstation, six working benches for sample digestions, chromatographic separations, and trace element purification.

IVI Envirovibe Truck

The IVI Envirovibe is a seismic vibration truck used to image subsurface faults in places like Nepal, Bangladesh, and Myanmar, where EOS conducts research projects. This mammoth machine works with a set of sensors detecting ground vibrations. The data is processed, providing high-resolution seismic reflection profiles that enable the EOS tectonics team to unravel fault behavior and fold growth in seismically active and densely populated regions.

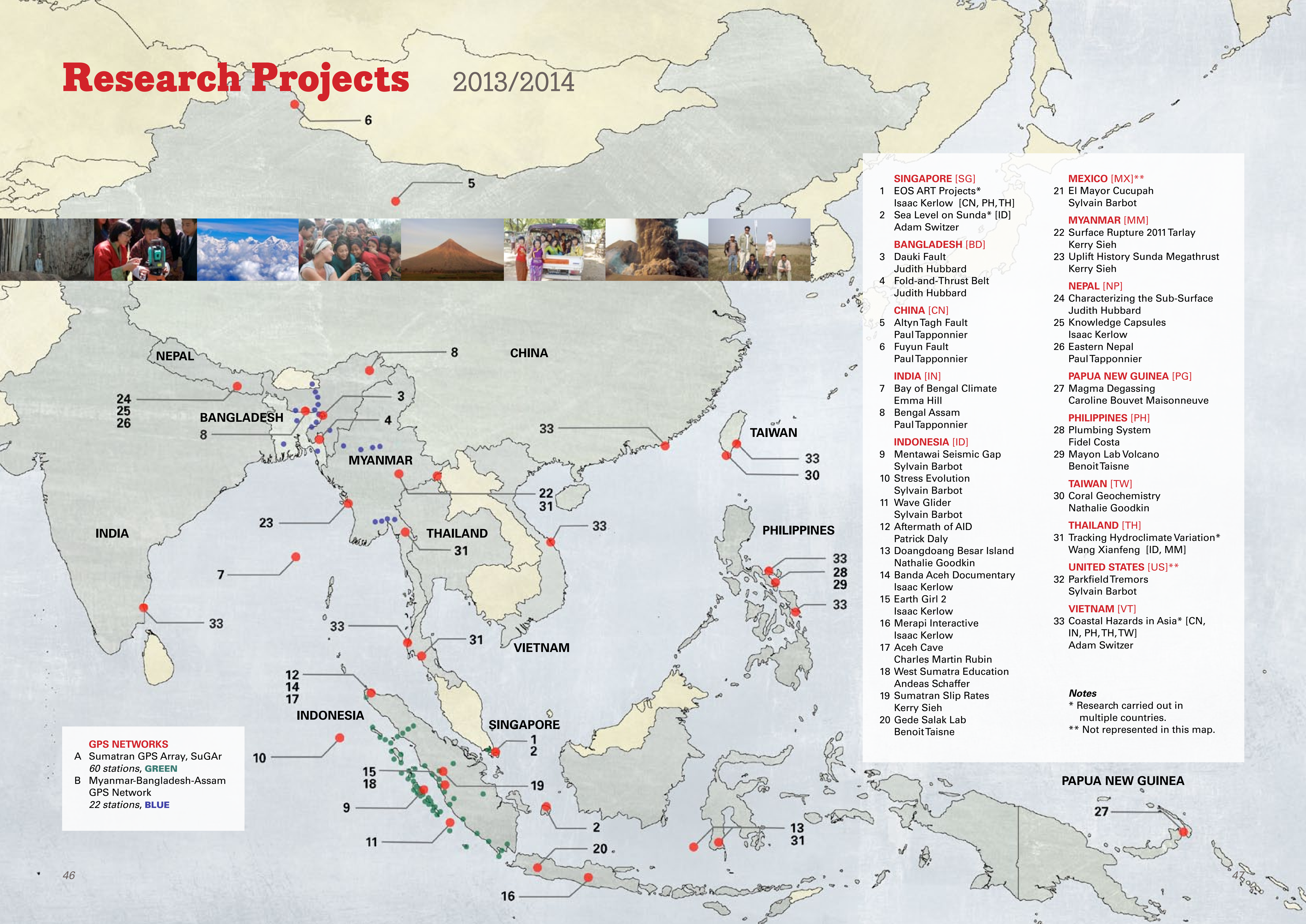
Wave Glider

The Wave Glider is a seagoing robot fitted with sensors for sea floor exploration that monitors the Enggano and Mentawai segments of the Sunda megathrust, off southern Sumatra that could trigger earthquakes and tsunamis. Working in conjunction with the Sumatran GPS Array (SuGAr) and offshore networks, this instrument helps EOS scientists understand potential hazards.

LIDAR Scanner

The LIDAR scanner is an instrument that digitizes a site's topography with exquisite precision. It measures the distance to a target by emitting light pulses. This equipment is used to map faults and earthquake rupture offsets with an accuracy that allows researchers to constrain precisely the slip-distribution of various faults in Asia. With complementary dating, scientists can also estimate earthquake cycles on a given fault. Sedimentologists also use the LIDAR to precisely map various outcrops.

Research Projects 2013/2014



SINGAPORE [SG]
1 EOS ART Projects* Isaac Kerlow [CN, PH, TH]
2 Sea Level on Sunda* [ID] Adam Switzer

BANGLADESH [BD]
3 Dauki Fault Judith Hubbard
4 Fold-and-Thrust Belt Judith Hubbard

CHINA [CN]
5 Altyn Tagh Fault Paul Tapponnier
6 Fuyun Fault Paul Tapponnier

INDIA [IN]
7 Bay of Bengal Climate Emma Hill
8 Bengal Assam Paul Tapponnier

INDONESIA [ID]
9 Mentawai Seismic Gap Sylvain Barbot
10 Stress Evolution Sylvain Barbot
11 Wave Glider Sylvain Barbot
12 Aftermath of AID Patrick Daly
13 Doangdoang Besar Island Nathalie Goodkin
14 Banda Aceh Documentary Isaac Kerlow
15 Earth Girl 2 Isaac Kerlow
16 Merapi Interactive Isaac Kerlow
17 Aceh Cave Charles Martin Rubin
18 West Sumatra Education Andeas Schaffer
19 Sumatran Slip Rates Kerry Sieh
20 Gede Salak Lab Benoit Taisne

MEXICO [MX]**
21 El Mayor Cucupah Sylvain Barbot

MYANMAR [MM]
22 Surface Rupture 2011 Tarlay Kerry Sieh
23 Uplift History Sunda Megathrust Kerry Sieh

NEPAL [NP]
24 Characterizing the Sub-Surface Judith Hubbard
25 Knowledge Capsules Isaac Kerlow
26 Eastern Nepal Paul Tapponnier

PAPUA NEW GUINEA [PG]
27 Magma Degassing Caroline Bouvet Maisonneuve

PHILIPPINES [PH]
28 Plumbing System Fidel Costa
29 Mayon Lab Volcano Benoit Taisne

TAIWAN [TW]
30 Coral Geochemistry Nathalie Goodkin

THAILAND [TH]
31 Tracking Hydroclimate Variation* Wang Xianfeng [ID, MM]

UNITED STATES [US]**
32 Parkfield Tremors Sylvain Barbot

VIETNAM [VT]
33 Coastal Hazards in Asia* [CN, IN, PH, TH, TW] Adam Switzer

Notes
* Research carried out in multiple countries.
** Not represented in this map.

GPS NETWORKS
A Sumatran GPS Array, SuGAr *60 stations,* **GREEN**
B Myanmar-Bangladesh-Assam GPS Network *22 stations,* **BLUE**

Prime Minister Lee Visit

2014 News Flash

Technical Director Paramesh Banerjee (right) jokes with PM Lee and Minister for Education Heng Swee Keat (left) as he shows them the LIDAR scanner that EOS scientists use in the field.

Prime Minister Lee Hsien Loong visited EOS to learn about the Observatory's research and new developments. PM Lee was given a tour of the facility, and had the opportunity to see the ongoing EOS projects.

Principal investigators and group leaders presented their work to the Prime Minister in the areas of climate change in Southeast Asia, monitoring of volcano eruptions around Singapore, analysis of major faults in South Asia, a casual strategy interactive game about preparing for the tsunami, and a cutting-edge monitoring network along the particularly seismically active Sumatra.
At the tea session after the main school tour, the Prime Minister exchanged thoughts with international scientists and PhD students from around the world who have chosen to make Singapore their home, and EOS their research center of choice.

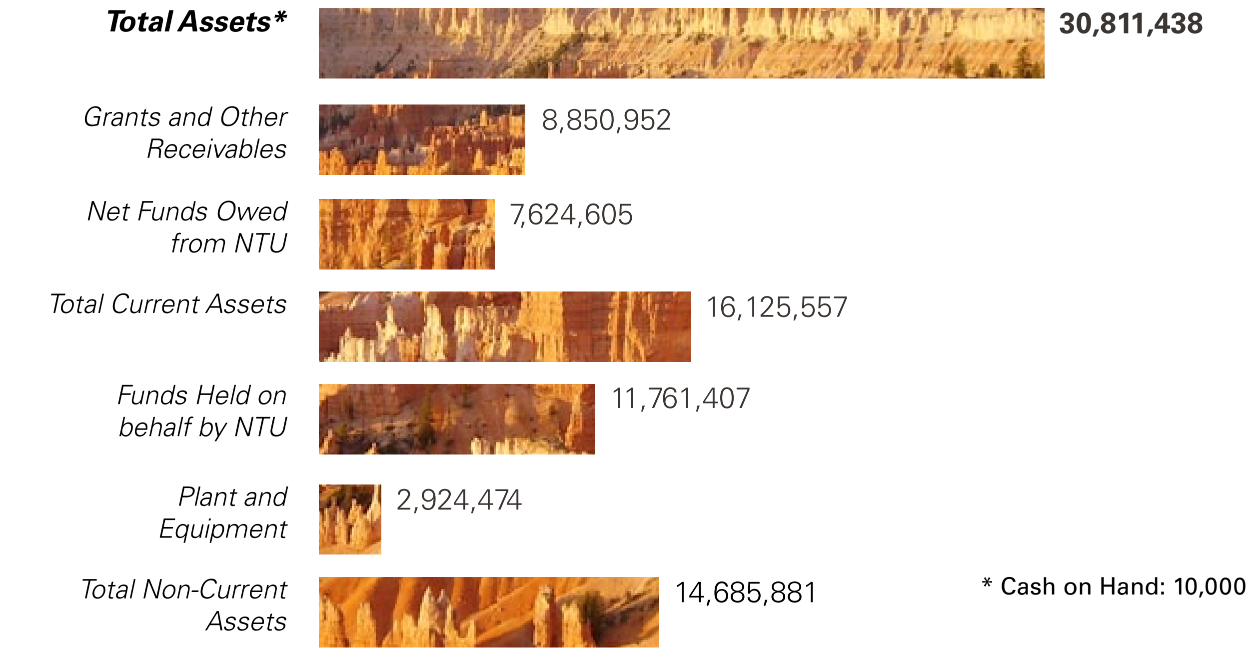
After the visit, Prime Minister Lee reflected in a FaceBook post: "The world is so much more interesting when we are curious. Learned some fascinating facts and developments on my visit to the Earth Observatory of Singapore today. EOS seeks to understand better how our dynamic planet works, to help us cope with natural disasters. It studies climate, volcanoes, earthquakes, and tsunamis."

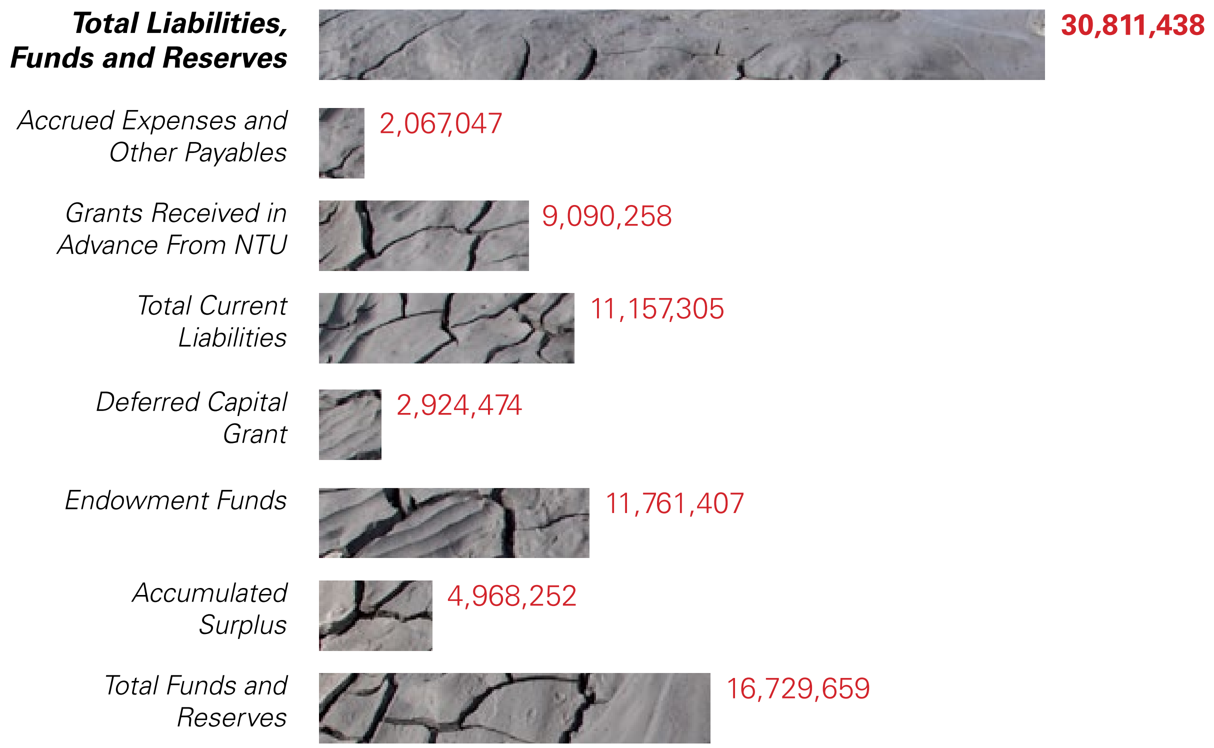
Fancy a hands-on approach to learning? Here, faculty member and researcher Fidel Costa (left) shows PM Lee a volcanic rock sample, which can give clues to a volcano's eruptive history. NTU President Bertil Andersson (center) and Provost Freddy Boey (far right) follow the demonstration with interest.

Faculty member and researcher Koh Tieh Yong (left) uses the EOS Geo-Touch system to present climate trends to PM Lee.

Financial Statements

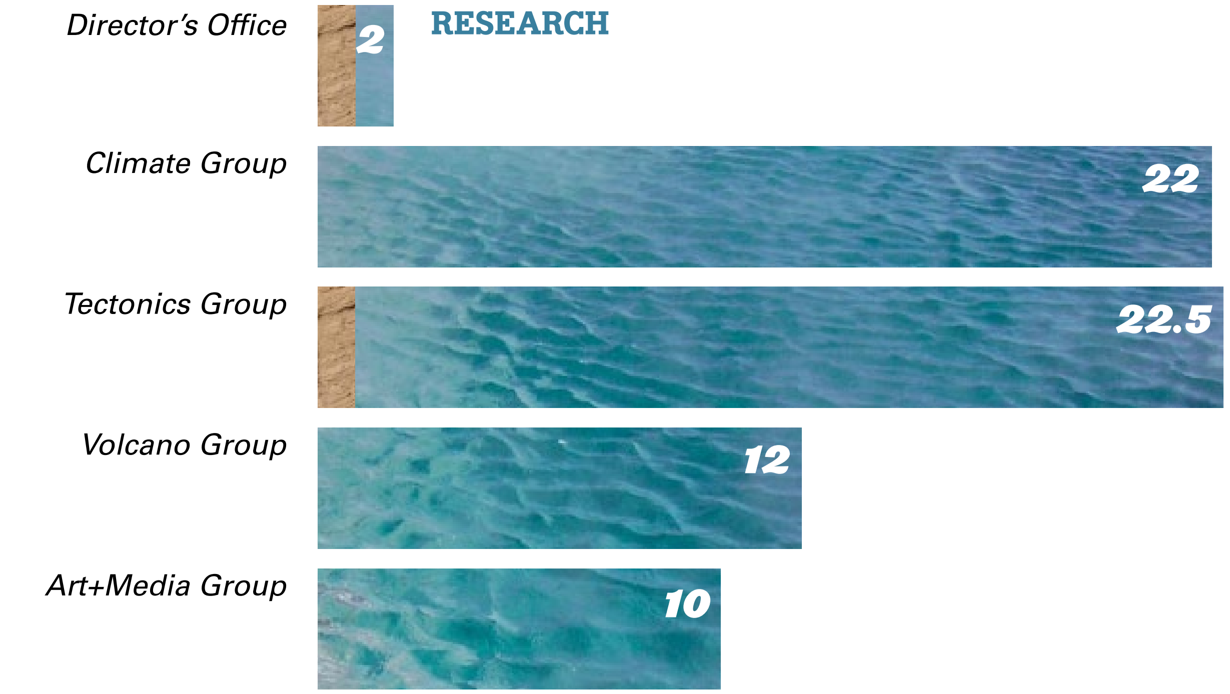
1 April 2013 – 31 March 2014

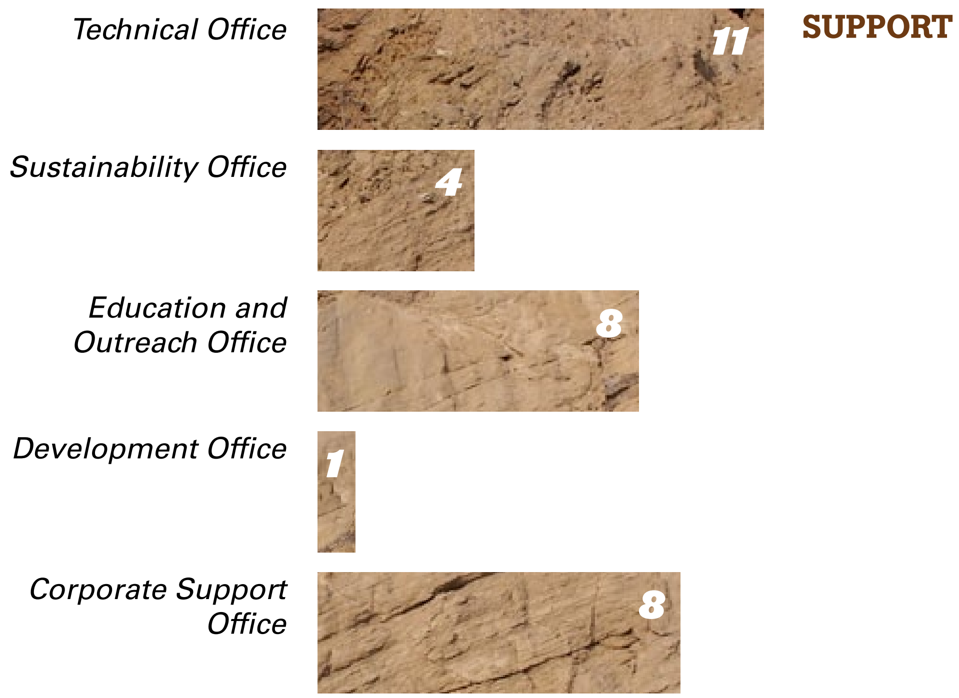




Staffing

1 April 2013 – 31 March 2014





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