A Report on International Travel Programme Visit to Earth Observatory, NTU Singapore from 26th - 30th January 2015 at NTU, Singapore

Submitted by: Ramji Dwivedi, Assistant Professor, GIS Cell

I have visited the Earth Observatory, NTU Singapore on 26th - 30th January 2015 at NTU, Singapore under the TEQIP-II sponsored International Travel Programme. Following is the detailed report of the visit with a little background on the Earth Observatory of Singapore followed by the summary of projects which may be picked up in near future:

1. Introduction to Earth Observatory of Singapore (EOS): The Earth Observatory of Singapore conducts fundamental research on earthquakes, volcanoes, tsunamis & climate change in and around Southeast Asia, towards safer and more sustainable societies. The EOS conducts research both on the dynamism of our planet and our scientific observations of the changing Earth. Four basic components which are studied at EOS are basically fire wind, water and earth. Followings are the brief summary of two projects which were discussed:

2. Thrust Area of Research at EOS:

Three major thrust area in which people at EOS contributes *i.e.* Tectonics, Climate and Volcano

2.1. Tectonics

Southeast Asia and surrounding areas have many large, active faults, as well as a number of major subduction zones that are responsible for some of the world's most complex movements by tectonic plates. This region provides a natural laboratory to study Earth deformation processes with global relevance.

The broad goal in this area of EOS research is to increase fundamental knowledge of the region's tectonic and seismic behaviour, as a basis for more reliable forecasting of earthquakes and tsunamis as well as action to reduce the potential hazards. EOS scientists help lay the groundwork to identify signs of previous earthquakes, their size, their recurrence, and eventually their capacity for destruction.

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27/2/15

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Active tectonics in the present

EOS scientists also study the very fast, dynamic processes associated with rapid breakage of Earth's rocks. Geodesists such as Prof. Emma Hill look at the current deformation of the Earth's surface. Her research group uses these surface measurements to infer the mechanics of earthquakes and the slow processes that prepare the earth for strong shaking. When an earthquake occurs, geodesists can actually see the rapid movement at the earth's surface. Understanding the modern behaviour is another piece of the puzzle that gives a complete look at the earthquake cycle.

Observational seismologist Shengji Wei uses seismic waveforms at wide distance ranges (from near field to thousands of kilometres away) and frequency ranges (several Hz to static) to determine fundamental source parameters of earthquake such as location, origin time, magnitude, focal mechanism and finite rupture process. These earthquake information are important proxies to understand the recent tectonic process and earthquake physics. Dr. Wei also conduct strong ground shaking simulations for large earthquakes, involving complicated rupture process and three-dimensional velocity structure, which are keys to understand the damages that an earthquake can generate.

To be able to forecast earthquakes like we forecast weather, it is also needed a full understanding of how rocks deform deep in the interior as there is tremendous uncertainty in how rocks behave under different pressure, temperature, and fluid conditions.

2.2. Volcano

Volcanic arcs in Southeast Asia are among the most active on earth. EOS Volcano Group conducts geologic, geochemical and geophysical studies to improve understanding of volcanic activity, particularly processes related to eruptions. EOS research in this field is designed to produce knowledge and tools that will aid forecasting of volcanic eruptions, assessment of their environmental and societal impacts, and efforts to mitigate the hazards.

Research Areas: From Genesis to Eruptions

EOS scientists take a multidisciplinary approach and combine geophysics, geochemistry, petrology, stratigraphy, hydrology, geomorphology, kinetic and numerical modelling to determine the reasons of volcanic unrest and explain the processes at stake in the reservoirs.

They bring an intense focus on a small number of targets to reconstruct past eruptive behaviour and to monitor and model a wide range of processes occurring at depth. The models are then used to test hypotheses on degassing and other controls on eruptions, allowing for time series and eruptions forecasting.

2.3. Climate

Climate research at EOS aims to fill a gap of much-needed information on climatic forces in Southeast Asia, which will allow better prediction of regional consequences that can expected from global climate change. Several major drivers of global climate, including the Western Pacific Warm Pool and the Indian Ocean Dipole, are active in this tropical region, yet scientific knowledge about them has been relatively scarce. Their emerging program of climate research concentrates on regional climate monitoring, and the measurement and modelling of past and modern tropical climates. The themes are mainly the lithosphere, the atmosphere, and the hydrosphere and across time.

3. Discussion on the prospective project proposals

Two project proposals were discussed with **Prof. Paramesh Banerjee, Technical Director, EOS** in the direction of disaster monitoring and crustal monitoring. Following is the brief summary of the discussed project:

1. GPS-RTK survey project in NW Himalaya (jointly by EOS, NTU and MNNIT)

Prof. Paramesh Banerjee was interested to jointly work on a project in near future to acquire populous data for understanding the Himalayan tectonics and slip rate estimation with more reliability. We may jointly prepare a draft proposal in near future which will highlight the objective where GPS and Seismogram observation are acquired in an integrated manner. Time series analysis using GPS data along with ground motion scenario using seismogram will add a social and more practical value to the achieved results.

2. Development of a Real Time Disaster Monitoring System (jointly by EOS, NTU and MNNIT)

Prof. Banerjee has presented his vision on development of Real Time Disaster Monitoring System with data acquisition to data processing and finally development of a software module for analysing the disaster scenario in real time and further develop an early warning kind of a system

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I conveyed him that we at MNNIT Allahabad are also working in the preparation of high quality DEM using airborne Lidar data and SAR data (available open source) and presently investigating the existing algorithm to prepare DEM. Data processing of such dataset should not be an issue if a good processing environment can be provided.

I have suggested that apart from airborne Lidar other resources can also be utilized to prepare DEM and a proper ground instrumentation support will be required to improve and validate the accuracy of such DEM. Further, as he proposed a software module/Web-GIS interface can be developed to perform the visual and automatic analysis.

We at GIS Cell may also contribute to the above mentioned project by forming a joint project proposal where people at GIS Cell with background on LiDAR, GPS SAR Interferometry and GIS can contribute and work toward a sustainable environment.

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we may assess recurrence intervals and the expected sizes of future earthquakes.

The SuMo Project is also designed to help capacity building between EOS-NTU, University of Bengkulu and LIPI Indonesia, we are c the SuMo GPS laboratory for students to learn earthquake geodesy.

Figure 1. Map of slip rate along the SFZ from geologic (white text) and geodetic observations (yellow text) (Natawidjaja and Triyoso, 2007).

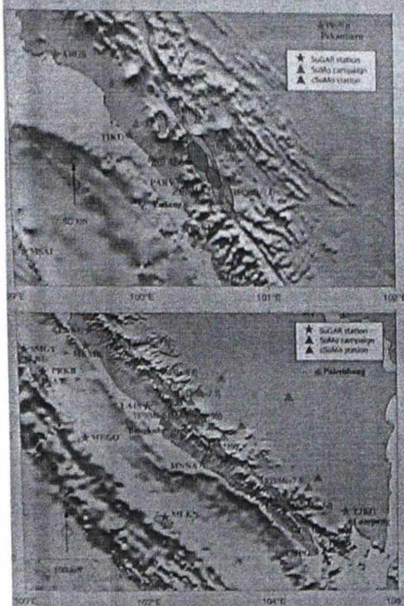
3. Updates on 2013-2014 SuMo GPS Campaign Project

In 2013, we installed 32 GPS monuments distributed over the southern part of the Sumatran Fault. Our network here comprise cross-sections, located at Kumering, Manna and Kepahiang Segments (Fig. 2 bottoms).

We have also conducted two GPS campaigns on the southern part of the Sumatran Fault ; the first campaign was held February - M 2014 and the second campaign October - November 2014. However, preliminary results from processing the data with GAMIT and G suggest that time series for the campaign sites are still too premature to be able to be used for interpretation, let alone to be usec further analysis of the slip rates. More data on the next GPS campaign will reduce the uncertainty to get more reasonable slip rates.

We anticipated the lack of data on the campaign sites by establishing semi-permanent or continous (cSuMo) stations (Fig. 2 bottom). Ti series of some cSuMo stations are shown in figure. 4

Also in 2014, a total of new 29 GPS monuments were installed in the central part of Sumatra (Fig. 2 top). Recently we also have conduct the first GPS campaign on the central part of the Sumatran fault in December 2014-January 2015.



...ure 2. Distribution of SuMo GPS stations, installed in 2014 (top) and in 2013 (bottoms).

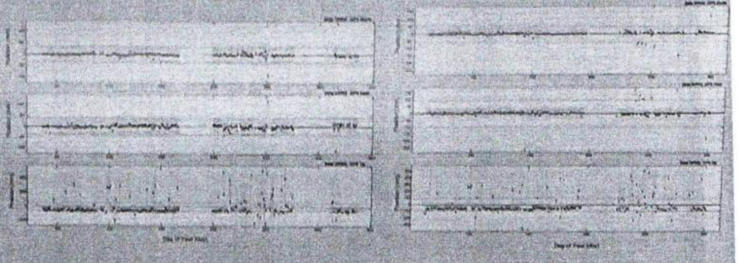
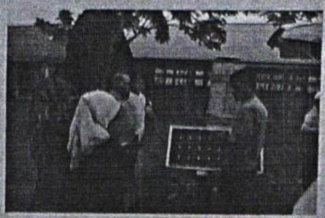


Figure 4. Time series of SuMo cGPS stations, UNBE and KPHG.

4. Team SuMo in the Field



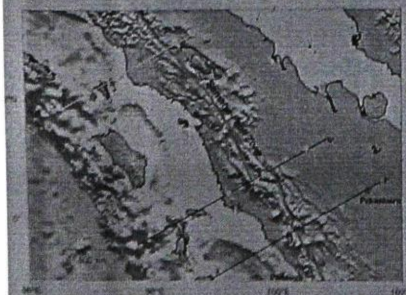


Figure 3. Plan for station installations (yellow dots) in 2015. Green ...

5. Future Work

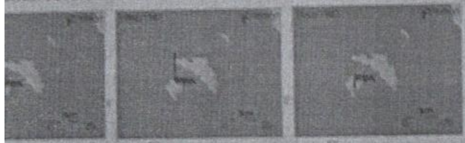
1. We will conduct the third GPS campaign on the southern part of the Sumatran fault at the end of March 2015, and we will continue in measuring the central part of the Sumatra network every 6 months, with 3-4 days of data collection for each occupation.
2. Education and Outreach Program : Involving students from EOS and Social sciences Departement from University of Bengkulu...

...at is the nature of the gap between the two slip patches of the ...5 Nias-Simeulue earthquake?

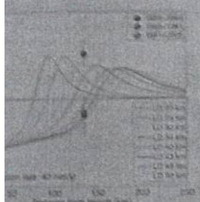
...Louisa L. H. Tsang[1], Aron J. Meltzner[1], Lujia Feng[1], Emma M. Hill[1], Iwan Hermawan[1], Paramesh Banerjee[1], ...Belle Philibosian[3], Bambang W. Suwargadi[4], Danny H. Natawidjaja[4] and Kerry Sieh[1]
...Observatory of Singapore, Nanyang Technological University, Singapore; 2. University of Alaska Fairbanks, United States; ...de Physique du Globe de Paris, France; 4. Research Center of Geotechnology, Indonesian Institute of Sciences (LIPI), Bandung, Indonesia.

...vidence for a slow-slip event (SSE) in the ...ra subduction zone from 1966 - 1981?

...show reversal from subsidence to uplift during 1966-1981



...966-1981 uplift rate not explained by pure backslip

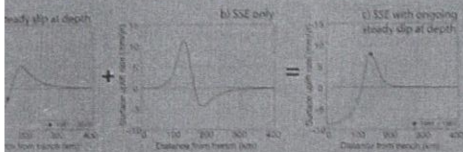


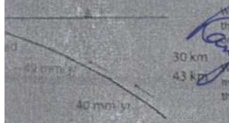
With Okada models, we calculated trench-normal surface uplift rate profiles for various locking depths on the megathrust, assuming a realistic slab geometry (Slab 1.0).

The 20th century subsidence rates are explained by a locking depth of 43 km. Similarly, the pre-20th century subsidence rates are explained by a locking depth of 43-50 km.

However, the 1966-1981 uplift rate cannot be explained by any of these profiles.

An SSE can explain the observed uplift rate





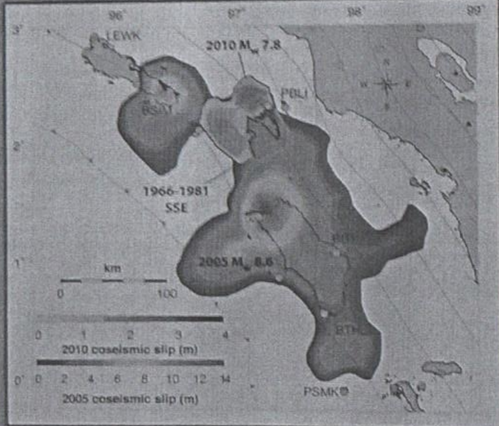
We modeled possible locations and slip rates of the SSE by superimposing an SSE of a certain size on the pure backslip model.

We sum the surface uplift profile for the backslip model and the SSE, and determine the model that visually best fits the 1966-1981 uplift rate.

...ble model to explain the observations is a long-duration SSE occurring at 30 to 43 km ...t a slip rate of ~ 49 mm/yr. These results offer first evidence for an SSE in the Sumatra ...n zone.

Motivations

- Could the low-slip patch of the 2005 M_w 8.6 Nias-Simeulue earthquake be explained by a weakly coupled patch, previous slow-slip events, or both?
- Does the 2010 M_w 7.8 Banyak Islands earthquake, five years after the 2005 earthquake, fill in the low-slip patch of the 2005 rupture?
- What is the spatial relationship between the 2005 low-slip patch, the 2010 Banyak Islands earthquake, and the 1966-1981 slow-slip event?
- Does the spatial relationship tell us anything about structural and frictional properties, and the nature of rupture barriers?
- Understanding these properties could lead to more insightful estimations for the size of future earthquakes, and the impending seismic hazard in the slip gap between Simeulue and Nias.

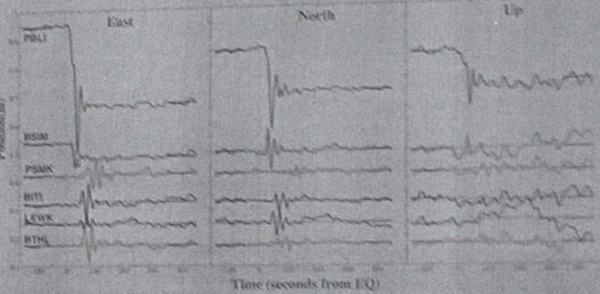


Plans for 2015

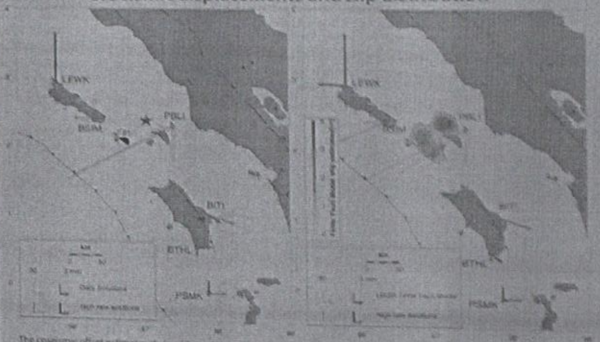
- Model the kinematics of the 1966-1981 SSE with additional coral observations on the Banyak Islands, Simeulue and Nias. This will help us better understand scaling relationships for long-duration SSEs at subduction zones.
- Model coseismic slip distribution of the 2010 Banyak Islands earthquake based on our near-field GPS displacement estimates.

Where did the 2010 M_w 7.8 Banyak Islands earthquake slip relative to the 2005 Nias rupture?

High-rate GPS time series and coseismic offset estimation



Coseismic displacements and slip distribution



The coseismic offset estimates derived from daily and high-rate GPS position time series are generally consistent. Error ellipses for the kinematic data only represent relative error, not an actual range of possibilities.

The predicted coseismic displacements from the ... fault model are generally consistent in orientation with our estimates but show large discrepancies at PBLI and BSIM, the stations with the largest coseismic displacements.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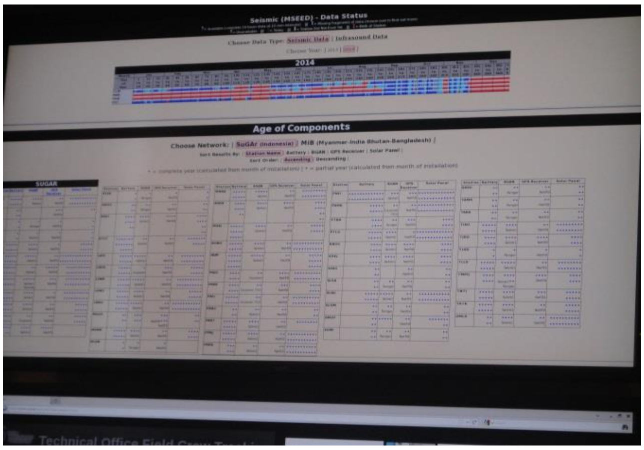
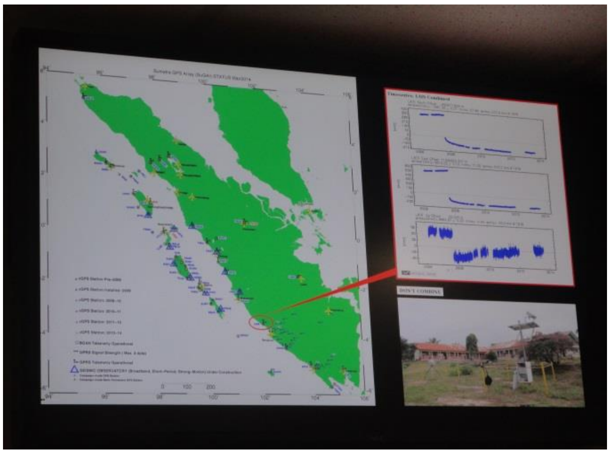
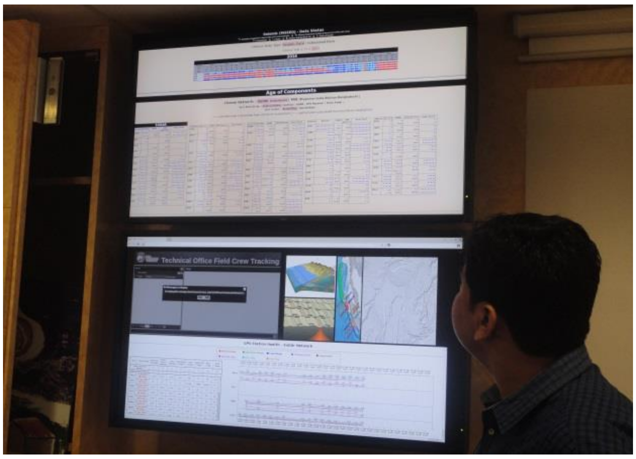
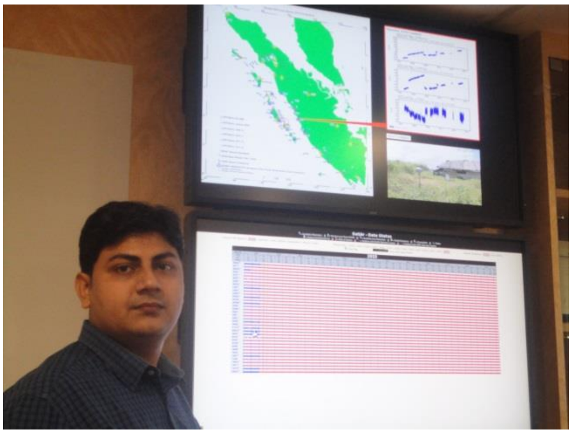
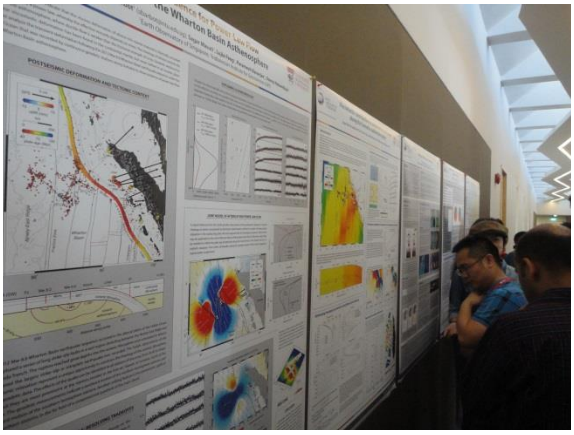

Seismic (MSEED) - Data Status
2014
Age of Components
SUGAR




Technical Office Field Crew Tracking




Wharton Basin Asthenosphere