July 26 - 28, 2017

SATREPS

Workshop 2017

Hazard Assessment
of Large Earthquakes and Tsunamis
in the Mexican Pacific Coast
for Disaster Mitigation

京都大学防災研究所
Disaster Prevention Research Institute, Kyoto University

GEOFISICA UNAM

CENAPRED MÉXICO

Venue: Nara Kasugano International Forum “IRAKA”
Annex Conference Room 5&6

Workshop on the collaborative project between Japan and Mexico: Hazard Assessment of Large Earthquakes and Tsunamis in the Mexican Pacific Coast for Disaster Mitigation

July 26–28, 2017, at Nara, Japan.
Venue: Kasugano International Forum (http://www.i-ra-ka.jp)

Registration fee: 3,000 JPY include excursion, coffee, and shuttle bus
Reception (for drink): 3,000 JPY

Organizers: Yoshihiro Ito, Víctor M. Cruz Atienza, Satoshi Ide, Vala Hjörleifsdóttir, Allen Husker, Vladimir Kostoglodov, Shoichi Yoshioka, Nobuhito Mori, Ángel Ruíz Angulo, Michinori Hatayama, David Novelo Casanova, Katsuya Yamori, Carlos Valdés González

Day 1 (July 26)
Opening Remarks:
9:30: Yoshihiro Ito
9:35: Ambassador Carlos Almada, Ambassador of Mexico to Japan
9:45 Keynote: Irasema Alcántara-Ayala,

The milestone of the 1985 earthquake and the Civil Protection System in Mexico: the way forward

10:30: Summary of 2-years achievements on the SATREPS project
10:30 A1: Yoshihiro Ito & Vala Hjorleifsdottir
10:45 A2: Satoshi Ide & Allen Husker
11:00 B1: Shoichi Yoshioka & Víctor M. Cruz-Atienza
11:15 B2: Nobuhito Mori & Ángel Ruíz Angulo
11:30 C1: Michinori Hatayama & David Novelo Casanova
11:45 C2: Katsuya Yamori & Carlos Valdés González
12:00-13:00 Lunch
13:00 Oral Presentations

13:00 O01: Yoshihiro Ito, Prospect from near field ocean bottom seismic and geodetic observations

13:20 O02: Vladimir Kostoglodov *et al.*, SATREPS onshore networks: Scientific goals and expected results

13:40 O03: Masatoshi Miyazawa, Towards detecting and investigating tectonic tremors in Guerrero, dynamically triggered by surface waves from distant large earthquakes

14:00 O04: Josué Tago Pacheco *et al.*, Slow slip inversion in Guerrero using the adjoint method

14:20 O05: Allen Husker *et al.*, The structure of the Guerrero Gap and the down-dip slow slip region

14:40 O06: Arturo Iglesias *et al.*, Surface wave tomography for Central and South of Mexico

15:00-15:20 Coffee break

15:20 Oral Presentations

15:20 O07: Julie Maury, Satoshi Ide *et al.*, Slow earthquakes variations along the Mexican subduction zone

15:40 O08: Takuya Nishimura *et al.*, Preliminary result on detecting short-term SSEs in the Mexican subduction zone

16:00 O09: Víctor Manuel Cruz-Atienza *et al.*, Tectonic Tremor in Guerrero: Its Driving Force and What Fluids May Explain

16:20 O10: Tomoaki Nishikawa *et al.*, Earthquake swarms in the Mexico subduction zone and their relation with slow slip events and the 2014 M7.3 Papanoa earthquake

16:40 O11: Luis Antonio Dominguez Ramirez *et al.*, Missing foreshocks and afterslip estimates of the 2012 Mw 7.4 Ometepec Earthquake

17:00 Poster session

Day 2 (July 27)

9:00: Oral presentations (4 talks)

9:00 O12: Vala Hjörleifsdóttir *et al.*, Characteristics of earthquakes occurring on the shallowest portion of the Mexican subduction megathrust

9:20 O13: Gerardo Suárez *et al.*, The Mexican Seismic Alerting System (SASMEX)and its potential contribution to the *SATREPS* project

9:40 O14: Masumi Yamada *et al.*, Application of Japanese earthquake early warning system (IPF method) to SASMEX seismic network

10:00 O15: Xyoli Pérez-Campos *et al.*, Simple seismo-geodetic methodologies for a tsunami early warning in Mexico

10:20-10:40 Coffee break

10:40-12:00: Oral presentations

10:40 O16: Paco Sánchez-Sesma *et al.*, Fast computation of approximate near-source elastodynamic Green's function in a layered half-space using the Equipartition Theorem

11:00 O17: Emmanuel Soli Garcia *et al.*, Interpretation of Subducting Topography at the Cocos-North America Subduction Zone offshore Guerrero, Mexico using Residual Bathymetric Anomalies

11:20 O18: Angel Ruiz Angulo *et al.*, Hotspots for local tsunami amplification along the Mexican Pacific coastline

11:40 O19: Nobuhito Mori *et al.*, Probabilistic tsunami hazard analysis (PTHA) of the Pacific Coast of Mexico

12:00-13:00 Lunch

13:00 Poster session

14:00: Excursion (Horyu-ji)

https://en.wikipedia.org/wiki/Hōryū-ji

19:00~ Reception at Restaurant "Half time"

http://www.narahaku.go.jp/english/info/08.html

Day 3 (July 28)

9:00: Poster session

10:00-10:20 Coffee break

10:20 Oral presentations

10:20 O20: Hajime Naruse *et al.*, Inverse modeling of the tsunami deposit

10:40 O21: María-Teresa Ramírez-Herrera *et al.*, Tsunami deposits - Multiple proxies prove evidence of past events, Mexican Subduction zone

11:00 O22: Davíd Novelo *et al.*, Vulnerability assessment of Zihuatanejo, Guerrero, Mexico

11:20 O23: Genta Nakano *et al.*, From "instructors/followers" to "facilitators/implementers": how can we foster school teachers' initiative in tsunami evacuation drill?

11:40 O24: Tomas Sanchez Perez *et al.*, Take benefit of SINAPROC capabilities to strengthen the SATREPS Project Mexico-Japan

12:00-13:00 Lunch

13:00 Breakout sessions (Group A, B & C):

What we need to do next three years?

What are possible collaborative activities among groups?

14:30-15:00 Coffee break

15:00-16:00 Breakout session report & General discussion

Concluding Remarks:

16:00: Prof. Fujii (PO of the SATREPS project)

16:15: Víctor M. Cruz Atienza (Closing Remarks)

Presentation guidelines:

Oral: 15-min talk and 5-min discussion

Poster: W900 mm × H2,100 mm in maximum

Posters:

P01: Motoyuki Kido,

Seafloor geodetic surveys in Japan

P02: Jorge Arturo Real Perez et al.,

Analysis of ambient seismic noise levels for the SATREPS stations and their technical aspects

P03: Tomoya Muramoto et al.,

On the interpretation of the variety of oceanic fluctuation in terms of ocean bottom pressure

P04: Miguel Angel Santoyo et al.,

The Mexican subduction zone: Effects of the 3D geometry on the stress transfer due to interplate slip events

P05: Raúl W. Valenzuela et al.,

Shear Wave Splitting and Upper Mantle Flow in the Mexican Subduction Zone: Looking Backward and Forward Äb0

P06: Marco Calò et al.,

Trans-dimensional inversions for detecting layered structures, and Enhanced Seismic Tomography for imaging 3D high-resolution models. Two methods for improving the knowledge of the Guerrero region

P07: Ketzallina Flores et al.,

The long duration, April 18, 2002 (Mw 6.7), Mexico earthquake; a small tsunami earthquake next to the Guerrero Gap

P08: Authors Raymundo Plata et al,

Seismic energy release at the seismogenic zone of Guerrero, Mexico

P09: Ta-Wei Chang et al.,

Source inversion of very large earthquakes using empirical Green’s function with P and S wave data

P10: Guillermo González et al.,

Study of repeating events in the Jalisco subduction zone, Mexico

P11: Emmanuel Caballero-Leyva et al.,

Moment tensor inversion of tectonic tremors in the Guerrero subduction zone

P12: Naoto Mizuno et al.,

Development and evaluation of modified envelope correlation method for deep tectonic tremor

P13: Ekaterina Kazachkina et al.,

Complex interaction between thrust and strike-slip motion in the oblique Mexican subduction zone

P14: Hiromu Sakaue et al.,

Estimation of the spatiotemporal evolution of slow slip events in the Tokai region, central Japan, since 2013 using GNSS data

P15: Suguru Yabe et al.,

Heterogeneous friction model for slow earthquakes

P16: Carlos Villafuerte et al.,

Toward realistic dynamic-rupture scenario earthquakes in the Guerrero subduction zone

P17: Takuya Miyashita et al.,

Numerical Modeling of Tsunami Inundation in City Scale

P18: Takashi Sugiyama et al.,

Why do we need to pass down the narratives of disaster?

Date and Venue

The Workshop is scheduled to be held from 26 to 28 July 2017 at **Nara Kasugano International Forum** (101, Kasugano-cho, Nara-shi, Nara; Tel: +81-742-27-2630), which is located in the center of Nara Park. Please see the map below for information on how to get there.

More information can be found at: http://www.i-ra-ka.jp/en/

Accommodation

Room reservations have been made for all participants coming from Mexico.

For the investigators, reservations have been made at **Hotel Nikko Nara** (8-1 Sanjo-hommachi, Nara-shi, Nara; Tel: +81-742-35-8831; https://www.okura-nikko.com/japan/nara/hotel-nikko-nara/), which is located close to the Nara JR station. The room rate includes breakfast and internet (Wi-Fi). The payment has already been made by Kyoto University, and therefore there is no need for you to make a payment at the hotel.

For the students, reservations have been made at **Nara Youth Hostel** (4-3-2, Houren Saho-Yama, Nara-City, 630-8108 Nara; Tel.+81-742-22-1334; http://www.jyh.gr.jp/nara/en/index.html). Please note that the payment has not been made yet, and those staying at this hostel are requested to make a payment at the reception desk. The accommodation fee will be paid in cash by Kyoto University upon arrival at the workshop venue.

Transportation

Itami Airport to the Hotel

We regret that it will not be possible to arrange your transport from the airport to your hotel. However, public transportation is available to take you from the airport to Nara.

The most economical way to travel to Nara is by train (1,220 yen).

Itami-Airport Sta. – (Osaka- Monorail) – Hotarugaike Sta. – (Hankyu Takarazuka Line) – Hankyu-Umeda Sta. – (Transfer on foot) – Osaka Sta. – (Osaka Loop Line) – Tennoji Sta. – (Yamatoji Line Yamatoji Rapid) – Nara

It takes around 1.5-2 hours including transfer. It may be difficult to travel by train on your own if you do not know the area. However, some Japanese colleagues will be waiting at the airport to pick you up and take you to the hotel in Nara. The colleagues waiting for you at the airport are:

- JL0115 arriving at 12:30 - Dr. Kazuaki Ohta and Dr. Soliman Garcia
- JL0117 arriving at 13:30/NH3152 arriving at 13:25 - Mr. Takuya Miyashita
- JL 0133 arriving at 19:30 - Dr. Takuya Iwahori and/or Mr. Genta Nakano

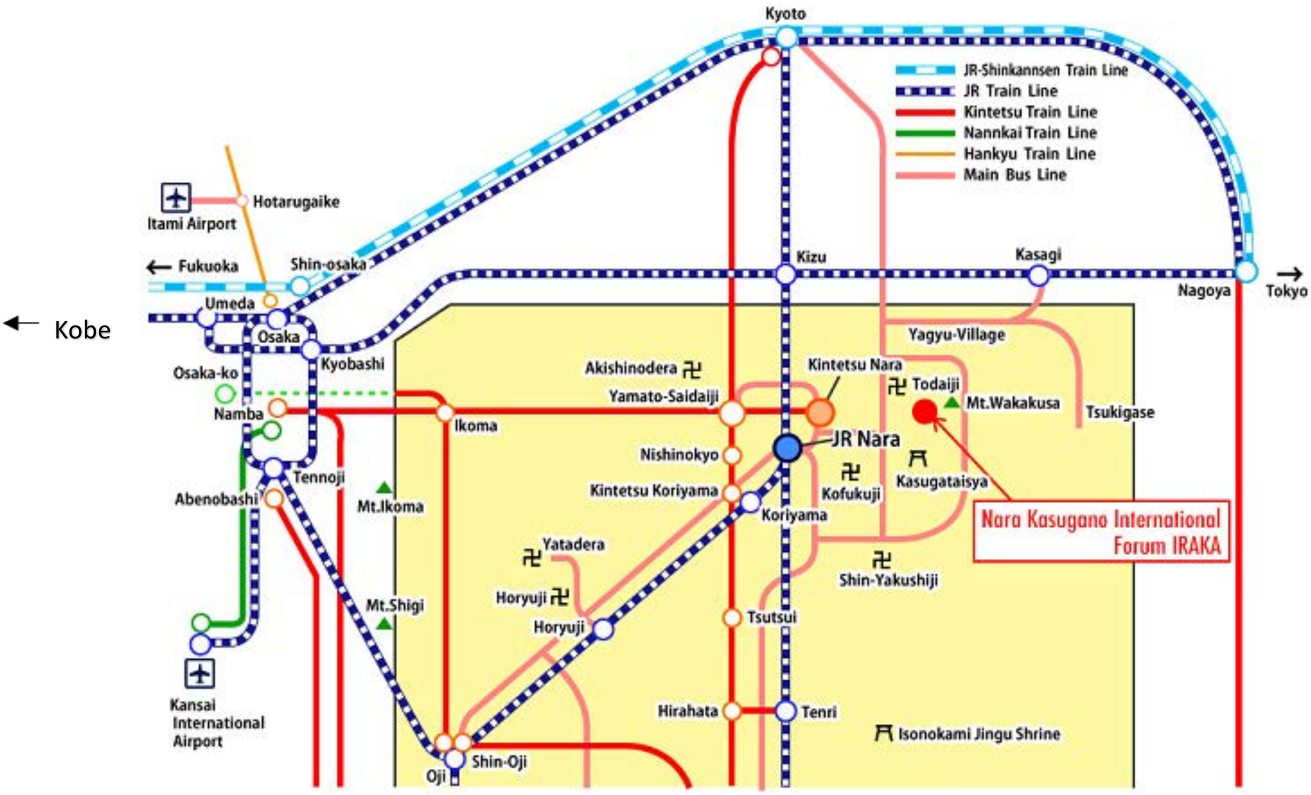
You can also travel by limousine bus (http://www.okkbus.co.jp/en/timetable/itm/f_nra.html), which is slightly faster (approx. 1 hour to Nara) but a little more expensive (1,480 yen). Please note, however, that the reimbursement will be only be made for the cost of the most economical route (i.e. 1,220 yen by train) and any additional cost will have to be borne by you.

Hotel to the Workshop Venue

A shuttle bus will be arranged between the hotel and workshop venue. The participants are requested to be at the reception of Hotel Nikko Nara **at 8:10 AM on the first day** and **7:50 AM on the second and the third day.** The bus will leave from Nara Youth Hostel 15 min. later.

Useful links to travel in and around Nara

- JR Train (To/From Kyoto, Uji): http://www.westjr.co.jp/global/en/
- Kintestu Train (To/From Kyoto, Kobe Sannomiya): http://www.kintetsu.co.jp/foreign/english/index.html



Useful links to travel in and around Tokyo

- Airport limousine (Narita-Haneda): https://www.limousinebus.co.jp/en/bus_services/haneda/narita.html
- Airport limousine (Haneda-various areas of Tokyo) : https://www.limousinebus.co.jp/en/bus_services/haneda/index
- Airport limousine (Narita-various areas of Tokyo) : https://www.limousinebus.co.jp/en/bus_services/narita/index
- Metro: http://www.tokyometro.jp/en/tips/from_airport/index.html
- JR Train: http://www.jreast.co.jp/e/

Communication

For any inquiries regarding the workshop, please contact:

For general and technical matters:

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Keynote

The milestone of the 1985 earthquake and the Civil Protection System in Mexico: the way forward

Irasema Alcántara-Ayala
(Research Center for Disaster Reduction Systems, DPRI, University of Kyoto)

Generated by the displacement of the Cocos plate beneath the North American plate, on September 19th 1985, an 8.1 M_w earthquake struck at 7:19 a.m. in the Pacific Ocean, off the coast of the state of Michoacán, and caused considerable damage, particularly in Greater Mexico City. Some hours after, on the following day, a second earthquake of 7.3 M_w induced scenes of panic among the population. Direct and indirect losses amounted US$8.3 billion, and although the number of fatalities has been controversial, recent records generated by the civil registration office suggested that between September 19 and November 5th, 1985, 12,843 people died as a result of the collapse of the buildings and infrastructure, or associated trauma due to the earthquake. The aftermath included damage to buildings and infrastructure (87% of total losses), in addition to loss of income or production, increased costs of service provision, emergency response, and temporary rehabilitation (13%). Approximately 1,700 schools were damaged, and one third of the hospital capacity in Mexico City was destroyed. Nearly 250,000 people became homeless and practically 900,000 suffered with damaged homes (The International Bank for Reconstruction and Development/The World Bank, 2012).

The Mexico City Earthquake of 1985 can be regarded as a milestone for the Civil Protection in Mexico, as a National Commission for Reconstruction was established one month after the disaster, and on May 6, 1986, the creation of the National System of Civil Protection (Sistema Nacional de Protección Civil, SINAPROC) was conceived under the umbrella of the Ministry of Interior. In this paper, a brief historical account of the institution of the Civil Protection System in Mexico is offered, as well as a general review of its structure and legal framework in order to identify a series of challenges to move towards integrated disaster risk management.

The International Bank for Reconstruction and Development/The World Bank (2012), FONDEN: Mexico's Natural Disaster Fund – A Review, Global Facility for Disaster Reduction and Recovery, Washington DC, 63 pp.

O01

Prospect from near field ocean bottom seismic and geodetic observations

Yoshihiro Ito (Kyoto University)

Slow earthquakes as a transient acceleration of plate motion are now being identified as ubiquitous phenomena in subduction zones. They are distributed around the strong interplate coupling area or near the asperity of megathrust earthquakes in several subduction margins; consequently, they have triggered megathrust earthquakes. Recent seismic and geodetic facilities have successfully captured some slow-earthquake activity leading up to large earthquakes and triggering the megathrust events, especially in subduction zones. Specifically, in the Japan Trench, slow earthquakes, such as tremors and slow slip events, have been identified by near-field seismic and geodetic observations before the occurrence of the 2011 Tohoku-Oki earthquake. Both seismic and geodetic observations suggest that the low-frequency tectonic tremor and slow slip event prior to the occurrence of the mainshock were located near the trench, where huge coseismic-slip exceeding 30 m was observed. A recent laboratory rock experiment on the frictional properties of slow earthquakes by using gouge samples from the plate boundary in the Japan Trench subduction zone shows that an increase in sliding velocity on the slow-earthquake's fault could induce frictional weakening behavior, and in particular, slip-weakening. These suggest that the slow earthquake may have facilitated the large coseismic slip of the mainshock on the plate boundary fault, as well as having triggered the initiation of the mainshock rupture.

O02

SATREPS onshore networks: Scientific goals and expected results

Vladimir Kostoglodov[1], Victor Cruz-Atienza[1], Allen Husker[1] and Yoshihiro Ito[2]
[1]Instituto de Geofísica, UNAM, México, [2]DPRI, Kyoto University, Japan

Guerrero seismic gap (G-GAP) is a primary target of the SATREPS project dedicated for hazard assessment of large earthquakes and tsunamis in the Mexican Pacific coast for disaster mitigation. The G-GAP is roughly a 100 km segment of the subduction zone to the NW from Acapulco City where subduction thrust earthquakes with Mw>6.5 have never occurred since 1911. Relatively low long-term rate of elastic strain buildup in the G-GAP is apparently related to very large (equivalent Mw~7.5) periodic aseismic slow slip events (long-term SSE, Lt-SSE). These SSEs are releasing partially the stress accumulating on the subduction plate interface in the gap area (Kostoglodov et al., 2003). Lt-SSE can also trigger large subduction trust seismic events on the mature seismogenic segments of the subduction zone. An example of such a succession is the April 18, 2004 Mw7.3 Papanoa earthquake incited by the 2014 SSE (Radiguet et al., 2016).
Therefore it is not an excessive speculation that the next SSE, which is anticipated to develop in Guerrero in 2017-2018, may trigger large Mw7.5-7.8 subduction thrust earthquake in the G-GAP. Apart of practical issues associated with the hazard assessment of potential large earthquakes and tsunamis in Guerrero there are several challenging scientific problems. The G-GAP is anomalous sector of the Mesoamerica subduction zone with a long extending sub-horizontal plate interface, shallow seismogenic zone, abnormally long seismic quiescence, largest recorded SSEs, entire spectrum of slow seismicity (NVT, LFE, VFE), complicated geologic structure and tectonic history.
SATREPS onshore deployments of 11 new GPS stations and 7 broadband seismometers will be a notable contribution to densify local geodetic and seismological networks operated by the UNAM in the G-GAP area (Figure 1, 2). The SATREPS+UNAM networks, starting from the second part of 2017, should provide very detailed data to investigate future long-term and short-term SSEs on the plate interface and on the La Venta strike slip crustal fault (LVF). GPS time series and seismic records will be examined to study a relation between the SSEs and seismicity regime in the G-GAP. In a case of large subduction earthquake these data will be of particular importance. Local seismic observations will help to analyze the overriding plate structure, detailed geometry of the plate interface (Figure 3), and to generate a complete (M>~2) local seismic catalog.

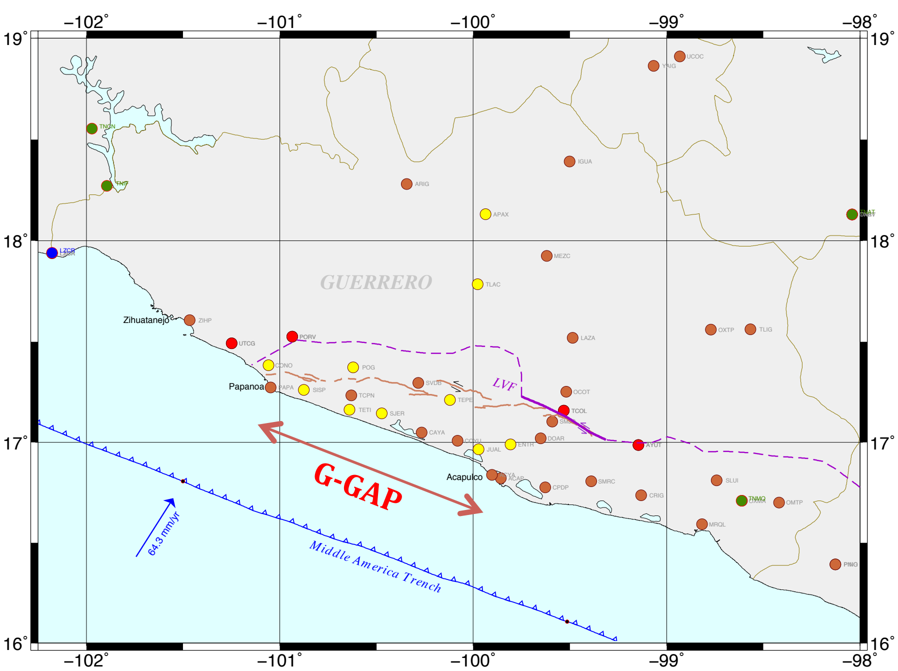

Figure 1. The SATREPS study area (G-GAP) and location of permanent GPS stations (SATREPS plan - yellow circles, and red circles are the stations already installed. The circles of other colors are permanent stations of other GPS networks). The solid-dashed purple line delineates the La Venta (LVF) fault zone (Solari et al., 2007), which is roughly the northern border of the Xolapa allochthonous terraine. Segmented dark brown line is a trace of the LVF mapped by Gaidzik et al. (2016). Blue vector shows the Cocos-North America MORVEL convergence velocities (DeMets et al., 2010) at the Middle America trench.

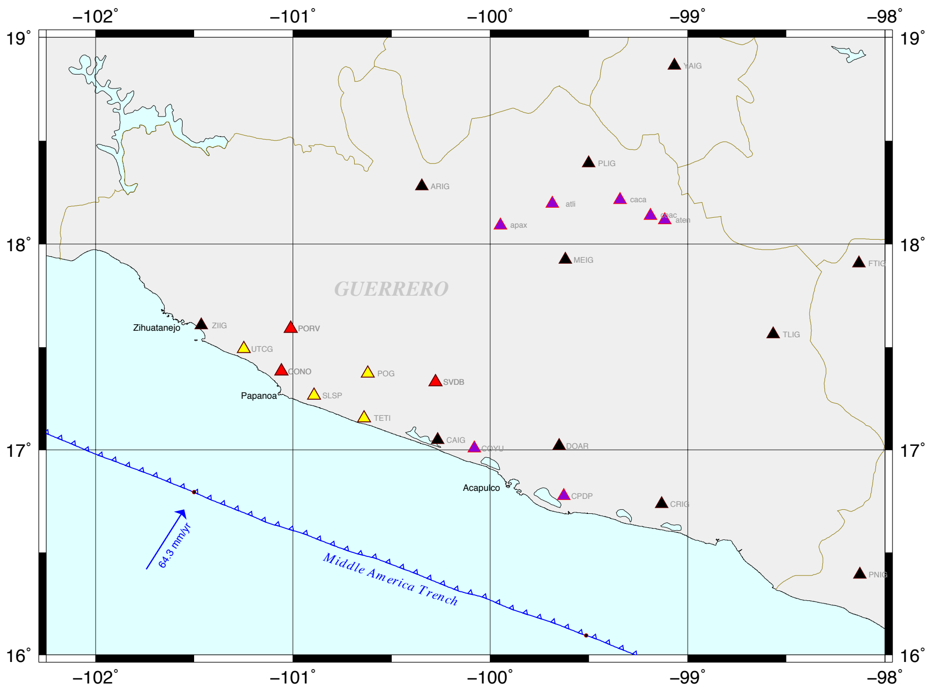

Figure 2. The SATREPS location of permanent broadband (BB) stations (SATREPS plan - yellow triangles, and red triangles are the stations already installed. Triangles of other colors are permanent stations of other BB networks). Blue vector show the Cocos-North America MORVEL convergence velocities (DeMets et al., 2010) at the Middle America trench. Total of 20-22 BB seismic stations (including 7 SATREPS stations) will form the Guerrero network.

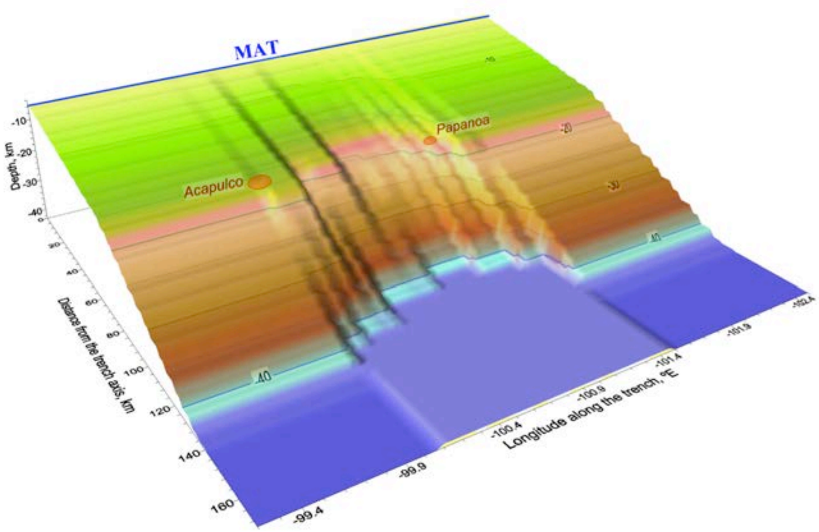

Figure 3. Preliminary geometry of the interface between the Cocos and North America tectonic plates in the G-GAP obtained by the analysis of seismic data from local short-period network (1997-1995). The G-GAP zone corresponds to a concave anomaly in this geometry. New data will be obtained from the SATREPS experiment to constrain the configuration of the interface and to understand its role in the seismic cycle. MAT – The Middle America trench.

References

Gaidzik, K., Ramírez-Herrera, M. T., and Kostoglodov, V., 2016, Active Crustal Faults in the Forearc Region, Guerrero Sector of the Mexican Subduction Zone: Pure and Applied Geophysics, v. 173, no. 10, p. 3419-3443.

Kostoglodov, V., Singh, S. K., Santiago, J. A., Franco, S. I., Larson, K. M., Lowry, A. R., and Bilham, R., 2003, A large silent earthquake in the Guerrero seismic gap, Mexico: Geophysical Research Letters, v. 30, no. 15.

Radiguet, M., Perfettini, H., Cotte, N., Gualandi, A., Valette, B., Kostoglodov, V., Lhomme, T., Walpersdorf, A., Cabral Cano, E., and Campillo, M., 2016, Triggering of the 2014 Mw7.3 Papanoa earthquake by a slow slip event in Guerrero, Mexico: Nature Geosci, v. advance online publication.

Solari, L. A., de León, R. T., Hernández Pineda, G., Solé, J., Solís-Pichardo, G., and Hernández-Treviño, T., 2007, Tectonic significance of Cretaceous,ÄìTertiary magmatic and structural evolution of the northern margin of the Xolapa Complex, Tierra Colorada area, southern Mexico: Geological Society of America Bulletin, v. 119, no. 9-10, p. 1265-1279.

O03

Towards detecting and investigating tectonic tremors in Guerrero, dynamically triggered by surface waves from distant large earthquakes

Masatoshi Miyazawa (Disaster Prevention Research Institute, Kyoto Univ.)

Tectonic tremors are often triggered by passing surface waves from distant large earthquakes in Nankai, Japan (e.g., Miyazawa and Brodsky, 2008) and Guerrero, Mexico (Zigone et al., 2012). This process is called dynamic triggering or remote triggering. These observations show that dynamically triggered tremor is clearly correlated with both the period and amplitude of surface waves. The dynamic Coulomb failure stress changes for the shear slip on the plate interface, seem to correlate with the amplitude of triggered tremor. For example, in Nankai, the surface waves from the 2004 Mw9.2 Sumatra earthquake caused the transient stress changes of a few tens of kPa, which repeatedly triggered tremors with a period of about 20 sec during the passage of waves. The largest amplitudes of triggered tremor were about 1 μm/s, one order of magnitude larger than those of typical tremor observed in the region. Based on a rate and state dependent friction law, a product of fault constitutive parameter a and normal stress σ, can be obtained by the relationship between the triggered tremor amplitude and the triggering stress. The estimated value is 10^4 Pa, which may suggest extraordinarily high-fluid pressures to reduce effective normal stresses (Miyazawa and Brodsky, 2008).

In this SATREPS project, we would like to detect dynamically triggered tectonic tremors in Guerrero by using long-term seismic data, and investigate the relationship between the tremor amplitude and the amplitude of the incoming waves. Development of this study could advance our fundamental understanding of the mechanisms that cause tremor occurrences and of the plate interface at depth in terms of fault friction parameters.

References

Miyazawa, M. & E. E. Brodsky (2008). Deep low-frequency tremor that correlates with passing surface waves, *J. Geophys. Res.*, 113, B01307, doi:10.1029/2006JB004890.

Zigone, D. *et al*. (2012). Triggering of tremors and slow slip event in Guerrero, Mexico, by the 2010 Mw 8.8 Maule, Chile, earthquake, *J. Geophys. Res.* 117, B09304, doi:10.1029/2012JB009160.

O04

Slow slip inversion in Guerrero using the adjoint method

J. Tago[1], V.M. Cruz-Atienza[2], H.S. Sánchez-Reyes[3], A. Iglesias-Mendoza[2], V. Kostoglodov[2] and T. Nishimura[4]

[1]Facultad de Ingeniería, UNAM, [2]Instituto de Geofísica, UNAM, [3]Institut des Sciences de la Terre, UGA, [4]Disaster Prevention Research Institute, KU

With the SATREPS project we will monitor the Guerrero seismic gap as it has never been done before. In total, there will be will 46 geodesic stations, with 7 ocean bottom pressure gauges (OBP) and 2 underwater acoustic positioning equipments (GPS-A). Besides the onshore instrumentation that comprises 32 seismic stations on land and 7 ocean bottom seismometers (OBS). The amount of collected data, so close to the trench, will allow us to better understand the complex behavior of the Mexican subduction zone during any tectonic deformation process.

As part of the activities of Group B1 in collaboration with Group A, we are working in the development of a new method to invert geodetic data for imaging the slow slip event that is expected to start at the end of 2017. We will estimate the slip evolution at the plate interface to further analyze the seismic coupling and the associated fault frictional properties. The method will allow us to carry out spatial and temporal resolution analysis that depends on the observational network configuration.

Our inversion strategy is inspired in the adjoint method that has been recently and successfully used for earthquake kinematics inversion (Somala et al., 2014; Tago et al., 2014). We have adapted this strategy for solving the quasi-static inversion problem of slow slip, formulated as a constrained optimization problem. The strategy does not parameterize the slip vector in the fault (i.e. neither its magnitude nor its direction). We require the pre-computation of the Somigliana tensor, medium impulse response (i.e. the static Green's functions), such that the forward and adjoint problems can be solved efficiently.

For Nara's workshop, we will present the 3D formulation of the method and show synthetic inversion tests. We will address the problem of dealing with sparse data coverage through the computation of spatial-temporal resolution, and how it could be overcome through penalization and regularization terms.

References:

- Somala S., J. Ampuero and N. Lapusta (2014). Resolution of rise time in earthquake slip inversions: Effects of station spacing and rupture velocity. Bull. Seismo. Soc. Am., 104(6):2717–2734.
- Tago J., L. Metivier, R. Brossier and J. Virieux (2014) Full Waveform Inversion Using the Adjoint Method for Earthquake Kinematics Inversion. AGU Fall Meeting Abstracts. (the formal paper of this work is about to be submitted to an international journal)

O05

The structure of the Guerrero Gap and the down-dip slow slip region

Allen Husker (UNAM, Mexico City), Xyoli Pérez-Campos (UNAM, Mexico City), Luca Ferrari (UNAM, Juriquilla), Claudia Arrango (UNAM, Mexico City), Jorge Castillo (Caltech) , Luis Antonio Dominguez-Ramirez (UNAM,Morelia)

The (M>4) seismicity from 1990 – 2014 in the region in the Guerrero Gap does not exhibit the cyclical increase with SSEs that is observed during the SSEs in Japan. The Guerrero SSEs are the largest in the world (M~7.5) and they invade the seismogenic zone, so the stress change caused within the seismogenic zone is much larger than those in Japan. So why do the Japanese SSEs trigger small earthquakes, but the Guerrero SSE's do not? To begin responding this open question we look at the current state of knowledge of the structure of the Gap and the potential role of fluids. Better understanding of the structure of the two zones and the knowledge we will gain from the SATREPS project may eventually lead to a more precise answer.

Combined geological and magnetotelluric studies suggest that long lasting Cenozoic magmatic activity most likely produced an impermeable gabbroic layer in the lower crust within the Gap. This layer has acted as a seal to trap fluids into an over-pressurize plate interface, allowing for SSEs. Further away from the coast, tremor activity and seismological evidence of an over pressurized crust-slab interface coincide as well. There, in the flat-slab region, receiver function studies have found 3 distinct layers above the mantle: (1) The lower subducted oceanic crust; (2) a thin layer interpreted as a remnant mantle wedge between the oceanic and continental crust; and (3) the continental crust. The first layer is relatively homogeneous with a trench parallel anisotropy as expected from remnant faulting within the slab. Seismic anisotropy in the second layer is highly complex, but consistently strong in the LFE source regions. Weak anisotropy and low Vp/Vs are found in the continental crust near 150 km from the trench above the corner of the slab correlate with the expected high stress region there.

O06

Surface wave tomography for Central and South of Mexico

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We use a set of mixed Rayleigh wave group velocity measurements obtained from regional earthquakes and from noise cross correlations between pair of stations, to obtain tomographic images for periods between 5 and 50s.

Our data consists on regional broad band seismic records of earthquakes registered in stations of the Mexican Seismological Service (SSN) and in stations of two dense temporary networks (MASE and VEOX). Additionally, we compute the noise cross correlations (CCF) for pairs of contemporary stations. Vertical components or records for regional earthquakes and CCFs are processed by the Multiple Filter Technique (Dziewonsky et al., 1969) to obtain Rayleigh waves group velocity dispersion curves for pairs of event-station or station-station.

Using the computed dispersion curves, tomographic inversions are carried out for individual periods between 5 and 50s. Resolution tests show that we can obtain reliable information between ~102°W to 92°W, and ~14°N to 21°N.

For the periods which we have the group velocity for the maximum number of paths (between 20 and 30 s) we obtain images with resolution of ~15 x 15km^2.

The anomalies observed in tomographic images show good correlation with main tectonic and geological features.

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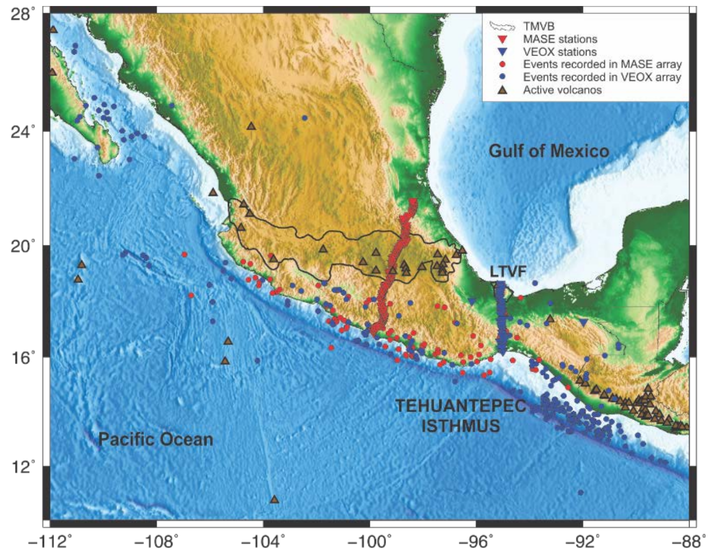
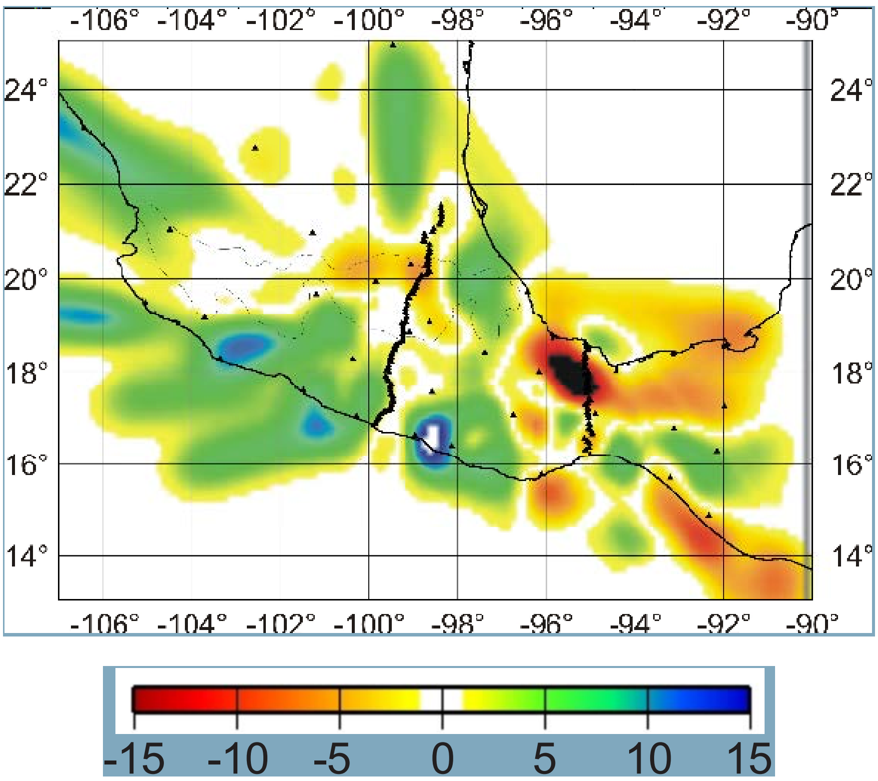


Stations and earthquake locations used for process.



Group Velocity Perturbation (%)

Tomographic image Rayleigh wave group velocity for T=20s

O07

Slow earthquakes variations along the Mexican subduction zone

Julie Maury (BRGM), Satoshi Ide (Univ. Tokyo)
Victor Manuel Cruz-Atienza, Vladimir Kostoglodov (UNAM)

Slow earthquakes in Mexican subduction zone have been investigated in different regions, Jalisco, Colima, Michoacan, Guerrero, and Oaxaca, independently. Here, we look at the Mexican subduction zone as a whole to understand its diversity and universality. We review the differences in slow slip events along the subduction from previous studies, and examine tremor behavior, using continuous seismic recordings. We detected and located tremor hypocenters, evaluated tremor energy after evaluation of site amplification factors, determined focal mechanism of slow deformation using signals in a very low-frequency (0.02-0.05 Hz) band, and investigated the sensitivity of tremors to tidal stress.

Large differences in slow earthquake behavior are found between western (Jalisco, Colima, and Michoacan) and eastern (Guerrero, and Oaxaca) regions. Western tremors are more infrequent than that of eastern, and focal mechanisms show higher dip in western region. The main sources of these differences must be the shape of subducting plate that yields different temperature profiles. Tremor characteristics in Guerrero and Oaxaca regions are very similar, but tremors are spatially clustered with a gap of about 100 km. However, previous studies suggest this gap might be just artificial one due to our observation limit.

Clear tidal sensitivity of tremor is observed all along the subduction zone. Some tremor sources in Guerrero seem to be sensitive to tidal normal stress rather than shear stress. This may be due to a large friction coefficient or simply due to the error estimating the local dip of the plate interface.

Estimated tremor energy is almost proportional to the seismic moment estimated in very low-frequency band. The proportionality coefficient, which is also known as the scaled energy, is similar in all regions and around 10−9, which is also similar to the values estimated in Nankai and Cascadia subduction zones. There must be a common mechanism behind all slow earthquakes in different subduction zones.

O08

Preliminary result on detecting short-term SSEs in the Mexican subduction zone

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Vladimir Kostoglodov, Sara Ivonne Franco Sánchez (UNAM)

The Mexican subduction zone is known as one of the most active regions of slow slip events (SSEs) in the world (e.g., Kostoglodov et al., 2003; Correa-Mora et al., 2008; Frank et al., 2015; Graham et al., 2015). Short-term SSEs with low-frequency earthquakes (LFEs) were detected near a down-dip edge of long-term SSEs in Guerrero (Frank et al., 2015). Although the previous study uses LFEs as a proxy of SSEs, SSEs do not always accompany LFEs as shown in studies of slow earthquakes in southwest Japan and Cascadia. Here, we try to detect short-term SSEs solely from the GNSS data using the detection method of short-term SSEs in southwest Japan (Nishimura et al., 2013).

We used daily coordinates on ~40 cGPS stations from 2001 to 2014. A component in a direction of relative plate convergence is used to fit linear functions with and without a step. A fitting of both functions is evaluated with a difference of AIC (Akaike Information Criterion). Large ΔAIC means a significant step which may be caused by a short-term SSE. Our result (Fig. 1) shows that most peaks of ΔAIC simultaneous at several GPS stations correspond to initiations of known long-term SSEs in Oaxaca and Guerrero. We found some peaks relating to possible unknown short-term SSEs, though it is a challenge to detect more SSEs in Mexico due to the sparse GNSS network in Mexico.

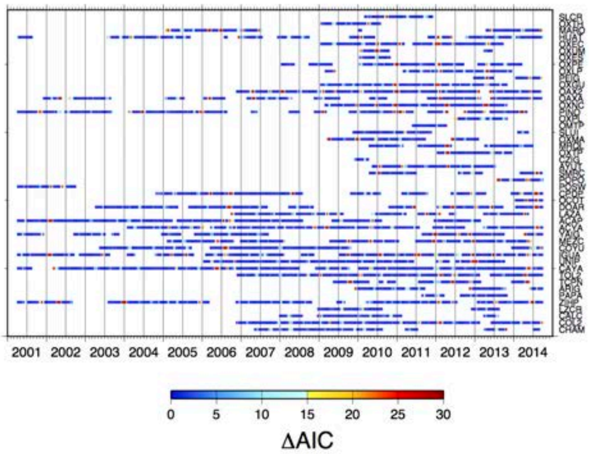

Figure 1. Distribution of ΔAIC of all used stations. 4 characters along the left edge indicate GPS station ID aligned along a direction of N68ºW parallel to the trench.

O09

Tectonic Tremor in Guerrero: Its Driving Force and What Fluids May Explain

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The spatial correlation between tectonic tremors (TT) and slow slip events (SSE) in Guerrero, Mexico, is not as clear as the Episodic Tremor and Slip observed in other subduction zones. In this study we provide insights into the causal relationship linking TTs and SSEs in Guerrero by analyzing the evolution of the elastic fields induced by the long-term 2006 SSE together with independent new locations of TTs and low-frequency earthquakes (LFE). Unlike previous studies, we find that the SSE slip rate modulates the TT and LFE occurrence rate in the whole tremor region (Villafuerte and Cruz-Atienza, 2017). This suggests that the driving force of TTs is the stressing rate history of the locked asperities that is modulated by the SSE slip rate (Figure 1). We have estimated that the frictional strength of the asperities radiating tremor downdip in the sweet spot (Figure 2a) is around 3 kPa, which is ~2.2 times smaller than the corresponding value updip in the transient zone, partly explaining the overwhelming tremor activity of the sweet spot despite that the slow slip there is almost three times smaller. Based on the LFEs occurrence rate history during the inter-SSE period we determined that the short-term SSEs in Guerrero take place further downdip (about 35 km) than previously estimated by Frank et al. (2015), with maximum slip of about 8 mm overlapping the sweet spot. This new model features a continuum of slow slip extending across the entire tremor region of Guerrero.

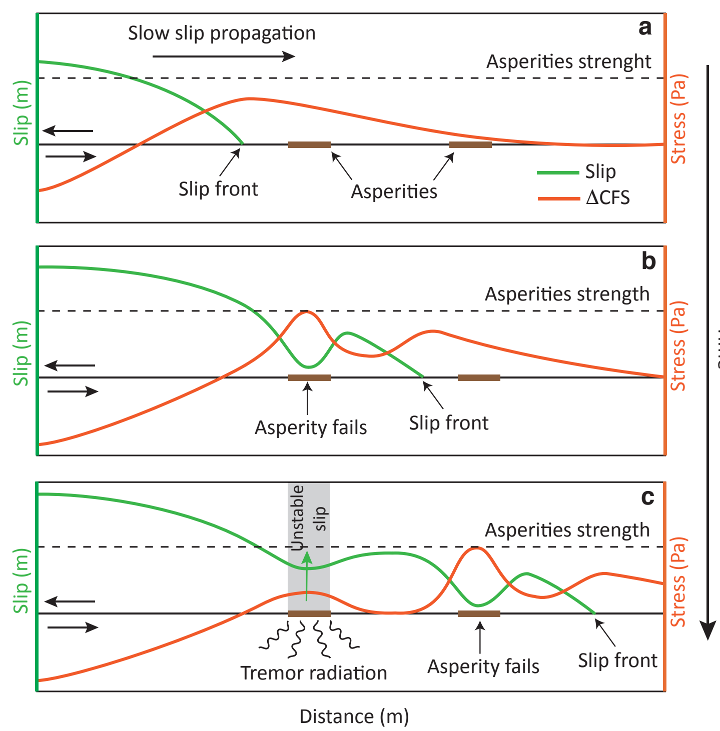

Figure 1 Cartoon illustrating the causal relationship suggested by our analysis between SSEs and TTs in Guerrero. The stress ahead of the slip front does not break tremor asperities. It is the stable slip surrounding the asperities that brings them to failure behind the slip front (taken from Villafuerte and Cruz-Atienza, 2017).

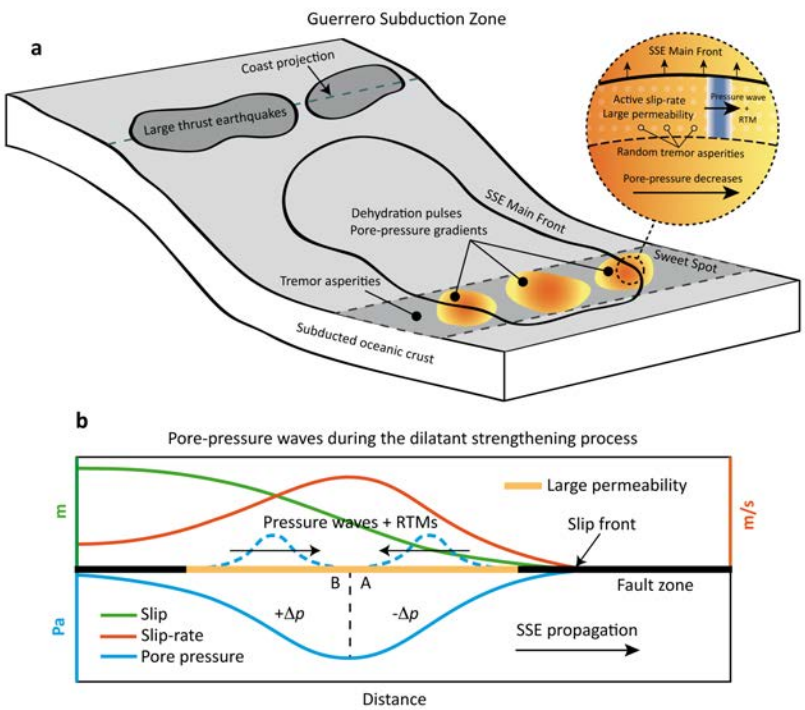

Figure 2 a) Cartoon illustrating the Guerrero subducted slab with preexistent and SSE-induced pore-pressure gradients in the sweet spot. The slow slip front increases the bulk permeability in the over-pressurized and fluid-saturated fault zone producing pressure waves and secondary slip pulses that trigger tremor; b) cartoon illustrating the pore-pressure gradients induced by the "dilatant strengthening" mechanism during SSEs. These gradients may produce pressure waves traveling in the RTR direction (Taken from Cruz-Atienza et al., 2017).

Rapid tremor migration (RTM) in subduction zones (including Guerrero) suggests complex fault-zone processes on the plate interface. Recent observations have revealed a large diversity of RTM patterns that are always associated with aseismic, shear strain at the interface. Small unstable asperities embedded in the stable shear zone are thus responsible of tremor radiation. Overpressured fluids in the upper part of the subducted slab have been recognized across the globe right where tectonic tremors take place. Spatial variations of fluid pressure may lead to non-linear diffusion processes with potentially large implications in tremor generation. Here we show that solitary pore-pressure waves are likely to exist in the plate interface, propagating with speeds similar to those observed for the RTMs (Cruz-Atienza et al., 2017). These waves may explain the whole spectrum of RTM patterns (e.g., rapid tremor reversals and slip-parallel streaks) (Figure 2) by producing transient reductions of the fault strength in the observed RTM directions during slow earthquakes. This model satisfies expectations from different subduction zones and is confronted with new high-resolution RTM locations in Guerrero, Mexico, to provide a physical explanation of this phenomenon in the region.

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O10

Earthquake swarms in the Mexico subduction zone and their relation with slow slip events and the 2014 M7.3 Papanoa earthquake.

Tomoaki Nishikawa and Satoshi Ide (Univ. Tokyo)

An earthquake swarm, which is an increase in seismicity rate without a clear mainshock and does not follow the Omori's law [Utsu, 1961], occurs in various tectonic settings. In subduction zones, they are often triggered by slow slip events (SSEs) on the plate interface [e.g., Sagiya, 2004]. Therefore, detecting earthquake swarms in subduction zones and examining their spatio-temporal distribution are important for understanding the relationship between slow slip events and fast earthquakes.

Here we used the epidemic type aftershock sequence (ETAS) model [Zhuang et al., 2005] in the Mexico subduction zone and detected earthquake swarms as seismic sequences with much higher seismicity rates than expected from the ETAS model. We analyzed seismicity during 1995-2015 using the ANSS catalog ($M \geq 4.2$) and compared the spatio-temporal distribution of swarms with that of SSEs and the 2014 M7.3 Papanoa earthquake.

We detected thirty-eight swarms in the Mexico subduction zone during 1995-2015. We found some areas where two or more earthquake swarms repeatedly had occurred. For example, just west of Acapulco (16.9 N°, 100.0 W°), we detected eight swarms. Downdip of this area, five SSEs (1998, 2001-2002, 2006, 2009-2010, and 2014) were detected by previous studies [e.g., Radiguet et al., 2012; Radiguet et al., 2016]. We detected one swarm about one month after the 1998 SSE and two swarms during the time period of the 2001-2002 SSE. These three swarms correspond with increases in seismicity rate in this area [Liu et al., 2007]. These swarms and increases in seismicity rate might have been triggered by SSEs. Regarding the remaining five earthquake swarms, we couldn't find corresponding SSEs.

Near the hypocenter of the 2014 M7.3 Papanoa earthquake (17.4 N°, 101.0 W°) [UNAM Seismology Group, 2015], we detected two swarms during the time periods of the 2001-2002 SSE and the 2006 SSE. This result suggests that the 2001-2002 SSE and the 2006 SSE ruptured the hypocentral area of the 2014 M7.3 Papanoa earthquake and triggered the earthquake swarms. GPS measurements suggest that the 2014 SSE also ruptured the hypocentral area [Radiguet et al., 2016]. Therefore, it is possible that the hypocentral area has been repeatedly ruptured by the SSEs.

Offshore Chiapas is characterized by an especially high swarm activity. Thirteen earthquake swarms are detected during 1995-2015. The relationship between these earthquake swarms and SSEs is unclear because any SSEs have not been reported offshore Chiapas. This may be due to a lack of geodetic measurements offshore Chiapas.

Our study reveals the possible relationship between SSEs and fast earthquakes in the Mexico subduction zone, and this may be useful for seismic risk assessments in Mexico.

O11

Missing foreshocks and afterslip estimates of the 2012 Mw 7.4 Ometepec Earthquake

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The 2012 Mw 7.4 Ometepec earthquake is a large megathrust event that rupture near the 2011-2012 Mw 6.9 Oaxaca slow slip event. Five months before the mainshock, the rupture of the SSE began, moved towards the epicentral area and continued afterwards (Graham et al. 2014). Long-term seismicity changes suggest a possible triggering mechanism between the SSE and the regular megathrust earthquake (Colella et al. 2017). Furthermore, along this area characteristic repeating sequence activity was significantly increased after the mainshock, and new sequences developed for more than two years after the event (Dominguez et al. 2016). Thus, we examined continuous records and data from an aftershock deployment using fingerprint analysis (Yoon et al. 20016) and a match filter approach (Frank et al. 2013, 2014) to search for uncataloged seismicity before and after the mainshock. Fingerprint analysis yields to a vast number of detections that largely exceeds the reported seismicity. During the week before the mainshock 332 foreshocks were detected, whereas the week following the mainshock 6931 earthquakes were identified. In comparison the National Seismological Service only reported 3 foreshocks with magnitudes M3.8, M4.0 and M4.2, and 219 aftershocks. Based on these newly detected events, we computed slip rate estimates based on the location, magnitude and recurrence intervals of the detected characteristic repeating sequences to examine the postseismic relaxation history. Our analysis increases the number of detected events more than 100 times, and provides an ample dataset for the investigation of seismic interaction and stress transfer between transient and short-term seismicity.

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O12

Characteristics of earthquakes occurring on the shallowest portion of the Mexican subduction megathrust

Vala Hjörleifsdóttir (UNAM), Ketzallina Flores (UNAM), Shri Krishna Singh (UNAM), Arturo Iglesias (UNAM)

The large magnitude of the 2011 Tohoku earthquake, and the enormous tsunami it generated, came as a surprise to the seismological community. An event of this magnitude had not been documented in the zone for more than 1000 years, and the events in the previous 100 years had M_w 7.8 or smaller. These events ruptured the fault interface far from the trench, with a notable exception of the 1896 Sanriku earthquake [*Tanioka and Satake*, 1996]. There was also a notion that in general the near trench fault surface creeps and therefore does not accumulate strain energy [e.g. *Pacheco et al.*, 1993]. Yet, the 2011 earthquake had slip of up to 60 m near the trench [*Ito et al.*, 2011; *Kido et al.*, 2011; *Sato et al.*, 2011]. How can we in Mexico learn from this tragedy?

The Mexican subduction interface has repeatedly ruptured in magnitude M_w 7-8 earthquakes in the last 100 years [e.g. *Singh et al.*, 1981, *Kostoglodov and Pacheco*, 1999]. Most of the events for which there are well located aftershocks have rupture areas centered on the coast, breaking a depth range from 10-30 km and not the shallowest, near trench portion (Fig. 1). However, in 1787, an earthquake that seems to have been much larger, M~8.6, broke the Oaxaca segment of the subduction zone, causing a tsunami that reached more than 5 km inland [*Suarez and Albini*, 2009]. The large tsunami suggests that the near trench area broke in this event. Could this event be the Mexican equivalent to the 2011 Tohoku earthquake? If so, should we expect this type of event in other parts of the Mexican subduction zone? Is the near trench megathrust interface in Mexico (fully or partially) seismogenic?

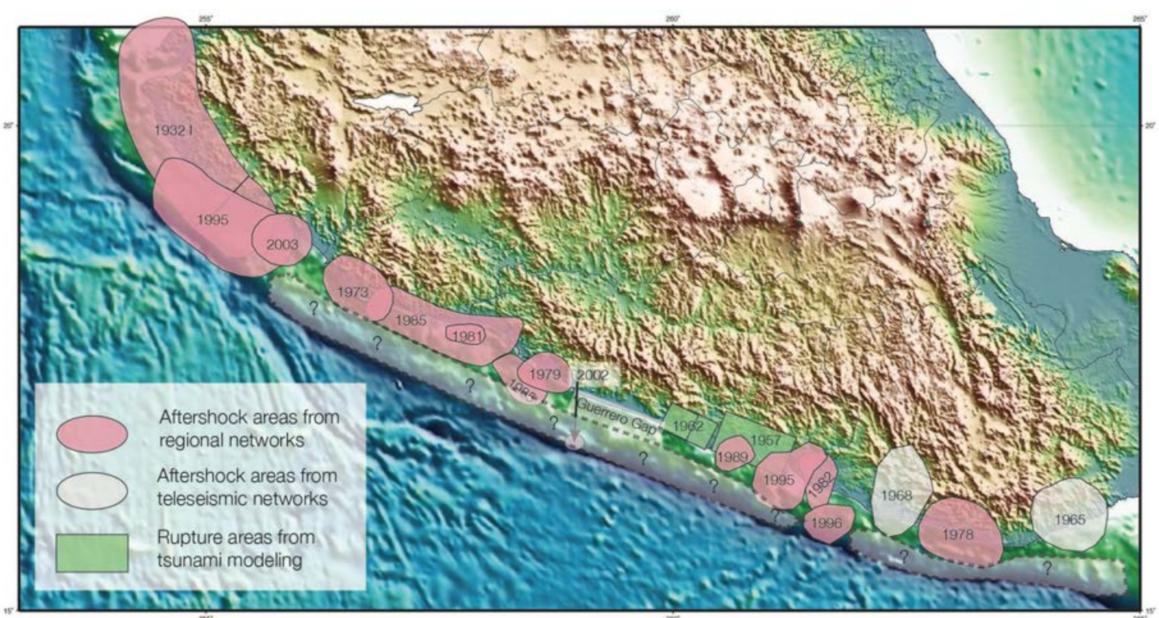

Fig 1. Fault areas of large earthquakes in the Mexican subduction zone, for which we have well determined fault areas. The dashed shaded area near the trench indicates the region that has not broken in a large earthquake during this time.

With this in mind, we have studied the four largest events that have been suggested to break the shallowest part of the subduction interface; the M_w 8.0, 1995 Jalisco earthquake [*Hjorleifsdottir et al, to be submitted*], the Mw 6.7, 2002 Guerrero [*Flores, this conference*] and the M_w 7.2 and Mw 6.7, 1996 and 1997 Offshore Oaxaca earthquakes. We confirm that these events do indeed break the shallowest part of the fault interface, however, each with their own style. For example the 1995 event propagated with a rupture speed of 2.5 km/s, more typical of deeper events. Contrastingly, the 2002 event had a rupture velocity of 1 km/s, more typical of tsunami earthquakes, and duration of 60 seconds. However, this event does not have a smooth source time function as observed for tsunami earthquakes such as the 1992 Nicaragua and 1994 Java events [*Kanamori and Kikuchi*, 1993; *Polet and Thio*, 2003], but a rugged one, suggesting a rupture of multiple separate asperities. Finally, the M_w 6.7 Offshore Oaxaca earthquake is remarkable for the very strong water layer reverberations, observed even at stations at teleseismic distances with take-off angles towards the coast, suggesting that it occurs near the trench where the ocean is deep.

The contrasting behavior of these events, all breaking the shallowest portion of the subduction interface, suggests a heterogeneous fault surface, varying strongly along the trench. Furthermore, it is worth to note that at least parts of the near trench fault surface can slip rapidly in earthquakes, pointing towards the possibility that the rest of the shallow fault also is seismogenic and able to slip in a future large tsunamigenic earthquake.

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O13

THE MEXICAN SEISMIC ALERTING SYSTEM (SASMEX) AND ITS POTENTIAL CONTRIBUTION TO THE *SATREPS* PROJECT

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The Mexican seismic early warning system (SASMEX) was built after the devastating losses observed in Mexico City after the 1985 earthquake. The system was originally conceived to alert Mexico City of a major earthquake along the Guerrero gap. This was considered then, as it is now, thirty years later, as the segment of the Mexican subduction zone with the highest potential of producing the next destructive earthquake. SASMEX became operational in 1989 with only 12 stations, covering only the southeastern half of the Guerrero gap. Today, after a major expansion and modernization process in 2012, about one hundred SASMEX stations monitor the entire Mexican subduction zone. In addition, several instruments are also located in the region where in-slab earthquakes in the subducted Cocos plate occur beneath continental Mexico.

SASMEX originally developed an algorithm that measures the energy growth rate of the quadratic sum of the ground acceleration observed in three-component instruments in the time interval $2(t_S\text{-}t_P)$. The growth rate was calibrated with magnitude using a limited set of acceleration records of subduction earthquakes from the Guerrero Strong Motion Network that existed at the time. The government of Mexico City prescribed two levels of seismic alerts: a preventive alert broadcast to the city´s school system for earthquakes $5.5 \leq m_b < 6.0$, and a public alert, broadcast also by some television and radio stations for events $m_b \geq 6$. Over the years, the $2(t_S\text{-}t_P)$ algorithm has been modified and recalibrated.

The current version of the algorithm was thoroughly evaluated by Cuellar et al. (2017) using 52 acceleration records corresponding to all earthquakes with $M_w \geq 6{:}0$, located along the Mexican subduction zone in the last 30 years. When retroactively executing the $2(t_S\text{-}t_P)$ algorithm on these strong-motion records, all earthquakes, with the single exception of one accelerogram, were classified as having $M_w \geq 6{:}0$. The only accelerogram not properly classified has a very large epicentral distance to the closest strong-motion station. Considering that no earthquakes with magnitude $M_w > 7.5$ have occurred in the Mexican subduction zone recently, the algorithm was also tested retroactively on strong motion data of the great 1985 Michoacán earthquake, the

2010 Chile and the 2011 Tohoku earthquakes. As expected for these great earthquakes, the magnitudes were severely underestimated. Nevertheless, the $2(t_S\text{-}t_P)$ algorithm classified them as $M_w \geq 6$ and, therefore, a public seismic alert would have been issued. It need not be emphasized that the function of a seismic early warning system is not to determine magnitude. The sole responsibility is to issue alerts for earthquakes with magnitudes above the prescribed threshold magnitude. Based on these criteria, the performance evaluation demonstrated that SASMEX is a reliable and effective alerting system.

The geographic growth of the SASMEX network gave rise to increasing demands by other cities to benefit from a seismic alerting system. Unfortunately, the 60-second warning time that Mexico City has for earthquakes occurring in the Mexican subduction zone is reduced to only a few seconds for cities lying close to the seismic sources. Thus a new algorithm was developed that halves the time required to issue a potential seismic warning. The $(t_S\text{-}t_P)$ algorithm is built using a machine learning process that iteratively parameterizes in segments the linear fit between the maximum and the quadratic average of the ground acceleration to M_w, in the $(t_S\text{-}t_P)$ period. A performance evaluation of the algorithm used records from 80 earthquakes in the Mexican subduction zone. The results show that 71 earthquakes, out of the 80 tested, were successfully classified. The magnitude of six events was overestimated and for three it was underestimated. A test of the algorithm was made also on the M_w 6 South Napa, California earthquake of 24 August 2014. The test shows that two strong motion stations near the epicenter would have identified it as an earthquake $M_w>5.8$ within 2 s after the arrival of the *P* phase. The resulting seismic alert would have given a warning time of ~10 s in Berkeley and ~12 s in San Francisco, prior to the arrival of the *S* waves. Thus the $(t_S\text{-}t_P)$ algorithm is a reliable tool for early warning where seismic sources are close to the target cities.

One of the main challenges for SASMEX remains the establishment of procedures to install and use the alerts issued by the seismic early warning system. Today, an alert for all earthquakes $M_w \leq 6$ is being broadcast using loudspeakers installed throughout Mexico City. Although the warning time for earthquakes originating in the subduction zone is about one minute or slightly more, not everyone will benefit from it. For example, high-rise buildings cannot be evacuated in this time span. A greater challenge is posed in cities that lie near the subduction zone. Several of them now have a seismic alert installed, but have only a few seconds of warning time before the strong shaking of the ground arrives. For these cases, strict and carefully thought out protocols should be established to determine how and under which circumstances the alert should be used.

SATREPS is tackling the challenge to understand more thoroughly the tectonic and seismic behavior of the Guerrero gap. Also, it has the goal to reevaluate the seismic hazard posed by this seismic scenario. The SASMEX infrastructure may play an important role in the civil protection efforts envisioned by SATREPS by integrating its potential use into the project. Also, one of the goals of SATREPS is to increase the coverage of seismic and GPS stations in the Guerrero region in order to better understand the local seismic phenomena of both slow and tectonic earthquakes. The dense coverage of SASMEX strong motion stations may be a valuable asset to be incorporated into this effort. Although SASMEX seismic stations do not yet have absolute time, the resulting *S-P* times, routinely observed and reported openly, may prove an important contribution to the accuracy of the hypocentral locations determined with the rest of the SATREPS instruments and by the national network of the Mexican Seismological Service. With a spacing of approximately 20 km between stations on the subduction zone, SASMEX will certainly improve the quality of the earthquakes hypocenters located with the onshore and offshore instruments.

O14

Application of Japanese earthquake early warning system (IPF method) to SASMEX seismic network

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Earthquake Early Warning systems (EEWS) are designed to quickly determine locations and magnitudes of earthquakes and then provide predictive warnings about the arrival time and amplitude of the strong shaking within seconds of a quake. In Japan, the EEWS has been in place since 2007 and has provided warnings of strong earthquakes — by cellular phone, television, radio and local-community speaker system.

In 2011, the M9 Tohoku earthquake occurred, and there were many aftershocks followed. The early warnings for strong shaking were broadcast more than 70 times for aftershocks within 2 months of the mainshock. The false alarm rates were doubled for the aftershocks, because of the complication of simultaneously occurring earthquakes.

We proposed a new EEW algorithm to provide a better estimate of the strong shaking by applying the particle filter (Wu et al., 2015, GJI). It is a sequential Monte Carlo method, and it reduces the time for optimization. The algorithm results in over 90% reduction in the number of incorrect warnings compared to the existing EEW system operating in Japan.

In this presentation, we apply this Integrated Particle Filter (IPF) method to the Mexican strong motion SASMEX network (Cires). First, we create synthetic records based on a velocity structure and attenuation relationship, and evaluate the performance of the method given the network configuration. In the next step, we use the strong motion records of recent large earthquakes in the Mexican subduction zone (20/03/2012 M7.6 and 18/04/2014 M7.2) and show the performance of the IPF method using actual data.

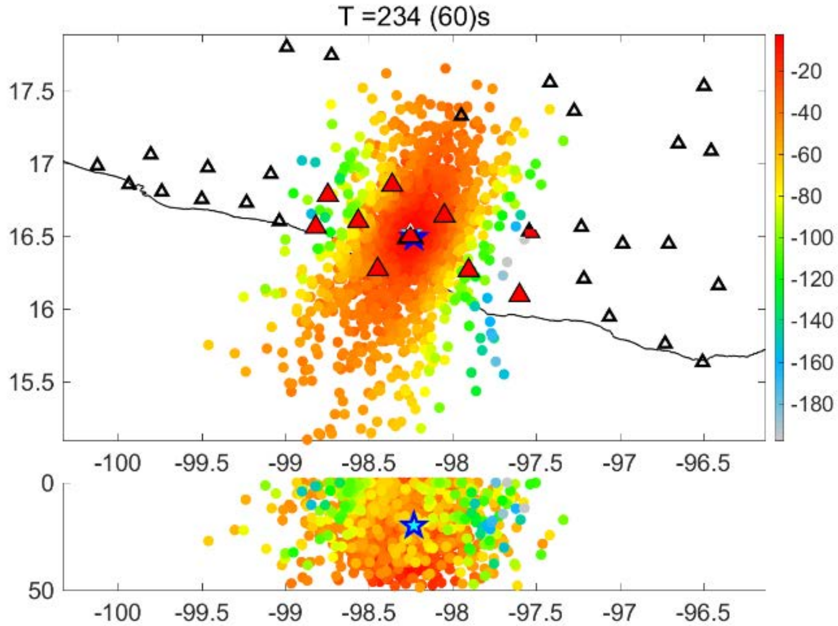

Fig1. Simulation of IPF method for the SASMEX stations. The triangles show the stations, and the red ones are used for the simulation. The star shows the location of an earthquake (20/03/2012, M7.6). The color of the samples is proportional to the likelihood of the hypocenter location.

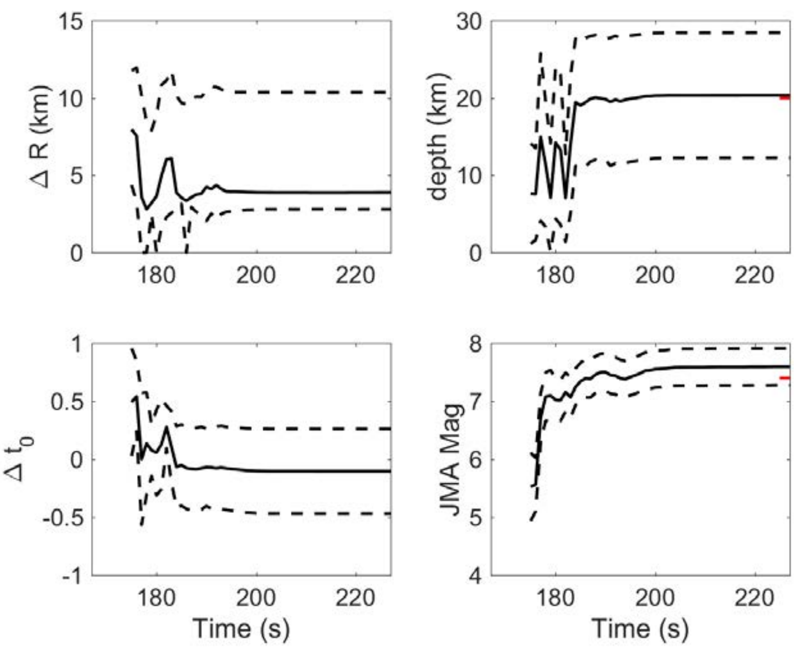

Fig2. Time history of the estimated parameters. Top-left: error of location, top-right: estimated depth (as given 20km), bottom-left: error of origin time, and bottom-right: estimated magnitude (as given 7.4). The left edge of the horizontal axis shows the origin time of the event and the line starts when the IPF was triggered.

O15

Simple seismo-geodetic methodologies for a tsunami early warning in Mexico

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Three parameters are essential for a fast estimation of the tsunamigenic potential of an earthquake: location, size, and rupture duration. Slow ruptures of large earthquakes near the trench have been identified as tsunami earthquakes. Therefore, their fast identification contributes to a robust tsunami early warning. Dense seismic and geodetic networks make this task easier. However, with sparse networks, other strategies should be implemented. Here we present two strategies. The first one, described by Singh et al. (2016), detects near-trench (hence, potentially tsunami) earthquakes. It consists of the estimation of three parameters computed from recordings at station CU, located in Mexico City, ~300–600 km from the trench, for fast detection of near-trench earthquakes. These parameters are: 1) E_R, the ratio of total to high-frequency energy, 2) $Sa^*(6)$, the pseudoacceleration response spectrum with 5% damping at 6 s normalized by peak ground acceleration (PGA), and 3) R_{ESN}, the PGA residual with respect to a newly derived ground-motion prediction equation at CU. An example is the earthquake of 18 April 2002 (M_w6.7), which occurred off-coast the Guerrero Gap, near the trench. The three seismic parameters clearly classified it as a slow-rupture, near-trench earthquake.

The second strategy, proposed by Singh et al. (2008; 2012), detects location and size of large/great earthquakes. It is based on GPS stations located along the coast. Near-source static displacement vectors are used to estimate the location of the downdip edge of the fault and its length, L. The width, W, of the rupture is approximated from L and prior knowledge of the seismogenic zone. Then a uniform slip, D, on the fault is estimated such that it is consistent with the average observed horizontal displacement vectors over length L, which leads to the estimation of the seismic moment, M_0, therefore moment magnitude. This has been tested on GPS data of eight recent megathrust earthquakes and for a scenario earthquake in the Guerrero Gap (Pérez-Campos et al., 2013). With the current station configuration, a robust solution for earthquakes $M_w \geq 7.8$ with rupture areas within the Guerrero coast would be possible in less than 5 minutes.

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O16

Fast computation of approximate near-source elastodynamic Green's function in a layered half-space using the Equipartition Theorem

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The imaginary part of the elastodynamic Green's function is proportional to the average of the cross-correlations within a diffuse field. Theory asserts that a diffuse field within an unbounded, homogeneous elastic medium can be engendered by the isotropic illumination of plane waves fulfilling the principle of equipartition of energy. A diffuse field can arise within an irregular medium, possibly heterogeneous or layered, which is totally or partially embedded in a homogeneous medium, regarded as an envelope, with adequate illumination. This is the case for systems with known Green's function which is retrieved from correlations. The associated field is diffuse but cannot be otherwise verified. This understanding is now paying-off for simple systems in which the Green's function is obtained from correlations of motions that belong in a diffuse field constructed from the illumination of a cocktail of equipartitioned elastic waves.

The Green´s functions are the basic ingredient to construct dislocations and compute the ground motion in the near-source region. In an active subduction regime, considering slab geometry is a must and the computations can be made with high performance computing. It seems convenient to explore an alternative scheme to compute this economically.

In this work a method is presented to the fast computation of the imaginary part of the elastodynamic Green's functions in a layered half-space in the near-source region by means of cross correlations of the fields generated by the incidence of equipartitioned homogeneous plane waves. The contributions of surface waves in the near-source region are quantified. The principle of equipartition of energy allows to compute the weighting factors. The real part of Green's tensor is obtained using the Hilbert transform. Some examples allow establishing advantages and limitations of this approach.

O17

Interpretation of Subducting Topography at the Cocos-North America Subduction Zone offshore Guerrero, Mexico using Residual Bathymetric Anomalies

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The subduction of topographic relief on the incoming plate at subduction zones causes deformation of the plate interface as well as the overriding plate. Whether the resulting geometric irregularities play any role in inhibiting or inducing seismic rupture is a topic of interest for megathrust earthquake source studies. A novel method to discern the small-scale structure at subduction zone forearcs was developed by Bassett and Watts (2015). Their technique constructs an ensemble average of the trench-perpendicular topography, and the removal of this regional tectonic signal reveals the short-wavelength residual bathymetric anomalies. Using examples from selected areas at the Tonga, Mariana, and Japan subduction zones, they were able to link residual bathymetric anomalies to the subduction of seamount chains, given the similarities in wavelength and amplitude to the morphology of seamounts that have yet to subduct. We focus here on an analysis of forearc structures found in the Mexico segment of the Middle America subduction zone, and their possible mechanical interaction with areas on the plate interface that have been previously identified as source regions for earthquake ruptures and slow slip events.

We used a map of residual bathymetric anomalies to identify features possibly associated with subducting relief in the vicinity of the Guerrero seismic gap (Figure 1). There are several positive residual bathymetric anomalies in this area, mainly in the shallow portion of the plate interface and between 15 and 50 kilometers away from the trench axis. We note that these residual bathymetric anomalies are also in a portion of the plate interface that has been modeled as a low coupling region (Radiguet et al, 2016).

While these residual bathymetric anomalies we have identified are found landward of small seamounts on the incoming Cocos plate, further efforts using forward modeling of gravity anomalies and vertical gravity gradients could provide additional support for their origin as subducted seamounts. Wang and Bilek (2011) suggested that the normal stresses associated with seamount subduction could lead to the formation of adjacent fracture networks. Lineations associated with these fractures might be found on the seafloor of the continental margin using high-resolution bathymetry data. If so, this would bolster the evidence for the presence of subducting relief on the shallow portion of the plate interface at the Guerrero segment of the Mexico subduction zone.

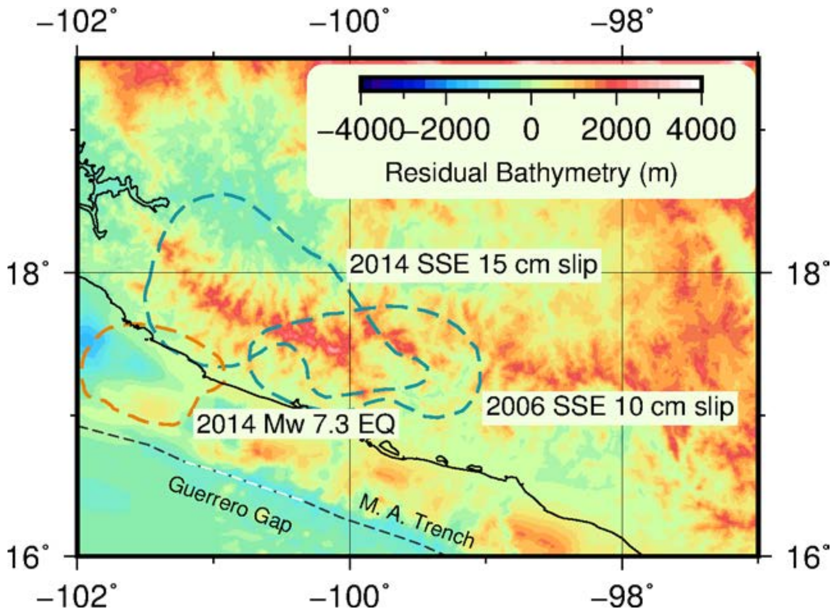

Figure 1: Shown in the map is an image of the residual bathymetry as calculated for the Cocos-North America subduction zone around central Mexico. The location of the northwest Guerrero seismic gap along the trench is labeled. Also outlined is the rupture area of the 2014 Mw 7.3 Papanoa earthquake (from Radiguet et al, 2016), as well as a model of the 15-cm slip contour of the 2014 slow slip event (SSE) inverted from geodetic data. The 10-cm slip contour of the 2006 SSE from a different study (Cavalié et al, 2013) is also plotted for reference.

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O18

Hotspots for local tsunami amplification along the Mexican Pacific coastline

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Teletsunami events have been recorded at tide gauge stations along the Mexican Pacific. Among those stations, there has been evidence for substantial local amplification at specific sites such as Zihuatanejo and Acapulco. Those two sites are vulnerable to future events, specifically the possible rupture of the Guerrero Gap. The M9.0 Tohoku-oki, Japan, 2014 M8.1 Iquique, Chile and 2015 M8.3 Illapel, Chile earthquakes were recorded at the stations along the Mexican Pacific. Particularly, for those three events, the region of Zihuatanejo showed a relatively large amplification. Whilst the incidence angle of the main beam towards Zihuatanejo is rather different for the studied events, local wave amplification occurred for all events. Although it is important to estimate the range of future tsunami events, the local tsunami amplification is also important to understand local vulnerability, which could be independent of the rupture characteristics. To estimate the amplification effect associated with the direction of the main tsunami energy beam we carried out numerical simulations of hypothetical tsunamis varying the incidence angle of this main beam. We identify the locations where amplification of the waves is present. The Ixtapa-Zihuatanejo region was chosen as a special focus area because it is one of the 5 pilot sites within the SATREPS project.

O19

Probabilistic tsunami hazard analysis (PTHA) of the Pacific Coast of Mexico

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This study develops a novel computational framework to carry out probabilistic tsunami hazard assessment for the Pacific coast of Mexico. The new approach enables the consideration of stochastic tsunami source scenarios having variable fault geometry and heterogeneous slip that are constrained by an extensive database of rupture models for historical earthquakes around the world. The assessment focuses upon the 1995 Jalisco-Colima Earthquake Tsunami from a retrospective viewpoint. Numerous source scenarios of large subduction earthquakes are generated to assess the sensitivity and variability of tsunami inundation characteristics of the target region. Analyses of nine slip models along the Mexican Pacific coast are performed and statistical characteristics of slips (e.g. coherent structures of slip spectra) are estimated. The source variability allows exploring a wide range of tsunami scenarios for a moment magnitude (M_w) 8 subduction earthquake in the Mexican Pacific region to conduct thorough sensitivity analyses and to quantify the tsunami height variability. The numerical results indicate a strong sensitivity of maximum tsunami height to major slip locations in the source, and indicate major uncertainty at the first peak of tsunami waves.

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O20

Inverse modeling of the tsunami deposit

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Tsunami deposits provide important clues to understand ancient tsunami events. Here we propose a new inverse model of tsunami deposit emplacement. The inversion model proposed by the authors is named as FITTNUSS (Framework of Inversion of Tsunami deposits considering Transport of Non-uniform Unsteady Suspension and Sediment entrainment). The model considers both transport of non-uniform suspended load and entrainment of basal sediments. Turbulent mixing, resuspension from basal active layer, and advective transport of suspension are incorporated in this model, although flow dynamics is simplified to the quasi-steady condition. In addition, damping of turbulence caused by density stratification due to suspended sediment itself is also incorporated in a form allowing computational efficiency. This inversion model requires the spatial distribution of deposit thickness and the pattern of grain-size distribution of the tsunami deposit along 1D shoreline-normal transect as input data. It produces as output run-up flow velocity, inundation depth and concentration of suspended sediment. To solve for advection of non-uniform suspended load, a transformed coordinate system is adopted, which increase computational efficiency. The generality of the physics embedded in this model suggests wider applicability to a range of situations. Indeed, we apply our model to the 2011 Tohoku-Oki Tsunami deposit without any parametric calibration, and nevertheless obtain reasonable estimations of run-up flow velocity and the inundation depth using only measurements of the tsunami deposit along a 4 km transect normal to the shoreline. The result of our inversion fits well with the observations from aerial videos and field surveys. We conclude that this method is suitable for the analysis of ancient tsunami deposits, and that it has the advantage of requiring the minimum information about the condition of the emplacing paleotsunami for reconstruction.

O21

Tsunami deposits - Multiple proxies prove evidence of past events, Mexican Subduction zone

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The study of tsunami deposits has significantly advanced since the 2004 earthquake and tsunami in the Indian Ocean. Most significantly the Chilean 2010 and Tohoku 2011 tsunamis have provided unique opportunities to analyze tsunami deposits and their characteristics. A baste range of analysis has been further developed over the last 5 years, including historical records, sedimentary, microfossil, geochemical, magnetic properties, modeling, x-ray tomography of tsunami deposits, and even DNA of marine foraminifera preserved in tsunami deposits e.g. Bogaló et al., 2017; Chagué-Goff 2012, 2016; Cerny et al, 2016; Dura et al., 2016; Falvard and Paris, 2017; Font et al., 2013, Goguitchaichvilli et al., 2013; Pilarczyk et al., 2012, Ramírez-Herrera et al., 2007, 2016; Shinozaki et al, 2016; Szczucinski et al., 2016; and many others).

In tropical environments, the combination of multiple proxies has demonstrated to be a necessity to prove evidence of ancient earthquakes and tsunamis (e.g. Ramírez-Herrera et al., 2007, 2012; Williams et al., 2011). A number of studies has previously discussed the challenges presented in the study of tsunami deposits in tropical areas and the intrinsic difficulties of these coasts frequently affected by the effects of hurricanes, as well as the problems related to the differentiation between tsunami and storm deposits (Castillo-Ajá and Ramírez-Herrera, 2016; Ramírez-Herrera et al., 2012; Atwater et al., 2016, 2017; Dura et al., 2016), sometimes misinterpreted as tsunamis by enthusiasts who start studies of paleotsunamis (e.g. Ocampo-Rios et al., 2016) or misinterpreted as evidence of climate or seasonal changes (e.g. Bianchette et al, 2016; Chagué-Goff et al., 2017).

We present here an overview of earthquake geology and tsunami deposits studies along the Guerrero coast, parallel to the Mexican subduction zone, an area hit by both earthquakes and tsunamis in the past, but also by storms. Multiproxy approach aided in identifying evidence of past earthquakes and tsunamis in the geologic record. A series of rigorous analysis combining historical archive documentation, sedimentological and stratigraphic, microfossil, geochemical, magnetic properties analysis, dating techniques and modeling, demonstrate the past occurrence of earthquakes and tsunamis along the Guerrero coast. We discuss here strategies and approach for further develop work onshore on this section of the Mexican subduction zone.

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O22

VULNERABILITY ASSESSMENT OF ZIHUATANEJO, GUERRERO, MEXICO

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An integrated risk assessment includes the analysis of all components of individual constituents of risk such as baseline study, hazard identification and categorization, hazard exposure, and vulnerability. Vulnerability refers to the inability of people, organizations, and societies to withstand adverse impacts from multiple stressors to which they are exposed. These impacts are due to characteristics inherent in social interactions, institutions, and systems of cultural values. Thus, vulnerability is a pre-existing condition that affects a society's ability to prepare for and recover from a disruptive event. Risk is the probability of a loss, and this loss depends on three elements: hazard, exposure and vulnerability. Then, risk is the estimated impact that a hazard event would have on people, services, facilities, structures and assets in a community. In this research, using the methodology developed by the U.S.A. National Oceanic and Atmospheric Administration (NOAA), we will assess the social, economic and structural vulnerability of Zihuatanejo's community. Due to its geographical and geological location, this community is continuously exposed to many different natural hazards (mainly earthquakes, tsunamis and floods). Vulnerability will be quantified from existing local data, the Mexican National Institute of Statistics, Geography, and Informatics (INEGI) and/or from local families interviews. Basically, four variables will be considered: household structure quality and design, price of housing, availability of basic public services, and family economic and social conditions. To facilitate our analysis, vulnerability will be represented spatially using a Geographical Information System (GIS). These results will support the local estimation of earthquake and tsunami risk.

O23

From “instructors/followers” to “facilitators/implementers”: how can we foster school teachers’ initiative in tsunami evacuation drill?

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1. Problematic relationship between experts as instructors and teachers as followers in drills

Planning and implementation of tsunami evacuation drills at school are mostly held through the intervention of disaster prevention experts in Japan as well as in Mexico. As school teachers are not specialized in the theme, they have little choice but to follow the instruction of experts. At the same time, experts apply their abundant knowledge and experiences of the drill hence their basic attitude is to instruct teachers for the drill. This style of disaster education is often reproduced unproductively without changing problematic fundamental structure in which disaster experts from outside play exclusively as active instructors while leaving local school teachers as passive followers. Importantly, those who respond in case of an earthquake are the teachers. From this viewpoint, teachers cannot be remained as just followers of evacuation drill, but initiative of teachers should be fostered at the phase of the tsunami evacuation drill. Based on this background, this presentation shows the comparison of two school tsunami evacuation drills in Zihuatanejo, Guerrero, to examine the ideal relationship of teachers and experts.

2. Two schools at high risk of tsunami

Two schools, Vicente Guerrero primary school with 300 students and Luis Donaldo primary school with 100 students were the targeted schools. They share same school buildings and the former school holds classes in the morning and the latter holds in the afternoon. As they are completely separated schools, all teachers are also different from each other. The schools are located in the urban area of Zihuatanejo only 30 meters away from the coast line. According to the preliminary study of SATREPS, tsunami arrives at the area after 15 minutes of the earthquake in spite of the distance of 1.5 kilometers from the schools to the nearest hill.

3. Comparison of two different types of tsunami education at schools

As first intervention of tsunami education at both school, author and staffs of Civil Protection described the mechanism of earthquake and tsunami, results of the preliminary survey of the SATREPS and tsunami histories in Zihuatanejo. Throughout the education, teachers at both schools have recognized the necessity of tsunami evacuation drill as they started to discuss “what is the quickest way to reach higher place?” etc. After this first intervention, different approaches were taken. For Vicente Guerrero primary school, author and staffs of Civil Protection jointly implemented the workshop. Basics of designing the evacuation route such as “less possibility of road blockage after earthquake” was explained to teachers, and teachers have discussed the appropriate evacuation route in small groups and shared their opinions afterwards. Workshop session, participated by not only outside experts but also local school teachers, guaranteed bi-lateral communication among stakeholders, and also successfully aroused the teachers’ interests and commitment to evaluation drills. At Luis Donaldo primary school, on the other hand, it was adopted one-way communication as expert has just instructed to teachers all the procedures of tsunami evacuation drill including the evacuation route. Then the evacuation drills were held at each school and both schools evacuated to the same hill.

4. From “instructors/followers” to “facilitators/implementers”

As a result, Vicente Guerrero primary school reached to the hill with the time of 17’35” while Luis Donaldo primary school took 23’00” to reach. Since the estimated arrival time of first tsunami is 15 minutes, the difference of two schools (5’25”) may produce critical outcomes. In addition, teachers of Vicente Guerrero primary school devised ideas for safer and quicker evacuation such as assigning person in charge of opening the lock of main gate, deciding the order of evacuation, implementing pre-evacuation drill to line up quickly, etc, which movements were not observed at Luis Donaldo primary school. Luis Donaldo primary school followed the instructions of Civil Protection. This case study shows that if the educational method does not reinforce the structure of experts as instructors/teachers as followers, teachers are not fallen into the attitude of followers as Vicente Guerrero primary school was. Then, tsunami evacuation drill can be more effective and even quicker and safer to evacuate through the customization by teachers. On the other hand, as long as expert is an instructor, only teachers do is to follow. Even if reliable tsunami risk information is provided sufficiently from experts, it will not be so effective to awake active responses on teachers’ side, if communication design stays in a conventional one-way framework, spoiling teachers’ intrinsic motivation and their own initiatives. Role of expert should be to facilitate teachers’ participation to foster their attitude of taking initiative and to give the suggestions from experts’ point of view. Method of Tsunami evacuation drill should be designed to restructure from the problematic relation of experts as instructors/teachers as followers of drills, to the ideal relation of teachers as implementers/experts as facilitators.

O24

Take benefit of SINAPROC capabilities to strengthen the SATREPS Project Mexico-Japan

Tomas A. Sanchez Perez (CENAPRED) and Carlos M. Valdes Gonzalez (CENAPRED)

Public policy for disaster risk reduction in Mexico has significantly increased its technical, operational, regulatory, educational and linking capabilities since the establishment of the National Civil Protection System (SINAPROC for its acronym in Spanish) three decades ago. Nevertheless, it is recognized that there are still lags and that vulnerability growth overcomes advances in science and technology for risk reduction. On the other hand, the contributions and efforts that are made from the academy, and that are enriched notably when including multidisciplinary approaches, must be maximized.

The SATREPS Mexico-Japan Project to mitigate the risk of earthquakes and tsunamis on the Mexican Pacific coast is a good example of the above. Due to its characteristics, it requires to have a greater support of public communication of science and technology. It is therefore anticipated that the results of the research carried out under this project will have the greatest benefits in terms of public utility insofar as they are linked to the existing instruments, tools, procedures and capacities of SINAPROC, which will allow to influence and enrich key items of risk management that operate as part of the public administration in Mexico, like the ones listed below:

- Count with new documentary collections that integrate the generated knowledge about earthquake and tsunami hazards in Mexico and its effects.
- Complement the methodologies and the minimum content guides published for the elaboration of risks atlas.
- Incorporate new information layers into the National Risk Atlas, about hazards, exposed elements and vulnerabilities, favoring the right of access to public information and the decision making process in prevention and emergency management.
- Complement the alert protocols incorporated into the National Alerts System.
- Link with the five Working Groups (WG) that integrates the National Tsunami Warning

System (WG1: Monitoring and Detection; WG2: Assessment and Risks; WG3: Alert and Communications; WP4: Dissemination, Preparation and Recovery; and GT5: Legal).

- Count with local intervention strategies to improve education, preparedness and response plans to earthquakes and tsunamis in coastal areas, focusing attention on the most vulnerable sectors.
- Build a culture of civility and compliance with norms and regulations, aimed at reducing geological risks and participating in dissemination events, such as, among others, the World Tsunami Awareness Day.

P01

Seafloor geodetic surveys in Japan

Motoyuki Kido (IRIDeS, Tohoku University, Japan)

Seafloor geodetic data provide one of the most crucial information on the state of source region of a possible large earthquake along the subduction zones. The definite advantage is that it can monitor displacement or strain of the crust just above the target, although its precision and sampling frequency are generally poor. Because seafloor geodesy technique is still developing with trial and error, its method, instrumentation, utilization, data availability are much different among research groups. Here we summarize the various system and their merit/demerit. Then introduce applications of our group to plate boundaries not only in Japan.

Our current major target is evaluating post seismic deformation field following the 2011 Tohoku earthquake along the Japan trench, where we constructed up to 20 seafloor benchmarks for GPS-A measurement since 2012. Through 4-years of survey, once or twice a year in average, revealed prominent feature that coherent westward movement in the main ruptured area due to viscoelastic response and that the dominance of eastward movement in the southern adjacent area sue to postseismic slip. At some benchmarks, even the temporal decay in the displacement rate can be visible. More frequent survey must be needed, however, to resolve then clearly. Considering the total number of the benchmarks, traditional survey style cannot be in practical. A sort of an unmanned vehicle that can continue to make surveys for months in the presence of string sea current should be utilized in near future.

The other promising survey is seafloor acoustic ranging, that can measure local strain in a short baseline with higher frequent (but off-line) data sampling. We deployed the system across Japan trench and submerged strike slip fault in Marmara Sea, Turkey. The precision reaches a few ppm of distance change after 1-year continuous observation, which revealed no significant convergence across the trench axis at the major ruptured area of Tohoku Eq. and partial creep of the North Anatolian Fault in the Marmara Sea.

In the presentation, we also introduce recently developed realtime monitoring system using a moored buoy for continuous and realtime monitoring of the seafloor movement in the disaster-mitigation of point of view.

P02

Analysis of ambient seismic noise levels for the SATREPS stations and their technical aspects

* M.C. Jorge Real , Dr. Vladimir Kostoglodov , Dr. Allen Husker, Dr. Víctor Cruz

(Universidad Nacional Autónoma de México, IGEOF)

The joint research project between Japan and Mexico entitled "Evaluacion del peligro asociado a grandes terremotos y tsunamis en las costas del Pacifico mexicano para la mitigacion de desastres" under the "Science and Technology Research Partnership for Sustainable Development" (SATREPS) program, contemplates the installation of 7 broadband seismological stations in the state of Guerrero, Mex. It is important to know the levels of environmental seismic noise, so in this work we present the seismic and background noise curves and compare the maximum admissible noise (HNM) and minimum (LNM) curves defined by Peterson (1993) to evaluate characteristics and design of the site of the seismic station, in addition to showing the technical aspects of the installation.

P03

On the interpretation of the variety of oceanic fluctuation in terms of ocean bottom pressure

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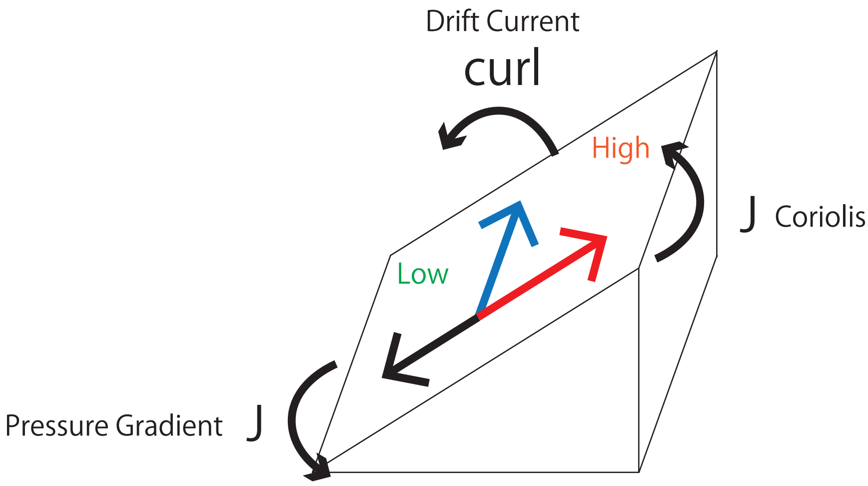
Ryota Hino, Syuichi Suzuki, (Graduate School of Science, Tohoku University)

SSE is the phenomenon that rupture progress slowly compared with regular earthquake. Many examples are reported all over the world. (e.g. Yoshioka et al., 2004) Also, this phenomenon was observed before 2011 Tohoku earthquake. It is thought that deformation in the SSE area at the time of the main shock contribute to tsunami damage. (e.g. Ito et al., 2013) In general, the detection of SSE on the subduction zone, especially at the shallower part is difficult using only GNSS data. Therefore, the study for the sea floor crustal deformation observation and monitoring are receiving attention recently. Among them, the observation using Ocean Bottom Pressure Recorder is useful for observing crustal deformation due to SSE at a point where it can observe pressure change including vertical crustal deformation component in high resolution continuously. On the other hand, to extract the pressure change due to crustal deformation from Ocean Bottom Pressure Record, it is essential to understand exactly what caused the observed pressure change.
In this study, we consider about the factor of sea floor pressure change, especially temporal variation of several months to annual cycle from observed data. In this study, we use observed pressure records which spanned from June 2014 to June 2016 at off the coast of north island in New Zealand and Kumanonada using independent type Ocean Bottom Pressure Recorders. By using Baytap-G, we calculated the tidal component and subtracted it from the raw data. Then, we calculated sea-level anomaly (non-tidal oceanic variation) driven by air pressure and wind using barotropic ocean model. Comparing with Ocean Bottom Pressure Record after removing tidal component and calculated sea-level anomaly using ocean model, we found that there is a long-term component included in the Ocean Bottom Pressure Record that cannot be expressed by calculating ocean model. This long-term component's amplitude is about 1.5hPa and has about a 20-day cycle. In evaluating the pressure change derived from crustal deformation due to SSE, the

amplitude of this component we detected in this study cannot be ignored. In this study, we consider the origin of this tong-term component from multiple viewpoints such as gravity observation satellite GRACE or tide gauge record etc. As a result, we found that there is a "fluctuation" which can be approximated as summation of harmonic mode. After subtracting the long-term component we identified in this study, we detected crustal deformation due to SSE at off the coast of north island in New Zealand. Then, we estimated fault slip due to the SSE from vertical displacement observed by Ocean Bottom Pressure and horizontal displacement observed by GNSS.



P04

THE MEXICAN SUBDUCTION ZONE: EFFECTS OF THE 3D GEOMETRY ON THE STRESS TRANSFER DUE TO INTERPLATE SLIP EVENTS

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We analyze the effects of the 3D geometry of the Mexican Subduction Zone plate interface on the coulomb stress transfer produced by large subduction thrust earthquakes and aseismic slow slip events, using a non-planar slab model and explicit slip distributions. The 3D interface geometry was obtained based on previous profiles and interplate seismicity along the subduction zone (Figure 1). For reference, we first obtained the stress change over extended fault planes. Next we computed the stress transfer for the same slip distributions along the non-planar 3D interface. The interfaces were discretized by 2.0 x 2.0 km^2 segments, setting the observation points along the same interface surface in a staggered-type grid that helps to avoid possible singularities. Stress tensor changes were computed for the 3D half-space and analyzed using the Coulomb Failure Stress criterion. The stress changes due to each subfault of each earthquake were computed on every grid segment of the interface and resolved along the specific normal-vector and slip-vector directions for all segments of the interface. The computation procedure implies that for a given rupture with a specific slip setting, the corresponding coulomb stress change distribution may vary depending on its relative location along the interface. Results are presented for the studied segments along the real model of 3D plate interface. The stress changes on the main rupture patches show relatively small variations between both interface assumptions; however, relatively larger variations could be found outside the main patches, especially where the interface presents acute bends along the strike or dip directions. Results suggest that the assumption of a planar tectonic interface might be carefully explored in this region.

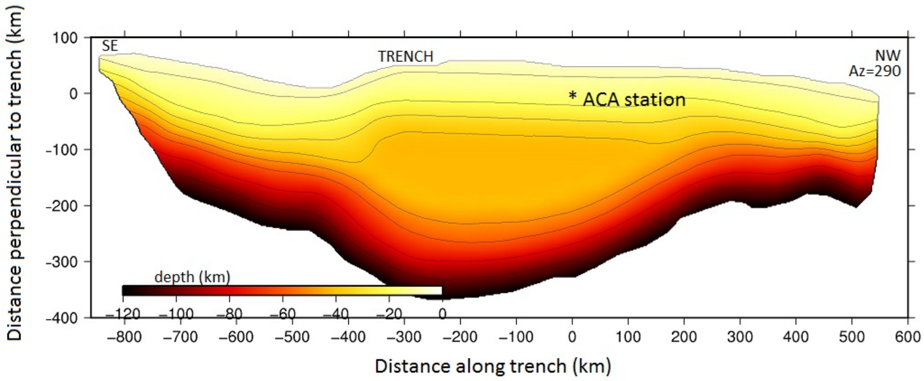

Figure 1. Depth contours of the tectonic interface of the Mexican Subduction Zone

P05

Shear Wave Splitting and Upper Mantle Flow in the Mexican Subduction Zone: Looking Backward and Forward

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Xyoli Pérez-Campos, Steven van Benthem, Alberto Bernal-Díaz (IGF, UNAM)
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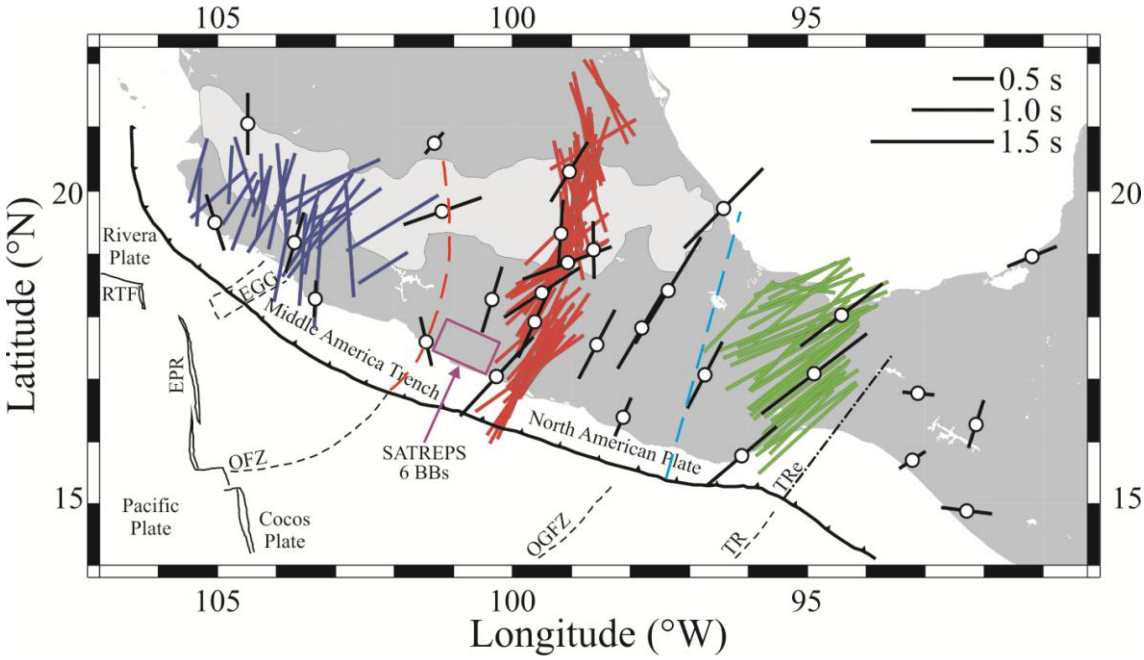
Upper mantle seismic anisotropy is the result of the strain induced lattice preferred orientation of mantle minerals, predominantly olivine. Therefore, seismic anisotropy is often used to infer the direction of mantle flow. Upon entering an anisotropic medium, a shear wave becomes split, meaning that a fast and a slow wave are produced. Seismic anisotropy was quantified in the Mexican segment of the Middle America Trench, where the oceanic Cocos and Rivera plates subduct under the continental North American plate [*Valenzuela and León Soto,* 2017], using the covariance method of *Silver and Chan* [1991]. Two parameters are needed, the fast polarization direction and the delay time between the fast and the slow waves. Measurements mostly involved core-transmitted phases such as *SKS* recorded by the permanent network of Servicio Sismológico Nacional (SSN), and also by several temporary deployments, but some observations were also made using *S* waves from local intraslab events in southeastern Mexico. In the Mexican subduction zone, the fast polarization directions are predominantly trench-perpendicular, which is consistent with subslab entrained flow and also with corner flow in the mantle wedge. Observations are also consistent with rollback of the Rivera slab and with mantle flow in the gap between the Rivera and Cocos slabs. Data from the Meso-American Subduction Experiment (MASE) show fast axes oriented NE-SW in the region where the Cocos slab subducts subhorizontally (fore-arc) and are consistent with subslab entrained flow. In the back-arc, however, MASE stations within the Trans-Mexican Volcanic Belt (TMVB) and farther north (i. e. where the slab subducts steeply at ~75°) have their fast axes oriented N-S and are indicative of corner flow within the mantle wedge. In southeastern Mexico, near the Guatemala border, delay times are small and suggest that only little anisotropy is present. Current work is focused on determining the mantle flow pattern at the eastern termination of the TMVB, where a possible tear in the South Cocos slab has been proposed [*Dougherty and Clayton,* 2014]. Data from the onshore, SATREPS broadband seismometers will allow for better characterization of anisotropy within the Guerrero gap. In this region the slab goes from flat subduction in the east to steeper subduction to the west. In fact, Bandy and coworkers [*Bandy,* 1992; *Bandy et al.,* 2000] proposed that the slab is fragmenting into a northern Cocos plate and a southern Cocos plate along the eastern projection of the Orozco Fracture Zone. *Dougherty et al.* [2012] provided additional evidence supporting the idea that such a tearing event is taking place. Furthermore, *Stubailo et al.* [2012] suggested that their anisotropy measurements using Rayleigh waves are consistent with toroidal mantle flow around the slab edges driven by slab rollback. Shear wave splitting measurements in this region are available from a single SSN station. The fast polarization direction is oriented roughly NNW-SSE and is different from the trench-perpendicular fast axes observed farther east over the flat slab. SATREPS data will make it possible to better map the change of orientation of the fast axes and its implications for mantle flow.



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P06

Trans-dimensional inversions for detecting layered structures, and Enhanced Seismic Tomography for imaging 3D high-resolution models. Two methods for improving the knowledge of the Guerrero region.

Marco Calò [(1)], Allen Husker[(1)], Arturo Iglesias Mendoza[(1)],
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The detailed knowledge on the structure of the Guerrero region is of fundamental importance for numerical modeling of slow slip events and the reconstruction of the rupture process of large events. In this paper two techniques will be presented that will be applied in order to reconstruct the geometry of the crust and uppermost mantle of the Guerrero region.

First will be presented a trans-dimensional inversion method that jointly inverts dispersion curves of Love and Rayleigh waves and converted body waves phases. This method allows detecting the anisotropic layered structure of the crust and upper mantle beneath stations in a Bayesian framework where errors are treated as unknown during the procedure, making it particular suitable to extract reliable information also in presence of noisy data. The application of this method will better define depth and nature of the interfaces of the subducting slab together with the presence of the mayor crustal discontinuities.

Therefore an improved earthquake based tomography technique will be presented. This method uses a double difference tomography technique (Zhang and Thurber, 2003) complemented with a post processing called Weighted Average Model (WAM, Calò et al., 2009,2012, 2013). WAM is based on sampling models compatible with data sets using different input parameters and then synthesizing results in a new and more reliable model using weighting functions based on the ray density of each model. Synthetic tests and applications to several regions around the World show that WAM can increase reliability and resolution of the final models of at least 20% with respect to the traditional methods, allowing a better picture of the smallest structures.

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P07

The long duration, April 18, 2002 (Mw 6.7), Mexico earthquake; a small tsunami earthquake next to the Guerrero Gap

Ketzallina Flores, Vala Hjörleifsdóttir, Shri Krishna Singh, Arturo Iglesias, Xyoli Pérez-Campos

We estimate the duration, extent and rupture velocity of the April 18, 2002 (Mw 6.7) earthquake, located about 55 km off the coast of Guerrero, very near to the Mesoamerican Trench. The hypocenter location (Pacheco & Singh, 2010) is inside what is known as the Guerrero Gap, a segment of the Mexican subduction zone that has not had a large (M>7) earthquake in at least 100 years (Singh et al 1981).

The 2002 earthquake is anomalous in the sense that it produced very small accelerations for its size (Iglesias et al 2003) and it is one of the earthquakes with longest duration relative to its magnitude recorded globally in the last 40 years (Duputel et al, 2013).

The long duration relative to the size is a characteristic of tsunami earthquakes (Kanamori, 1972). Events of this type are particularly hazardous because they produce relatively large tsunamis and small ground motions for their size, so they may be mistaken for smaller events by people near the coast, who may not prepare for the large tsunami. As near trench earthquakes are relatively rare, and due to their destruction potential, it is important to study in detail the few recorded events of this type.

In this study we calculate the duration of the 2002 earthquake by observations of far-field records. We use the difference in time between the first and last coherent signals of the peculiar P wavetrain of the event, to conclude that the rupture had a duration and along strike length of approximately 56s and 60 km, respectively. The rupture propagated to the north-west with a rupture velocity of 1 km/s.

Surprisingly, the efficiency of the earthquake, or the ratio of the radiated energy to the moment, is not low, despite the very long duration. We propose this is due to the “ruggedness” of the moment rate function, which contrasts with the very smooth moment-rate function of typical tsunami earthquakes, such as the 1992 Nicaragua and 2006 Java earthquakes.

Our results show that the majority of the rupture area of this earthquake is not in the Guerrero Gap but adjacent to it, indicating that there is still a gap in the Gap.

P08

Seismic energy release at the seismogenic zone of Guerrero, Mexico.

Authors Raymundo Plata, Xyoli Pérez-Campos, Shri K. Singh

To study the mechanisms that control seismic energy release along the Guerrero, Mexico, subduction zone, we estimated radiated seismic energy, stress drop and radiation efficiency of two recent large earthquakes and their aftershocks. The first earthquake occurred at the border of the states of Guerrero and Oaxaca in Ometepec on March 2012 (Mw7.5), the second earthquakes occurred 300 km away, in Papanoa on April 2014 (Mw7.2). Estimations of radiated energy scaled with seismic moment (Es/M0), show no evidence of dependence of radiated seismic energy with distance from the trench, depth, or size of earthquakes. However, scaled energy distribution behaves in a heterogeneous way parallel to the trench, and it might be influenced by lateral heterogeneities along the subduction interface. Stress drop and efficiency also reveals rough changes parallel to the trench, in a similar way as scaled energy. However, results show that Ometepec earthquakes had lower stress drops and higher radiation efficiency values compared with Papanoa sequence.

P09

Source Inversion of Very Large Earthquakes Using Empirical Green's Function with P and S Wave Data

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For roughly 20 years, finite fault slip inversion on faults have been applied on numerous earthquakes to investigate rupture patterns as well as source parameters. Among which, the EGF (Empirical Green's Function) approach is able to eliminate complicated site and path effect by using EGF events as the kernel in inversions, provided that the focus of the two events are close enough, both having similar focal mechanisms, and are different in magnitude of roughly over 2. In this study, starting from the study by *Ide et al., 2011*, we re-investigated the rupture process of 2011 M_W 9.0 Tohoku-Oki Earthquake, using far-field SH waveforms in addition to the original P waveforms. Bootstrapping were done among the station selection to eliminate errors from station sampling. 4 EGFs were included, as in the study of *Ide et al., 2011*. By comparing results using P and SH waves, we observe that the slip pattern by P waves is more scattered than SH waves, which centers at shallow region and is very concentrated.

Since the slip pattern by P or SH wave alone are rather different from each other, we further include both P and SH wave data, bootstrapping over station selection and wave selection. The results show a mixture of pattern of the two waves as expected; but now we can achieve a model that we can more confidently interpret. We can observe that small deeper rupture initiated around the epicenter from 20 (sec), then gradually propagated up-dip, until the shallow main rupture extended from 60 to 80 (sec). At around 70~90 (sec), the rupture extended down-dip, and then gradually ceased. These results are comparable to *Ide et al., 2011*, but notably more concentrated owing to the addition of the very concentrated S wave results. The calculated waveforms are systematically different from the observation at some stations located in small part of the focal sphere, despite the great reduction in variance in processing. This may be owing to the inherent limit in the EGF method, e.g. the Green's functions are different for the locations of EGF events and the mainshock.

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P10

Study of repeating events in the Jalisco subduction zone, Mexico.

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Universidad Nacional Autónoma de México[1], Massachusetts Institute of Technology[2]

One of the events observed at the Rivera subduction zone, Eastern part of Mexico, is repeating low amplitude regular earthquakes. We use the "Mapping the Rivera Subduction Zone" (MARS) seismic array, which is a large array of 51 stations located in Jalisco, Colima and part of Michoacán, to detect and locate them. For the temporal detection, we used a matched filter search (Frank et al., 2014). We found templates for the repeating earthquakes by stepping through 60s window and crosscorrelating with the rest of the data stream on a single station. We have increased the window compared with previous detections so that, most of the events in all stations are bounded in those 60s window. High correlation coefficients are thought to be events/templates, which then are used in the matched filter search over the whole array spanning at least eight months. The searching is performed in two steps. First, we list all of the templates and calculate coherency between them to find redundancy, then we do the matched filter, set a detection threshold to the correlation coefficient sum of 0.3 and stack all repeaters found. Second, the stacked for each template is used as a new template. In order to find them, we use a grid search using p wave time arrivals automatically picked with STA/LTA technique. Results are compared with tremor catalogs and local seismic activity.

P11

Moment tensor inversion of tectonic tremors in the Guerrero subduction zone

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Slow earthquakes have exposed the actual complexity of the tectonic processes involved in subduction zones around the world. Despite different studies addressing these phenomena, its causal relationship is still debated. Recent studies in different subduction zones suggest that tectonic tremors (TT) are caused by point dislocations at depth. Consequently, a systematic study of focal mechanisms of tremor sources turns out to be important to understand the processes that originate this phenomenon and the implications they have in the occurrence of slow earthquakes. *Cruz-Atienza et al. (2015)* introduced the "Tremor Energy and Polarization" (TREP) method to locate tectonic tremors assuming horizontal point dislocations, which is a reasonable hypothesis for deep tremors in the state of Guerrero. However, this assumption could be a limitation in other cases where the fault dip is different (e.g., Japan and Cascadia subduction zones, or San Andreas fault). The simultaneous determination of tremor locations and focal mechanisms would allow studying this phenomenon in any tectonic environment.

In this work, we generalize the TREP method employing a global inversion technique (i.e., simulated annealing) to determine simultaneously the source location and the associated moment tensor from the energy spatial distribution and the azimuth of the particle motion polarization ellipsoid. Although in some cases the method has some difficulties to resolve the focal mechanism because of the ambient noise, our results using real data in Guerrero show that most of the obtained mechanisms are consistent with the geometry of the plate interface and with the plate convergence direction, which are similar to those reported for LFEs (Frank. et al 2013) and VLFs (Maury et al. 2016) in Mexico.

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P12

Development and evaluation of modified envelope correlation method for deep tectonic tremor

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We develop a new location method for deep tectonic tremors, as an improvement of widely used envelope correlation method, and applied it to construct an updated tremor catalog. Using the cross-correlation functions as objective functions and weighting components of data by the inverse of error variances, the envelope cross-correlation method is redefined as a maximum likelihood method. This method is also capable of multiple source detection, because when several events occur almost simultaneously, they appear as local maxima of likelihood.

The average of weighted cross-correlation functions, defined as ACC, is a nonlinear function whose variable is a position of deep tectonic tremor. The optimization method has two steps. First, we fix the source depth to 30 km and use a grid search with 0.2 degree intervals to find the maxima of ACC, which are candidate event locations. Then, using each of the candidate locations as initial values, we apply a gradient method to determine horizontal and vertical components of a hypocenter. Sometimes, several source locations are determined in a time window of 5 minutes. They appear as local maxima, therefore we use the local solutions instead of the global solution.

P13

Complex interaction between thrust and strike-slip motion in the oblique Mexican subduction zone

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Large, equivalent to Mw~7.5, subduction thrust slow slip events (tSSE) are observed with the GPS data in Guerrero, Mexico with a period of about ~4 years. The last 2014 tSSE started in January and ceased before the end of 2014. The secular GPS velocity vectors in the Pacific coast of Mexico are oblique to the Middle America trench (MAT). The along-trench, lateral velocity components abruptly diminish to the north by 4-5 mm/year across the area of La Venta-Chacalapa fault zone (LVC), which is striking at ~105 km inland from the MAT along the Pacific coast of Guerrero and Oaxaca states for almost 650 km. This velocity slump reveals a partitioning of the oblique convergence between the Cocos and North America plates with a sinistral motion of the Xolapa forearc sliver.

Long-term GPS records show that the tSSEs are accompanied each time by strike-slip SSEs (sSSE) on the La Venta-Chacalapa fault. GPS displacement records in Guerrero reveal that during the inter-SSE periods (~3 years) the LVC fault is mainly locked, and the shear strain rate distributed across it remains constant at ~14 nrad/year. During the tSSE episodes (with a recurrence interval of ~4 years) there is a noticeable increase of lateral sinistral displacement of the GPS stations located on the coast, south of the fault. Meanwhile the stations to the north off the LVC undergo minor dextral displacements. The secular shear strain rate drastically changes across the fault from 64 nrad/year south of it to 11 nrad/year to the north. This means that the LVC fault is currently active but the slow accumulation of shear strain on it is periodically interrupted with sSSEs, which are highly synchronized with the subduction type tSSEs.

Focal mechanism analysis of thrust events in Guerrero and Oaxaca obtained from local catalogs has shown that the direction of slip vectors lays between the vectors of plate convergence and trench normal (figure 1). Obliquity of slip vector for thrust events (1.2-5.6°)

grows southward along the coast together with the increasing convergence obliquity (10.2-13.1°). Part of the oblique subduction motion is accumulated by trench parallel displacement at the rate of ~8.2 mm/yr. Secular trench parallel velocity calculated from GPS data is ~6.5 mm/yr. Slower motion at the surface (GPS stations) compared to the one at the subduction interface (thrust earthquakes) may be caused by the properties of the media where the signal propagates.

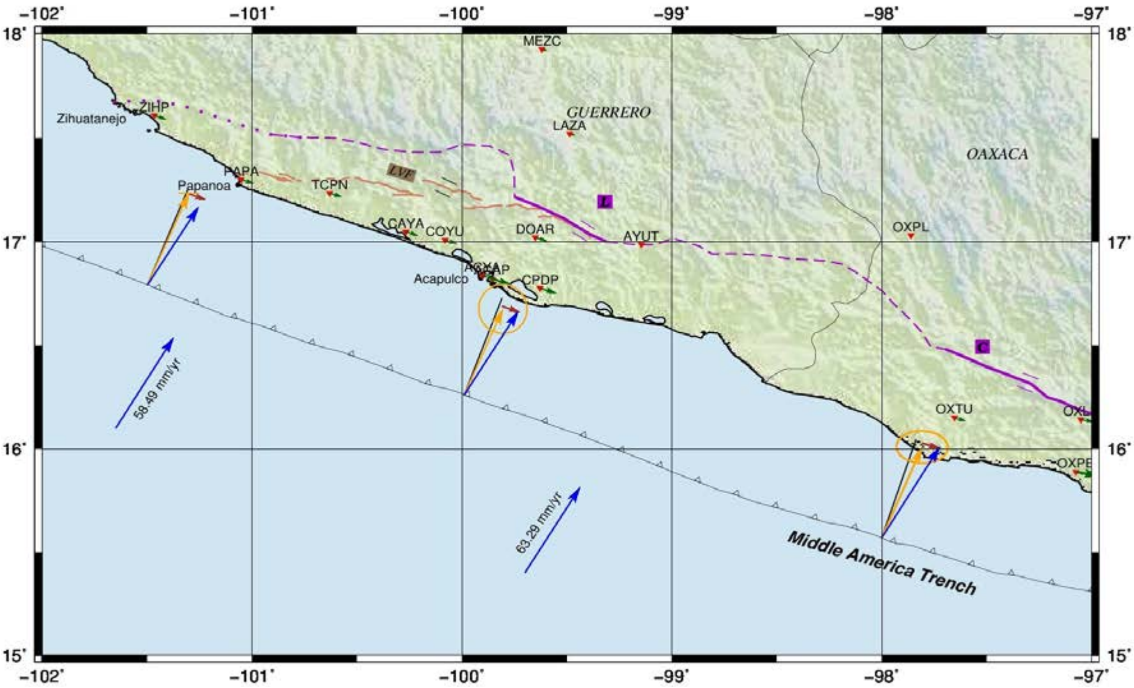

Figure 1: Slip partitioning in the Mexican subduction zone. Black lines - trench normal, orange vectors - average slip velocities by region, blue vectors - convergence velocities, red vectors - strike-slip motion from focal mechanism analysis, green vectors - trench parallel velocities from GPS measurements.

P14

Estimation of the spatiotemporal evolution of slow slip events in the Tokai region, central Japan, since 2013 using GNSS data

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In the Tokai region, central Japan, very slow and long-term aseismic slip regarded as a long-term slow slip event (L-SSE) has been observed on the subducting Philippine Sea Plate several times. In addition, many short-term slow slip events (S-SSEs) accompanied by low frequency tremors (LFTs), have been detected using not only tiltmeter of the NIED Hi-net but also GNSS of the GSI GEONET recently. Although several previous studies have reported the spatiotemporal evolution of L-SSEs, there are few previous studies that estimated the spatiotemporal evolution of S-SSEs. In this study, we applied a time-dependent inversion method to GNSS data to obtain the spatiotemporal evolution of an L-SSE and S-SSEs on the Philippine Sea plate beneath the Tokai region, since 2013.

GNSS data from January 1, 2008 to January 31, 2016 are used in this study. We use GIPSY-OASIS II software to estimate daily coordinates of 250 GNSS stations (231 stations of GEONET operated by the GSI and 19 stations constructed by the Japanese University Consortium for GPS research and operated by ERI and allied universities) in the Tokai region. It is well known that GNSS time series are contaminated by many systematic signals that are not derived from SSEs. These systematic signals include, for example, seasonal variations and post-seismic deformation of the 2011 Tohoku-oki earthquake (M_w9.0). After removing of these systematic signals, we applied a modified Network Inversion Filter (NIF) [Fukuda et al., 2008]. The original NIF [Segall & Matthews, 1997] assumes a constant hyperparameter for the temporal smoothing of slip rates and thus often results in oversmoothing of slip rates. The modified NIF assumes a time-variable hyperparameter, so that changes in slip rates are effectively extracted from GNSS time series.

The results indicate that the maximum total slip and the moment magnitude of L-SSE were estimated to be ～7.0 cm and M_w～6.7, respectively, from January 1, 2013 to January 31, 2016, respectively (Figure 1). Estimated moment evolution for the L-SSE suggests that the

L-SSE seems to have started from beginning of 2013 and continued until the end of 2015.

In addition to the L-SSE, we found several periods of slip acceleration that can be regarded as S-SSEs. Spatiotemporal evolution during S-SSE was successfully estimated near the Ise Bay. For example, maximum slip and moment magnitude for S-SSE were estimated to be ～0.7 cm and M_w～5.86 for S-SSE during December 20, 2015 to January 16, 2016. The front and peak of slip for this S-SSE migrated along the strike of the slip region at ～18 km/day and ～8 km/day. This study is probably the first case that migration of slip for S-SSE ($M_W <$ 6.0) was estimated solely using GNSS data in southwest Japan.

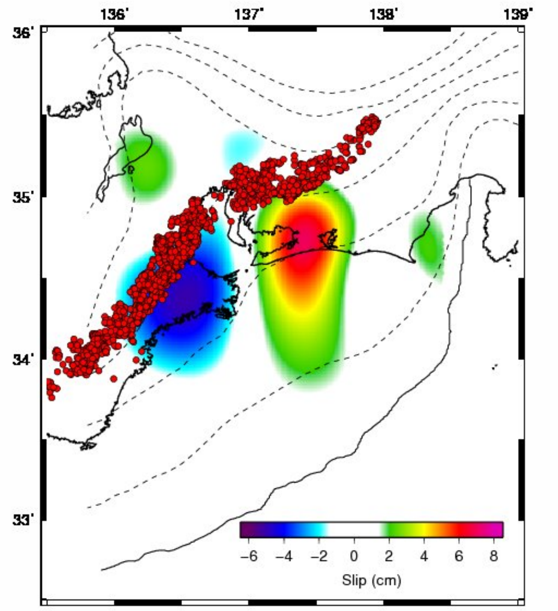

Figure 1. Cumulative slip distribution from January 1, 2013 to January 31, 2016. Red circles represent epicenters of low frequency tremors [Obara et al., 2010].

P15

Heterogeneous friction model for Slow Earthquake

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Dense seismic and geodetic measurements revealed that seismic slips on the plate interface in subduction zones are diverse, including regular earthquakes and slow earthquakes. Understanding the source physics, which cause this diversity, is important to consider the whole seismic cycle in subduction zones. Although many models are proposed, we suppose that slow earthquake can be modeled using the fault with frictional heterogeneity, based on the spatial correlations among duration, amplitude, and tidal sensitivity distributions. In this study, we investigated the slip behavior of the frictionally heterogeneous fault, which is governed by the rate-and-state dependent friction law (RSF).

To simplify the situation, we consider the infinite linear fault, where velocity-weakening zones (VWZs) and velocity-strengthening zones (VSZs) have bimodal distributions. When the shear stress at the infinite boundary is kept at a constant value, the fault shows three types of slip behaviors; (i) stable slip, (ii) stick slip in VWZ and afterslip in VSZ, and (iii) locking on the entire fault. The boundary between (i) and (ii) is controlled by the nucleation size determined from assumed frictional parameters. On the other hand, the transition from (ii) to (iii) occurs when the spatial average of a-b value of RSF is zero. When the shear stress is loaded with time, the fault shows following behaviors; (i) stable slip, (ii) stick slip in VWZ and afterslip in VSZ, and (iii) stick slip on the entire fault. At the boundary between (ii) and (iii), we found the transient behavior, in which slow deformation dominates during stick-slip events. Slow earthquake may correspond to this transitional slip behavior (Yabe and Ide, 2017, JGR).

We also tested slip behaviors of the finite planar fault with frictional heterogeneities. Similar slip behaviors are observed as in cases of the infinite linear fault; (1) stable slip, (ii) isolated stick slip in VWZs and afterslip in VSZ, and (iii) stick slip on the entire fault. In case (iii), the stick slip on the entire fault is preceded by stick slip in each VWZ, which reflect the unlocking process of the fault. At the boundary between (ii) and (iii), transitional behaviors have been observed, in which stick-slip events and long-lasting slow slip occur in VWZs and VSZs respectively. We will also explore the slip behavior when the frictional heterogeneity varies spatially on the fault.

P16

Toward Realistic Dynamic-Rupture Scenario Earthquakes in the Guerrero Subduction Zone

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We simulate dynamic ruptures of hypothetical earthquakes in three dimensions (3D) occurring in the Guerrero Subduction zone by means of an hp-adaptive discontinuous Galerkin finite-element method (DGCrack, Tago et al., 2012). This method simulates the propagation of seismic waves generated by dynamic ruptures governed by a linear slip-weakening friction law embedded in heterogeneous media. DGCrack uses a non-structured tetrahedral discretization of the simulation domain incorporating non-planar fault geometries (i.e. realistic plate interface configurations) and 3D heterogeneous distributions of the visco-elastic crustal properties (Cruz-Atienza et al., 2016). The tetrahedral mesh satisfies the numerical accuracy criterion of three finite elements per minimum wavelength across the whole domain by refining the mesh (h-adaptivity) and adapting the approximation order (p-adaptivity) according to the local properties of the medium. The study has three ultimate goals: (1) assessing the dynamic stability of the seismic gap to determine whether a larger than expected rupture could take place considering information about both, the seismic coupling and crustal properties (e.g. fluid content, velocity structure and plate interface geometry); (2) quantifying the seismic hazard (e.g. SA, PGA, PGV, etc.) along the Mexican Pacific coast associated with a population of stochastically generated (kinematic and dynamic) rupture scenarios satisfying plausible expectations in the seismic gap; and (3) generating source models for ancient tsunamigenic earthquakes in Guerrero to explain paleoseismological data such as tsunami deposits and geomorphological expressions of large historical events. In this workshop we will present initial results regarding the tetrahedral meshing of a 3D tomographic model for central Mexico (including Guerrero) (Spica et al., 2016) that incorporates the real topography and bathymetry, as well as the geometry of the plate interface recently proposed by Radiguet et al. (2016) (Figure 1). We will present a couple of dynamic-rupture scenario earthquakes to illustrate the DGCrack capabilities in the model by assuming heterogeneous pre-stress and friction conditions in the plate interface. This exercise represents the first step towards the simulation of realistic earthquake scenarios in the

Guerrero seismic gap and will provide initial hints about the role of the interface geometry and the initial stress conditions for the occurrence of large earthquakes in the region.

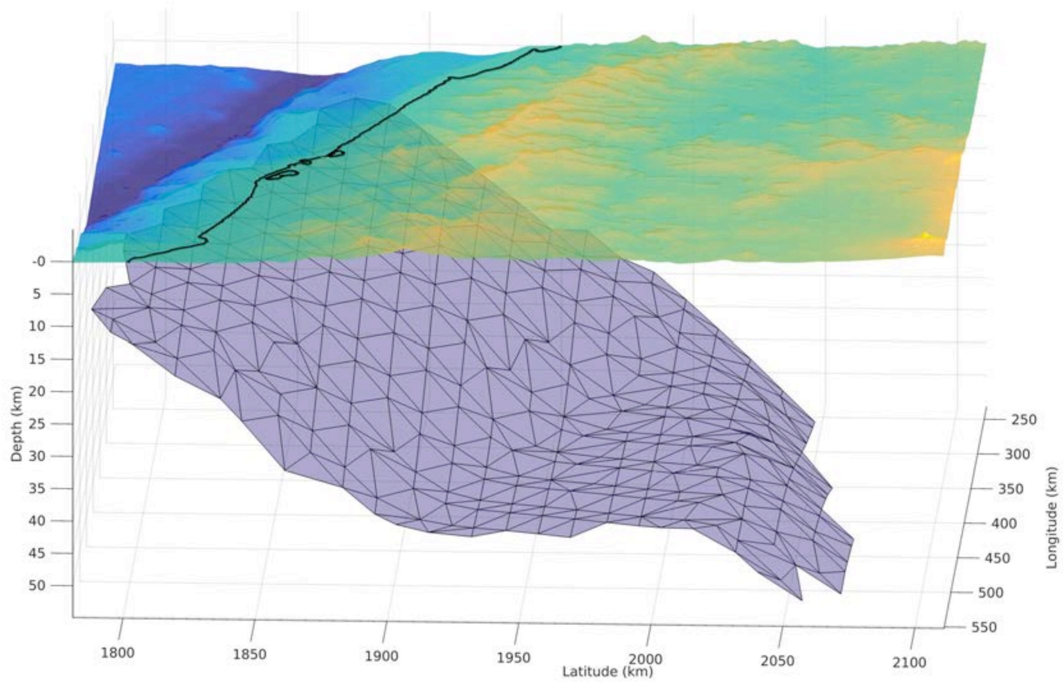

Fig. 1 Discretization for the Guerrero subduction zone that incorporates the real topography and bathymetry, as well as the 3D geometry of the plate interface proposed by Radiguet et al. (2016).

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P17

Numerical Modeling of Tsunami Inundation in City Scale

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The 2011 Tohoku Earthquake Tsunami showed complex behaviour of tsunami inundation over the land, especially in city areas, along the Japanese coast. The tsunami behaviour in these city urban areas was different from rural areas and indicated importance of physical roughness (e.g. buildings, houses and streets) on inundation characteristics and hydrodynamic force estimations. The purpose of this study is to understand and validate of two numerical models of tsunami inundation in the city area. This study used quasi-three-dimensional (Q3D) model and two-dimensional (2D) nonlinear shallow water model for numerical simulation. Both models are hydrostatic model, but vertical discretization are different each other. The two different numerical models are compared to the physical experiments of Seaside, Oregon, by Park et al. (2013), which examined tsunami inundation in an idealized urban shoreline at 1/50 scale. Both 2D and Q3D model agreed well with the experimental results on the strait street from shorelines. However, the numerical models were differed from the experiment at the points behind large scale buildings. The inundation depth and velocity of the 2D simulation tended to be smaller than those of the Q3D model especially further inland. This is because the 2D model allows for larger wave energy dissipation due to a fixed vertical velocity profile and excluded turbulence and vorticity modeling. The 2D and Q3D model are available to estimate the damage of the tsunami in city scale but the accuracy of inundation depends on the local reflection and diffraction due to large scale buildings. According to the comparison of Q3D model and 2D model, it is likely that the 2D model underestimates the inundation extent and local hydrodynamic forces during the tsunami inundation process.

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P18

Why do we need to pass down the narratives of disaster?

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1. The importance of passing down the stories.

This study investigated the disaster narratives of the people in Zihuatanejo, Mexico. Disaster narratives are considered as significant measures to grasp the history and the impact of past disasters. Also, those narratives are used as educational tools for risk reduction, since personal stories enable participants to imagine the impact of possible disasters according to survivors' experience. Disaster-prone countries, such as Japan, also utilize disaster narratives as measures for research and education. For instance, the story of "the fire of rice sheaves." This story describes the importance of quick tsunami evacuation. The story was created based on real experiences people had in a small community in the south-western Japan (Hirogawa town, Wakayama prefecture) during the 1854 great tsunami. Since then, the story has been passed down from generation to generation, with slight modifications, and gave positive impacts on actual evacuation behaviors of local residents in the next tsunami which hit the same region after around 100 years. The story is still used widely in school education in modern Japanese society, coupled with science education programs about earthquake and tsunami researches.

Locally developed and shared stories about the history of natural disasters in the past could have powerful educational impact on local people. Scientific knowledge, provided mainly by scientists based on academic researches, is undoubtedly important for tsunami preparedness education. However, such a local story also has positive influences, when it is skillfully combined with scientific evidences. Thus, visiting the past in old local stories is not just for retrospective history learning, but for prospective awareness building for the future. In this study, interviews were implemented to consider the needs of collecting survivors' narratives in Zihuatanejo.

2. Overview of research field, Zihuatanejo City

Zihuatanejo is a coastal city at the Pacific and has a population of 118,211. The city has experienced various earthquakes and Tsunami in the past. The greatest

Tsunami was recorded as 11 meters when a magnitude seven earthquake hit the area on November 11, 1925. The city is vulnerable to disasters such as earthquake and tsunami. In addition, the population of the city has been rapidly increasing within past two decades, therefore there are few people who are familiar with the history of disaster in Zihuatanejo.

3. Outline of interviews

This study interviewed 14 people in Zihuatanejo (Average Age 55.6, Max Age 84 and Min Age 29). These participants were recruited by civil protection staff. The interviews were videotaped and conducted using semi-structured interviewing techniques. There are small numbers of the population over 60 in the city because of the young average life span of the population due to the epidemic of diabetes and lifestyle diseases. Therefore, we put extra meaning to recruit elderly people and record their narratives.

4. Learning the past for preparing for the future

This study recorded various narratives from the participants. For instance, the earthquake in 1925, the earthquake in 1957, the earthquake in 1985 and the earthquake in 2014. Below are some of the significant results. First one is the various description of Tsunami by participants. One participant (82 years old) who is a long-time resident of the city described tsunami in 1925 as "waves rose up in a storm". Disaster education had not been provided in school when he was child, therefore various descriptions of Tsunami were observed in the interviews. The participants were not familiar with the technical terms. Secondly, we observed that the narratives were likely to include only some parts of a past disaster. There were no participants who could describe past disasters comprehensively. Possible reasons could be that past disasters were not fully covered by media and the citizens could not access the disaster information at the time. Specific reasons for this phenomenon should be further investigated.

As stated above, collecting disaster narratives of Zihuatanejo were similar to collecting historical information of the city. Therefore, recording stories of the survivors enables us to discover new insights on disaster history of the city but also to develop educational tools for disaster risk reduction. As a conclusion, there is a significant need to investigate further about disaster narratives in Zihuatanejo.