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AGU Fall Meeting 2009

December 14 - 18, 2009

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Monday, December 14, 2009

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Tuesday, December 15, 2009

Time	Session Info
8:00 AM-12:00 PM, Poster Hall (Moscone South), **U21E. The 29 September 2009 Tsunami and Earthquake I Posters**	
8:00-8:00 AM	**U21E-2193. On infragravity motions of the 2009 Samoa tsunami at Penrhyn Island** L. Lin; C. Kuo; C. Shum; Y. Song; Y. Yi; M. Liang
8:00-8:00 AM	**U21E-2178. Field Observations Of The 29 September Tsunami In American Samoa: Spatial Variability And Indications Of Strong Return Flow** B.E. Jaffe; B.M. Richmond; G.R. Gelfenbaum; S. Watt; A.A. Apotsos; M.L. Buckley; W.C. Dudley; B. Peck
8:00-8:00 AM	**U21E-2189. Tsunami inundation mapping: Comparing inundation limits interpreted from satellite imagery to field observations in American Samoa and Sumatra** S.G. Watt; B.E. Jaffe; G.R. Gelfenbaum; A.A. Apotsos; M.L. Buckley; B.M. Richmond
8:00-8:00 AM	**U21E-2184. Role of State Tsunami Geoscientists during Emergency Response Activities: Example from the State of California (USA) during September 29, 2009, Samoa Tsunami Event** R.I. Wilson; L.A. Dengler; J.D. Goltz; M. Legg; K.M. Miller; J.G. Parrish; P. Whitmore
8:00-8:00 AM	**U21E-2187. Rapid Estimation of Tsunami Impact Following the Samoa Earthquake** H.K. Thio; J. Polet
8:00-8:00 AM	**U21E-2192. The 2009 Samoa Tsunami and Its Formation Mechanism Replicated from Satellite Altimeters and Tide Gauges** Y. Song; C. Shum; Y. Yi
8:00-8:00 AM	**U21E-2176. 2009 Samoa tsunami: factors that exacerbated or reduced impacts in Samoa and American Samoa** L.A. Dengler; L. Ewing; J. Brandt; J.L. Irish; C. Jones; K. Long; H. Lazrus; N. McCullough
8:00-8:00 AM	**U21E-2179. Coarse clast transport and deposition during the September 29, 2009 tsunami in American Samoa and Samoa** M.L. Buckley; B.M. Richmond; S. Etienne; S. Watt; G.R. Gelfenbaum; B.E. Jaffe; K. Wilson; A.A. Apotsos; B. Peck
8:00-8:00 AM	**U21E-2181. Ofu and Ologesa survey of the 29 September 2009 tsunami** F. Spyridon; C. Synolakis; V.V. Titov

8:00-8:00 AM	**U21E-2180. Damages in American Samoa due to the 29 September 2009 Samoa Islands Region Earthquake Tsunami** Y. Okumura; T. Takahashi; S. Suzuki
8:00-8:00 AM	**U21E-2182. LARGE EARTHQUAKES AND TSUNAMIS AT THE SAMOA CORNER IN THE CONTEXT OF THE 2009 SAMOA EVENT** E. Okal; S.H. Kirby
8:00-8:00 AM	**U21E-2183. Tsunami warning in French Polynesia during the 2009 Samoa event** D. Reymond; H. Hebert; O. Hyvernaud; S. Allgeyer
8:00-8:00 AM	**U21E-2188. Challenges Integrating Bathymetric and Topographic Datasets of American Samoa** E. Lim; B. Eakins; L.A. Taylor
8:00-8:00 AM	**U21E-2177. Distribution and Characteristics of the 2009 Samoa Earthquake Tsunami Deposit on Tutuila Island, American Samoa** Y. Nakamura; Y. Nishimura; S. Koshimura; Y. Namegaya; G.J. Fryer; A. Akapo; L.S. Kong; D. Vargo
8:00-8:00 AM	**U21E-2185. The 29th September Samoa Islands tsunami: preliminary simulations based on the first focal mechanisms hypotheses and implications of uncertainties in tsunami early warning strategies** R. Tonini; G. Pagnoni; A. Armigliato; S. Tinti
8:00-8:00 AM	**U21E-2186. Near-field Tsunami Inundation Forecast Modeling of the 2009 Samoa Tsunami.** C. Chamberlin; Y. Wei; V.V. Titov; B.U. Uslu; L. Tang; D. Arcas; C.W. Moore
8:00-8:00 AM	**U21E-2190. Plate Boundary Observatory Borehole Strainmeter Recordings Of The 29 September 2009 Tsunami** D.B. Henderson; K.M. Hodgkinson; A.A. Borsa; D. Mencin; E. Van Boskirk; M.E. Jackson
8:00-8:00 AM	**U21E-2191. HF RADAR observations of coastal currents induced by the 29-30 September 2009 tsunami South of O'ahu** P.J. Flament; J.L. Cass; M.A. Merrifield; K. Gurgel
10:20 AM-12:20 PM, 3020 (Moscone West), **U22B. The 2009 Samoan and Sumatran Earthquakes: Origins, Impacts and Consequences III**	
10:20-10:35 AM	**U22B-01. The 2009 Samoan and Sumatran Earthquakes: A Coincidence with Precedents** ***(Invited)*** A.J. Michael
10:35-10:50 AM	**U22B-02. Imaging the ruptures of the 2009 Samoan and Sumatran earthquakes using broadband network back-projections: Results and limitations** A.R. Hutko; T. Lay; K.D. Koper
10:50-11:05 AM	**U22B-03. Performance of Buildings in the 2009 Western Sumatra Earthquake** G. Deierlein; T. Hart; N. Alexander; E. Hausler; S. Henderson; K. Wood; V. Cedillos; S. Wijanto; C. Cabrera; S. Rudianto

11:05-11:20 AM	**U22B-04. Planning Matters: Response Operations following the 30 September 2009 Sumatran Earthquake** L.K. Comfort; V. Cedillos; H. Rahayu
11:20-11:35 AM	**U22B-05. Geological Investigation and analysis in response to Earthquake Induced Landslide in West Sumatra** D. Karnawati; W. Wilopo; S. Salahudin; I. Sudarno; P. Burton
11:35-11:50 AM	**U22B-06. Impacts of the 2009 Sumatran Earthquake and Its Relation to the Great Megathrust Events** K.A. Grijalva; R. Burgmann; K.E. Sieh; P. Banerjee; C. Vigny; D.H. Natawidjaja; I. Meilano
11:50-12:05 PM	**U22B-07. The September 2009 Padang earthquake and implications for seismic risk in western Sumatra** J. McCloskey; S.S. Nalbant; A.F. Bell
12:05-12:20 PM	**U22B-08. GPS Observations Following the Sept. 30, 2009, Padang Earthquake** R. McCaffrey; C. Subarya; Y. Bock
1:40 PM-3:40 PM, 3006 (Moscone West), **U23F. The 29 September 2009 Tsunami and Earthquake II**	
1:40-1:55 PM	**U23F-01. A new approach to UNESCO-IOC Post-Tsunami Field Surveys** L.S. Kong; J. Steffen; D. Dominey-Howes; L. Biukoto; A. Titimaea; R. Thaman; R. Vaa
1:55-1:55 PM	**U23F-02. The past, present and future of tsunami field surveys post-Samoa, 2009** J.C. Borrero; C. Synolakis; E. Okal; P. Liu; V.V. Titov; B.E. Jaffe; H.M. Fritz
1:55-2:10 PM	**U23F-03. Preliminary assessment of the impacts and effects of the South Pacific tsunami of September 2009 in Samoa** D. Dominey-Howes
2:10-2:25 PM	**U23F-04. Reconnaissance Survey of the 29 September 2009 Tsunami on Tutuila Island, American Samoa** H.M. Fritz; J.C. Borrero; E. Okal; C. Synolakis; R. Weiss; B.E. Jaffe; P.J. Lynett; V.V. Titov; S. Foteinis; I. Chan; P. Liu
2:25-2:40 PM	**U23F-05. Regional Impact of the 29 September 2009 North Tonga Tsunami on the Futuna and Alofi Islands (Wallis & Futuna)** G. Lamarche; B. Pelletier; J.R. Goff
2:40-2:55 PM	**U23F-06. Field Survey and Preliminary Analysis of the September 29, 2009 Tsunami on Upolu and Manono Islands, Samoa** ***(Invited)*** J.C. Borrero; E. Okal; H.M. Fritz; R. Weiss; C. Synolakis; S. Foteinis; P. Liu; I. Chan; J. Simcock
2:55-3:10 PM	**U23F-07. Field survey of the 2009 tsunami in American Samoa** S. Koshimura; Y. Nishimura; Y. Nakamura; Y. Namegaya; G.J. Fryer; A. Akapo; L.S. Kong; D. Vargo

3:10-3:25 PM	**U23F-08. Field Survey of the 29 September 2009 Tsunami on Savai'i Island, Samoa** R. Weiss; H.M. Fritz
4:00 PM-6:00 PM, 3005 (Moscone West), **U24A. The 29 September 2009 Tsunami and Earthquake III**	
4:00-4:15 PM	**U24A-01. Survivor Interviews from the Sept. 29, 2009 tsunami on Samoa and American Samoa** B.M. Richmond; W.C. Dudley; M.L. Buckley; B.E. Jaffe; S. Fanolua; M. Chan Kau
4:15-4:30 PM	**U24A-02. Identifying Precursors to the 2009 South Pacific tsunami?** J.R. Goff; C. Chague-Goff; S. Etienne; G. Lamarche; B. Pelletier; B.M. Richmond; L.C. Strotz; M.L. Buckley; K. Wilson; W.C. Dudley; G. Urban; M. Sale; D. Dominey-Howes
4:30-4:45 PM	**U24A-03. Tsunami Sediment Transport and Deposition in a Sediment Limited Environment on American Samoa** A.A. Apotsos; G.R. Gelfenbaum; B.E. Jaffe; S. Watt; B. Peck; M.L. Buckley; B.M. Richmond; A.W. Stevens
4:45-5:00 PM	**U24A-04. Effect of Fringing Reefs on Tsunami Inundation: American Samoa** G.R. Gelfenbaum; A.A. Apotsos; B.E. Jaffe; S. Watt; B. Peck; P.J. Lynett; B.M. Richmond; M.L. Buckley
5:00-5:15 PM	**U24A-05. Geologic Signatures of the September 2009 South Pacific Tsunami *(Invited)*>** B.M. Richmond; M.L. Buckley; S. Etienne; L.C. Strotz; C. Chague-Goff; K. Wilson; J.R. Goff; W.C. Dudley; F. Sale
5:15-5:30 PM	**U24A-06. Real-time Modeling Forecast of the 29 September 2009 Samoa Tsunami** Y. Wei; V.V. Titov; L. Tang; C. Chamberlin; B.U. Uslu; D. Arcas; D.W. Denbo; C.W. Moore; M.C. Eble
5:30-5:45 PM	**U24A-07. The 29 September 2009 Samoan earthquake and tsunami in the ionosphere: analysis of the near- and far-field GPS-TEC perturbations.** L.M. ROLLAND; G. Occhipinti; A. Loevenbruck; P. Coïsson; P. Lognonne; H. Hebert; E.I. Astafyeva
5:45-6:00 PM	**U24A-08. Search for Evidence of the 29 September 2009 Tsunami in Altimeter Data** P.S. Callahan; J.K. Willis

Wednesday, December 16, 2009

You have nothing scheduled for this day

Thursday, December 17, 2009

You have nothing scheduled for this day

Friday, December 18, 2009

You have nothing scheduled for this day

Final ID: U21E-2193

On infragravity motions of the 2009 Samoa tsunami at Penrhyn Island

L. Lin; [1]; *C. Kuo;* [2]; *C. Shum;* [3]; *Y. Song;* [4]; *Y. Yi;* [3]; *M. Liang;* [1, 5];

1. Research Center for Environmental Changes, Academia Sinica, Taipei, Taiwan.
2. Department of Geomatics, National Cheng Kung University, Tainan, Taiwan.
3. Geodetic Science, School of Earth Sciences, The Ohio State University, Columbus, OH, USA.
4. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA.
5. Graduate Institute of Astronomy, National Central University, Zhongli, Taiwan.

Body: The energetic infragravity oscillation (period of 3-5 min) of the 2009 Samoa tsunami dominated the sea surface disturbance with an amplitude of ~10 cm at Penrhyn Island of the largest atoll of the Cook Islands in the South Pacific Ocean are observed, whereas the typical tsunami around this region varies at the period of ~10 min. Two frequency modes particularly coincide during two tsunamis generated at Mindanao, Philippines and Vanuatu and Santa Cruz Islands on 4 and 7 October 2009. To investigate this characteristic , we apply the topographic transfer function to character a frequency transformation from open sea to shallow water region indicated the notable results at the infragravity period which may be affected by topographic features or frequency dispersion effects at period reduced from ~10 to 3-5 min. Infragravity oscillation, however, is not linked to the fundamental mode of the local bathymetry at the atoll and the nonlinear dispersion will be particularly discussed in the tsunami simulation.

Final ID: U21E-2178

Field Observations Of The 29 September Tsunami In American Samoa: Spatial Variability And Indications Of Strong Return Flow

B. E. Jaffe; [1]; *B. M. Richmond;* [1]; *G. R. Gelfenbaum;* [2]; *S. Watt;* [1]; *A. A. Apotsos;* [2]; *M. L. Buckley;* [1]; *W. C. Dudley;* [3]; *B. Peck;* [4];
1. U.S. Geological Survey, Santa Cruz, CA, USA.
2. U.S. Geological Survey, Menlo Park, CA, USA.
3. University of Hawaii, Hilo, HI, USA.
4. US Department of Agriculture, Pago Pago, AS, USA.

Body: The 29 September 2009 tsunami caused 181 fatalities and displaced more than 5000 people on the islands of Samoa, American Samoa, and Tonga. This is the first tsunami to cause significant damage and fatalities on U.S. soil in more than 30 years. Scientists from around the world quickly mobilized to help document the tsunami water levels before this ephemeral data was forever lost as recovery activities and natural processes overtook the effected area.

A USGS team collected data in American Samoa from October 6-22 and November 5-12, 2009. The tsunami was large, reaching elevations of greater than 15 m, however wave heights and devastation varied from village to village in American Samoa. Even within villages, some structures were completely destroyed, some flooded and left standing, and others barely touched. Wave heights, flow depths, runup heights, inundation distances, and flow directions were collected for use in ground-truthing inundation models. The team also collected nearshore bathymetry, topography and reef flat elevation, sediment samples, and documented the distribution and characteristics of both sand and boulder deposits. Eyewitness accounts of the tsunami were also videotaped.

One striking aspect of this tsunami was the abundance of indicators of strong return flow. For example at Poloa in the northwest of Tutuila, where the runup was greater than 11 m along a 300-m stretch of coast and flow depths exceeded 4 m, the coral reef flat was strewn with debris including chairs, desks, and books from a school. On land, River channels were excavated and new channels formed as return flow scoured sediment and transported it offshore. Possible causes for the strong return flow and the relation between the stength of the return flow, inundation distance, and runup in American Samoa are presented. These relationships and others based on data collected by field survey teams will ultimately reduce loss of life and destruction from tsunamis in the Pacific and elsewhere.

URL: http://walrus.wr.usgs.gov/news/samoareports.html

Final ID: U21E-2189

Tsunami inundation mapping:

Comparing inundation limits interpreted from satellite imagery to field observations in American Samoa and Sumatra

S. G. Watt; [1]; *B. E. Jaffe;* [1]; *G. R. Gelfenbaum;* [2]; *A. A. Apotsos;* [2]; *M. L. Buckley;* [1]; *B. M. Richmond;* [1];

1. USGS, Santa Cruz, CA, USA.
2. USGS, Menlo PArk, CA, USA.

Body: Tsunami inundation limits are one of many parameters used to assess both the immediate impact of and potential risk from future tsunamis. If identified quickly, inundation information can be used to direct relief, aid, and research efforts to the most heavily impacted areas. Following the immediate response, tsunami inundation limits are used to verify tsunami models, improve plans for rebuilding, prepare evacuation routes, and can be compared with other impacted locations either locally or from previous tsunami events world-wide. Ultimately accurate and detailed tsunami inundation information will help governments and citizens reduce the loss of life and property caused by tsunamis in coastal areas world-wide.

Tsunami inundation limits are determined by interpreting wave disturbed areas in satellite imagery or through direct field mapping. Both methods have advantages and disadvantages. Image interpretation is limited by the availability, quality, and resolution of satellite images but the results cover a large area and can be produced relatively quickly without traveling to the impacted area. Inundation limits mapped in the field are more detailed, accurate, and reliable than image interpretations but can be difficult or impossible to collect in remote areas, typically cover a small area, and the results take more time and effort to produce.

This study compares tsunami inundation limits produced by the two methods described above for locations in American Samoa impacted by the September 29, 2009 tsunami and locations in Sumatra impacted by the December 26, 2004 tsunami. Preliminary results suggest that satellite image interpretations may in some cases underestimate the limit of tsunami inundation. The two methods will be evaluated to provide guidance for inundation mapping of tsunamis.

Final ID: U21E-2184

Role of State Tsunami Geoscientists during Emergency Response Activities: Example from the State of California (USA) during September 29, 2009, Samoa Tsunami Event

R. I. Wilson; [1]; *L. A. Dengler;* [2]; *J. D. Goltz;* [3]; *M. Legg;* [5]; *K. M. Miller;* [4]; *J. G. Parrish;* [1]; *P. Whitmore;* [6];

1. California Geological Survey, Sacramento, CA, USA.
2. Humboldt State University, Arcata, CA, USA.
3. California Emergency Management Agency, Pasadena, CA, USA.
4. California Emergency Management Agency, Oakland, CA, USA.
5. Legg Geophysical, Huntington Beach, CA, USA.
6. West Coast and Alaska Tsunami Warning Center, NOAA-NWS, Palmer, AK, USA.

Body: California tsunami geoscientists work closely with federal, state and local government emergency managers to help prepare coastal communities for potential impacts from a tsunami before, during, and after an event. For teletsunamis, as scientific information (forecast model wave heights, first-wave arrival times, etc.) from NOAA's West Coast and Alaska's Tsunami Warning Center is made available, state-level emergency managers must help convey this information in a concise and comprehendible manner to local officials who ultimately determine the appropriate response activities for their jurisdictions. During the Samoa Tsunami Advisory for California on September 29, 2009, geoscientists from the California Geological Survey and Humboldt State University assisted the California Emergency Management Agency in this information transfer by providing technical assistance during teleconference meetings with NOAA and other state and local emergency managers prior to the arrival of the tsunami. State geoscientists gathered additional background information on anticipated tidal conditions and wave heights for areas not covered by NOAA's forecast models. The participation of the state geoscientists in the emergency response process resulted in clarifying which regions were potentially at-risk, as well as those having a low risk from the tsunami. Future tsunami response activities for state geoscientists include: 1) working closely with NOAA to simplify their tsunami alert messaging and expand their forecast modeling coverage, 2) creation of "playbooks" containing information from existing tsunami scenarios for local emergency managers to reference during an event, and 3) development of a state-level information "clearinghouse" and pre-tsunami field response team to assist local officials as well as observe and report tsunami effects.

Final ID: U21E-2187

Rapid Estimation of Tsunami Impact Following the Samoa Earthquake

H. K. Thio; [1]; *J. Polet;* [2];
1. URS Pasadena, Pasadena, CA, USA.
2. Dept. of Geological Sciences, Cal Poly Pomona, Pomona, CA, USA.

Body: Rapid estimation of the tsunami waveheight after a large earthquake can significantly aid in disaster recovery efforts, planning of post-tsunami surveys and even early warning for more distant regions. We are exploring methods for refining these estimates by addressing variability due to uncertainties in the source parameters. After the Samoa earthquake, we used the solution from the near real-time Research CMT system at the National Earthquake Information Center to compute the tsunami wavefield. Given the close proximity to Samoa and American Samoa, details of the rupture geometry are very important for the character of the tsunami wavefield and we computed tsunami waveforms for several different geometries that are consistent with the rCMT solution. We will evaluate these results by comparing them with observed runups and explore ways to express the uncertainties in the simulated runup maps. We will also evaluate other real-time source estimates for use in rapid tsunami impact simulation.

Final ID: U21E-2192

The 2009 Samoa Tsunami and Its Formation Mechanism Replicated from Satellite Altimeters and Tide Gauges

Y. Song; [1]; *C. Shum;* [2]; *Y. Yi;* [2];
1. Jet Propulsion Laboratory, Pasadena, CA, USA.
2. Ohio State Univ., Columbus, OH, USA.

Body: At least four satellite altimeter tracks, NASA's Jason-1 and European's Envisat, had observed the 2009 Samoa tsunami. Their observing time is between 3 and 8 hours after the initial earthquake (Fig. 1). Unlike the 2004 Indian Ocean tsunami, the tsunami generated by the Samoa earthquake is almost comparable with other ocean dynamic signals during the observing period, and therefore difficult to be isolated from. By synchronizing all the satellite tracts into a three-dimensional tsunami model, we are able to identify some of the leading tsunami waves and their propagation patterns. These identified waves are also confirmed independently by nearby tidal observations. Based on the observations and a recently-developed tsunami theory, we are able to explain why the 8.0-magnitude Samoan temblor generated a deadly tsunami but two other earthquakes, one with a magnitude of 7.6 in the same day and another with a magnitude of 8.7 in 2005, both off the Sumatra Island in the Indian Ocean, failed to produce a strong tsunami.

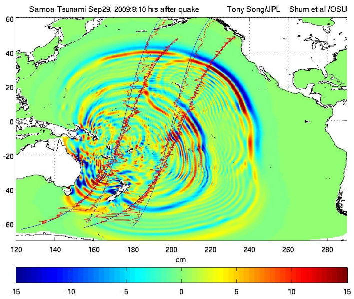

Fig 1. Satellite altimeter tracks synchronized into a tsunami model.

Final ID: U21E-2176

2009 Samoa tsunami: factors that exacerbated or reduced impacts in Samoa and American Samoa

L. A. Dengler; [1]; *L. Ewing;* [2]; *J. Brandt;* [3]; *J. L. Irish;* [4]; *C. Jones;* [5]; *K. Long;* [6]; *H. Lazrus;* [7]; *N. McCullough;* [8];
1. Geology, Humboldt State Univ, Arcata, CA, USA.
2. California Coastal Commission, San Francisco, CA, USA.
3. CA Dept. Fish and Game, Ontario, CA, USA.
4. Zachry Department of Civil Engineering, Texas A and M University, College Station, TX, USA.
5. Christopher P. Jones, P.E., Durham, NC, USA.
6. Earthquake and Tsunami Program, California Emergency Management Agency, Pasadena, CA, USA.
7. Social Science Woven into Meteorology, University of Oklahoma, Norman, OK, USA.
8. CH2M HILL, Portland, OR, USA.

Body: An interdisciplinary team with expertise in coastal and port engineering, coastal management, environmental science, anthropology, emergency management, and mitigation visited Samoa and American Samoa in late October and November, 2009. The team, sponsored by ASCE/COPRI, EERI, and the NTHMP focused on identifying the factors which effected the impacts of the September 29, 2009 tsunami. The engineering group assessed the value of engineered coastal protection and natural protective features (reefs, mangroves, etc.) in reducing tsunami inundation by comparing protected and unprotected coastlines and examined possible correlations between damage to the built environment and hydrodynamic forcing, namely loading by runup and velocity. The EERI group looked at how coastal land use planning and management, emergency planning and response, and culture, education and awareness of tsunami hazards affected outcomes. The group also looked at public response to the natural warnings of September 29 and the official warnings following the October 7 Vanuatu tsunami warning.

Final ID: U21E-2179

Coarse clast transport and deposition during the September 29, 2009 tsunami in American Samoa and Samoa

M. L. Buckley; [1]; *B. M. Richmond;* [1]; *S. Etienne;* [2]; *S. Watt;* [1]; *G. R. Gelfenbaum;* [3]; *B. E. Jaffe;* [1]; *K. Wilson;* [4]; *A. A. Apotsos;* [3]; *B. Peck;* [5];

1. US Geological Survey, Santa Cruz, CA, USA.
2. Université De La Polynésie Française, Tahiti, French Polynesia, France.
3. US Geological Survey, Menlo Park, CA, USA.
4. GNS Science, Lower Hutt, New Zealand.
5. USDA NRCS, Pago Pago, AS, USA.

Body: Isolated boulders, boulder fields, and boulder ridge formations have been used as evidence of ancient tsunami. In the literature tsunami origin has been ascribed to coastal boulders based in part on clast size, distribution, and long-axis orientation. Hindering this effort has been the lack of data from boulders transported by known tsunami. The September 29th 2009 tsunami provides an opportunity to increase our knowledge of coarse clast deposits. Deposits investigated include basalt boulder fields in coastal plain environments in Maloata Bay, Tutuila Island, American Samoa, and Satitoa, Upolu Island, Samoa and isolated coral boulders of Porites sp. on the reef flat and shore face of Poloa and Fagasue Bay, Tutuila Island, American Samoa. Field observations and measurements were collected of the physical setting (vegetation, bed composition, and topography), evidence of tsunami flow characteristics (run-up elevation, flow depth, and flow direction), and coarse clast deposit characteristics (boulder location, composition, source location, dimensions, and long-axis orientation). These data allow us to begin to assess spatial patterns of tsunami-deposited boulders, and relate these patterns to the local topography and tsunami flow characteristics. The data also provide a rare opportunity to assess the applicability of boulder transport formulations found in the literature using data from a known tsunami. Boulder transport formulations are typically based on variations of the semi-empirical Morison equations, which estimate drag and inertial forces on submerged bodies in an acceleratory flow. We apply previously suggested boulder transport formulations to boulder deposits of the 29 September tsunami, investigate sensitivity to drag and inertial coefficients and assess the validity of the calculations. The results of this research will be used to improve the ability to discriminate between tsunami and storm coarse-clast deposits and to extract information about tsunami size from tsunami-deposited boulders.

Final ID: U21E-2181

Ofu and Ologesa survey of the 29 September 2009 tsunami

F. Spyridon; [1]; *C. Synolakis;* [1, 3]; *V. V. Titov;* [2];
1. Technical University of Crete, Chanea, Greece.
2. NCTR, NOAA-PMEL, Seattle, WA, USA.
3. TRC, University of Southern California, Los Angeles, CA, USA.

Body: On 29 September 2009 an Mw~8.0 earthquake struck the Samoan Islands generating a tsunami at least 189 deaths and substantial damage to many coastal infrastructure. An incarnation of the ITST surveyed the impacted region between 4 Oct and 11 Oct measuring inundation per the protocol discussed in Synolakis and Okal (2005).

We report here survey results from Ofu and Ologesa, two sparsely populated adjacent islands connected with a bridge. No human casualties were reported. Buildings did not sustain substantial damage, due to light construction materials and open wood frame construction. The strongest effects of the tsunami were recorded in the northern part of Ofu, with runup ranging to 6.1m, with 50m inundation. The longest inundation distance was 74 m (3m runup), in Ofu village. The runup at the airport was 3.9m and inundation 27m.

Near the bridge there is motel where runup reached 5.1m with 50m inundation. On the north of Ologessa at Sili village, runup ranged up to 4m with inundation less than 25m. Iin Ologessa village, runup ranged from 2.7m to 4.4m and inundation from 5 to 55m.

By serendipity, the team of surveyors experienced a tsunami warning while working in a fairly vulnerable locale. The warning resulted from the 7 October 2009 Mw ~7.6, off Vanuatu . The evacuation message was broadcast by a passing police vehicle in the sole road connecting Ofu and the Ologesa. There was no information where to evacuate to. With the exception of a school bus that drove children from the sole school of the island, evacuations were orderly with care for the elderly and special needs neighbors, although the latter were delayed for tens of minutes on some neighborhoods. In this regard, had there been a real local tsunami, the school bus would had been swept away as allegedly happened in Poloa. For over three hours, there was no further information provided, and residents relied on unofficial reports from radio stations in Samoa relating that there had been no tsunami generated and then returned back to their homes. The tsunami was a no show, nonetheless it was clear that there is substantial outreach work needed to reinforce the concept that people should wait for official notifications for the all clear and that evacuations can not take place by car, particularly where there are hills within hundreds of feet from the shoreline. The airport was not closed and airline employees reported that there was no official information there either. Some eyewitnesses questioned the false alarm, and, despite the catastrophe only a week earlier, doubted they would keep self-evacuating if there were more of the same.

We conclude that education saves lives and should be continuously reinforced through lectures discussing lessons learned, and explaining that for near field events occasional false alarms are inevitable. Local authorities should begin paying attention to broadcasting information during the warning and eventually all clear messages as soon as practical.

Synolakis, C.E., and E.A. Okal, 1992-2002: Perspective on a decade of post-tsunami surveys, Adv. Natur. Technol.

Hazards, 23, 1-30, 2005.

Final ID: U21E-2180

Damages in American Samoa due to the 29 September 2009 Samoa Islands Region Earthquake Tsunami

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Body: A large earthquake of Mw 8.0 occurred in Samoa Islands Region in the early morning on 29 September 2009 (local time). A Large Tsunami generated by the earthquake hit Samoa, American Samoa, Tonga. Total 192 people were died or missing in these three countries (22 October 2009). The authors surveyed in Tutuila Island, American Samoa from 6 to 8 in October 2009 with the aim to find out damages in the disaster. In American Samoa, death and missing toll was 35. The main findings are as follows; first, human damages were little for tsunami run-up height of about 4 to 6 meters and tsunami arrival time of about 20 minutes. We can suppose that residents evacuated quickly after feeling shaking or something. Secondly, houses were severely damaged in some low elevation coastal villages such as Amanave, Leone, Pago Pago, Tula and so on. Third, a power plant and an airport, which are important infrastructures in relief and recovery phase, were also severely damaged. Inundation depth at the power plant was 2.31 meters. A blackout in the daytime lasted when we surveyed. On the other hand, the airport could use already at that time. But it was closed on the first day in the disaster because of a lot of disaster debris on the runway carried by tsunami. Inundation depth at the airport fence was measured in 0.7 to 0.8 meters. Other countries in the south-western Pacific region may have power plants or airports with similar risk, so it should be assessed against future tsunami disasters.

Inundated thermal power plant in Pago Pago

Debris on runway in Tafuna Airport (Provided by Mr. Chris Soti, DPA)

Final ID: U21E-2182

LARGE EARTHQUAKES AND TSUNAMIS AT THE SAMOA CORNER IN THE CONTEXT OF THE 2009 SAMOA EVENT

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Body: We examine the seismic properties of the 2009 Samoa earthquake in the context of its tsunami, the first one in 45 years to cause significant damage on U.S. soil. The event has a normal faulting geometry near the bend ending the 3000-km long Tonga-Kermadec subduction zone. Other large normal faulting tsunamigenic earthquakes include the 1933 Sanriku, 1977 Sumba and 2007 Kuril events. The 2009 Samoa earthquake shares with such intraplate earthquakes a slightly above average E/M0 (THETA = -4.82), but has a more complex geometry, a relatively long duration, and large CLVD (11%). Same-day seismicity appears detached to the SW of the fault plane, and 7 out of the 8 CMT regional solutions following the main shock are rotated at least 69 deg. away from its own mechanism. This points out to a mechanism of stress transfer rather than genuine aftershocks, in a pattern reminiscent of the 1933 Sanriku earthquake.
Most of the seismic moment release around the Samoa corner involves normal faulting. To the South (16.5-18 deg. S; 1975, 1978, 1987, 2006), solutions consistently feature a typical intraplate lithospheric break.
To the NW (15.5 deg. S), the 1981 event features a tear in the plate along Govers and Wortel's [2005] STEP model. The 2009 event is more complex, apparently involving rupture along a quasi-NS plane.
An event presumably similar to 2009 took place on 26 June 1917, for which there is a report of a 12-m tsunami at Pago Pago. That event relocates 200 km to the NW,
but its error ellipse includes the 2009 epicenter. The 1917 moment, tentatively 1.3 10**28 dyn*cm, is comparable to 2009. As suggested by Solov'ev and Go [1984], the report of a 12-m wave in Samoa during the 01 May 1917 Kermadec earthquake is most probably erroneous. We will present studies of the other large earthquakes of the past century in the area, notably the confirmed tsunamigenic events of 01 Sep. 1981 (damage on Savaii), 26 Dec 1975 (24 cm at PPG), 02 Apr 1977 (12 cm at PPG), 06 Oct 1987 and 07 Apr 1995 (only centimetric at PPG).

Final ID: U21E-2183

Tsunami warning in French Polynesia during the 2009 Samoa event

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2. DAM, DIF, CEA, Arpajon Cedex, Essone, France.

Body: An effective tsunami warning was in effect in French Polynesia for the big Samoa event on September 2009; a rapid warning was generated from the seismic parameters obtained via near real-time processing. Different methods were used to characterize and quantify the source parameters like: evolving scalar moment along the time, average mantle magnitude Mm, slowness, and use of the new concept of magnitude with the W phase.
The expected tsunami amplitudes were estimated from seismic parameters such obtained, and were communicated to Civil Defense; a red warning was then broadcasted to population during about one hour (2 hours in Marquesas).
In fact, French Polynesia was spared by the tsunami, with relatively weak amplitudes in Society Island, and, as expected, larger ones in Marquesas (justifying the this warning and state of watch). Numerical simulations involving different seismic source models, were used in a later stage to explain the observed tsunami amplitudes.

Final ID: U21E-2188

Challenges Integrating Bathymetric and Topographic Datasets of American Samoa

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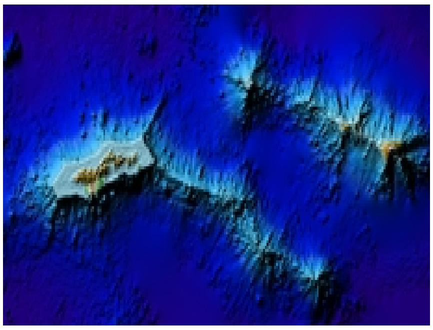
Body: Integrated bathymetric–topographic digital elevation models (DEMs) encompassing the region of American Samoa have been built by the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), in conjunction with the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado at Boulder. A 3 arc-second (~90 m) DEM spans the islands of Tutuila, Ofu, Olesega, and Ta'u, while a 1/3 arc-second (~10 m) DEM covers Tutuila Island. The DEMs are used to simulate tsunami propagation and inundation as input for the Method of Splitting Tsunami model developed by NOAA's Pacific Marine Environmental Laboratory, and will improve the understanding of tsunami dynamics in the region. The DEMs were generated from diverse digital datasets that were obtained from NGDC, the United States Geological Survey, Fagatele Bay National Marine Sanctuary, and other U.S. agencies, and are part of a multi-year project by NOAA to develop tsunami inundation DEMs of 75 U.S. coastal communities.

This poster focuses on the challenges of integrating bathymetric and topographic datasets to create a DEM that is seamless at the coast. Challenges included: inconsistencies between datasets, horizontally shifted data, vegetation in unprocessed lidar topography, features not accurately represented in any dataset, and errors in many of the datasets. We also describe our methods to assess DEM quality and accuracy.

URL: http://www.ngdc.noaa.gov/mgg/inundation/tsunami/inundation.html



A shaded relief image of the 3 arc-second American Samoa DEM. Shown with 5 times vertical exaggeration.

Final ID: U21E-2177

Distribution and Characteristics of the 2009 Samoa Earthquake Tsunami Deposit on Tutuila Island, American Samoa

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2. Graduate School of Engineering, Tohoku University, Sendai, Japan.
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5. National Weather Service, NOAA, Pago Pago, AS, USA.
6. International Tsunami Information Center, UNESCO/IOC-NOAA, Honolulu, HI, USA.
7. American Samoa Community College, Pago Pago, AS, USA.

Body: Tsunami deposits and coastal landform changes caused by the September 29 2009 Samoa earthquake tsunami were investigated at five localities along the southwestern coast of Tutuila Island, American Samoa, from October 5 to October 8, 2009. Although the localities faced sandy beaches, tsunami sands were very limited and discontinuous. The small volume of the deposits is probably the consequence of extensive beachrock formation immediately offshore, which limited the sand supply. At most sites, on-land deposits were less than 1 cm thick, with both thickness and grain size decreasing with distance from the coast. Deposits were comprised of white grains of coral and shell fragments and black grains of basalt. The composition matched the nearby beach sand at each site. In addition to the sand deposits, basalt boulders were distributed within the tsunami inundation area and on the nearshore coral reefs. The tsunami eroded coastal scarps and removed soil near the shoreline. The number of sites which could be investigated was small: extensive tsunami inundation was limited to coastal lowlands which are also the sites of settlements. Since residents were quick to clean up after the tsunami, geological information was destroyed in all but a few locations.

For each observation site, we investigated the tsunami erosion and deposition along a profile from the beach to the inundation limit. For example, at Utumea, southwestern Tutuila, the tsunami sand sheet began 30 m inland from the shoreline and extended to the inundation limit at 60 m from the shoreline. Runup here was 4.0 m above sea level. The sand sheet had patchy and discontinuous distribution with a thickness of less than 5 mm. The grain size decreased with distance from the shoreline: the sand deposit contained very coarse sand 30 m inland and medium sand at 42 m. The sample at 58 m from the shoreline, however, contained both coarse and medium sand. Most tsunami deposits and beach sand contained 6-8% basalt fragments, but the sand at 35m from the shoreline contained 13% basalt fragments. The latter sample likely contained terrestrial materials carried shoreward by a retreating wave. From 30 m to 49 m from the shoreline, 20-30 cm size basalt gravels were scattered on the ground. These gravels were overlay the living grass and tsunami sand, and were presumably also left by retreating waves.

Final ID: U21E-2185

The 29th September Samoa Islands tsunami: preliminary simulations based on the first focal mechanisms hypotheses and implications of uncertainties in tsunami early warning strategies

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Body: At 6:48 AM local time (17:48 UTC time) a strong earthquake of magnitude Mw=8.0 occurred less than 200 km south of the Samoa Islands (Western Samoa and American Samoa), triggering a tsunami that was detected by several tide gauges located all around the source area.

The areas most affected were the south coasts of Western and American Samoa, where almost 200 persons were killed and run-up heights were measured in excess of 5 meters on several locations along the coast and and the tide gauges reached a maximum peak-to-peak height of about 3 meters near Pago-Pago (American Samoa) and 1.5 meters in front of Apia (Western Samoa)

The existence of many tide gauge records is important to support the investigation of the source mechanism. The epicenter of this earthquake is located very close to the point where the Tonga trench turns its direction from northward to westward. Here the Pacific plate moves westward beneath the Australia plate, determining a subduction zone along the north-oriented segment of the trench and a transform zone along the west-oriented segment. The epicenter location in this complex tectonic context makes identifying the fault mechanism responsible for the tsunami generation a non-trivial task.

The goal of this preliminary work is testing different fault models based on the focal mechanism solution proposed by USGS, CMT and EMSC for this earthquake, through the comparison between the tide gauge records and the synthetic signals provided by the numerical simulations, and possibly suggesting new source solutions trying to reproduce as better as possible the tsunami recordings.

The numerical simulations are computed by means of the UBO-TSUFD code, developed and maintained by the Tsunami Research Team of the University of Bologna, Italy. The code solves the linear and non-linear shallow water equations and can compute inundation inland. Furthermore the computational domain can be split in grids of different space resolution in order to have more detailed results in specific areas.

The objective difficulties in the identification of the tsunami source, due to the quite complex tectonic setting of the Tonga region in the epicentral area introduce uncertainties in the fault determination that maybe relevant a posteriori, and are a fortiori much more relevant in the real-time data processing practice. This reflects in uncertainties in the possibility of accurately forecasting tsunami propagation and arrival, which poses problems concerning the best strategy to adopt for tsunami early warning.

Final ID: U21E-2186

Near-field Tsunami Inundation Forecast Modeling of the 2009 Samoa Tsunami.

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2. NOAA Center for Tsunami Research, NOAA Pacific Marine Environmental Laboratory, Seattle, WA, USA.

Body: The 29 September 2009 Samoa tsunami was the first tsunami event in which detailed, high-resolution tsunami inundation model results were available for the impacted near-field areas before any other quantitative information had been obtained. This first forecast of the near-field tsunami impact was used by disaster recovery and scientific survey teams in advance of their arrival in the field, and for testing the real-time capability of the new tsunami forecast system. While there were no tsunami forecast models completed for American Samoa before the event, we assembled a preliminary model hours after the event, followed by a high-resolution model covering all of the island of Tutuila. The inundation forecast was prepared from inversion of deep-ocean bottom pressure recorder timeseries, and was later validated with tide gauge records. We describe the modeling products produced immediately after the event, and assess the quality of the initial modeling results by comparison with field survey results and with modeling performed after the surveys were completed. This forecast comparison provides lessons for the use of inundation modeling in surveying and recovering from future tsunamis.

Final ID: U21E-2190

Plate Boundary Observatory Borehole Strainmeter Recordings Of The 29 September 2009 Tsunami

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2. UNAVCO, Boulder, CO, USA.

Body: On 29 September 2009 a M8.3 earthquake on the Australian-Pacific plate boundary generated a tsunami that caused widespread damage in Samoa, American Samoa, and Tonga. Peak to trough wave heights of 314 cm were recorded 250 km from the epicenter at Pago-Pago, American Samoa approximately 20 minutes after the event. NOAA's West Coast and Alaska Tsunami Warning Center predicted the tsunami would arrive at Tofino, Vancouver Island, British Columbia, at 05:12 UTC, 30 September 2009. Tide gauges at Tofino recorded a 7.3 cm amplitude wave arriving at 05:45 UTC.

As part of the Plate Boundary Observatory, UNAVCO has installed 74 borehole tensor strainmeters along the western United States for the purpose of recording short-term strain transients associated with plate boundary deformation. Two of these strainmeters, Ucluelet and Bamfield, are located on the west coast of Vancouver Island within a few hundred meters of the Pacific shore line. A third, Port Alberni, is located at the north-east end of Port Alberni Inlet, ~ 50 km inland. The strainmeters at Ucluelet and Bamfield recorded strain signals associated with the arriving tsunami at times consistent with arrival times recorded by tide gauges at Tofino and Bamfield, ~05:45 UTC. A much smaller signal is recorded about 10 minutes later at Port Alberni. The largest strain signals were recorded at Ucluelet between 06:19 and 06:24 UTC. For this study we document the arrival times, nature and frequency content of the tsunami signal as recorded by PBO strainmeters on Vancouver Island and compare these strain measurements against the crustal loading signature predicted by water height changes at nearby tide gauges.

Final ID: U21E-2191

HF RADAR observations of coastal currents induced by the 29-30 September 2009 tsunami South of O’ahu

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2. Institute of Oceanography, University of Hamburg, Hamburg, Germany.

Body: A High-Frequency RADAR collected radial current observations at 1.5 km resolution every 15 minutes along O’ahu’s South Shore. Following the arrival of the tsunami generated by the September 29 Samoan earthquake, radial currents fluctuations of up to 4 cm/s were recorded 25-35 km off shore. The bursts of shoreward surface current associated with the tsunami are located at the transition between deep and shallower water on Penguin Bank, a submerged bank extending westward from the Lanai-Molokai group. The RADAR currents and supporting sea level data from other sensors in the area, showed oscillations at a dominant period of 500 sec. excited by the tsunami, which persisted for more than 8 hours after the tsunami’s initial arrival.

Final ID: U22B-01

The 2009 Samoan and Sumatran Earthquakes: A Coincidence with Precedents ***(Invited)***

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Body: The 29 September 2009 M8.1 earthquake near Samoa was followed in less than a day by an M7.5 earthquake near Sumatra. This raises the question of whether two such events can be considered a coincidence or are evidence for long-range triggering of large earthquakes. I use coincidence as the null hypothesis and examine global earthquake catalogs to determine if that null hypothesis can be rejected with 95% significance.

First, I define a large earthquake pair as two or more M≥7.5 events, which are not part of an aftershock sequence, within 24 hours. Aftershocks are removed using the Gardner and Knopoff (BSSA, 1974) method modified to use distances based on the Wells and Coppersmith (BSSA, 1994) fault lengths so that the method works on a global catalog. The catalogs used are the Centennial Catalog (Engdahl and Villaseñor, 2002), the USGS Preliminary Determination of Epicenters (PDE) catalog from 1973 to October 2009, and a merged catalog by using the Centennial catalog through 1972 and the PDE catalog thereafter.

After declustering, the Centennial catalog has distant pairs of large earthquakes on single days in 1901, 1906, 1934, and 1993 while the PDE catalog has such a pair in 2002. Thus, large earthquake pairs have precedents. The 1993 pair is not found in the PDE catalog due to magnitude differences. Interestingly, the 2009 pair does not appear because the Sumatra event was determined to be an aftershock of the 2007 M8.5 earthquake there.

The statistical analysis is done by first computing the Poisson probablity (Pp) of 2 or more events occuring within 24 hours based on the long-term rate of M≥7.5 earthquakes after declustering (R events/year). While these Poisson probabilities are very small, one must consider the probability of observing these high activity days during the length of the catalogs (Nyears). To do this, I simulate Poisson sequences of earthquakes given the observed rate and, by repeating these simulations many times, compute the probability of obtaining at least the number of observed pairs (Npairs) during the length of the catalog. If this simulation probability (Ps) is less than 0.05 then the null hypothesis is rejected. To include the 2009 pair in the analysis, I did a second declustering where aftershock sequences are limited to 18 months duration (* in the table below). Including the 2009 pair in the test of the hypothesis is questionable because it was used to develop the hypothesis.

In all cases Ps is much greater than 0.05 and thus the data do not reject the null hypothesis of coincidence. My interpretation is that these pairs are coincidental and do not provide evidence for long-range triggering between large earthquakes.

Catalog	Nyears	Npairs	R	Pp	Ps
Centennial	103	4	3.3	0.000041	0.37
Centennial *	103	4	3.4	0.000044	0.40
PDE	36.8	1	3.8	0.000054	0.76

PDE *	36.8	2	3.9	0.000058	0.44
Merged	109.8	4	3.4	0.000044	0.27
Merged *	109.8	5	3.6	0.000049	0.35

Final ID: U22B-02

Imaging the ruptures of the 2009 Samoan and Sumatran earthquakes using broadband network back-projections: Results and limitations

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Body: Applications of teleseismic P-wave back-projection to image gross characteristics of large earthquake finite-source ruptures have been enabled by ready availability of large digital data sets. Imaging with short-period data from dense arrays or broadband data from global networks can place constraints on rupture attributes that otherwise have to be treated parametrically in conventional modeling and inversion procedures. Back-projection imaging may constrain choice of fault plane and rupture direction, velocity, duration and length for large (M>~8.0) earthquakes, and can robustly locate early aftershocks embedded in mainshock surface waves. Back-projection methods seek locations of coherent energy release from the source region, ideally associated with down-going P wave energy. For shallow events, depth phase arrivals can produce artifacts in back-projection images that appear as secondary or even prominent features with incorrect apparent source locations and times, and such effects need to be recognized. We apply broadband P-wave back-projection imaging to the 29 September 2009 Samoa (Mw8.2) and 30 September 2009 Sumatra (Mw7.6) earthquakes using data from globally distributed broadband stations and compare results to back-projections of synthetic seismograms from finite-source models for these events to evaluate the artifacts from depth phases. Back-projection images for the great normal-faulting Samoa event feature two prominent bright spots, which could be interpreted to correspond to two distinct slip patches, one near the epicenter in the outer trench slope and the other approximately 80 km to the west near the plate boundary megathrust where many aftershocks occurred. This interpretation is at odds with finite-fault modeling results, which indicate a predominantly bilateral rupture in the NW-SE direction on a steeply dipping trench slope fault, with rupture extending about 60 km in each direction. Back-projections of data and synthetic seismograms from the finite-fault modeling with common source-receiver geometries are nearly identical, with both having the two prominent bright regions as well as many secondary features. The prominent feature to the west is an artifact resulting from constructive interference of azimuthally varying depth phases; this coincidentally projects in the same region as many aftershocks. Similar analysis for the Sumatra event yields back-projections of data and synthetics for a finite-fault model that closely match and indicate a very compact source with virtually all of the coherent radiation located within 20km of the epicenter. Weak features in the back-projections with arrival times consistent with pP and sP are visible offset from the epicenter. Back-projection methods can be useful for constraining aspects of large earthquake rupture processes, particularly if the variation of waveforms across the imaging network is small, but it is always important to assess what features of the back-projections are artifacts from the path geometry or depth phases to avoid misinterpreting the images, particularly when using globally distributed stations rather than large-aperture arrays.

Final ID: U22B-03

Performance of Buildings in the 2009 Western Sumatra Earthquake

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2. Forell Elsesser, San Francisco, CA, USA.
3. Degenkolb Engineers, San Francisco, CA, USA.
4. Build Change, San Francisco, CA, USA.
5. Pt. Gistama Intisemesta, Jakarta, Indonesia.
6. Geohazards International, Palo Alto, CA, USA.
7. Geo-Optima, Inc, Tangerang, Indonesia.
8. Risk Management Solutions, Newark, CA, USA.

Body: The M7.6 earthquake of 30 September 2009 in Western Sumatra, Indonesia caused significant damage and collapse to hundreds of buildings and the deaths of 1,117 people. In Padang City, with a population of about 900,000 people, building collapse was the primary cause of deaths and serious injuries (313 deaths and 431 serious injuries). The predominant building construction types in Padang are concrete moment frames with brick infill and masonry bearing wall systems. Concrete frames are common in multistory commercial retail buildings, offices, schools, and hotels; and masonry bearing wall systems are primarily used in low-rise (usually single story) residential and school buildings. In general, buildings that collapsed did not conform to modern seismic engineering practices that are required by the current Indonesian building code and would be expected in regions of moderate to high seismicity. While collapse of multi-story concrete buildings was more prevalent in older buildings (more than 10 years old), there were several newer buildings that collapsed. Primary deficiencies identified in collapsed or severely damaged buildings included: (a) soft or weak stories that failed in either by sidesway mechanisms or shear failures followed by loss of axial capacity of columns, (b) lack of ductile reinforcing bar detailing in concrete beams, columns, and beam-column joints, (c) poor quality concrete and mortar materials and workmanship, (d) vulnerable building configurations and designs with incomplete or deficient load paths, and (e) out-of-plane wall failures in unreinforced (or marginally reinforced) masonry. While these deficiencies may be expected in older buildings, damage and collapse to some modern (or recently rennovated buildings) indicates a lack of enforcement of building code provisions for design and construction quality assurance. Many new buildings whose structural systems were undamaged were closed due to extensive earthquake damage to brick infill walls, glass facades, ceiling systems and other architectural finishes. These demonstrated the importance of considering deformation compatibility and seismic considerations in the design and detail of architectural elements and non-structural components. Another important lesson learned from this earthquake is the critical role that buildings serve for vertical evacuation (refuge) from tsunami inundation in Padang and similar coastal cities in regions of high tsunami hazards. Severe traffic congestion immediately after the September 30 earthquake demonstrated that horizontal evacuation alone is insufficient to safely evacuate Padang City residents to high ground. Therefore, efforts must be stepped up to pre-screen, assess, and engineer buildings tha can be utilized for vertical evacuation.

URL: http://www.eqclearinghouse.org/20090930-padang/

Final ID: U22B-04

Planning Matters: Response Operations following the 30 September 2009 Sumatran Earthquake

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Body: Response operations following the 9/30/2009 West Sumatra earthquake tested extensive planning that had been done in Indonesia since the 26 December 2004 Sumatran Earthquake and Tsunami. After massive destruction in Aceh Province in 2004, the Indonesian National Government revised its national disaster management plans. A key component was to select six cities in Indonesia exposed to significant risk and make a focused investment of resources, planning activities, and public education to reduce risk of major disasters. Padang City was selected for this national “showcase” for disaster preparedness, planning, and response. The question is whether planning improved governmental performance and coordination in practice.

There is substantial evidence that disaster preparedness planning and training initiated over the past four years had a positive effect on Padang in terms of disaster risk reduction. The National Disaster Management Agency (BNPB, 10/28/09) reported the following casualties: Padang City: deaths, 383; severe injuries, 431, minor injuries, 771. Province of West Sumatra: deaths, 1209; severe injuries, 67; minor injuries, 1179. These figures contrasted markedly with the estimated losses following the 2004 Earthquake and Tsunami when no training had been done: Banda Aceh, deaths, 118,000; Aceh Province, dead/missing, 236,169 (ID Health Ministry 2/22/05). The 2004 events were more severe, yet the comparable scale of loss was significantly lower in the 9/30/09 earthquake.

Three factors contributed to reducing disaster risk in Padang and West Sumatra. First, annual training exercises for tsunami warning and evacuation had been organized by national agencies since 2004. In 2008, all exercises and training activities were placed under the newly established BNPB. The exercise held in Padang in February, 2009 served as an organizing framework for response operations in the 9/30/09 earthquake. Public officers with key responsibilities for emergency operations immediately contacted one another by radio, and the mayor activated the emergency plan within five minutes of the earthquake. Second, public awareness of tsunami risk was high, and residents of Padang self-evacuated when they felt strong shaking from the earthquake. Signs posted on the streets prior to the earthquake showed the evacuation route to high ground and safety. Third, back-up generators at key facilities - radio station, hospitals, fire station, and mayor’s residence - enabled key officials to mobilize response operations immediately with continued electrical power.

Yet, this event revealed new lessons for disaster planning and response critical to protecting lives, property, and continuity of operations for this city of 900,000 residents. The evacuation procedure outlined in the plan proved inadequate for the 600,000 residents who live in the Red Zone, close to the beach. A mass exodus of residents to the streets trying to cross the one bridge that led to high ground created a monumental traffic jam. Emergency personnel need protection for their families in order to report for duty to protect the lives and property of city residents. The planning continues.

Final ID: U22B-05

Geological Investigation and analysis in response to Earthquake Induced Landslide in West Sumatra

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2. School of Environmental Studies, University of East Anglia, Norwich, England, United Kingdom.

Body: Substantial socio-economical loss occurred in response to the September 30. 2009 West Sumatra Earthquake with magnitude of 7.6. Damage of houses and engineered structures mostly occurred at the low land of alluvium sediments due to the ground amplification, whilst at the high land of mountain slopes several villages were buried by massive debris of rocks and soils. It was recorded that 1115 people died due to this disasters.

Series of geological investigation was carried out by Geological Engineering Department of Gadjah Mada University, with the purpose to support the rehabilitation program. Based on this preliminary investigation it was identified that most of the house and engineered structural damages at the alluvial deposits mainly due to by the poor quality of such houses and engineered structures, which poorly resist the ground amplification, instead of due to the control of geological conditions. On the other hand, the existence and distribution of structural geology (faults and joints) at the mountaineous regions are significant in controlling the distribution of landslides, with the types of rock falls, debris flows and debris falls.

Despite the landslide susceptibility mapping conducted by Geological Survey of Indonesia, more detailed investigation is required to be carried out in the region surrounding Maninjau Lake, in order to provide safer places for village relocation. Accordingly Gadjah Mada University in collaboration with the local university (Andalas University) as well as with the local Government of Agam Regency and the Geological Survey of Indonesia, serve the mission for conducting rather more detailed geological and landslide investigation. It is also crucial that the investigation (survey and mapping) on the social perception and expectation of local people living in this landslide susceptible area should also be carried out, to support the mitigation effort of any future potential earthquake induced landslides.

Final ID: U22B-06

Impacts of the 2009 Sumatran Earthquake and Its Relation to the Great Megathrust Events

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Body: On September 29th 2009, a M 7.6 earthquake ruptured offshore of Central Sumatra. The depth and focal mechanism of the earthquake suggest that it initiated in the downgoing Sunda slab. The Sumatra region has been the focus of four great thrust earthquakes during the past five years, with the 2004 Sumatra-Andaman and 2005 Nias earthquakes located to the northwest of the 2009 Padang event and the two 2007 Mentawai earthquakes located further south. We develop models of the co- and postseismic deformation and stress changes from the previous megathrust earthquakes to explore to what degree the 2009 earthquake may be considered a statically triggered event. The latest megathrust earthquake, the 2007 Mw 7.9 aftershock, exerted the largest coseismic stress change at the 2009 hypocenter. This 2009 earthquake is similar to the Mw 7.9 2000 Enggano strike-slip intraslab earthquake, which dynamically triggered a subevent on the plate interface. We use a distributed slip model, based on GPS data from the continuously operating SuGAr network and campaign field measurements, to model the impact of the 2009 earthquake on the surrounding fault zones. This recent intraslab earthquake has positively stressed the Sunda megathrust, in the region between Siberut Island and the west coast of Sumatra. This segment of the Sunda megathrust has not ruptured since 1797, and previous studies have suggested that the accumulated interseismic strain has exceeded levels relieved in the historic earthquake. Therefore, the increased stress on the plate interface imparted by the 2009 earthquake poses a great seismic risk to the populations of Central Sumatra. One day following the M 7.6 event, a M 6.6 earthquake ruptured the great Sumatra fault, 250 km to the southeast. Based on stress change modeling, the M 6.6 earthquake does not appear to have been triggered by the static effects of the M 7.6 event.

Final ID: U22B-07

The September 2009 Padang earthquake and implications for seismic risk in western Sumatra

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Body: The sequence of great earthquakes which has ruptured more than 2000km of the Sunda megathrust from the Andaman Islands to the Sunda Strait in the last 5 years has left a 300km gap under the Mentawai Islands to the west of the city of Padang. The plate interface beneath the Mentawai patch is firmly coupled, has not experienced a large earthquake for more than 200 years and is clearly advanced in its seismic cycle. The recent earthquakes have further loaded this area by static stress interaction and another, probably tsunamigenic, earthquake in the near future has been forecast. On 30 September 2009 an M=7.6 earthquake shook Padang causing great loss of life and widespread devastation. Nucleating at around 80 km depth the event was significantly deeper than the plate interface and the possible failure planes were approximately orthogonal to it. The event certainly did not substantially relieve the stress on the megathrust to the west but probably reactivated an existing fracture in or beneath the subducting cold oceanic plate. Rather than resetting the stress on the Sumatran plate boundary heralding a reduction of the seismic threat on the Sumatran coast the event has, locally, made the nucleation of the next earthquake more likely, though, on balance, has had probably little effect, especially where the forecast threat is highest. The need for urgent mitigation measures for Padang and its surroundings remains extremely high.

Final ID: U22B-08

GPS Observations Following the Sept. 30, 2009, Padang Earthquake

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Body: GPS field observations were conducted from October 13 to 18 at 17 sites in the vicinity of the M7.6 Padang earthquake. Eleven of them were previously surveyed from one to two months prior to the earthquake, providing strong constraints. Displacements at these mainland sites reached 35 mm. Five island sites west of Padang, where displacements are predicted to be higher, were last surveyed two years earlier. They have been displaced by other earthquakes and their afterslip motions so displacement estimates are not as straightforward. Inverting the measured displacements gives a source mechanism, depth and geodetic moment that are very similar to the seismic estimates. We are also using an approach to model the GPS time series that takes into account the previous earthquakes and the intervening long-term tectonic motions. We will present these results at the meeting.

Final ID: U23F-01

A new approach to UNESCO-IOC Post-Tsunami Field Surveys

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Body: The International Tsunami Survey Team (ITST-Samoa, Oct 14-23, 2009), and the Report presented to the Government of Samoa (GoS) immediately upon conclusion, was an unprecedented science effort, setting a benchmark for future coordinated international post-tsunami science surveys that will support national early recovery efforts, and through tsunami research, improve tsunami mitigation and preparedness and so build a stronger resilience of coastal communities. By working together, we achieved outcomes much stronger and more valuable than any one of us could produce alone. For the first time, strong principles of professional conduct, mutual respect, collaboration, partnership, and concern for the welfare of the affected communities, were explictly embeded in the work plan.

The 29 September 2009 regional tsunami resulted in loss of life and damage to human infrastructure and environmental systems. Common to many tsunamis, international scientists expressed the intent to undertake science assessments. Traditionally, these surveys, sometimes under UNESCO-IOC auspices, have been single-discipline, and conducted individually with moderate government coordination, so that afterward, the country was left with a large integration task to produce a single coherent study. This changed in Samoa, where an integrated and coordinated approach emerged.

The ITST-Samoa was comprised of more than 60 scientists (seismologists, geologists, engineers, social scientists, modellers) from Australia, Fiji, French-Polynesia, Italy, Japan, New Zealand and USA who volunteered to work in collaboration with the GoS, Samoa Red Cross Society, Samoa scientists, and non-government representatives. They worked as one survey team to collect data and assist the GoS to prioritise short- and long-term risk reduction strategies. Their novel work (1) partnered with a regional university to include South Pacific expertise and with the GoS to ensure that (a) international scientists worked in a culturally-sensitive and appropriate way and, (b) outputs achieved were relevant to both GoS and ITST scientists; (2) was interdisciplinary and multisectoral to capture a thorough understanding; and (3) used a ‘coupled human-environment systems framework’ to examine vulnerability and resilience before, during and after the tsunami.

ITST succeeded because of (1) the scientists’ strong desire to share their knowledge; (2) GoS’s belief that science will improve disaster risk reduction practices; (3) immediate engagement of UN and regional organizations to provide an umbrella framework for working together; (4) local support to provide the ITST’s command center and; (5) dedicated Science Coordinators to manage the scientific planning, logistics, information sharing, and Report preparation.

In 2010, UNESCO/IOC will revise its Post-Tsunami Field Survey Guide to document ITST-Samoa best practices and so provide guidance for future International Tsunami Survey Teams.

Final ID: U23F-02

The past, present and future of tsunami field surveys post-Samoa, 2009

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Body: During the past 17 years, field surveys following significant tsunamis have aimed to accurately document tsunami effects by gathering runup, inundation and sediment data while providing outreach and education to affected populations. Field observations have led to insights on tsunami dynamics which are now largely taken for granted, such as the existence of leading depression N-waves, the importance of beach topography to first order, underwater landslides as a tsunami source, and the value of public education in reducing deaths.

For these surveys, an ad-hoc, interdisciplinary group of scientists under the banner of the International Tsunami Survey Team (ITST) aims to begin work in affected areas after search and rescue operations have ceased but before significant cleanup work begins. Time is of the essence in these efforts; in East Java 1994, bulldozers were cleaning up almost immediately, while in Samoa, after one week, a robust cleanup effort in some areas had left almost no evidence of the catastrophe. Eyewitness accounts, often used to provide input on wave kinematics, tend to rapidly converge on a common story rather than an individual's direct observation.

The team works to quell rumors of impending tsunamis by organizing educational talks where the natural phenomenon is explained and simple steps for self-evacuation are repeated. When invited, debriefings are provided to local authorities (i.e. Nicaragua 1992, Mindoro 1994, PNG 1998, Vanuatu 1999, Peru 2001/2007, Sumatra 2004, Solomon 2007), and local scientists are engaged to be part of the survey team and generally included as coauthors on subsequent publications (i.e. Peru 2001/2007, PNG 2002, Sri Lanka 2005, Java 2006, Bengkulu 2007).

In past surveys, logistics have ranged from difficult to nearly impossible (i.e. Somalia, 2005), yet outreach remains a priority; whether it is educating village chiefs in Vanuatu, relief managers in PNG, government ministers in the Maldives or assuring tribes in the Solomon Islands that it is safe to go fishing again. Despite arriving after search and rescue is over, local authorities often state that they would have preferred an earlier arrival to aid in the outreach.

Since 2004, the ITST has grown and coordination of large local teams is impossible in high profile events that attract newer field scientists. Lower profile, but equally important events in terms of basic science and outreach attract fewer interested scientists. Extreme examples are the 2002 PNG and the 2007 Solomon and Bengkulu events where only 1 or 2 international researchers responded. It is important to underscore that field surveys are an important aspect of immediate relief operations and should be conducted quickly and efficiently by small teams of experienced tsunami scientists. These surveys are important in addressing the present, past and future of tsunami hazards worldwide.

Final ID: U23F-03

Preliminary assessment of the impacts and effects of the South Pacific tsunami of September 2009 in Samoa

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Body: The September 2009 tsunami was a regional South Pacific event of enormous significance. Our UNESCO-IOC ITST Samoa survey used a simplified version of a 'coupled human-environment systems framework' (Turner et al., 2003) to investigate the impacts and effects of the tsunami in Samoa. Further, the framework allowed us to identify those factors that affected the vulnerability and resilience of the human-environment system before, during and after the tsunami – a global first.

Key findings (unprocessed) include:

Maximum run-up exceeded 14 metres above sea level
Maximum inundation (at right angles to the shore) was approximately 400 metres
Maximum inundation with the wave running parallel with the shore (but inland), exceeded 700 metres

Buildings sustained varying degrees of damage
Damage was correlated with depth of tsunami flow, velocity, condition of foundations, quality of building materials used, quality of workmanship, adherence to the building code and so on
Buildings raised even one metre above the surrounding land surface suffered much less damage
Plants, trees and mangroves reduced flow velocity and flow depth – leading to greater chances of human survival and lower levels of building damage

The tsunami has left a clear and distinguishable geological record in terms of sediments deposited in the coastal landscape
The clear sediment layer associated with this tsunami suggests that older (and prehistoric) tsunamis can be identified, helping to answer questions about frequency and magnitude of tsunamis
The tsunami caused widespread erosion of the coastal and beach zones but this damage will repair itself naturally and quickly

The tsunami has had clear impacts on ecosystems and these are highly variable
Ecosystems will repair themselves naturally and are unlikely to preserve long-term impacts
It is clear that some plant (tree) species are highly resilient and provided immediate places for safety during the tsunami and resources post-tsunami
People of Samoa are forgetting their knowledge of the value and uses of indigenous plant and animal species and efforts are needed to increase the understanding of the value of these plants and animals (thus increasing community resilience)

Video recording survivor stories is important
Sadly, there is no tradition of story telling or memory of past tsunamis so the capturing of survivor accounts means that such stories can be introduced to the cultural memory
Permitting survivors to tell their stories allows them to heal emotionally, and also provides valuable information for

future education and community outreach

The people of Samoa are hurting after the tsunami

Impacts and effects are highly variable socially and spatially

Where lives have been lost, the impacts and associated fear are much higher

Communities require practical and long-term emotional care

A complex picture is emerging about community experiences of warning and response behaviour that presents challenges to the Government of Samoa in terms of education and outreach for hazard reduction

Final ID: U23F-04

Reconnaissance Survey of the 29 September 2009 Tsunami on Tutuila Island, American Samoa

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Body: On 29 September, 2009 a magnitude Mw 8.1 earthquake occurred 200 km southwest of American Samoa's Capital of Pago Pago and triggered a tsunami which caused substantial damage and loss of life in Samoa, American Samoa and Tonga. The most recent estimate is that the tsunami caused 189 fatalities, including 34 in American Samoa. This is the highest tsunami death toll on US territory since the 1964 great Alaskan earthquake and tsunami. PTWC responded and issued warnings soon after the earthquake but, because the tsunami arrived within 15 minutes at many locations, was too late to trigger evacuations. Fortunately, the people of Samoa knew to go to high ground after an earthquake because of education and tsunami evacuation exercises initiated throughout the South Pacific after a similar magnitude earthquake and tsunami struck the nearby Solomon Islands in 2007. A multi-disciplinary reconnaissance survey team was deployed within days of the event to document flow depths, runup heights, inundation distances, sediment deposition, damage patterns at various scales, and performance of the man-made infrastructure and impact on the natural environment. The 4 to 11 October 2009 ITST circled American Samoa's main island Tutuila and the small nearby island of Aunu'u. The American Samoa survey data includes nearly 200 runup and flow depth measurements on Tutuila Island. The tsunami impact peaked with maximum runup exceeding 17 m at Poloa located 1.5 km northeast of Cape Taputapu marking Tutuila's west tip. A significant variation in tsunami impact was observed on Tutuila. The tsunami runup reached 12 m at Fagasa near the center of the Tutuila's north coast and 9 m at Tula near Cape Matatula at the east end. Pago Pago, which is near the center of the south coast, represents an unfortunate example of a village and harbor that was located for protection from storm waves but is vulnerable to tsunami waves. The flow patterns inside Pago Pago harbor were characterized based on vessel motions. The runup was a few meters at the bay entrance and peaked at 8 m only a few kilometers away at the head of the bay. Inundation and damage occurred more than 500 m inland at Pago Pago along the Vaipito River. Similar inundation distances were observed along the river at Leone. Field observations, video recordings and satellite imagery are presented. The team interviewed numerous eyewitnesses and educated residents about the tsunami hazard. Community-based education and awareness programs are essential to save lives in locales at risk from locally generated tsunamis.

Final ID: U23F-05

Regional Impact of the 29 September 2009 North Tonga Tsunami on the Futuna and Alofi Islands (Wallis & Futuna)

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Body: The north Tonga earthquake occurred at 5:48am on 30 September local time in Futuna, ~650 km west of the epicentre. The PTWC issued a warning at 6:04am for tsunami arrival in Wallis (Wallis & Futuna) at 6.35am. No warning was issued by the territorial authorities for Wallis nor for Futuna, located 230 km to the south-west. There was no reported tsunami on Wallis. However a tsunami hit the archipelago of Futuna (islands of Futuna and Alofi) between 7.00 and 7.20am on 30 September. The tide was approximately 3/4 out.
We took advantage of an 8 days survey funded by the French Ministry of Foreign Affairs, previously planned for investigating palaeotsunamis on Futuna and Alofi. We measured run-up and inundation from the mid- to low-tide mark, as well as flow depths, and sediments associated with the 30 September tsunami at 41 sites around the islands. Run-ups were estimated based on visual evidence of recent coastal impact - burnt grasses and plants, sand and other displaced debris (e.g., on the road). We interviewed the population on multiple occasions. The maximum run-up of 4.5 m was observed on the eastern beach of Alofitai in Alofi, associated with an inundation of 85 m and a flow depth of 3m at the coast. On Futuna, we measured maximum run-ups of 4.4 m on the eastern tip and 4.3 m on the NW tip of the island, with maximum inundations of 95 and 72m, respectively. A flow depth of 2 m was inferred on the NE tip. Overall, the tsunami impact was more severe on the northern coast of Futuna, with run-ups ranging from 2.1 to 4.3 m. Very small run-ups and inundations were observed along the southern coast, with a 1.0 m run-up and 10 m inundation measured in Léava, the capital of Futuna. Most witnesses report two main waves equivalent in amplitude, the second one being sometimes described as the largest. All witnesses indicate that the sea withdrew first. A video suggests only a few minutes between the successive waves (likely not the first) in Léava. The video shows the reef exposed well below the lowest tides.
There were no casualties. One inhabitant was warned by LCI television at 06:30am and was able to witness the tsunami. There were unconfirmed reports of two women taken by surprise by the arrival of the tsunami on the reef near the eastern end of Futuna, but who managed to hold on to trees to avoid being taken out to sea by the backwash. A significant disaster was avoided essentially because it was early and the tide was low when the tsunami hit. Such an event at high tide would have added about 0.8-1m in height to the wave and have undoubtedly resulted in severe damage, injuries and possibly deaths. This event, together with a small tsunami triggered by a Mw 6.4 local earthquake in March 1993 and an oral legend about a deadly and destructive wave indicate that the tsunami risk for Futuna is high for the >4000 inhabitants who live almost exclusively on a 50-400 m-wide coastal strip, between a narrow reef and landward coastal cliffs. However, the hour and 10 minutes that the 30 September tsunami took to reach the island provided sufficient time to issue a warning to the population who can rapidly reach safety on this mountainous landscape.

Final ID: U23F-06

Field Survey and Preliminary Analysis of the September 29, 2009 Tsunami on Upolu and Manono Islands, Samoa *(Invited)*

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Body: A field survey of the tsunami effects on Upolu and Manono Islands, Samoa was conducted from 7 – 10 October, in the days following the Mw 8.0 (USGS) earthquake that occurred to the south east of the Samoan Islands on September 29, 2009. The field survey was part of the international scientific response to the event and aimed to collect time sensitive information on the tsunami effects including measurements of runup, inundation and flow depths as well as eyewitness accounts and other types of information useful in reconstructing the event.

On Upolu, the strongest effects were observed in the south-eastern corner of the island near Cape Tapaga. In this area, the tsunami runup height was between 6 and 14 m. The villages of Lepa, Saleapaga, Lalomanu experience the highest runup heights, with the highest runup of ~14.5 m measured at Lepa. The greatest inundation distances, 300 m and greater, were observed on the eastern shore of Upolu, near Satitoa. At Malaela in particular, the very flat topography allowed for a horizontal inundation of over 375 m with a tsunami height of 3.5 m (~3.0 m over ground level) and a total tsunami runup of less than 2 m. Despite the extensive destruction in this region, there were villages such as Vailoa that were completely unscathed due to steeper coastal topography and possibly the sheltering effect of Cape Tapaga itself.

Moving westward along the southern shore of Upolu, the tsunami heights diminished somewhat. The tsunami was on the order of 5 to 6 m in the central section of the coast and was particularly damaging at coastal areas located at river mouths or where there were breaks in the offshore reef system such as Salani, Poutasi or Ili'Ili. East of Cape Niuato'i tsunami heights dropped further in to the 1 to 3 m range and the wave was generally non-destructive. Tsunami runup aong the northern shore of Upolu was on the order of 1 to 3 m and did not cause significant damage. On Manono Island, runup varied from 2.4 to 5.8 m causing significant damage on the southwestern side and little damage on the eastern and northern sides of the island.

Among the more interesting pieces of data collected during the survey were photographs of the advancing tsunami obtained from an eyewitness in the Village of Le Vasa, just south of Cape Fatusofia on the western tip of Upolu. These photographs are valuable in understanding and visualizing tsunami hydrodynamics as well as in determining the precise arrival time from the time stamp data on the digital files.
In addition to the tsunami runup and inundation data, a preliminary data set of tsunami related injuries was obtained from medical personnel who responded to the event. This information will be used to correlate injury types and severity to the characteristics of the tsunami wave itself.

Final ID: U23F-07

Field survey of the 2009 tsunami in American Samoa

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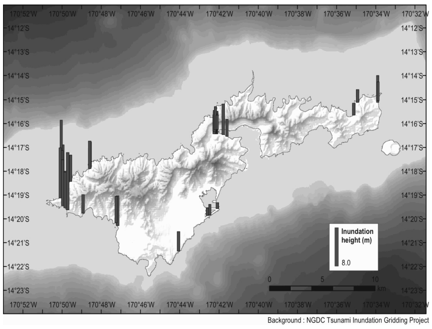
5. National Weather Service Pago Pago, NOAA, Pago Pago, AS, USA.
6. International Tsunami Information Center, UNESCO/IOC-NOAA, Honolulu, HI, USA.
7. American Samoa Community College, Pago Pago, AS, USA.

Body: We conducted a post-tsunami field survey of the 2009 tsunami in Tutuila island, American Samoa from 5 to 8 Oct., 2009, focusing on the measurements of tsunami run-up height, flow depth, extent of inundation zone, coastal erosion/sedimentation, structural damage inspection, and collecting eyewitness accounts. In total, we measured tsunami heights at 50 points in the island using the total station, hand-held GPS and survey rods.

Throughout the survey, we found that the tsunami devastated the villages along the western coast with the highest run-up of 16.3 m (above the sea level at tsunami arrival) at Poloa where almost all the houses were washed-away or collapsed, and 12.4 m inundation height at Amanave where the tsunami penetrated approximately 200 m inland. Also, severe damage were found at Leone (south western coast ; 6 m as inundation height), Pago Pago harbor (central coast; 5m as inundation height, 2 m as flow depth and approximately 500 m inland tsunami penetration), and Tula (eastern coast ; less than 6m as inundation height).

We also surveyed the structural damage in Pago Pago harbor, by the interpretation of high-resolution satellite images (QuickBird) and on-site inspection with GPS measurement, which leads to the understanding of relations between the tsunami hazard and structural vulnerability.



Measured tsunami inundation heights after tide correction.

Final ID: U23F-08

Field Survey of the 29 September 2009 Tsunami on Savai'i Island, Samoa

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Body: On 29 September, 2009 a magnitude Mw 8.1 earthquake occurred 200 km south of Samoa's largest island Savai'i and triggered a tsunami which caused substantial damage and loss of life in Samoa, American Samoa and Tonga. The most recent estimate is that the tsunami caused 189 fatalities with the majority on Samoa's Upolu Island, while only two deaths are confirmed on Savai'i. This marks the deadliest tsunami in Polynesia and Micronesia to the east of New Guinea since the 1975 Bougainville Island tsunami. PTWC responded and issued warnings soon after the earthquake but, because the tsunami arrived within 15 minutes at many locations, was too late to trigger evacuations. Fortunately, the people of Samoa knew to go to high ground after an earthquake because of education and tsunami evacuation exercises initiated throughout the South Pacific after a similar magnitude earthquake and tsunami struck the nearby Solomon Islands in 2007. A multi-disciplinary reconnaissance survey team was deployed within days of the event to document flow depths, runup heights, inundation distances, sediment deposition, damage patterns at various scales, and performance of the man-made infrastructure and impact on the natural environment. The ITST circled Savai'i Island from 8 to 9 October 2009 and collected more than 30 runup and flow depth measurements. The tsunami impact on Savai'i peaked with maximum runup exceeding 8 m at uninhabited Nuu Black Sand Beach located 7 km east of Cape Asuisui marking the center of the south coast. A significant variation in tsunami impact was observed on Savaii. The tsunami runup reached 6 m at Taga located 3 km to the east of Cape Asuisui, while along the northeast coast the runup remained below 3 m. The inundation distance at Taga approached 200 m and massive boulder fields covered the previously vegetated terrain more than 100 m inland. Fortunately no victims were reported at this location during this event, while the presumably smaller 1981 tsunami claimed one fatality at Taga. Savai'i was severely impacted by Category 5 tropical Cyclone Val in December 1991 causing 13 deaths and destroying about half of the island's coconut trees, resulting in a tremendous loss to the country's economy. Field observations and satellite imagery are presented. The team interviewed numerous eyewitnesses and educated residents about the tsunami hazard. Community-based education and awareness programs are essential to save lives in locales at risk from locally generated tsunamis.

Final ID: U24A-01

Survivor Interviews from the Sept. 29, 2009 tsunami on Samoa and American Samoa

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Body: Thirty-one video interviews were carried out on the islands of Tutuila, American Samoa and Upolu, Samoa with survivors of, and responders to, the September 29, 2009 tsunami event. Those interviewed included local residents caught by the waves while attempting to flee to higher ground, those who intentionally ran into the water to save others, individuals who recognized the potential tsunami hazard due to the severity of the earthquake and attempted to warn others, first-responders, aid workers, tourism managers, and others. The frank, often emotional, responses provide unfiltered insight into the level of preparedness of local residents, level of training of first responders, and challenges faced by aid workers. Among the important observations voiced by interviewees were: (1) recent tsunami education briefings and school drills were critical in preventing greater loss of life; (2) those who had not received training about the tsunami hazard were unaware that a tsunami could follow a strong earthquake; (3) first responders were not adequately trained or prepared for the specific impacts of a tsunami; (4) initial medical procedures did not adequately address the levels of bacterial contamination; and (5) survivors, first responders and aid workers suffer from post traumatic stress disorder as a result of the event and its aftermath. Valuable scientific data can also be gained from first-hand accounts. Several interviews describe waves “bending,” “funneling,” and one spoke of the waves coming together as a “monster that jumped up from the channel spitting boulders.” In the village of Fagasa on the north coast of Tutuila, American Samoa, the assumed transport direction of large boulders by scientists was dramatically revised based on first-hand accounts of the original position of the boulders.

The single most common message was that hazard education played a key role in saving lives in both Samoa and American Samoa. It is critically important to understand the reaction and response of individuals from different cultures to tsunami events in order to better design mitigation, education, response and recovery programs that best fit local communities. It is hoped that the analysis of these and other post-tsunami interviews will be used in that effort. Interviews were carried out in high-definition (1080i) video so as to capture the emotional impact of first-person, eye-witness accounts. Interviews will be translated in Samoa and English and transcribed with video time-code thus making them suitable for quality media production for use in local, regional, and international tsunami education programs. Additional observations gleaned from the interviews, as well as preliminary analysis based on specific location and demographic will also be presented.

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Identifying Precursors to the 2009 South Pacific tsunami?

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Body: The 29/30 September 2009 tsunami was a truly South Pacific event, spanning the dateline and affecting Samoa, American Samoa, Tonga, Fiji, Wallis & Futuna, and the Marquesas. Notable historical tsunamis in the region include the 1960 Chilean tsunami and a 1917 one from a source similar to the 2009 event. The historic record of large tsunamis varies between Pacific Island Countries (PICs), but it is short, rarely exceeding 200 years. It is sufficiently long however, to indicate that the tsunami hazard in the region may be high, but sufficiently short to give an extremely limited understanding of the hazard. Sadly, there are almost no South Pacific palaeotsunami data available to give a longer time and magnitude record of potential precursor events.

Core and trench work in Samoa and Wallis & Futuna reveals evidence for several possible palaeotsunamis. There are up to six sand layers with associated paleosols in Samoa, and up to four in Futuna. At Tavai in Futuna, there is also an oral tradition associated with evidence of a surface boulder scatter field, and probably a sand layer overlying a past occupation site. These data are compelling and a tsunami source seems likely. This event is currently undated. On a note of caution however, sand and paleosol interbeds are common in the sandy coastal plains of tropical Pacific islands. Possible causes include cyclones and tsunamis, and it will therefore be necessary to establish diagnostic criteria to help distinguish between these different modes of formation. If these are palaeotsunamis then whether they relate to regional or distant events is also yet to be determined. Ultimately, more precise source identification will likely have to wait until a more comprehensive palaeotsunami dataset has been established for PICs.

Mulivai - south coast of Samoa: Trench showing the 2009 South Pacific tsunami with at least two underlying sand unit and one palaeosol. Photo: C. Chagué-Goff

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Tsunami Sediment Transport and Deposition in a Sediment Limited Environment on American Samoa

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Body: On 29 September 2009 a large tsunami struck the US territory of American Samoa, killing 34 people. However, had it not been for the island's tsunami preparation, the death toll would have been much higher. An integral part of preparing for a tsunami is knowing how often large tsunamis occur, knowledge that can be improved by using paleo-tsunami sediment deposits to lengthen the historical tsunami record. Doing so requires a detailed understanding of the processes that control sediment transport during tsunamis and thus the patterns of deposition, which may vary substantially in sediment limited and sediment rich environments. As American Samoa is relatively young and composed of volcanic islands surrounded by coral reefs, sandy beaches occur primarily as pocket beaches between volcanic rock headlands. The extent and depth of littoral sediment available for transport is therefore limited. This is in contrast to previous studies which have focused primarily on coastal environments with extensive sand supply.

Here, field observations and a numerical model are used to investigate tsunami-induced sediment transport in two sediment limited embayments (Massacre and Fagafue Bays) on the north side of the island of Tutuila in American Samoa. Detailed measurements of bathymetry, topography, tsunami flow depth and direction, sediment deposition, reef and vegetative roughness, and the extent of sediment available for transport were collected approximately two weeks after the tsunami. Both embayments contain sandy sediments that extend all the way (Massacre Bay) and part of the way (Fagafue Bay) along the beach at the head of the embayment. The observed onshore sediment deposit created by the tsunami was limited and patchy in both embayments even though a number of large coral boulders were transported onshore at both locations.

The extent to which the limited supply of sediment plays in producing the patterns of deposition observed in these two bays is examined using a three-dimensional coupled hydrodynamic/sediment transport/morphological change model (Delft3D). To isolate this effect, model simulations examine the effects on sediment deposition of wave focusing owing to embayment shape and reef channels, and the strong return flow generated by the steep onshore topography. Differences between the depositional patterns in sediment limited and sediment rich environments are identified by comparing the results from these simulations with results from simulations where the extent and depth of the sediment source are increased and from simulations conducted in a sediment rich environment (Kuala Meurisi, Sumatra).

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Effect of Fringing Reefs on Tsunami Inundation: American Samoa

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Body: Soon after the Mw=8.0 Samoa earthquake of 29 September 2009 a tsunami impacted the island of Tutuila, American Samoa. Tutuila is volcanic in origin, about 30 km long and 6 km wide, and characterized by steep topography, an irregular shoreline with numerous embayments, and a discontinuous fringing reef. Both initial model simulations of inundation and field observations made soon after the tsunami indicate highly variable wave heights around the island of Tutuila and within individual embayments. Variations in tsunami inundation locally may be caused by a number of factors, including 1) nearshore bathymetry, 2) coastal topography, 3) the shape and orientation of the coast, 4) bottom roughness, and 5) coastal vegetation. Field data were collected on each of these factors and on the tsunami inundation (run-up, wave heights, inundation distance) at a number of different locations to help understand why the inundation varied so dramatically. It is speculated that the variations in run-up and inundation result in part from variations in the reef flat, including the presence or absence of deep channels that bisect the reef flat and terminate close to shore. A model of tsunami inundation is used to help quantify the influence of these factors separately on tsunami inundation.

We model tsunami inundation using Delft3D, which solves the non-linear shallow water wave equations on a staggered grid with a wetting and drying algorithm optimized for a rapidly changing interface. The model is run in 1-D on a schematized cross-shore profile based on the bathymetry, reef elevation, and topography measured on Tutuila to test the influence of reef depth and width on inundation. The model is also run in 2-D on a schematized embayment to test the influence of coastal shape and channel width, depth, and location. All simulations are initialized with an offshore water level boundary condition composed of multiple waves with a leading depression. Initial model results suggest that reef depth (a proxy for tide level at the time of the tsunami) can have a significant effect, on the order of 50%, on tsunami run-up. Reef width, however, does not seem to be an important factor in controlling tsunami inundation, at least for the range of reef widths found around Tutuila. Additional model simulations examine the influence on inundation of bottom roughness, embayment shape and channel depth, width, and location.

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Geologic Signatures of the September 2009 South Pacific Tsunami ***(Invited)*****>**

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Body: The September 29th 2009 tsunami caused widespread destruction along the shorelines of Samoa in the South Pacific. Preliminary measurements indicate maximum runup values of around 12 m (average ~3-6 m) and shore-normal inundation distances of up to ~ 400m. Geological field reconnaissance studies were conducted within three weeks of the event in order to document the erosion, transport, and deposition of sediment by the tsunami. Types of data collected included: a) general morphology and characteristics of the coast, b) tsunami water level measurements (inundation, flow depth and direction, and wave height, c) surficial and subsurface sediment samples, d) topographic mapping, and e) boulder size and location measurements.

Where available for transport, mud, sand, and gravel size material was moved by the tsunami and formed distinct sedimentary deposits. Four main sedimentary deposits were identified: 1) Gravel deposits that typically occurred as either isolated coral boulders derived from the adjacent reef system and deposited on the lower beach face, or, fields of basalt boulders derived from coastal engineering structures and deposited inland on the coastal plain. In both cases the boulders were found either on the surface or partially buried by sand. Patchy accumulations of staghorn corals (Acropora sp?) occurred along some shorelines, presumably where there was a nearby reef source. 2) Sand deposits that ranged from very thin patches (< 1 cm) to broad sand sheets up to 10's of cm thick. Localized thick sand accumulations were common in the lee of structures, such as low walls, and in topographic depressions. The thicker sand deposits had multiple laminations with varying degrees of particle segregation. In some localities clusters of the green alga Halimeda were incorporated in sand deposits. The sand appeared to be derived from the reef flats, beaches, and in some cases erosion of the land surface (i.e. from sandy soil). 3) Organic debris of over 10 cm thickness found further inland (at the forest edge) in topographic lows. 4) Surface mud deposits ranged from thin mud drapes (< 1 cm thick) to multi-layered, thick (4+ cm) mud caps that showed pronounced desiccation cracks two weeks after the tsunami.

Documenting the geologic characteristics of recent tsunami deposits is an important tool used in the identification of paleotsunamis in the geologic record. The spatial distribution of the deposits, combined with sediment texture and composition attributes, will provide valuable criteria in the discrimination between tsunami deposits and those formed by other processes such as extreme storms or variations in sea level.

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Real-time Modeling Forecast of the 29 September 2009 Samoa Tsunami

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Body: The 29 September 2009 Samoa tsunami provided an unexpected exercise for the NOAA's tsunami forecast system, undergoing operational testing at U.S. Tsunami Warning Centers (TWCs). Both TWCs and staff of the Pacific Marine Environmental Lab exercise the forecast system to provide tsunami prediction for the Pacific U.S. coastal communities where forecast models have already been developed. The forecast model from a tsunameter-constrained tsunami source, giving the U.S. coastlines more than three and half hours of lead time to respond to the approaching tsunami waves. Even with this unusual and complex earthquake source, the forecast provided required accuracy for important emergency management decisions. During the event, a high-resolution inundation model was quickly developed to compute the tsunami inundation in Samoa Islands - particularly in Tutuila Island. This allowed for the first test of the real-time inundation forecast capability of the system. In addition, the model inundation estimates provided valuable guidance for disaster recovery activities and for the post-tsunami survey guidance. The results illustrate recent improvements and new capabilities of the tsunami forecast system. The problems and lessons learned for both far-field and local tsunami forecast will be discussed.

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The 29 September 2009 Samoan earthquake and tsunami in the ionosphere: analysis of the near- and far-field GPS-TEC perturbations.

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Body: Tsunami warning signs in the ionosphere ? Thanks to the advent of satellite ionospheric monitoring techniques, a few were non-ambiguously observed. We report new observations related to the recent Samoan tsunami. We detected ionospheric disturbances in the hours following the earthquake. We extracted short time Total Electron Content (TEC) variations from data recorded by permanent Global Positioning System (GPS) stations located in the whole Pacific area.

At near field, a gravito-acoustic signal is clearly detected within 15 minutes after the seismic rupture. These coseismic ionospheric perturbations are now commonly detected after strong earthquakes through monitoring of TEC derived by GPS data. For underwater earthquakes, this kind of observation can improve the understanding of tsunami generation.

At far field, using a dense GPS network in Hawaii, we imaged a 10 to 15 minutes periodic signal around 6 hours after the earthquake, propagating between 150 and 200 m/s to the North-East. These observations are coherent with the Samoan tsunami arrival times near Hawaii, its propagation speed and direction. The coherency of the detected signals spectral signature is analysed and a comparizon is made to tide gauges data.

Those measurements confirm the detectability of tsunami induced gravity waves in the ionosphere, providing additionnal constraints to the first tsunamigenic ionospheric propagation models initiated after the 2004 giant Sumatra tsunami.

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Search for Evidence of the 29 September 2009 Tsunami in Altimeter Data

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Body: We have searched in Jason-1 and Jason-2 (OSTM) altimeter passes through the Pacific that occurred approximately 4 to 10 hours after the Samoan earthquake. Two ascending passes of each satellite intersected estimated wavefront positions both southwest of New Zealand and northeast of Hawaii. We have constructed local mean sea surfaces from data before and after the affected passes to difference from them in order to remove short-term oceanographic signals as well as the long-term mean sea surface. We find likely evidence of the tsunami in the southern area but little or none in the northern area. The arrangement of the passes in the southern ocean makes it possible to see snapshots of the wavefront and the propagation over short time (e.g., 112 min) intervals. The amplitude of the tsunami appears to be related to bathymetry.