Notable Events

The 12th January 2010 Mw 7.0 Haiti Earthquake

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8.1 The 12^{th} January 2010 M_W 7.0 Haiti Earthquake

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8.1.1 Introduction

The magnitude (Mw) 7.0 Haiti earthquake of 12 January 2010 is likely the most devastating earthquake to have occurred in the western hemisphere both in terms of the number of fatalities and the impact on a nation as a whole. Estimates of the death toll range from less than 50 000 to over 300 000 with the most likely value being in the range of 137 000 (Daniell and Vervaek, 2012). Another 300 000 were injured and 1.3 million left homeless. Two years after the earthquake many people are still living in temporary shelters.

The earthquake occurred at 16:53 local time (21:53 UT) approximately 25 km WSW of the capital city of Port-au-Prince (18.443°N, 72.571°W, USGS, 2012), The mainshock was followed by a vigorous aftershock sequence including a magnitude (Mw) 6.0 event that occurred about 7 minutes after the mainshock and an Mw 5.9 earthquake on 20 January.

The location and style of faulting (strike-slip) of the mainshock initially suggested that it occurred on the Enriquillo-Plaintain Garden Fault (EPGF), a fault known to be capable of generating large earthquakes and which may have ruptured during several comparable sized earthquakes in the past (1751, 1770) but which had been relatively inactive for the past 200 years leading to a lack of earthquake awareness among the general population. Figures 8.1 and 8.2 contrast the seismicity of the 50 years preceding the magnitude 7.0 earthquake to that of the two years following it. More discussion of historical earthquakes in Haiti may be found in Bakun *et al* (2012) and the references therein.

Despite the magnitude and relatively shallow depth (10-15 km) of the earthquake, reconnaissance teams found no evidence for surface rupture on the EPGF (Eberhard *et al*, 2010) perhaps providing the first clue that the situation was more complicated than it first appeared. Subsequent research discussed later in this paper suggests that the earthquake sequence may not have occurred on the EPGF or that it was not the sole fault to rupture during the earthquake sequence.

Prior to the 2010 earthquake, seismic monitoring in Haiti had been extremely poor. While global

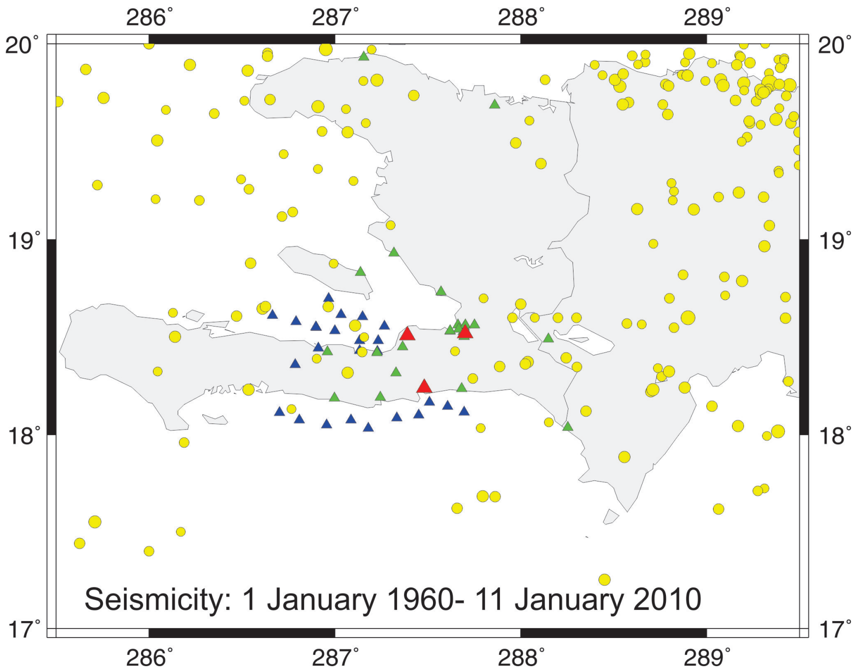

Figure 8.1: *Seismicity of Haiti and surrounding regions from 1960 until the day prior to the 2010 Mw 7.0 earthquake. Earthquakes of magnitude (any type) 3.5 and greater are plotted. Epicenters and magnitudes from the ISC catalog (ISC, 2012). Symbol size is scaled to magnitude. The triangles show the stations installed after the 2010 earthquake: Canadian real-time (red), French (blue) and American (green). The school station HAIF would plot very close to the stations at Port-au-Prince (upper right of the three red and in the cluster of green triangles).*

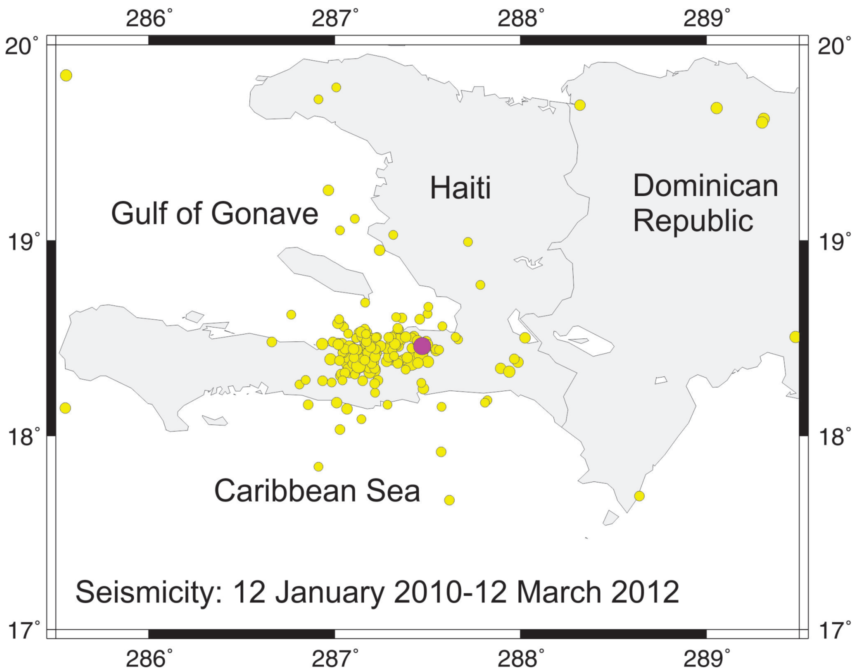

Figure 8.2: *Seismicity of Haiti and surrounding regions since 12 January 2012. The mainshock is shown in red. Magnitudes (3.5 and greater) and epicenters from the ISC (2012). Symbol size is scaled to magnitude.*

and Caribbean stations would have captured any moderate to large earthquakes, smaller ones would have for the most part gone undetected. At the time of the 12 January 2010 earthquake, the only seismograph station operating in Haiti was one at the Lycée français Alexandre Dumas in Port-au-Prince that formed part of a French-based school network (www.edusismo.org/index.asp). This station provided the closest recording of the mainshock (https://geoazur.oca.eu/spip.php?article672). Since that time several international organizations installed temporary or permanent stations in Haiti and the monitoring situation has somewhat improved (see subsequent section on New Stations and Figure 8.1).

The intent of this paper is to summarize the earthquake and work that has been done since January 2010 to better understand the earthquake sequence and seismic hazard in Haiti. The focus is on the seismological data and research but it should be noted that much has been learned through other data sets including, but not limited to, GPS and INSAR.

8.1.2 New Stations

Historically very few seismograph stations have operated in Haiti. At the time of the earthquake, the only known station in Haiti was a school seismograph in Port-au-Prince discussed in the previous section. Recent improvements to networks elsewhere in the Caribbean ensure that the moderate and larger earthquakes in Haiti are recorded but these stations do not catch all of the smaller earthquakes needed to establish relative recurrence rates and to build a reliable earthquake catalog for that country. Following the 2011 earthquake, many temporary and some long-term seismograph stations were deployed in and around Haiti by several organizations, in particular the Geological Survey of Canada, the United States Geological Survey and Géoazur (Figure 8.1).

In late January 2010, the United States Geological Survey sent a reconnaissance team to Haiti. Among other tasks, they installed four seismometers to monitor aftershocks (Eberhard *et al*, 2010; Hough *et al*, 2010). Data from these stations have been archived and are available from the Incorporated Research Institutes for Seismology (IRIS) data management center. Additional stations were installed over the next few months and included eight RefTek instruments, nine strong-motion (K2) accelerometers and three broadband stations all of which were installed primarily in the epicentral region (Altidor *et al*, 2010). Several of these temporary stations have since been replaced with permanent strong-motion NetQuakes instruments. Data from many of the K2 instruments and a list of station coordinates may be found at http://pasadena.wr.usgs.gov/office/hough/DATA.

In early February 2010 a team of French scientists primarily associated with Géoazur deployed twenty-one ocean bottom seismometers (OBS) in the nearshore regions surrounding the southern peninsula of Haiti. All were four component (3 seismograph and 1 hydrophone) stations. Fifteen short-period instruments operated until early March 2010. The remaining six broadband instruments remained in operation until mid-May 2010. Additionally, four broadband seismometers were installed on land in the eastern part of the rupture zone where the bathymetry was not suitable for OBS deployment. A more detailed account of the deployment including the station coordinates may be found at https://geoazur.oca.eu/spip.php?article670.

In February 2010 the Geological Survey of Canada installed three real-time, satellite-linked seismograph stations consisting of three-component broadband seismometers and three component strong motion instruments in Port-au-Prince, Jacmel and Leogâne (Figure 8.3). Aftershocks were located by GSC seismologists and the phase data and solutions were forwarded to the International Seismological Centre and other international organizations on a daily basis during the months immediately following the earthquake. The data are forwarded in real time to IRIS and the Caribbean Tsunami Warning Centre. The stations continue to operate but their reliability has somewhat decreased with time primarily due to problems with the power supply and security. Further information about the Canadian deployment may be found at http://www.earthquakescanada.nrcan.gc.ca/haiti/index-eng.php.

Figure 8.3: *The station installed in Léogâne by the Geological Survey of Canada. Photo by C. Andrews, GSC.*

8.1.3 Focal Mechanisms and Other Fault Parameters

While the initial focal mechanism for the mainshock (for example see GCMT, 2012, or USGS 2012) was primarily strike-slip consistent with rupture on the EPGF, subsequent analysis of aftershocks and non-seismological data implies that the rupture sequence was much more complex and raises significant doubts as to whether the events occurred on the EPGF. Analysis the mainshock and aftershocks using several different methods and data sets all find that the majority of the aftershocks are thrust events, incompatible with the strike-slip nature of the EPGF.

Hayes *et al* (2010) focused on modeling the mainshock in detail using a combination of seismological, geologic and geodetic data. Their model suggests a complex primarily unilateral rupture (toward the west) with small amounts of rupture occurring on subsidiary faults. The integrated data set suggests that little, if any, of the rupture occurred on the EPGF and raises the possibility of a future large earthquake on the EPGF. Mercier de Lépinay *et al* (2011) and Vallée (https://geoazur.oca.eu/spip.php?article614) also modeled the mainshock in detail and reached similar conclusions- a westward propagating but complex rupture unlikely to have occurred on the EPGF.

Many studies were undertaken to determine the focal mechanisms of the numerous aftershocks that followed the Mw 7.0 earthquake. A variety of methods and data sets were employed but all reached similar conclusions and raised the same questions about rupture on the EPGF as the in-depth mainshock models. Most of the aftershocks, including the largest, were found to have thrust mechanisms. Those that had strike-slip mechanisms generally occurred at the eastern end of the aftershock zone close to the epicenter of the mainshock. These studies include those of Nettles *et al* (2010) based on teleseismic moment tensor inversions, Bent (2011) from regional moment tensor analysis for the larger events and composite first motion mechanisms for the smaller ones, and Mercier de Lépinay *et al* (2011) from broadband modeling of regional data. A wide range of depths were obtained for the aftershocks through these studies but all were crustal and the largest number occurred at depths near 10 km.

8.1.4 Aftershock Locations

While existing global networks were used to monitor and locate the largest of the aftershocks, the newly deployed stations significantly lowered the magnitude location threshold. The earliest aftershock locations using the stations discussed in the previous section were generally undertaken by the organizations that deployed them using their own stations, primarily because much of the data were not available in real time. The data sets were in some cases supplemented by data from pre-existing regional stations, including Guantanamo Bay, Grand Turk and several stations in the Dominican Republic. Aftershock locations from the American, French and Canadian data sets all showed an aftershock zone extending roughly east-west and parallel to the EPGF. However, there were systematic differences in the locations with the American (USGS) locations being on or just north of the EPGF (USGS, 2012), the French (Géoazur) being north of those locations but generally onshore except at the western end of the aftershock zone (Mercier de Lépimay *et al*, 2011) and the Canadian (GSC) epicenters being mostly just offshore in the Gulf of Gonâve. While some of the differences may be due to differences in which events were being located, the fact that they are systematic suggests that they are more likely related to some combination of the choice of velocity model and to the network geometry.

Douilly *et al* (2011, 2012) are in the process of relocating the aftershocks using the data from all available stations, which should increase the accuracy of the locations. Their results suggest that the events are occurring not on the EPGF but on the Léogâne Fault, which is a previously unmapped fault just north of the EPGF described as 60° north dipping oblique thrust fault. They note that there is also some evidence that some of the activity at the western end of the rupture zone may be occurring on the offshore Trois Baies fault. The Léogâne Fault was also proposed for the mainshock rupture by Calais *et al* (2010) using GPS and INSAR data.

8.1.5 Summary/Conclusions

The 2010 Mw 7.0 earthquake that devastated much of southern Haiti occurred in a gap in the global earthquake monitoring system. Several international seismological agencies helped fill that gap in subsequent weeks and months through the deployment of temporary and permanent seismograph stations. Because much of the recorded data were not available in real time and therefore not immediately accessible to the international seismological community, valuable coordination was provided through data repositories such as the ISC for phase and other derived data and IRIS for waveform archiving.

The 2010 earthquake sequence has been and continues to be studied as the recovery continues. What initially appeared to be a simple rupture on a previously known fault (EPGF) has turned out to be a complex rupture sequence predominantly on the nearby and newly-identified Léogâne fault, raising concerns that the EPGF may be "due" for a larger earthquake. Although not explicitly discussed in this text, the data recorded by the Haitian stations are also being used to produce improved velocity and attenuation models for Haiti and to evaluate the site conditions beneath the stations. While seismic monitoring in Haiti continues to be poor it has considerably improved since the time of the earthquake and seismic awareness, at least for the moment, has increased.

8.1.6 Additional Information

By necessity this report is brief and failure to mention any particular paper on the 2010 Haiti earthquake is not intended as a slight or a criticism by this author. Following the earthquake many papers have been and continue to be published on the earthquake and related issues. These include a large collection of Haiti related articles in Nature Geoscience (November 2010) and Earthquake Spectra (October 2011), the latter of which focuses primarily on the engineering aspects of the earthquake but which includes new earthquake hazard maps for Haiti (Frankel *et al*, 2011). The Earthquake Engineering Research Institute established an online clearing house for information on the earthquake that is still available (www.eqclearinghouse.org/20100112-haiti/). The Group on Earth Observations also has a website containing a wide variety of information on the earthquake (supersites.earthobservation.org/Haiti.php). Several conferences, including the 2010 Seismological Society of America annual meeting, the 2010 European Seismological Commission general assembly, the 2010 fall meeting of the American Geophysical Union and the 2011 meeting of the International Union of Geodesy and Geophysics included special sessions on this earthquake. The abstract volumes for these conferences outline much of the early work on the earthquake, some of which has been subsequently followed up and published in more detail.

8.1.7 Acknowledgements

I thank Sue Hough and Bill Ellsworth for providing me with an update on the work of the USGS and Bernard Mercier de Lépinay for an update on the activities of Géoazur. John Adams provided constructive comments on an earlier version of the manuscript. The photo of the station at Léogâne appears courtesy of Calvin Andrews.

8.1.8 References

Altidor, J. R., D. Anglade, W. Ellsworth, D. Given, S. E. Hough, M. G. Janvier, J. Z. Maharrey, M. Meremonte, B. Saint-Louis Midor, C. Prepetit and A. Yong (2010). Seismic Monitoring and Post-Seismic Investigations following the 12 January 2010 Mw 7.0 Haiti Earthquake, (abstract) Fall Meeting of the American Geophysical Union.

Bakun, W. H., C. H. Flores and U. S. ten Brink (2012). Significant Earthquakes on the Enriquillo Fault System, Hispaniola, 1500-2010: Implications for Seismic Hazard, Bulletin of the Seismological Society of America, 102, 18-30, doi:10.1785/012010077.

Bent, A. L. (2011). Focal Mechanisms and Depths of Aftershocks of the 2010 Haiti Earthquake, Geological Survey of Canada Open File 6713, 23 pp.

Calais, E., A. Freed, G. Mattioli, F. Amelung, S. Jónsson, P. Jansma, S.-H. Hong, T. Dixon, C. Prépetit and R. Momplaisir (2010). Transpressional rupture of an unmapped fault during the 2010 Haiti rupture, Nature Geoscience, 3, 794-799.

Daniell, J. and A. Vervaek (2012). Damaging Earthquakes Database 2011- The Year in Review, earthquake-report.com/2012/01/09/catdat-damaging-earthquakes-database-2011-annual-review/.

Douilly, R., S. J. Haase, W. L. Ellsworth, M. Bouin, E. Calais, J. G. Armbruster, B. F. Mercier de Lepinay, A. Deschamps, and S. E. Hough (2011). Improving the resolution of the fault geometry of the 2010 Haiti earthquake (abstract), 2011 Fall Meeting of the American Geophysical Union.

Douilly, R., S. J. Haase, W. L. Ellsworth, M. Bouin, E. Calais, J. G. Armbruster, B. F. Mercier de Lepinay, A. Deschamps and S. E. Hough (2012). Triggered activity on an adjacent fault deduced from relocated aftershocks of the 2010 Haiti earthquake, (abstract) to be presented at the 2012 meeting of the Seismological Society of America.

Eberhard, M. O., S. Baldridge, J. Marshall, W. Mooney and G. J. RIx (2010). The Mw 7.0 Haiti earthquake of January 12, 2010, USGS/EERI Advance Reconnaissance Team Report, U. S. Geological Survey Open-File Report 2010-1048, 58 pp.

Frankel, A., S. Harmsen, C. Mueller, E. Calais and J. Haase (2011). Seismic Hazard Maps for Haiti, Earthquake Spectra, 27, S23-S41.

Global Centroid Moment Tensor Project (2012). On line data base,
http://www.globalcmt.org/CMTsearch.html.

Hayes, G. P., R. W. Briggs, A. Sladen, E. J. Fielding, C. Prentice, K. Hudnut, P. Mann, F. W. Taylor, A. J. Crone, R. Gold, T. Ito and M. Simons (2010). Complex rupture during the 12 January 2010 Haiti earthquake, Nature Geoscience, 3, 800-805.

Hough, S. E., J. R. Altidor, D. Anglade, D. Given, M. G. Janvier, J. Z. Maharrey, M. Meremonte, B. Saint-Louis, Mildor, C. Prepetit and A. Young (2010). Localized damage caused by topographic amplification during the 2010 M 7.0 Haiti earthquake, Nature Geoscience, 3, 778-782.

International Seismological Centre (2012). On-line bulletin, http://www.isc.ac.uk, International Seismological Centre, Thatcham, UK.

Mercier de Lépinay, A. Deschamps, F. Klingelhoefer, Y. Mazabraud, B. Delouis, V. Clouard, Y. Hello, J. Crozon, B. Marcaillou, D. Gaindorge, M. Vallée, J. Perrot, M.-P. Bouin, J.-M. Saurel, P. Charvis and M. St-Louis (2011). The 2010 Haiti earthquake: A complex fault pattern constrained by seismologic and tectonic observations, Geophysical Research Letters, 38, L22305, doi:10.1029/2011GL049799.

Nettles, M. and V. Hjörleifsdóttir (2010). Earthquake source parameters for the 2010 January Haiti mainshock and aftershock sequence, Geophysical Journal International, 183, 375-380, doi:10.1111/j.1365-246X.2010.04732.x.

United States Geological Survey, (2012). On line data base,

earthquake.usgs.gov/earthquakes/eqinthenews/2010/us2010rja6.