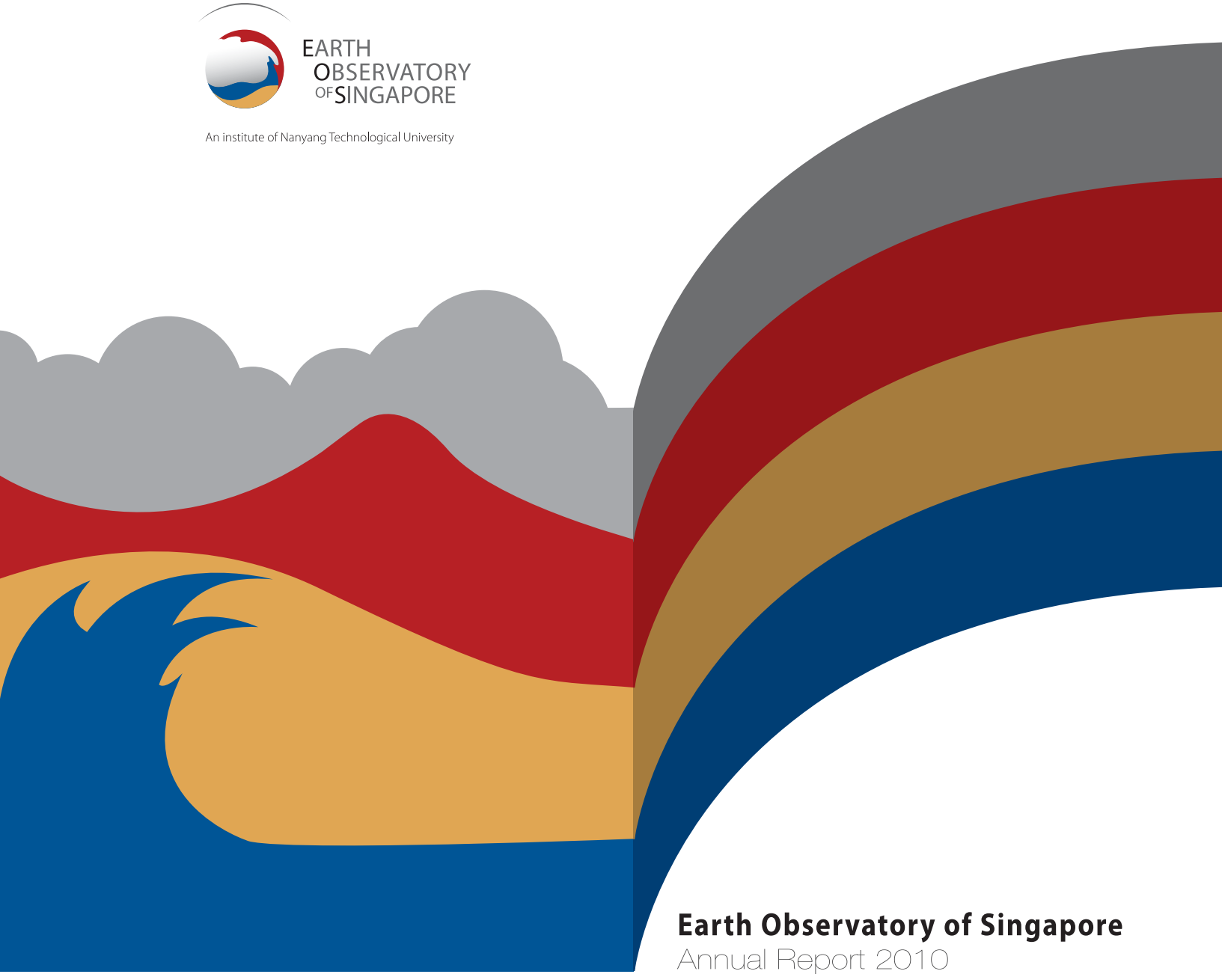
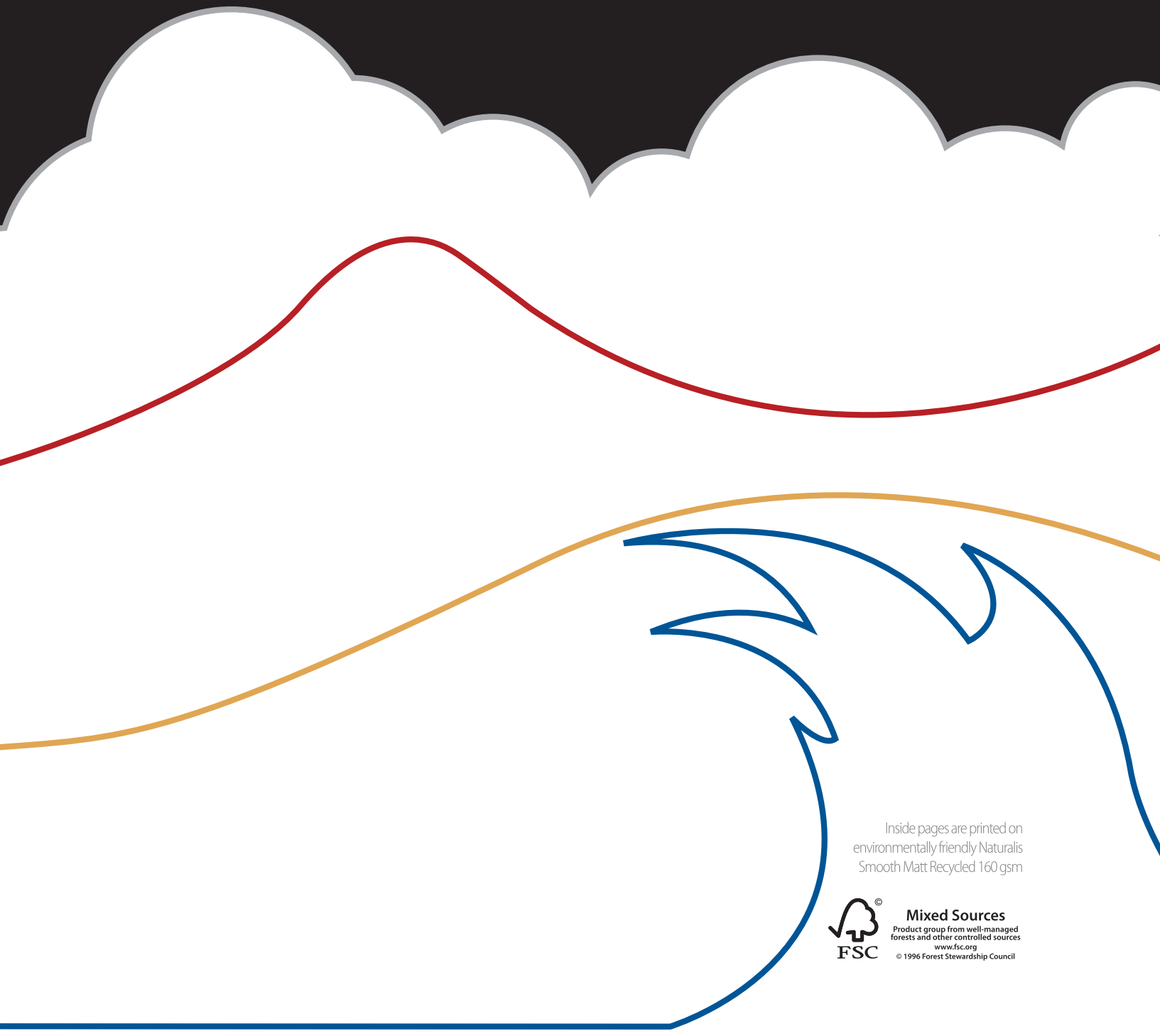


EARTH OBSERVATORY OF SINGAPORE

An institute of Nanyang Technological University

Earth Observatory of Singapore

Annual Report 2010



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Contents

During a visit from the Prime Minister's Research, Innovation and Enterprise Council (RIEC), EOS' Adam Switzer uses *GeoTouch* to explain tsunami and typhoon hazards along the Vietnamese coast. Listening (from left to right) are Koh Boon Hwee, Chairman, NTU Board of Trustees; Peter Schwartz, Chairman, Global Business Network; Subramaniam Ramadorai, Vice Chairman, Tata Consultancy Services; and Francis Yeoh, CEO, National Research Foundation.

Director's Message

As the Earth Observatory accelerates through its third year, our 2010 Annual Report shows that we have built a strong platform from which to launch into 2011 and beyond. Let me highlight some of our accomplishments in FY2010 and some of the challenges that lie ahead.

The primary roles of EOS' science leadership in 2010 were attracting talented young professors to the Observatory and building a superb infrastructure to support them and other EOS researchers.

Assistant professors Emma Hill and Wang Xianfeng joined our ranks this past year. Each won a National Research Foundation Fellowship – large grants that afford them exceptional financial support (even by Singaporean standards) to start their research programs. Several searches for other promising new researchers also began in 2010 and are proceeding at a speed commensurate with ensuring that the Observatory will be second to none as a crucible for scientific ideas, discoveries and impact in the earth sciences.

Throughout the latter half of the year, Charlie Rubin commuted monthly between the U.S. and Singapore to get a head start on creating the Division of Earth Sciences, EOS' academic connection to the University. As the founding Head of our fledgling DES, he accelerated the construction of offices and laboratory space and led the development of the academic infrastructure that we will need as teachers and mentors in the University.

Our major monitoring networks in neighboring countries became more robust and reliable in 2010. They continued to develop as collaboration foci and as platforms for EOS research. Thanks to the efforts of our technical staff, instrumentation of lab volcanoes Mayon and Gede is nearly complete, and the Sumatran GPS Array (SuGAr) has grown in size and robustness. New collaborative monitoring efforts in Myanmar, Bangladesh and the surrounding region, led by EOS Technical Director Paramesh Banerjee, will provide new opportunities to understand the earthquake and tsunami potential of the eastern flank of the Indian-Asian collision for years to come.

The principal roles of our younger faculty have been to ramp up their research and teaching programs. Fidel Costa taught an introductory course for our first cohort of graduate students and began using the new electron microprobe (that we operate in partnership with NTU materials scientists) to understand the movement and histories of lab-volcano magmas. Recent eruptions elsewhere provided interesting targets for his research, as well. His group's work on the magmas erupted from Indonesia's Merapi volcano in 2010 revealed that an unusual abundance of water in the magma was likely one of the reasons that the eruption was the volcano's largest and deadliest in over a century.

Emma Hill and Huang Zhenhua led efforts to understand the devastating M_w7.8 tsunami earthquake of October 2010. Analysis of a combination of SuGAr geodetic data and tsunami field measurements showed that this unusual event originated on the Sunda megathrust far from land, out near the trench. Conventional scientific wisdom has been that such shallow parts of megathrusts are aseismic and not capable of such earthquakes.

Other EOS principal investigators, with academic homes in computer engineering, civil engineering and applied physics, continued to conduct EOS-themed research in earthquake engineering, climate modeling, and in instrumentation and data-processing, while carrying substantial teaching loads in their home divisions.

Despite setbacks in bringing a leader for our climate program on board, we now have six professors working full- or part-time on climate related research – in paleoclimatology, extreme coastal events, climate downscaling and sea-level change. EOS also took an active role through 2010 in the long-term intellectual development of Singapore's climate-science landscape.

Our interactions with Singaporean and regional educators, with the media, with government agencies and with business continued to gain momentum through FY2010, under the leadership of Sharmini Blok, Andreas Schaffer and Isaac Kerlow. We responded to local and international needs for information in the wake of destructive earthquakes and tsunami in New Zealand, Sumatra, Myanmar and Japan. We continued to work with the Ministry of Education and the National Institute of Education to develop earth-science materials for Singaporean schools. We began programs to address climate-related sustainability issues regionally – in Vietnam, Malaysia, Indonesia and here at home. Our first writer-in-residence published

his popular book on Sumatran earthquakes and tsunamis. Professor Kerlow guided his creative team to completion of their second EOS documentary film, *Mayon: The Volcano Princess*, and made good progress on two other EOS-sponsored artistic projects.

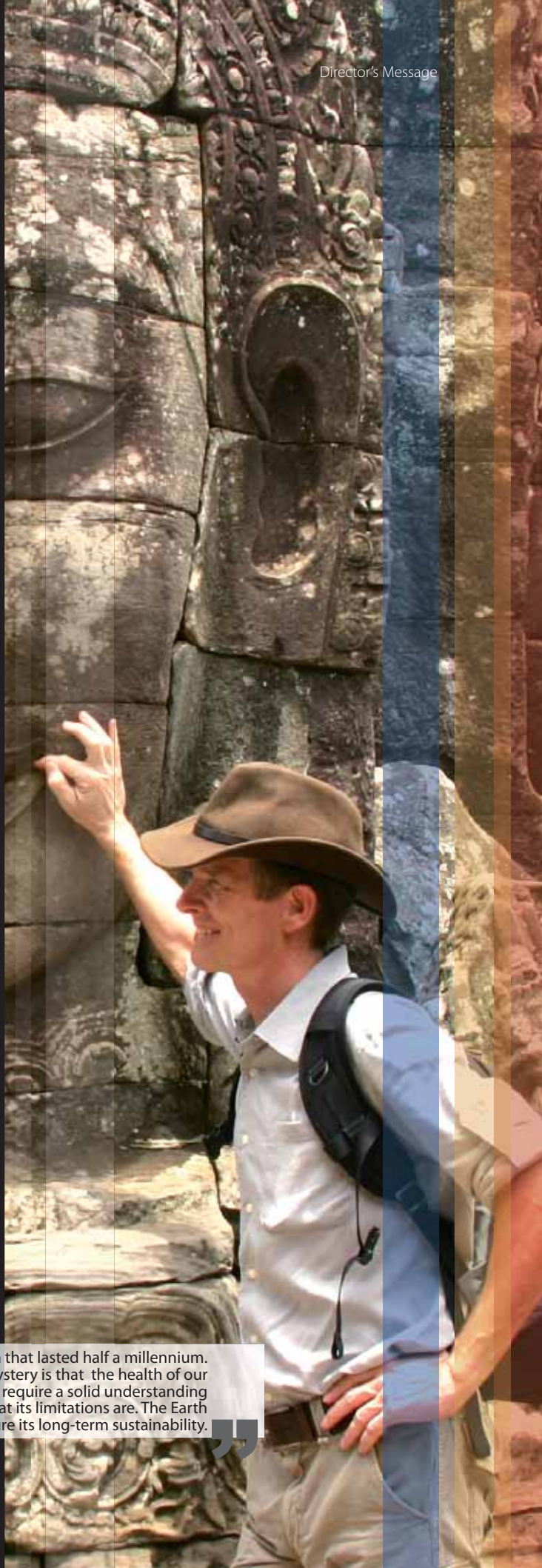
Here on campus, Adam Switzer, Andreas Schaffer and I taught a large undergraduate course in natural hazards, and other EOS professors taught their first EOS graduate courses in their specialties.

As the Earth Observatory evolves through the rest of 2011 and beyond, our opportunities and our impact will also grow – but so will the challenges. We will need to respond to external pressures to ramp up to full strength quickly while maintaining coherence of vision and quality of research and teaching. We will need to engage the University and our funders to create an administrative environment that is more efficient and more supportive of the Observatory and the Division, in our quest to become iconic institutions in Singapore and in the region. We must strengthen collaborations with Singapore's neighbors in ways that serve their needs as well as our own. We must continue to develop our strategy for raising competitive and endowment funding to sustain the Observatory's research, education and outreach through coming decades.

This annual report is our opportunity to share with you our ideas, our discoveries, and our impact on the world around us. I do hope that you enjoy your time among these pages.

Kerry Sieh
Director, EOS

August 27, 2011



"The Khmers built an empire in Southeast Asia that lasted half a millennium. Its demise remains a mystery. What is not a mystery is that the health of our societies through the 21st and later centuries will require a solid understanding of how our dynamic planet works and what its limitations are. The Earth Observatory is one of Singapore's efforts to ensure its long-term sustainability."

Management Team

Kerry Sieh
Director, EOS

Paul Tapponnier
Group Leader, Tectonics Group

Chris Newhall
Group Leader, Volcano Group

Andreas Schaffer
Sustainability Director

Paramesh Banerjee
Technical Director

Woo Kien Young
Corporate Services Director

Sharmini Blok
Education & Outreach Director (Until April 2011)

EARTH OBSERVATORY OF SINGAPORE

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The EOS logo reflects the dynamism of our planet and our scientific observations of the changing Earth. Represented are the four classical elements: fire (red for volcanic magma), air (gray evoking the atmosphere), water (the blue sea), and earth (brown for terra firma).

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Profiles of our Scientific Advisory Board members are at
http://earthobservatory.sg/people/list/SCIENTIFIC_ADVISORY_BOARD.html

Governing Board

The boat that EOS and LIPI researchers use in Sumatra for coral and GPS field work. This photo was taken during reconnaissance of the Banyak islands following the magnitude 7.8 earthquake of April 2010.

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Public Utilities Board and
Chairman,
EOS Governing Board

Jean-Lou Chameau
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California Institute of Technology , USA

Foong Chee Leong
Former Director-General,
Meteorological Services,
National Environment Agency

Lawrence Koe
Director (Projects),
National Research Foundation

Lam Chuan Leong
Ambassador-at-Large,
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Kerry Sieh
Director,
Earth Observatory of Singapore

Su Guaning
President Emeritus,
Nanyang Technological University

Tan Gee Keow
Director, Higher Education,
Ministry of Education

Profiles of our Governing Board members are at
http://earthobservatory.sg/people/list/GOVERNING_BOARD.html

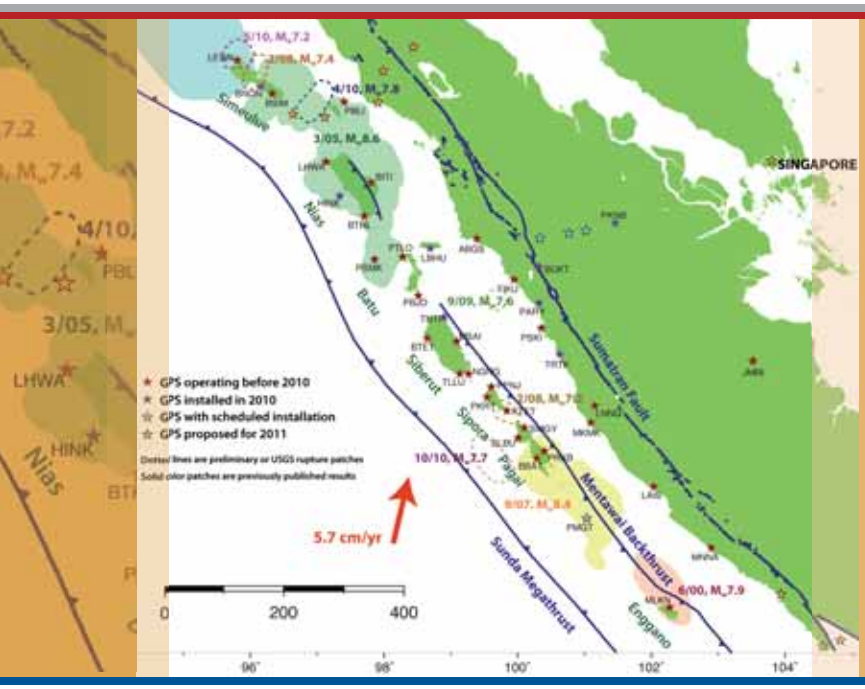
Folded and faulted ancient river sediments along the new highway from Yangon to Mandalay, Myanmar, May 2011. EOS researchers are working with colleagues from Myanmar to understand the great fault that bisects the country from north to south and runs a few kilometers behind this outcrop.

Tectonics • Earthquakes

Asia is home to several of the largest, most seismically active faults in the world, including the Sagaing fault in Myanmar, the Main Frontal Thrust of the Himalayas, the Sumatran fault, and the Sunda megathrust, which traces a 6,000-kilometre arc from Myanmar to northwest Australia. Tens of millions of people live near these earthquake faults, vulnerable to a temblor's destructive force.

One of the goals of the Tectonics Group is to increase the fundamental knowledge of these faults and others in the region in order to forecast earthquakes and their associated tsunamis more reliably.

We are also researching ways to mitigate the damaging effects of such natural hazards in the future.



The Sumatran GPS Array (SuGAr) is a 40-station GPS network designed to measure crustal deformation along the highly active Sumatran subduction zone.

Sumatran Tectonic Geodesy

Principal Investigator
Asst Prof Emma Hill,
EOS, Nanyang Technological University
(In 2010, Prof Kerry Sieh,
EOS, Nanyang Technological University)

Co-Investigators
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EOS, Nanyang Technological University
Prof Kerry Sieh,
EOS, Nanyang Technological University

Collaborators
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and Dr Ashar Lubis,
EOS, Nanyang Technological University
Dr Danny H. Natawidjaja,
Indonesian Institute of Sciences (LIPI)
Prof Roland Bürgmann & Kelly Wiseman,
Department of Earth and Planetary Science,
University of California-Berkeley, USA

In its first eight years of operation, the Sumatran GPS Array (SuGAr) has grown to be a network of 40 functioning GPS stations spanning 1,350 kilometres of the Sumatran plate boundary. Since 2004, 75 earthquakes greater than magnitude 6.0 have occurred within the network, including seven greater than 7.5. We are studying the behaviour of a 300-kilometre locked section of the fault in the northern Mentawai Islands that has not experienced a major rupture in more than 200 years. Another quake of magnitude 8.8 has been forecast to occur there in the coming decades. Much of our work involves unifying the stories of individual events into an overarching picture of future earthquake hazard throughout the region. In 2010, we collected and began analysing data from three large earthquakes: one in the Banyak Islands in April (7.8), one near Simeulue in May (7.2), and one in the Mentawai Islands in October (7.7).

The October 2010 earthquake produced an outsized tsunami compared to its magnitude, categorising it as a "tsunami earthquake", the first such quake to be measured by near-field GPS. The combination of high-rate GPS data captured by SuGAr, and tsunami field data and modelling (by Zhenhua Huang's group) for this earthquake are raising fundamental questions about the mechanical behaviour of the shallow crust.

What's more, the staggering number of Sumatran earthquakes greater than magnitude 4.5 since 2004, by virtue of their sheer numbers, could be playing a significant role in tectonic deformation of the region. Over the next year we'll also be working to characterise these smaller quakes. An important goal of doing so will be to see if episodic, or "slow", slip events are happening on the megathrust fault.

Microtremor measurement in Padang, 16 - 26 August 2010.

> Understanding the level of destruction to a coastal city from strong motion is essential, as collapsed buildings would trap inhabitants, and damaged roads and bridges would hamper human evacuation to higher grounds before the ensuing tsunami arrives.
>
> Kusnowidjaja Megawati, EOS

Integrated Seismic and Tsunami Hazard Assessment of West Sumatra, Indonesia

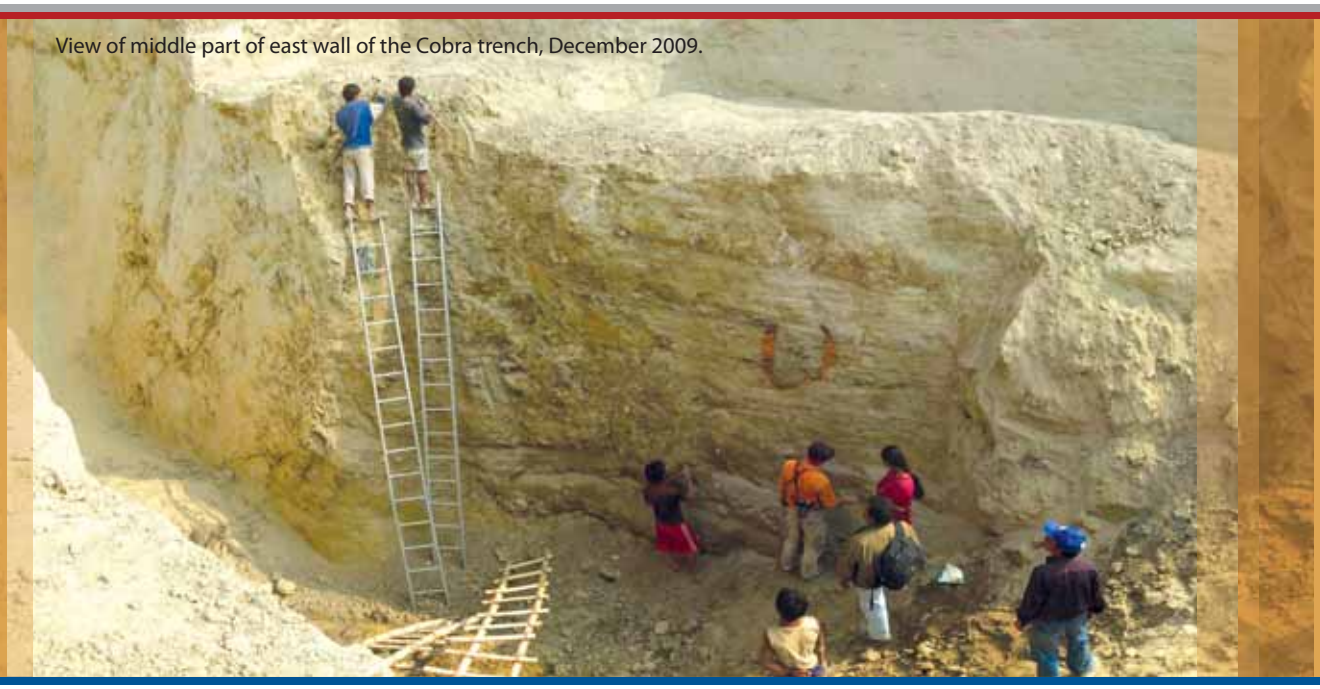
Principal Investigator
Asst Prof Kusnowidjaja Megawati,
EOS & School of Civil and Environmental Engineering, Nanyang Technological University

Co-Investigators
Prof Kerry Sieh, Prof Paul Tapponnier, and Asst Prof Zhenhua Huang,
EOS, Nanyang Technological University
Dr Danny H. Natawidjaja,
Indonesian Institute of Sciences (LIPI)
Prof Kazuki Koketsu,
Earthquake Research Institute, University of Tokyo
Prof Hiroaki Yamanaka,
Tokyo Institute of Technology

The objective of this project, together with the accompanying project on tsunami simulation led by Zhenhua Huang, is to develop a system that can integrate the seismic and tsunami hazard of West Sumatra. Some studies have assessed tsunami impact in West Sumatra, but no study has ever considered the combined effects of strong motion and tsunami in cities facing both types of hazards.

In 2010, we collaborated with University Bung Hatta in Padang to conduct microtremor measurements to determine the soil structure underneath Padang and Pariaman. Based on the results obtained – and available geological, geophysical and geotechnical information – we will construct 3D shear-wave velocity structures to determine the intensity and predominant frequencies of ground motion for both cities during an earthquake.

This year, we plan to collect an inventory of buildings in both cities, assess their seismic performance, and begin modelling human evacuation scenarios. The end product of our modelling will hopefully give insights to local and central government agencies to work out plans to mitigate the effects of an earthquake and tsunami.



View of middle part of east wall of the Cobra trench, December 2009.

Morphology and Paleoseismology of the Main Frontal Thrust in Nepal

Principal Investigator
Prof Paul Tapponnier,
EOS, Nanyang Technological University

Co-Investigator
Dr Laurent Bollinger,
Environmental Assessment and Monitoring Department, Atomic Energy Commission (CEA-DASE), France
Dr Soma Nath Sapkota,
Department of Mines and Geology, National Seismological Centre, Nepal
Dr Yann Klinger,
Institute of Geophysics of Paris (IPGP)
Dr Elise Kali,
EOS, Nanyang Technological University
Indira Siwakoti,
Central Department of Geology, Tribhuvan University, Nepal

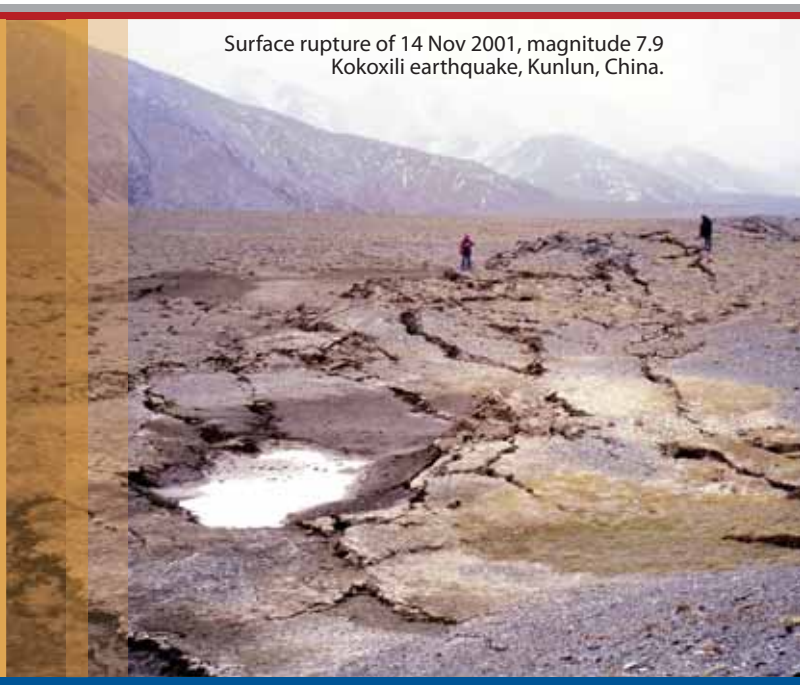
At 2,000 kilometres in length, the Main Frontal Thrust of the Himalayan range (MFT or MHT) is the largest active continental thrust fault on the planet. This megathrust has been the source of several, catastrophic historical earthquakes – the last ones being the 1905 Kangra quake (magnitude 7.8), the 1934 Bihar-Nepal quake (8.2), the 1950 Assam quake (8.7) and the 2005 Kashmir quake (7.4). The MFT is locally complex, and earthquake hazard along the fault – a major threat to densely populated India and Nepal – remains to be quantified.

From historical accounts and previous trenching studies, neither the 1905 or 1934 earthquakes appear to have produced surface ruptures. That leaves unanswered questions as to how frequently quakes occur, rupture lengths and sizes, and the surface geomorphic signature of large events.

In 2009, we dug a 60-metre-long, 15-metre-deep trench on the northeast bank of the Charnath River, 60 kilometres east of the Sir Khola valley. In 2010, we consolidated evidence that the Sir Khola trench exposes the first surface trace ever found of the 1934 earthquake. We interpret this quake to be a repeat of one in 1255, the only other event known to have caused massive destruction in Kathmandu, yielding a plausible recurrence interval of about 700 years.

Throughout 2011, we will continue to interpret the regional geomorphic, paleoseismological, and geophysical data to improve our 3D understanding of the geology and geomorphology of the MFT between the Mahara and Arun Rivers. Over the course of this project, we expect to obtain a complete record of the last 5,000 years of earthquake history on the MFT in eastern Nepal.

> The region that extends between the Himalayas and Siberia has become an unmatched 'museum' of well-preserved historic and more ancient strike-slip ruptures.
> Paul Tapponnier, EOS



Surface rupture of 14 Nov 2001, magnitude 7.9 Kokoxili earthquake, Kunlun, China.

Earthquake Ruptures in China: Testing Seismic Fault Behavior Models

Principal Investigator
Prof Paul Tapponnier,
EOS, Nanyang Technological University

Co-Investigators
Dr Yann Klinger, *Institute of Geophysics of Paris (IPGP)*
Dr Xiwei Xu,
Institute of Geology, China Earthquake Administration
Dr Jérôme van der Woerd,
Institute of Geophysics of Paris (IPGP)
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Institute of Geology, Ministry of Land and Resources, China
Dr Jing Liu,
Institute of Tibetan Plateau Research, Chinese Academy of Sciences
Dr Magali Rizza, *EOS, Nanyang Technological University*
Dr Marie Etchebes, *EOS, Nanyang Technological University*

To assess seismic hazard, earthquake recurrence models need data from repeated earthquake surface ruptures. But documentation of such repeated events is rare.

The scarcity of data makes it difficult to determine which, if any, of the seismic cycle and recurrence models is better than another.

Now, commercially available, sub-metric-resolution satellite images make it possible to map surface ruptures in fine detail over hundreds of kilometres, especially in regions where vegetation is scarce. Using QuickBird and GeoEye satellite images, we are augmenting the available rupture data for the region extending between the Himalayas and Siberia and encompassing Tibet and central Asia. Large earthquakes occur frequently in this region, and its undisturbed landscape contains many strike-slip ruptures, both historic and ancient.

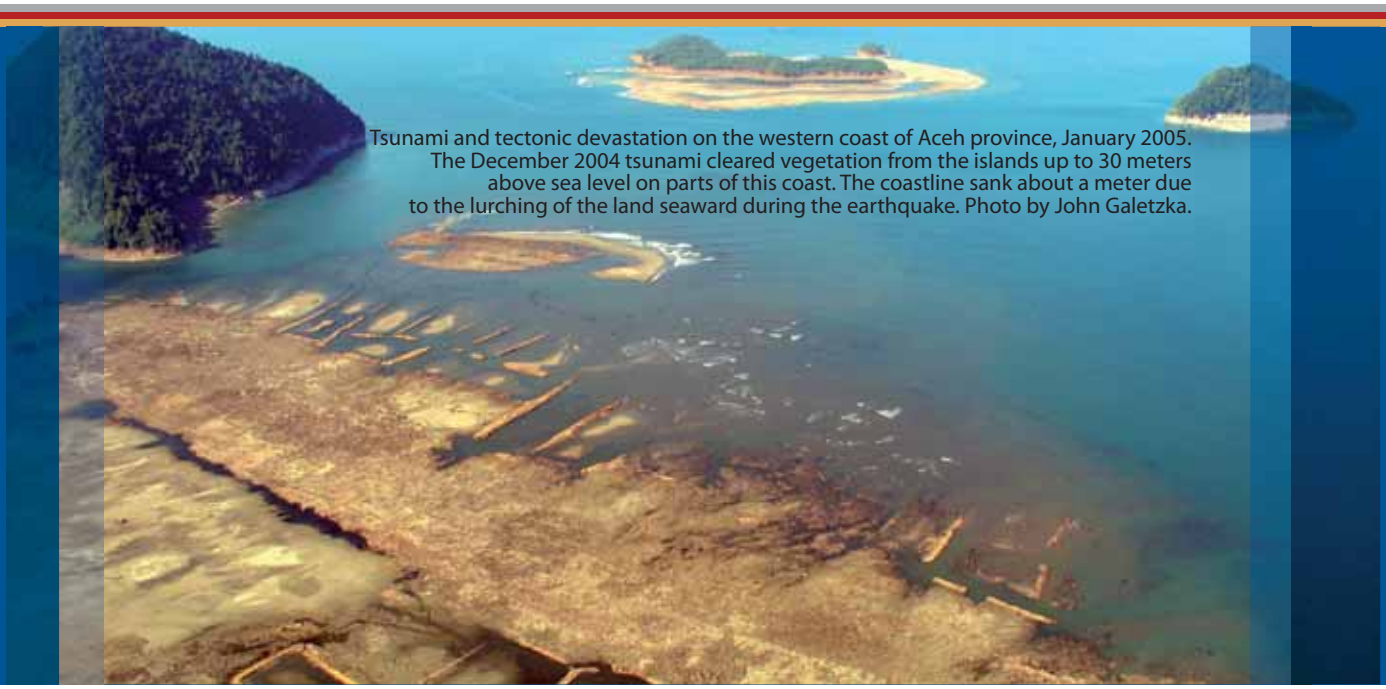
In 2010, we unravelled the records of multiple surface displacements along the Fuyun fault in Xinjiang, China, 180 kilometres of which ruptured in August 1931. On a trip to the site, we collected surface samples for cosmogenic isotope dating and two digital elevation models to help calibrate the satellite images. In 2011, we plan to do kilometre-scale, ground-based LIDAR surveys along the rupture. We are also procuring more satellite images on stretches of the Kunlun and Altyn Tagh faults in Tibet. Segments on the Altyn Tagh fault bear spectacular, free-faced traces of large earthquakes that we infer to be less than a few centuries old.

Beach sand washed past a grove of dead coconut palms and into a swamp by the December 2004 tsunami, west coast of Nias island. The coconut grove was planted above the sea, but slowly subsided into the intertidal zone due to strain accumulation in the century prior to the great earthquakes of 2004 and 2005. Photo taken January 2005.

Tectonics • Tsunamis

As evidenced by recent events in Tohoku, Japan, tsunamis can cause overwhelming destruction of infrastructure and loss of life. In December 2004, the Indian Ocean tsunami devastated many communities in Indonesia, Sri Lanka, India and Thailand. The location of large, active undersea faults makes coastal areas in South and Southeast Asia particularly vulnerable to these deadly waves.

The Tectonics Group not only works to understand how tsunamis are generated and surge onto land but also to find ways to protect people and property with engineered structures and evacuation plan scenarios.



Tsunami and tectonic devastation on the western coast of Aceh province, January 2005. The December 2004 tsunami cleared vegetation from the islands up to 30 meters above sea level on parts of this coast. The coastline sank about a meter due to the lurching of the land seaward during the earthquake. Photo by John Galetzka.

Tsunami Hazard Mitigation for West Sumatra

Principal Investigator
Asst Prof Zhenhua Huang,
EOS & School of Civil and Environmental Engineering, Nanyang Technological University

Co-Investigator
Prof Kerry Sieh,
EOS, Nanyang Technological University
Asst Prof Kusnowidjaja Megawati,
EOS & School of Civil and Environmental Engineering, Nanyang Technological University
Prof Yee Meng Chiew, Assoc. Prof Soon Keat Tan and Assoc Prof Edmond Y. M. Lo,
School of Civil and Environmental Engineering, Nanyang Technological University
Dr Danny H. Natawidjaja,
Indonesian Institute of Sciences (LIPI)
Asst Prof Adam Switzer,
EOS, Nanyang Technological University

Collaborators
Dr Linlin Li, Yanmei Zhang, & Qiang Qiu,
EOS, Nanyang Technological University

Our work focusses on integrating tsunami science with engineering measures for tsunami hazard mitigation, with the West Sumatran coast as our primary case-study area. We are conducting a systematic study that covers all aspects of the tsunami hazard, including choosing appropriate megathrust fault sources, initial tsunami prediction, tsunami-related debris flows, tsunami run-up and inundation, mitigation by coastal vegetation and coral reefs, design of vertical tsunami shelters, and plans for human evacuation.

From our work in 2010, we now have a tsunami-modelling package capable of simulating the entire lifespan of a tsunami. We carried out scenario studies for Painan, Pariaman and the island nation of Mauritius based on a magnitude 8.9 rupture of the Mentawai section of the Sunda megathrust. We also conducted a field survey in the southern Mentawai Islands following the October 2010 earthquake to collect data on tsunami wave height, inundation and damage throughout the affected area.

During a tsunami, floating debris causes casualties as well as the collapse of buildings. In 2011, we plan to investigate debris flow patterns through a series of laboratory experiments in idealised city models. Later, numerical models will be developed based on our experimental results. We are also coupling a sediment transport model with a tsunami simulation package to get results with finer spatial resolution. Using the coupled models and high-resolution bathymetric and topographic data, we will be able to better predict flow fields and sediment transport for the cities on the West Sumatra coast.

Muslim graves that now sit in the intertidal zone in Banda Aceh are evidence of the slow sinking of the city.

A Geoarchaeological Investigation of Paleotsunami and Paleoseismic Activity in Northern Sumatra

Principal Investigator
Prof Kerry Sieh, *EOS, Nanyang Technological University*

Co-Investigators
Prof Charles Rubin,
Division of Earth Sciences,
Nanyang Technological University
Dr Patrick Daly,
Asia Research Institute, National University of Singapore
Dr E. Edwards McKinnon,
Asia Research Institute, National University of Singapore
Asst Prof Benjamin Horton,
Department of Earth and Environmental Science,
University of Pennsylvania

Collaborators
Dr Aron J. Meltzner,
EOS, Nanyang Technological University
Asst Prof Adam Switzer,
EOS, Nanyang Technological University

The Aceh region was propelled onto the world stage by the 2004 Indian Ocean earthquake and tsunami, which caused tremendous damage and loss of life. Building a reliable chronology of seismic and tsunami activity in the region is vital for forecasting the frequency and severity of future events Our project combines geological, archaeological and historical methods to investigate paleotsunami and paleoseismic events, as well as their impact on coastal communities in northern Sumatra. In 2010, we published a paper that documented the two most recent predecessors to the 2004 earthquake - from coral uplifted in 1394 and 1450 AD on Simeulue island, about 100 kilometres off the west coast of Aceh. We are now finding evidence on the mainland coast of Aceh for the tsunamis caused by these big earthquakes. East of Banda Aceh, we have one site that contains evidence for two closely timed tsunamis in that time period and two additional sites that may hold such evidence as well.

In 2011, we plan to verify the 1394 and 1450 tsunamis through targeted field studies at three sites, determine whether other tsunamis occurred between 1450 and 2004, and begin mapping historical changes in the coastal geomorphology and ecology around Banda Aceh. These initial paleoseismic and paleotsunami studies suggest that the 2004 tsunami may be the first of a doublet, with another large tsunami to follow in the next half century.

The 2004 event also raises intriguing questions about the effects of previous earthquakes and tsunamis on human history in the region. Information on the 14th- and 15th-century tsunamis will help historians better understand the dynamics of trade and settlement in northern Sumatra during that time and how environmental processes might have influenced that activity.

More Tectonics Projects

Discrete Element Modelling of Fault Nucleation and Propagation in Collision Zones

Principal Investigator
Prof Paul Tapponnier

Most numerical computer modelling of continental deformation – based on fluid mechanics or classic finite element methods – fails to include the nucleation and propagation of faults and the kinematic compatibility between them. We are addressing this issue with Discrete Element Methods (DEM), first by developing and testing codes to reproduce the results of 2D experiments on sand or plasticine. The final goal will be to simulate the evolution of large scale faulting in Asia during the last 50 million years.

Kinematics of the Bengal-Assam Syntaxis

Principal Investigators
Prof Paul Tapponnier & Dr Paramesh Banerjee

The convergence of mountain ranges in the eastern Himalayas, known as the Bengal-Assam syntaxis, was the site of the largest continental earthquake ever recorded (a magnitude 8.7 in 1950). Straddling four countries and covered with dense vegetation, the syntaxis is complex and poorly understood. We plan to install GPS stations in Bangladesh, Myanmar and India and start field reconnaissance to bridge the gap between the major active faults in the region.

Earthquake Geology in Myanmar

Principal Investigator
Prof Kerry Sieh

The active faults of Myanmar are too poorly understood to quantify their role in regional neotectonic deformation or to make realistic estimates of seismic hazard. In 2010, our field work focussed on paleoseismic studies of young coastal terraces on two islands of the western coast, which will yield information on recurrence and help resolve whether these events are produced by thrust faults within the accretionary prism or by the subduction megathrust itself. An east-west transect of four GPS stations installed in January 2011, with additional ones to come, will enable an assessment of the distribution of strain across Myanmar.

Neotectonic Studies in Southeast Asia

Principal Investigator
Prof Kerry Sieh

We are constructing a smart, GIS-based active-fault map and database for Southeast Asia. Our three principal motivations are to compile what is already known, to reconnoiter poorly known parts of Southeast Asia and to meet the needs of the Global Earthquake Model project. We propose to complete during 2011 the compilation of reliable existing data and to continue focussing on original investigations in Myanmar, Indonesia and New Guinea.

Paleoseismology and Paleogeodesy of the Sumatran Subduction Zone

Principal Investigator
Prof Kerry Sieh

Large sections of the Sunda megathrust have failed progressively over the past decade in an extraordinary earthquake sequence. One question of humanitarian and scientific importance is how the remaining patches might fail in coming decades. We use annually banded coral microatolls, which preserve precise information about past relative sea levels, to deduce tectonic histories centuries into the past. In 2010, we worked above the 2004, 2005 and 2007 rupture patches – from Simeulue to the Mentawai Islands – to resolve lingering questions about the very high hazards we infer for the near future.

Fundamental Source-to-Site-to-Structure Study of Seismic Impacts and Hazards for Part of Southeast Asia Covering Sumatra, Java and the Malay Peninsula

Principal Investigator
Asst Prof Goh Siang Huat

We are developing large-scale 3D computational models that can perform "source-to-site-to-structure" simulations, starting with the rupture on an earthquake fault, followed by the propagation of the seismic waves to engineered structures of interest. The study includes the development of a regional seismo-tectonic model and the computational resources to perform large-scale wave propagation analyses. The results will

provide fundamental insights into the expected ground motions arising from different scenario earthquakes and will be useful for assessing the effects and hazards to infrastructure in Singapore and cities in the region.

Development of Standard Procedure for Seismic Hazard and Risk Assessment of Cities in Southeast Asia

Principal Investigator
Asst Prof Kusnowidjaja Megawati

The severity of earthquake disasters increases tremendously when major earthquakes hit densely populated urban centres. One focus of EOS is to re-examine seismic hazard of major cities in Southeast Asia to mitigate regional earthquake catastrophes. We are developing a standard procedure to assess seismic hazard and risk levels of urban areas, taking the Indonesian city of Surabaya as a study case. We are evaluating the seismic hazard deterministically by first identifying scenario earthquakes based on geologic and tectonic evidence, and then by computing the expected ground motions using a 3D discrete model, establishing building inventory from satellite photos and estimating potential loss.

Data Sensing, Communications and Processing for Earth Observation in the Singapore Region

Principal Investigator
Assoc Prof Ian McLoughlin

Our team of three computer engineering professors – comprising sensor, communications and data processing experts – helps bridge science at EOS with the research engineers at NTU. This work continues the team's role in enhancing the current Sumatran GPS Array (SuGAr) but also extends the work to encompass volcanology and climatology. Our 2010 achievements include drastically reducing the power consumption of platforms for tectonic and seismic monitoring, developing an inexpensive monitoring tool for volcanoes, developing a flat LCD version of the GeoTouch interactive presentation tool and improving the reliability of data telemetry for SuGAr like wireless monitoring systems.

Modelling Submarine Landslide Tsunamis with a Case Study for Vietnam

Principal Investigator
Asst Prof Zhenhua Huang

Submarine earthquakes and landslides are two important tsunami sources, but tsunami hazard modelling in the South China Sea has been primarily concerned with the potential large submarine earthquakes. We are developing an efficient and accurate method to model initial tsunamis generated by submarine landslides and carrying out a risk analysis of such landslides in mid-Vietnam. The work we accomplished in 2010 includes development of a deformable landslide model, verification of the landslide model and code, and completion of a scenario study for the Vietnam coast.

Hunting the Tsunami Deposits of the AD551 Beirut-Tripoli Earthquake

Principal Investigator
Asst Prof Adam Switzer

The AD551 Beirut-Tripoli earthquake is reported to have generated a large tsunami that flooded the cities of Beirut and Tripoli. In 2010, we conducted a pilot study to investigate whether sandy and bouldery tsunami deposits associated with this event could be found in the low-lying coastal plains and coastal platforms of the Lebanese coast. Although the coastline is primarily modified or rocky, we have identified two sites that potentially record the event (and others) in their recent coastal stratigraphy. In 2011, we plan to excavate and core in the Akkar delta plain and sample a second site at Damour.

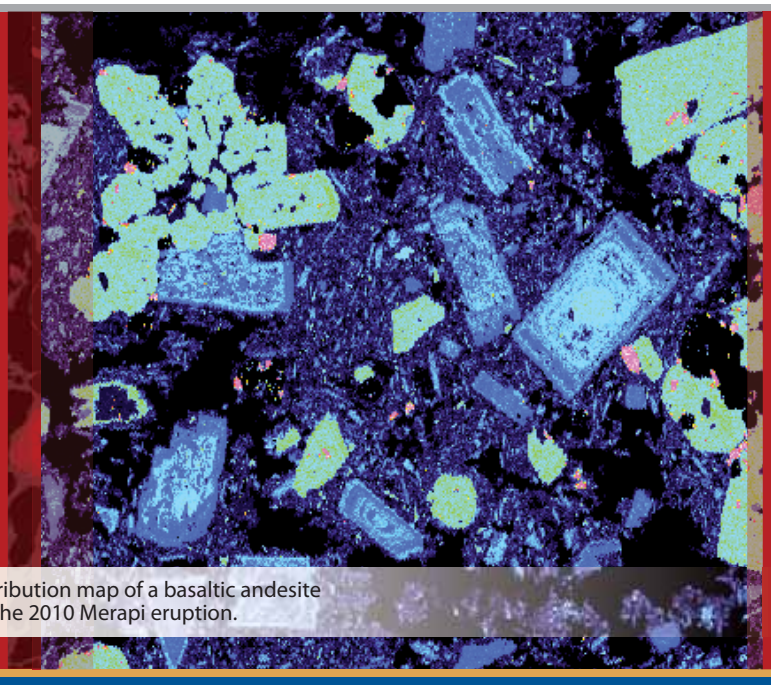
Photo of Pangrango volcano taken from the top of Gede, EOS lab volcano in Indonesia.

Volcanoes

The volcanoes in Southeast Asia are among the most active on Earth, having produced some of the most famous explosive eruptions in written and geologic history. In countries such as Indonesia, the Philippines and Papua New Guinea, many people live in the shadow of active volcanoes, and the potential for such eruptions puts their safety at risk.

We are studying several volcanoes as natural laboratories, with the goal of developing tools and acquiring data to improve forecasts and to assess the environmental and social impact of volcanic events. Information about increased hazards is conveyed to and through collaborating host-country scientists. Complementing our field research is development of a searchable, global database of volcanic unrest that will also serve as a useful tool for better prediction.

> Most monitoring work is descriptive, with limited insight into understanding processes. By looking at erupted rocks, we have the tools to reveal the processes. The general goal is to integrate our findings with monitoring data so that we can better forecast future eruptions.
> Fidel Costa, EOS



Calcium distribution map of a basaltic andesite bomb from the 2010 Merapi eruption.

Reconstructing the Plumbing Systems and Dynamics of Magmatic Processes Below Active Volcanoes

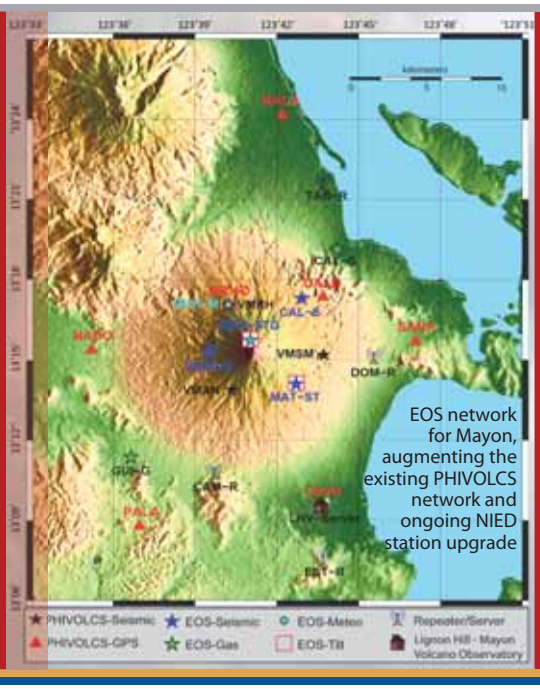
Principal Investigator
Asst Prof Fidel Costa,
EOS, Nanyang Technological University

Collaborators
Dr Joan Cabato, Tarsilo Girona and Daniel Krimer,
EOS, Nanyang Technological University

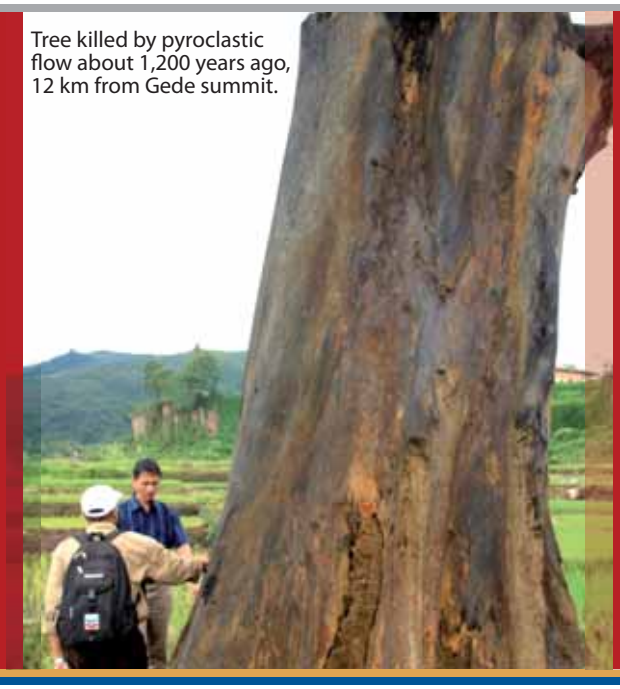
Technological advances in volcano monitoring have greatly improved our ability to measure changes in a volcanic system before, during and after an eruption. Still, it remains a challenge to relate external monitoring signals to the processes occurring deep inside a volcano.

The chemical compositions and microcrystalline structures of erupted rocks, however, can reveal the environmental conditions inside the volcanoes that produced them. Our approach is to use micro- and nano-analytical techniques, thermodynamics, and kinetic models to reconstruct the plumbing system and the timeline of magmatic events leading to eruptions. The main targets are the EOS laboratory volcanoes of Mayon, Gede and Salak. Our overall goals, along with others working on the laboratory volcanoes, are to relate monitoring signals to specific magmatic processes and to gain insights into the variable time scales – ranging from weeks to decades – of volcanic unrest.

During the first year of the project, we set up essential facilities, such as labs for optical microscopy, an electron microprobe, and a facility for rock cutting and polishing. At Mayon, we did field work and initial petrological characterisation of the most relevant eruption products, and we have started numerical calculations to understand its constant degassing. At Gede, we have characterised magma mixing processes and time scales by analysing a suite of banded pumices. This year, we will also work on rock samples from the Merapi volcano in central Java.



EOS network for Mayon, augmenting the existing PHIVOLCS network and ongoing NIED station upgrade



Tree killed by pyroclastic flow about 1,200 years ago, 12 km from Gede summit.

Laboratory Volcanoes

Principal Investigator
Prof Chris Newhall,
EOS, Nanyang Technological University

Mayon

Collaborators
Dr Renato Solidum, Mariton Bornas & Staff,
Philippine Institute of Volcanology and Seismology (PHIVOLCS)
Asst Prof Fidel Costa, Dr Florian Schwandner, Dr Dannie Hidayat, Dr Christina Widiwijayanti, and Joey Marcial,
EOS, Nanyang Technological University

Gede-Salak

Collaborators
Dr Surono & Staff,
Center of Volcanology & Geological Hazard Mitigation (CVGHM)
Asst Prof Fidel Costa, Dr Sasha Belousov, Dr Marina Belousova, Dr Florian Schwandner, Dr Dannie Hidayat, Dr Christina Widiwijayanti, Dr Antonius Ratdomopurbo, Dr Chris Harpel, & Daniel Krimer,
EOS, Nanyang Technological University

EOS has been developing natural volcano laboratories at Mayon in southeast Luzon in the Philippines and Gede and Salak in West Java, Indonesia. These three volcanoes span a wide range of degassing behaviors. Mayon, near the openly degassing end, tends to produce small, frequent eruptions. The threat of explosive activity requires costly evacuations of about 50,000 people for weeks at a time. We aim to understand the timing, rates and other details of magma supply and degassing at Mayon and thereby improve forecasts of future eruptions. In 2010 and the first half of 2011, we constructed five typhoon-resistant instrument shelters, installed new broadband seismometers and tiltmeters, installed equipment for continuous monitoring of sulfur gas, developed and installed a prototype instrument for continuous CO_2 monitoring, helped PHIVOLCS model its GPS station data, and started numerical modelling of magma degassing in Mayon's conduit.

Gede and Salak, toward the other end of the spectrum, are moderately plugged arc volcanoes that exhibit only minor degassing yet suggest recent magma and gas input from depth. Our overall goals are to understand the inner workings of such volcanoes, especially how their plugging affects eruptions and might contribute to their relatively frequent collapses. In 2010, we acquired and tested equipment to upgrade geophysical, geochemical and hydrologic monitoring of Gede and Salak and installed some of it in early 2011. Gede showed briefly but sharply elevated volcanic seismicity in November-December 2010. Geologic fieldwork on Gede and Salak is well underway, and we're getting interesting new information about when, how often and how explosively these volcanoes have erupted.

More Volcano Projects

World Organization of Volcano Observatories Database (WOVOdat)

Prof Christopher Newhall (P.I.), Dr Antonius Ratdomopurbo, and Dr Christina Widiwijayanti, *EOS*

The members of the World Organization of Volcano Observatories have collected a wealth of valuable data on volcanic activity. But lack of standardisation makes it nearly impossible to do comparative studies of volcanic unrest – or to search the data during a crisis. We have begun translating and compiling these myriad data into a comprehensive database with the goal of making it freely accessible over the Web.

Exploratory Projects on Volcanoes

Prof Christopher Newhall (P.I.), Dr Alexander Belousov, Dr Marina Belousova, Dr Florian Schwandner, & Dr Dannie Hidayat, *EOS*; Assoc Prof Khin Zaw, *University of Tasmania*; Dr Bruce Christenson, *GNS Science, New Zealand*; and Herman Patia, *Rabaul Volcano Observatory, Papua New Guinea*

Revisiting Deposits of the 1951 Eruption of Mt. Lamington, Papua New Guinea

The 1951 eruption of Mt. Lamington devastated an area of 230 square kilometres and killed 3,500 people. The main goal of the project was to understand the eruptive blast and an associated large landslide. We also collected evidence on the pre-1951 eruptive history of the volcano.

Estimating CO_2 Emissions from Volcanoes Using Japan's IBUKI (GOSAT) Satellite

Our aim is to detect and quantify volcanic CO_2 emissions from space for the first time. CO_2 is the first early indicator of volcanic unrest, long before SO_2 is emitted. The project uses data from Japan's IBUKI (GOSAT) satellite, designed to measure greenhouse gases. Early results are promising.

3D Revisit of Chemistry, Gas Bubbles and Temperature in Pinatubo Caldera Lake

In 2000, the caldera lake of Mt. Pinatubo in the Philippines showed a high, inverted temperature gradient, which we speculated was being stabilized by CO_2 bubbles. In 2010, we resurveyed the lake and no longer found a gradient. We corroborated the idea that decreasing CO_2 flux now allows waters heated at the bottom of the lake to rise and mix.

Sector Collapse of Mt. Iriga, The Philippines

This project near Mayon determined the character and ages of the most recent eruptions of the Iriga volcano and also dated its voluminous gravitational collapse to between 1,500 and 1,650 years ago. The collapse formed a large, horseshoe-shaped crater 2 kilometres in diameter and dammed a valley on its southeastern foot, forming Lake Buhi.

Collapse of Mt. Popa, Myanmar

At the invitation of Assoc Prof Khin Zhaw of the University of Tasmania, we did a one-week study of Mt. Popa, documenting and dating gravitational collapse of the volcano.

Inexpensive New Monitoring Tools for Volcanoes

We designed and assembled a low-rate datalogger and tested it with tiltmeters at the volcanoes Mayon in Luzon, the Philippines, and Sinabung in North Sumatra, Indonesia. The datalogger can also be used for other analog sensors such as seismometers, microphones, and microbarographs. We also tested a type of 5.8GHz radio telemetry at Sinabung, which is low-cost, versatile, and requires no frequency license.

Coring of Buhi lake at the foot of Iriga volcano, the Philippines, for reconstruction of the volcano's eruptive history and estimations of paleoclimate.

Speleothems, precipitated from carbonate-supersaturated water in caves, are a unique archive for studying past climate change. Photo courtesy of Dr Augusto Auler.

Climate

Over the next decades, changes in average global temperatures will perturb the weather patterns that we have long relied upon to support agriculture. Warmer oceans and a warming atmosphere will reduce the size of the polar ice caps, resulting in changing sea levels, which will in turn pose a threat to coastal areas – especially in the Tropics. Several major drivers of global climate are active in Southeast Asia, yet scientific knowledge about them is relatively scant.

Our emerging program of climate research is concentrating on sea-level change, regional climate monitoring, paleoclimate studies and modelling of past and modern tropical climates. We aim to conduct research that will lead to better prediction of regional consequences of climate and sea-level change.

Slabbing a living coral microatoll at Tanjung Kubu site, Belitung Island, Indonesia. June 2011.

> If a large chunk of the Antarctic ice cap snaps off and melts, what would happen to sea levels in the Tropics? Hopefully, this new sea-level curve from Belitung will provide the very data set needed to test such glacial-melting models.
> Adam Switzer, EOS

High-Resolution Sea-Level History at Belitung Island, Indonesia, on the Sunda Shelf, Over the Past 8,000 Years

Principal Investigator
Asst Prof Adam Switzer,
EOS, Nanyang Technological University

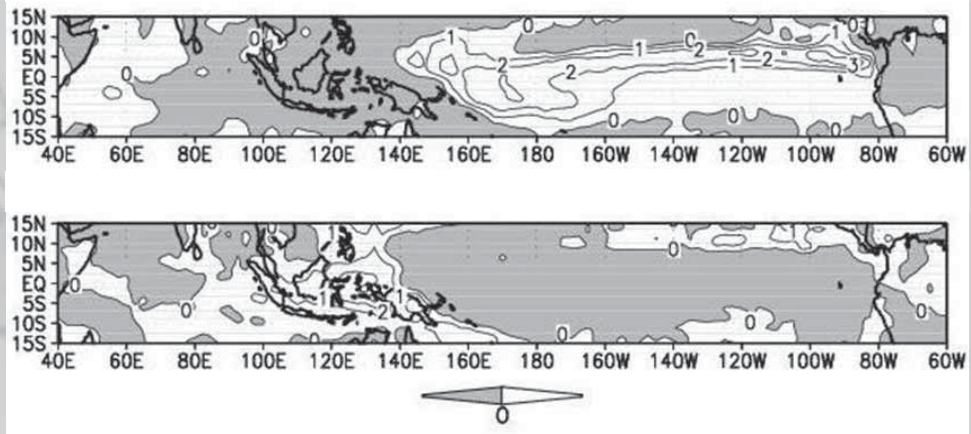
Co-Investigators
Dr Aron J. Meltzner,
EOS, Nanyang Technological University
Assoc Prof Benjamin P. Horton,
Department of Earth and Environmental Science, University of Pennsylvania
Assoc Prof Chuan-Chou Shen,
HISPEC Lab, Department of Geosciences, National Taiwan University

Coral microatolls preserve high-resolution data on sea-level change, often to within a few centimeters. What's more, precise ages of long-dead corals can be determined very precisely using radiometric dating techniques, allowing us to reconstruct a detailed history of sea-level changes.

At a site west of Borneo, we are collecting an exceptionally accurate and precise record of sea-level spanning the past 7,000 years. Such records of sea-level change are needed to validate geophysical and climate models.

In 2010, we collected new relative sea-level data from coral microatolls on the stable Sunda Shelf. We searched for sites around Belitung and Mendanau Islands, Indonesia, and identified three sites with living and multiple generations of fossil microatolls. We cored ten, which all dated to between 7,400 and 5,200 years ago. We observed lower microatolls that could not be collected this year for logistical reasons but found no higher ones. The lack of higher microatolls suggests that this marked the highest sea level in the mid-Holocene.

Already, this record is noteworthy for the extent to which it contradicts the preferred models of sea-level change due to glacial melting. Sea-level change is not globally uniform and is relatively unexplored in the Tropics as compared to temperate regions. The new data we have collected – and propose to collect in 2011 – will be critical for calibrating these models.



Composite of rainfall anomaly (mm/day) for El Nino (top panel) and La Nina (bottom panel) years in the period 1982-2002 in June-July-August-September computed from CPC Merged Analysis of Precipitation (CMAP).

Regional Climate Downscale of El Niño and Indian Ocean Dipole

Principal Investigator
Asst Prof Tieh-Yong Koh,
EOS & School of Physical and Mathematical Sciences, Nanyang Technological University

Co-Investigators
Prof Shigeo Yoden,
Department of Geophysics, Kyoto University
Dr Jeff Chun-Fung Lo,
Temasek Laboratories, Nanyang Technological University
Dr Kazuo Saito,
Forecast Research Department, Meteorological Research Institute, Japan

Understanding current regional climate is necessary for achieving EOS' objective of addressing climate change in Southeast Asia. This project aims to elucidate the impact of large-scale climate patterns – El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) – on temperature, humidity and rainfall on the western Maritime Continent, including the Malay Peninsula, Sumatra, Borneo and Java. We are using a limited-area atmospheric model to dynamically interpolate, or "downscale", a high-quality climatological dataset, the Japanese 25-Year Re-Analysis (JRA-25).

The downscale will provide present-day ENSO and IOD patterns at mesoscale resolution. We also plan to run simulations to test hypotheses on the influence of terrain, coastline and sea-surface temperature on climactic conditions in this region.

Adam Switzer and Yu Feng Ling with collaborators from Sun Yat-sen University, drilling on Nanao Island, Southeast China.

Geological Records of Environmental Change and Coastal Hazards, South China Sea*

Principal Investigator
Asst Prof Adam Switzer,
EOS, Nanyang Technological University

Co-Investigators
Assoc Prof Dale Dominey-Howes,
Australian Tsunami Research Centre & Natural Hazards Research Laboratory, University of New South Wales
Assoc Prof Yongqiang Zong,
Department of Earth Sciences, University of Hong Kong
Prof Zhuo Zheng,
Department of Earth Sciences, Sun Yat-sen University Guangzhou, China
Dr Craig Sloss,
School of Natural Resource Sciences, Queensland University of Technology
Dr Kangyou Huang,
Department of Earth Sciences, Sun Yat-sen University Guangzhou, China
Dr Fengling Yu,
EOS, Nanyang Technological University

The coastal areas of the South China Sea are some of the most densely populated and rapidly developing in the world. The majority of people on this coast live in areas lower than 10 metres above mean sea level, which makes them vulnerable to typhoons and storms, as well as less frequent – but more catastrophic – tsunamis. To adequately plan and manage future coastal development, it is necessary to understand regional risk and resolve inconsistency in the historical records of catastrophic events. This study aims to construct a geological record of catastrophic marine inundations in the South China Sea area, including the Southeast China coast, the Philippines and Vietnam. That information will help us to estimate the periodicity of different oceanic hazards and assess the likelihood of corresponding damage.

*Funded as part of a Singapore National Research Foundation Fellowship

Technical Office

Imam Suprihanto and Dudi Prayudi (two of EOS' Indonesian collaborators) constructing a GPS station in Pariaman, West Sumatra.

Director
Dr Paramesh Banerjee,
EOS, Nanyang Technological University

The Technical Office (TO) is the crucible for geophysical observation, instrumentation and data-processing at EOS. From forming collaborations with scientific institutions in the region, to delivering processed products, the Technical Office plays a key role in facilitating scientific research at EOS.

The TO maintains and upgrades the Sumatran GPS Array (SuGAr) in cooperation with the Indonesian Institute of Sciences (LIPI). The TO also archives and processes the data from SuGAr, which now consists of 40 GPS stations, most of which are now telemetered via satellite.

In 2010, our upgrades to the SuGAr enabled faster responses to and a better understanding of the earthquakes greater than magnitude 7 in April, May and October. In addition to our responses to these events, we established 10 new GPS stations aimed at answering important scientific questions about the behavior of the Sunda megathrust and Sumatran faults. Ten more will be installed in 2011. By the end of 2011, all SuGAr stations will be equipped with satellite telemetry.

The TO is also playing a key role in initiating collaborative research involving Myanmar, Bangladesh and India. After signing the necessary MOU in 2010, we installed four GPS stations in Myanmar in early 2011 and plan to site several more this year. We also have selected GPS sites in Bangladesh and plan to install four stations in a north-south transect and four in an east-west transect.

We expect to sign an MOU with India in 2011, which will pave the way to install eight stations there. The GPS stations in this region will measure deformations across this tectonically complex eastern edge of the India-Asia collision.

The TO also provides specialised support in instrumentation, data acquisition and data processing for other EOS projects. We maintain a ground-based LIDAR and a pool of surveying and geophysical instruments. A powerful but low-cost Linux-based clustered network is a key part of the EOS' computational facilities. GPS data from SuGAr and other networks are being telemetered to the TO database and routinely processed.

While providing state-of-the-art technical support to the EOS and its collaborating agencies, the TO also endeavors to carry out innovative experiments and develop new techniques to facilitate earth science research in South and Southeast Asia.

Education & Outreach

Director
Sharmini Blok,
EOS, Nanyang Technological University
(Current Interim Director: Andreas Schaffer, EOS, Nanyang Technological University)

The Education & Outreach (E&O) Office communicates EOS research to the public by working with students, teachers, the media, government and non-governmental organisations.

It creates materials and provides programmes for schools and communities to improve basic understanding of natural hazards such as earthquakes, tsunamis, volcanic eruptions and climate change. Also, by facilitating workshops and developing partnerships with local and international organisations, the E&O office is helping to build regional capacity for disaster risk reduction.

E&O is collaborating with the Singapore Science Centre on a permanent exhibit, *Our Dynamic Earth*, which will launch early in 2012. This exhibit will cover basic concepts as well as highlight the dynamic Earth processes of Southeast Asia.

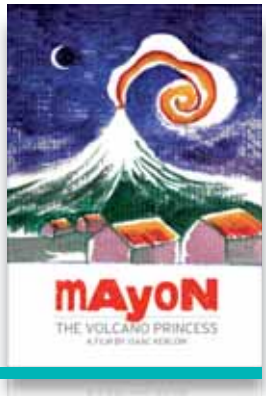
EOS participated in the Asia Oceania Geosciences Society (AOGS) exhbition and conference in Hyderabad, India, in 2010.

Paul Tapponnier speaks to student contestants during an outdoor segment of the *National Science Challenge 2010*.

Artist-in-Residence

Mayon: The Volcano Princess includes testimonies by Rolando and Milagros Banaña, two survivors of the 2006 Mayon lahar.

The documentary premiered to a full house at the Golden Village Grand Theater. The Mexican and Philippines Embassies helped to sponsor the event.



Principal Investigator
Prof Isaac Kerlow,
EOS & School of Art, Design and Media,
Nanyang Technological University

EOS' Artist-in-Residence, Isaac Kerlow, heads a group of students and research assistants from NTU's School of Art, Design and Media. The group produces films about EOS research topics and creates artworks inspired by earth science and environmental themes.

Kerlow's feature-length documentary, *Mayon: The Volcano Princess*, chronicles the lives of people living around the Mayon volcano in the Philippines. The film won international accolades after its premiere in October 2010, including a United Nations Best Concept Award at the International Festival of Environmental Cinema.

A computer game and an animated short called *Earth Girl* are under development. Aimed primarily at a young audience, the story stars a Southeast Asian girl who can save her family and friends from natural disasters. In the edutainment game the protagonist gains special powers to fight earth hazards only after she saves her community.

A short film titled *Sudden Nature*, the first part of a multimedia art project, has been completed. The allegorical piece explores the uneasy relationship between Man and Nature and is scheduled to premiere in October 2011.

Killer Waves is a new film in early production. The tentative goal of this feature is to present the impact of the interrelated Earth systems that conspire to produce tsunamis and typhoons. The documentary focuses on communities and individuals impacted by such phenomena. It also aims to make use of original EOS research and scientific visualization.

Artist-in-Residence Projects:
http://www.thevolcanoprincess.com
http://earthgirlproject.wordpress.com
http://suddennature.com

Sustainability Directorate

Director
Andreas Schaffer,
EOS, Nanyang Technological University

In 2010, EOS built the foundations of a major branch of its organisation, the Sustainability Directorate, headed by the former business executive from Monitor Group, Andreas Schaffer.

The mandate of the group is to integrate climate science into decision making and thus make EOS relevant to senior decision makers in business and policy. For example, the Sustainability Directorate is planning to host a new initiative of Corporate Leaders on Climate Change in Southeast Asia. In addition, the group is conducting economics and policy research to address issues relevant to stakeholders.

In the future, the Sustainability Directorate will branch out to address issues related to other natural hazards such as earthquakes and tsunamis.

In January 2010, the directorate launched its flagship workshop series, "*Starving Tigers? Impacts of Climate Change in Southeast Asia*". In response to the success of the first workshop, we are planning to offer similar workshops in regional climate-change hotspots, collaborating with local policy and business leaders as well as leading climate scientists.

The directorate also designed and sponsored a pilot project for NTU in 2010 to measure the environmental footprint of EOS, the building in which it's housed, and the School for Physical and Mathematical Sciences at NTU. The study obtained a baseline footprint for the three units and served as a springboard for a new campus-wide sustainability office.

The "*Starving Tigers?*" workshop conducted by EOS and the RSIS Centre for Non-Traditional Security (NTS) Studies in January 2010.

> "Climate change is increasingly important to senior executives and policy leaders in Southeast Asia. The Sustainability Directorate tackles regional climate issues of highest priority. We seek to seamlessly integrate relevant climate science into policy and business decisions."
> Andreas Schaffer, EOS

Getting Results
Publication Highlights of FY2010

Costa, F., and D. Morgan (2010), "Time constraints from chemical equilibration in magmatic crystals", *Timescales of magmatic processes: from core to atmosphere*, eds. A. Dosseto, S.P. Turner, and J.A. Orman. New York, Wiley-Blackwell, pp. 125-159.

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Macpherson, K., D. Hidayat, and S.H. Goh (2010), "Receiver function structure beneath a broad-band seismic station in south Sumatra", presented at the Annual Meeting of the American Geophysical Union, 2010.

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McLoughlin, I., L.M. Ang, and W.B. Goh (2011), "Multitouch wall displays for informational interactive collaborative space", *Digital Urban Planning and Modelling*, eds. S. Müller Arisona, P. Wonka, G. Aschwanden, and J. Halatsch. Springer, vol. 242.

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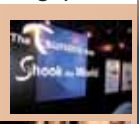
Wiseman, K., P. Banerjee, K. Sieh, R. Bürgmann, and D.H. Natawidjaja (2011), "Another potential source of destructive earthquakes and tsunami offshore of Sumatra", *Geophysical Research Letters*, vol. 38, L10311.

For more publications and links to papers, go to
http://earthobservatory.sg/publications/overview.html

A Year... in Outreach Activities

26 May 2010
Forces of Nature, special screening of IMAX movie to mark the start of collaboration with the Science Centre Singapore



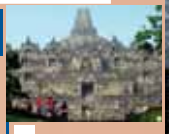
24 Sept 2010
Senior and Lead Geography Teachers' Visit to EOS

7 Oct 2010
Premiere of *Mayon: Volcano Princess* at Golden Village Grand Cinema

12 Mar 2011
Life @ NTU, open-house exhibition showcasing EOS and DES

May – June 2010
National Science Challenge 2010

5-9 July 2010
EOS booth and participation in Asia Oceania Geosciences Society (AOGS) in Hyderabad, India



27 Nov - 1 Dec 2010
Overseas field seminar in Yogyakarta

26 Jan 2011
Tsunami Alert book talk and launch

March 2011
Kerry Sieh using *GeoTouch* to explain the March 2011 Japan earthquake and tsunami to Channel News Asia

GPS station on the west coast of Sumatra near the equator.
The coastal town of Air Bangis is in the background.

Moving Forward
New Research Projects for 2011

EARTHQUAKES

GEOBOULDER, an Online Research Portal Dedicated to Coastal Boulder Studies

Principal Investigator
Asst Prof Adam Switzer

GEOBOULDER is an online research portal of environmental data on coastal boulders and megaclasts. In coastal settings, their transport is usually restricted to high-energy wave events such as cyclones, extratropical storms or tsunamis. The key objective of GEOBOULDER is to centralize available data on coastal boulders. With expanded global coverage, we hope that researchers working after an event will have a free-access tool where they can find data on pre-transport settings of mobilized boulders. Modelling with precise information on pre-event settings is a way to greatly improve modelling of sediment transport during modern events and our reconstructions of paleo-events.

TSUNAMIS

A Preliminary Assessment of Volcanogenic Tsunami Hazard in Southeast Asia

Principal Investigator
Asst Prof Adam Switzer

There is an obvious need to assess the risk of volcanogenic tsunami events in Southeast Asia, as the region is surrounded by densely populated, economically important and rapidly developing coastlines. In an initial step, the historical records of catastrophic volcanogenic tsunami events throughout the region are being compiled, assessed and cross-checked to remove errors and misinterpretations, to refine early work and ensure a robust dataset. This primarily desktop study will provide a regional synthesis that will guide further geological investigations and modelling of key identified events.

Real-Time Measurement of Onshore Tsunami Flows

Principal Investigator
Asst Prof Zhenhua Huang

In the past, real-time tsunami measurements have been focussed on water levels offshore, and information about onshore tsunami flows (flow depth and run-up) are usually obtained through post-tsunami surveys. There is a lack of key information about the tsunami flow velocity and suspended sediment. We are developing a system for real-time measurements of onshore tsunami flows to collect information about water level, flow velocity, and suspended sediment of such flows. The proposed system will be integrated with the network of existing EOS GPS stations in West Sumatra.

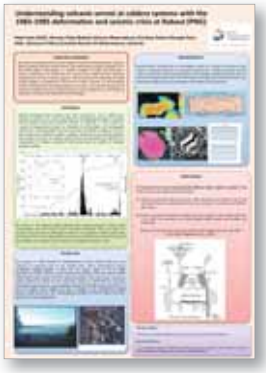
VOLCANOES

Laboratory Volcano: Ulawun

Principal Investigator
Prof Christopher Newhall

Working with Rabaul Observatory in Papua New Guinea, we are establishing a new laboratory volcano project at Ulawun, an active, basaltic andesite stratocone very much like Mayon in The

Philippines. Ulawun would yield interesting comparisons with Mayon at the open end of the degassing spectrum, provide another setting in which to test for magma convection in the conduit, let us look for why volcanoes like Mayon or Ulawun can collapse, and open the door for other collaborations in a third, volcano-rich country.



Understanding Volcanic Unrest at Caldera Systems with the 1983-1985 Deformation and Seismic Crisis at Rabaul, Papua New Guinea

Principal Investigator
Asst Prof Fidel Costa

We seek to understand the unrest signals of caldera-related volcanic systems. Rabaul caldera showed strong seismic and deformation activity between 1971 and 1996 before culminating in a plinian eruption in 1996. This provides a unique opportunity to determine the causes (e.g., hydrothermal, tectonic, magmatic) of unrest in caldera systems. We are using kinetic modelling of crystal zoning patterns to determine if the time of mafic intrusion in the plumbing system coincides with the largest period of unrest or not. We will also perform numerical models aimed at reproducing the unrest signals (e.g., deformation) using the intrusion times obtained from petrology.

Exploratory Projects on Volcanoes

Principal Investigator
Prof Christopher Newhall

Ongoing exploratory projects include a low-cost instrument project; and GOSAT, which aims to detect and quantify volcanic CO_2 from space. New projects include studying the geologic history of Isarog volcano in southeastern Luzon, the Philippines; determining the Holocene eruptive history of Ambang volcano in North Sulawesi, Indonesia; and responding to InSAR anomalies at Agung volcano in Bali, Indonesia.

CLIMATE

Temporally and Spatially Varying Signals in GRACE Measurements of Glacier Melting and Water Storage*

Principal Investigator
Asst Prof Emma Hill

GRACE time series are commonly modelled assuming constant rates and seasonal cycles at each location. However, temporal variations in these parameters mean that this model is unlikely to provide a good fit to the data, and in using it, we are likely to lose valuable information. We are therefore constructing a stochastic filter for the GRACE data, which will allow for time-varying rates and seasonal cycles. Resulting time series for rates and seasonal cycles in surface mass change will have a wide range of geophysical applications, including measuring accelerations in rates of glacier melting and groundwater depletion.

Tracking Hydro-Climate Variation in the Tropical Indo-Pacific with Highly Resolved Cave Records*

Principal Investigator
Asst Prof Xianfeng Wang


Photo courtesy of Dr Augusto Auler

Climate of the tropical Indo-Pacific, particularly rainfall, is critical to the socio-economic health of the region. However, the current lack of long and precisely dated paleoclimate records prohibits a full understanding of the spatio-temporal pattern of the regional climate variability. This study aims to reconstruct continuous, well-dated, high-resolution hydro-climate records covering the last 100,000 years in the tropical Indo-Pacific using cave carbonate samples. The records will be compared with instrumental data and other regional and global proxy datasets to investigate the forcing mechanisms in the regional climate system and the role of the Tropics in global climate cycles.

*Funded by a Singapore National Research Foundation Fellowship

Combined Statistical Downscaling and Disaggregation of Regional Climate Data Considering Temporal and Spatial Variability

Principal Investigators
Asst Prof Xiaosheng Qin
Asst Prof Sai Hung Cheung

This study aims to develop a combined downscaling and disaggregation methodology for building linkages between regional climate model (RCM) outputs and high-resolution local weather data and examining the related uncertainties and complexities. The large-scale variables obtained from RCM projections of future regional climate can then be used to drive the statistical relationships and estimate the smaller-scale temporal and spatial details. The project outcomes could form the basis for in-depth hydrological climate-change impact studies and help enhance collaborative links to local scientific partners in Singapore.

SUSTAINABILITY/ EDUCATION & OUTREACH

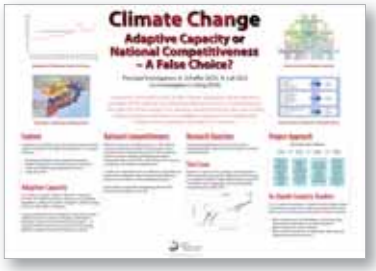
Reducing Greenhouse Gas Emissions from Deforestation: Valuation Modelling of Natural Assets in Gunung Palung National Park, Indonesia

Principal Investigator
Andreas Schaffer

The objective of the project is to assess the economic case for reducing greenhouse gas emissions from deforestation in Gunung Palung National Park, situated in the administrative district of Kayong Utara (Kalimantan, Indonesia). Indonesia is the third largest emitter of greenhouse gases globally, with approximately 80 percent of emissions stemming from deforestation. The proposed project will model the long-term economics underlying current deforestation practices (e.g., illegal logging and farming, land conversion for palm oil) and contrast them with the modelled value of forestry and biodiversity conservation via carbon and biodiversity credits, ecotourism, sustainable forestry products and bioprospecting.

Climate Change: Adaptive Capacity or National Competitiveness – A False Choice?

Principal Investigator
Andreas Schaffer



Building and strengthening national-level adaptive capacity is a prerequisite for Southeast Asian countries to reduce the adverse impacts of climate change. However, there is a common framing among decision makers that investments into climate change adaptation are made at the expense of enhancing national competitiveness. A linkage between adaptive capacity and national competitiveness is poorly understood and explored by public and private sector decision makers. The objective of this project is to develop national-level insights and case studies illustrating how investments into adaptive capacity in response to climate change could simultaneously enhance national competitiveness, which would prove the common framing to be a false choice.

Education for Disaster Risk Reduction, Mentawai Islands, West Sumatera, Indonesia

Principal Investigator
Andreas Schaffer (Interim)

Based on paleoseismology and geodesy around the Mentawai patch of the Sunda megathrust, EOS researchers have forecast the likelihood of a devastating earthquake and its tsunami in the coming decades in the area around the Mentawai Islands. People in the Mentawai Islands remain confused about the hazard and unsure of how to mitigate the risk and thus are highly vulnerable. We are working with local partners through training and educational materials and seminars to enhance existing public education efforts and foster the development of new ones.

Financial Summary & Staffing for 2010

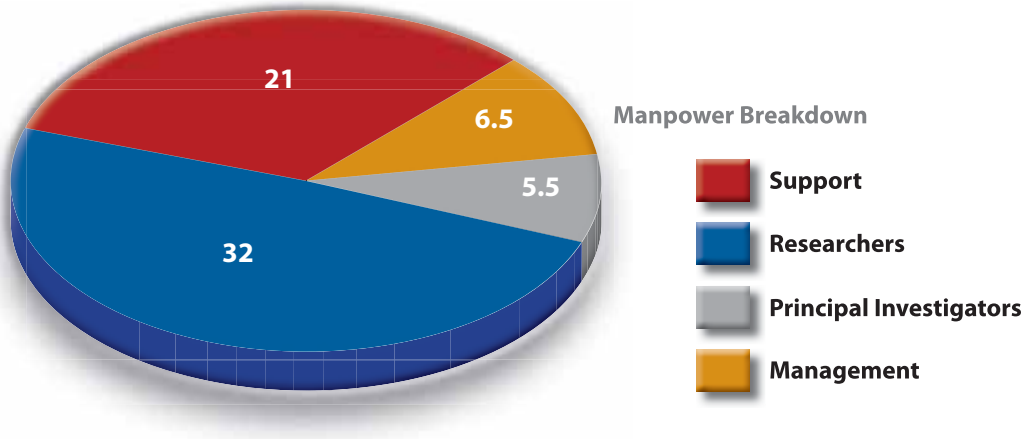
Financial Summary for Fiscal Year 2010

Categories	Budget *(S$)*	Actual Expenditure *(S$)*
Expenditure On Manpower	6,286,000	5,649,952
Equipment	1,101,631	1,094,222
Other Operating Expenditure	8,067,829	6,105,336
Total	**15,455,460**	**12,849,510**

Manpower Summary as of March 31, 2011

		General	Volcano Group	Tectonics Group	Climate Group	Total
Management		4.5	1	1	-	6.5
Principal Investigators		-	1.25	2.75	1.5	5.5 *
Researchers:	Senior Fellow	-	6	-	-	6
	Fellow	-	2	8	-	10
	Associate	-	1	6	-	7
	Assistant	4	1	4	-	9
	Technical	-	-	-	-	-
Support:	Administration	10	1	1	1	13
	Technical	4	-	-	-	4
	Sustainability, Education & Outreach	4	-	-	-	4
Total		**26.5**	**13.25**	**22.75**	**2.5**	**65**

** 8.5, including Group Leaders and Director*



EOS staff mingle at a monthly birthday celebration in the lounge.

Management

- 6.5 **Management** = Kerry Sieh, Paul Tapponier, Chris Newhall, Andreas Schaffer, Woo Kien Young, Paramesh Banerjee, 0.5 Isaac Kerlow

Volcano Group

- 1.25 **Principal Investigators** = 1 Fidel Costa, 0.25 Ian McLoughlin
- 6 **Senior Research Fellows** = Antonius Ratdomopurbo, Christina Widiwijayanti, Dannie Hidayat, Alexander Belousov, Marina Belousova, Florian Schwandner
- 2 **Research Fellows** = Christopher Harpel, Joan Cabato
- 1 **Research Associate** = Alexandre Baguet
- 1 **Research Assistant** = Sergio Marcial
- 1 **Administration** = Harpreet Kaur

Tectonics Group

- 2.75 **Principal Investigators** = 0.5 Adam Switzer , 0.5 Emma Hill, 0.5 Kusnowidjaya Megawati, 0.25 Ian McLoughlin, 0.5 Huang Zhenhua, 0.5 Goh Siang Huat
- 8 **Research Fellows** = Meya Yanger Walling, Kenneth Macpherson, Li LinLin, Aron Meltzner, Chris Gouramanis, Yu Feng Ling, Afroz Shah, Manuela Di Mauro
- 6 **Research Associates** = Zhang Yan Mei, Qiu Qiang, Mudrik Rahmawan Daryono, Maggie Chan, Farzaneh Ahmadi, Jiao Li Qing
- 4 **Research Assistants** = Linus Ang, Han Xiao Han, Zhu Cheng, Lee Ying Sin
- 1 **Administration** = Clair Elaine Jerusha Devan

Climate Group

- 1.5 **Principal Investigators** = 0.5 Adam Switzer, 0.5 Emma Hill, 0.5 Koh Tieh Yong
- 1 **Administration** = Susan Wee

Support

- 10 **Administration** = Loh Li Kiang, Carol Jean-Chan Poh Har, Foo Pow Choo, Bu Su Xian, Oh Hwee Hong, May Pea, Evelyn Tan, Aggie Lee, Jhoanna Jovero, Linda Chua
- 4 **Technical** = Jeffrey Encillo, Jonah Yong, Daniel Sin, Michael Goh
- 3 **Education and Outreach** = Liow Hon Sang, James McCaughey, Elaine Chong
- 1 **Sustainability** = Ding Li
- 4 **Research Assistants** = Jeannie Loo, David Lee, Nur Aisyah Binte Suhaimi, Muhammad Khadafi

Working Together

EOS has signed Memoranda of Understanding (MOU) with many partners in the region:

The Indonesian Institute of Sciences (LIPI), Republic of Indonesia

The Philippines Institute of Volcanology and Seismology (PHIVOLCS) -
Department of Science and Technology,
The Philippines

Myanmar Earthquake Committee, Myanmar Engineering Society, Myanmar

Geological Survey of Bangladesh, Bangladesh

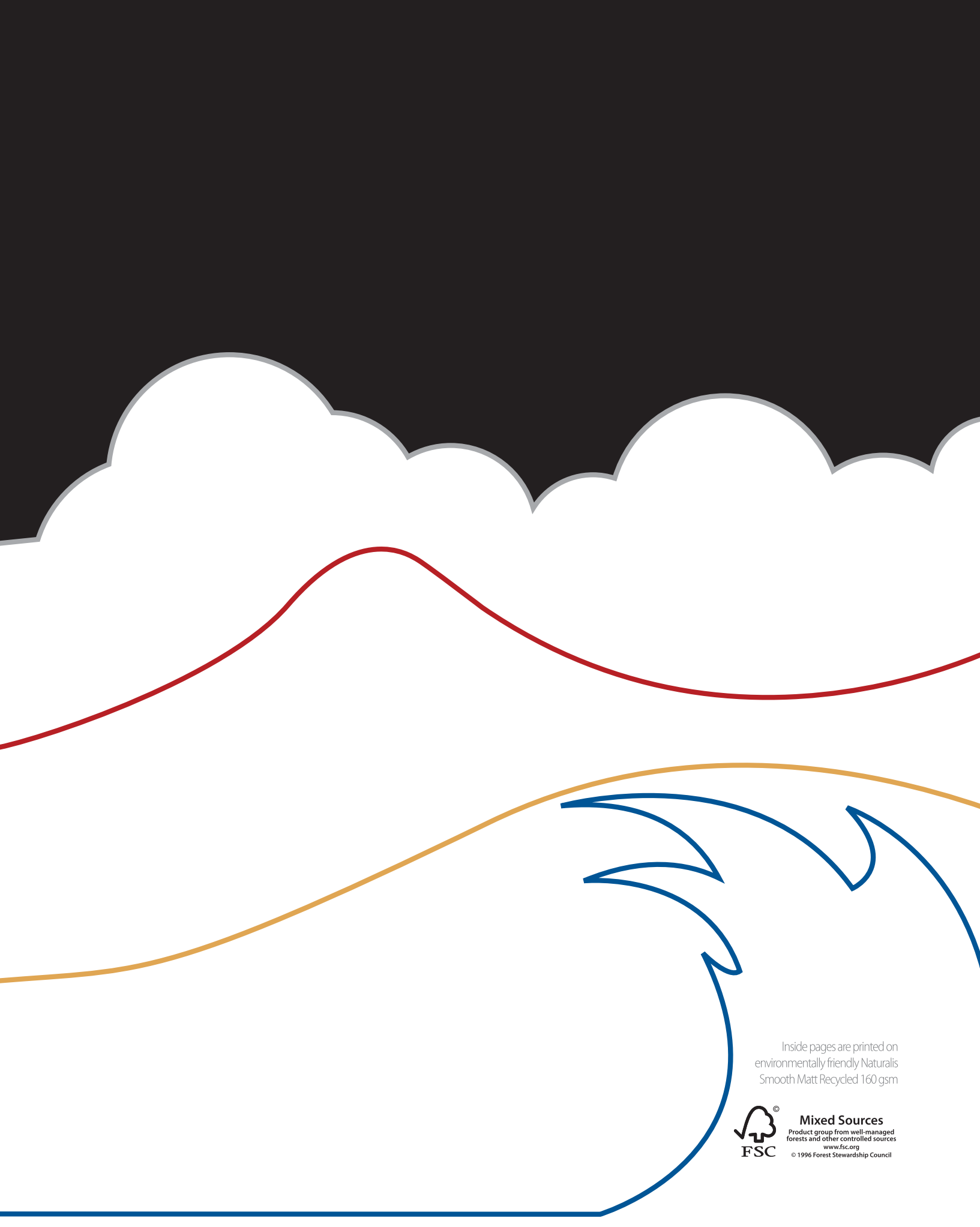
The Center for Volcanology and Geological Hazard Mitigation (CVGHM), Geological Agency,
Ministry of Energy and Mineral Resources,
Republic of Indonesia

Hanoi University of Mining and Geology (HUMG) and Institute of Geosciences, Vietnam Academy of Science and Technology (VAST), Vietnam

The Agency for Meteorology, Climatology and Geophysics of the Republic of Indonesia (Pending)

EOS collaborates with institutions around the world:

Alternative Energies and Atomic Energy Commission (CEA), France
American University of Beirut, Lebanon
Bandung Institute of Technology (ITB), Indonesia
California Institute of Technology, USA
China Earthquake Administration, China
Clermont University, France
Columbia University, USA
Danube University Krems, Austria
Forest Carbon, Indonesia
Georgia Institute of Technology, USA
Gunung Palung National Park, Indonesia
Harvard University, USA
Indonesian Centre for Archaeology (ARKENAS), Indonesia
Institute of Geophysics of Paris (IPGP), France
Institute of Tibetan Plateau Research, China
Jadavpur University, India
Jet Propulsion Laboratory, USA
Joseph Fourier University, France
Kayong Utara, Indonesia
Kyoto University, Japan
Massachusetts Institute of Technology, USA
Mediterranean Centre for Marine and Environmental Research, Spain
Meteorological Research Institute, Japan
Michigan Technological University, USA
Ministry of Land and Resources, China
National Institute for Geophysics and Volcanology (INGV), Italy
National Oceanographic Centre, U.K.
National Seismological Centre, Nepal
National Taiwan University, Taiwan (R.O.C.)
National University of Singapore, Singapore
North East Institute of Science and Technology, India
Queensland University of Technology, Australia
Rabaul Volcano Observatory, Papua New Guinea
Russian Academy of Sciences, Russia
Sepuluh Institute of Technology (ITS), Indonesia
University of Hong Kong, Hong Kong SAR, China
Tohoku University, Japan
Tokyo Institute of Technology, Japan
Tribhuvan University, Nepal
U.S. Geological Survey, USA
University of California-Berkeley, USA
University of Coruña, Spain
University of French Polynesia, Tahiti
University of New South Wales, Australia
University of Palermo, Italy
University of Pennsylvania, USA
University of Sheffield, U.K.
University of Tokyo, Japan
Yale University, USA



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