RMS FAQ: 2010 Haiti Earthquake and Caribbean Earthquake Risk

1. What were the earthquake characteristics and source of the 2010 Haiti Earthquake?

The magnitude (M)7.0 Haiti Earthquake of January 12, 2010, which occurred at 4:53 p.m. local time, ruptured along a known fault zone on the island of Hispaniola, with an epicenter approximately 25 km WSW of the city center of Port-au-Prince (Figure 1). Initiating at a shallow depth (13 km), most of the energy released by the event occurred over about 15 seconds, although the strongest shaking was of a shorter duration. The major earthquake was followed by a particularly energetic aftershock sequence along the western end of the fault rupture, including a M5.9 at 5:00 p.m. local time and M5.5 at 5:12 p.m. local time on January 12, 2010. Significant aftershocks continue a full week after the main event, including a M5.9 earthquake on January 20, 2010.

An initial tsunami warning was issued for the Caribbean region by the Pacific Tsunami Warning Center (PTWC) on the basis of the event magnitude and an offshore sensor measurement. However, it was quickly rescinded, as the event triggered waves measuring only 12 cm at Santo Domingo, Dominican Republic, and less than 1 cm on a deep-ocean gauge in the Caribbean Sea.

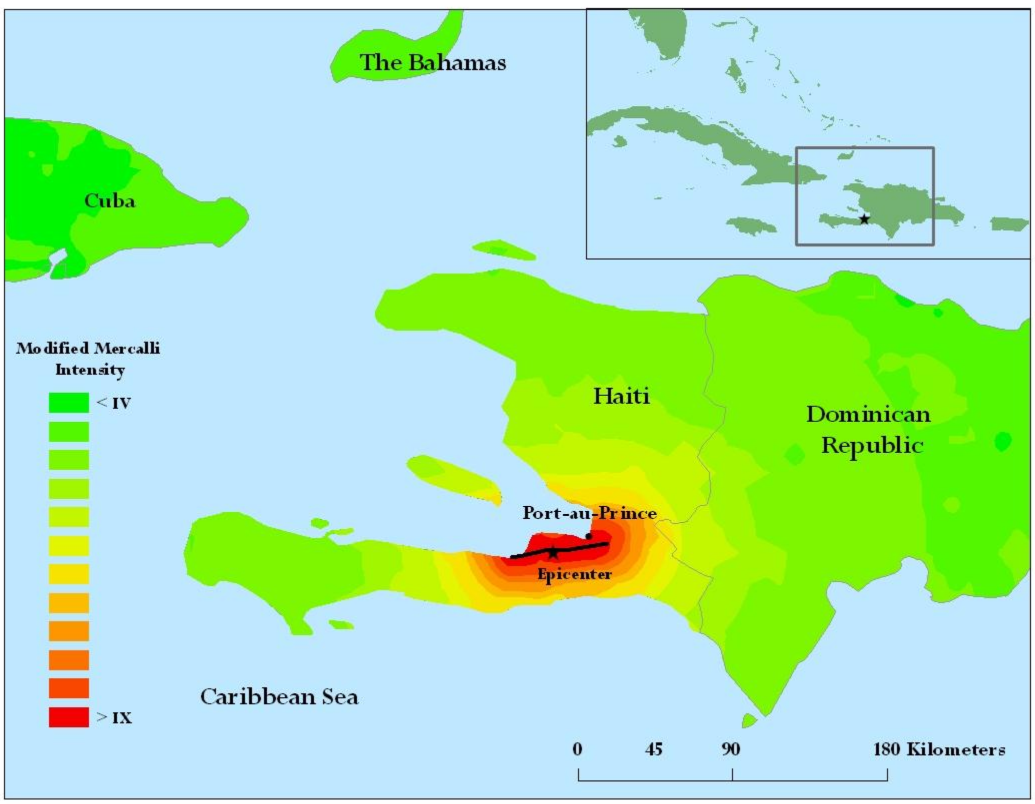


Figure 1: Map of region overlaid with distribution of shaking intensity from the January 12, 2010 earthquake, as measured by the Modified Mercalli Intensity (MMI) scale (Source: USGS ShakeMap, 2010). The star indicates the event epicenter while the bold black line shows the extent of the fault rupture.

The 2010 Haiti Earthquake occurred within the tectonic boundary between the Caribbean and North American plates. This boundary experiences ~20 mm/yr of plate motion through a combination of strike slip and interplate thrust faulting. The strike-slip component of the motion is due to the eastward movement of the Caribbean Plate relative to the North American Plate. On Hispaniola, the majority of the strike-slip plate motion is accommodated across two major features: the Septentrional fault zone, which runs across the northern boundary of the island, and the Enriquillo-Plantain Garden fault zone, which extends from southern-central Hispaniola to Jamaica. The location and characteristics of the January 12 event indicate that it occurred on a segment of the Enriquillo-Plantain Garden fault zone.

While this fault system has not produced a major earthquake in several decades, recent GPS surveying in Haiti indicates that strain is building on the Enriquillo-Plantain Garden fault zone at a rate of approximately 8 mm/yr. Historically, this system is thought to be a potential source for several Hispaniola earthquakes, including events in 1615, 1673, 1684, 1691, 1751, 1761, 1770 and 1860 (Figure 2)[1]. The event in 1770 is referred to as the Port-au-Prince Earthquake and is assumed to have occurred on the same fault segment as the January 12, 2010 event—though with a larger rupture length and estimated magnitude of 7.5.

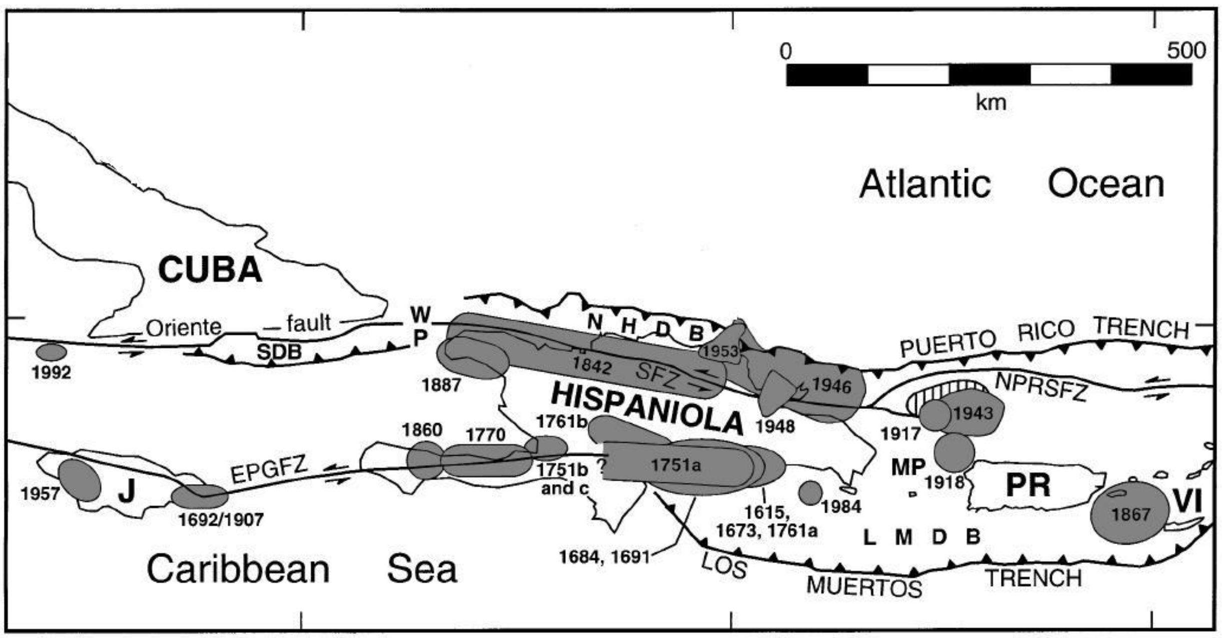


Figure 2: Neotectonic map of north-central Caribbean showing great width (250 km) and complexity of the northern Caribbean plate boundary zone (NCPBZ), as well as the location of major historical earthquakes (year of occurrence shown for each event; 1751a event occurred in October and 1751b earthquake occurred in November). Adapted from Dolan and Wald (1998). EPGFZ is Enriquillo-Plantain Garden fault zone; J is Jamaica; LMDB is Los Muertos deformed belt; MP is Mona Passage; NHDB is northern Hispaniola deformed belt; NPRSFZ is northern Puerto Rico slope fault zone; PR is Puerto Rico; SDB is Santiago deformed belt; SFZ is Septentrional fault zone; VI is Virgin Islands; WP is Windward Passage.

[1] For a full listing of historical earthquakes on Hispaniola from 1551 to 1900 with Intensity ≥VIII, see Appendix.

2. Did the 2010 Haiti Earthquake increase the probability of an earthquake on nearby faults?

The 2010 Haiti Earthquake was the result of concentrated slip along an approximately 36-km long portion of the Enriquillo-Plantain Garden fault zone (shown in dark black line in Figure 3). Slip in this event caused stress changes in the surrounding crust. These stresses can be resolved into so-called Coulomb driving stresses acting on adjacent fault planes that can act to increase or retard the likelihood of future rupture on nearby faults. These stress changes typically extend a distance of 1 to 2 fault lengths from the rupture.

Within a few days of the earthquake, Dr. Eric Calais of Purdue University developed a Coulomb stress analysis for the January 12 event, predicting stress changes on faults of similar trend as the main shock (Calais, 2010). As illustrated in Figure 3, regions where the driving stresses were enhanced are shown in warm colors (e.g., yellow to red) and regions where driving stresses were reduced are shown in cool colors (e.g., aqua to blue). As expected, the M7.0 earthquake loaded adjacent, parallel and semi-continuous fault segments at both ends of the rupture.

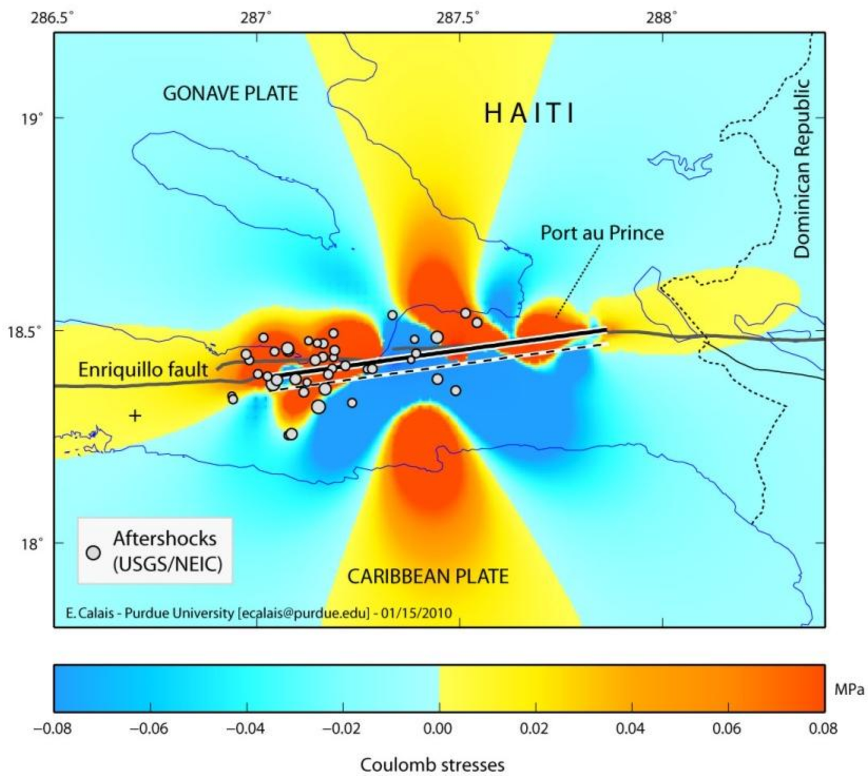


Figure 3: Changes in Coulomb failure stresses caused by the M7.0 Haiti Earthquake, with red indicating regions that have been brought closer to rupture. Calculations assume friction of 0.2 on receiver faults with strike = 90°, dip = 90°, and rake = 0° (i.e., assuming pure left-lateral strike-slip). (Source: http://web.ics.purdue.edu/~ecalais/haiti/)

Such loading could be sufficient to trigger earthquakes on the adjacent segments—particularly if those fault segments were close to failure prior to the January 12 earthquake. As no significant earthquake has occurred along the adjacent segments in the last 150 years, this is a reasonable assumption. A clustering of aftershocks at the western end of the rupture is consistent with the calculation indicating areas of the greatest increase in Coulomb stress.

In addition, it is possible that clustered historical events on the Enriquillo-Plantain Garden fault zone were due to stress triggering. Recent research by Manaker and others (2008) tentatively assigned the 1770 and 1751 earthquakes to this fault system (See events labeled on EPGFZ in Figure 2). With the close spatial and temporal association of these two events along adjacent segments of the fault, one can infer the possibility of stress triggering. A similar explanation has been proposed for the propagating earthquake sequence along the North Anatolian Fault in Turkey, starting in 1939 and ending in a series of two events in 1999 (See RMS, 2008).

While increased likelihood for future events exists at both ends of the 2010 rupture, the timing of such future events remains unconstrained (i.e., we can not say if the events will occur in the next week, the next twenty years, or even longer). However, it is clear from the scientific research that future major earthquakes along this complex plate boundary are inevitable.

3. What is the scope of property damage in the 2010 Haiti Earthquake?

The property at risk in Haiti was, unfortunately, very susceptible to damage (Figure 4). Haiti is one of the poorest countries in the world and the condition of the building stock and infrastructure is a reflection of this poverty. Unlike more developed countries, there is no national building code to which structures are designed and water and power distribution systems are extremely limited.

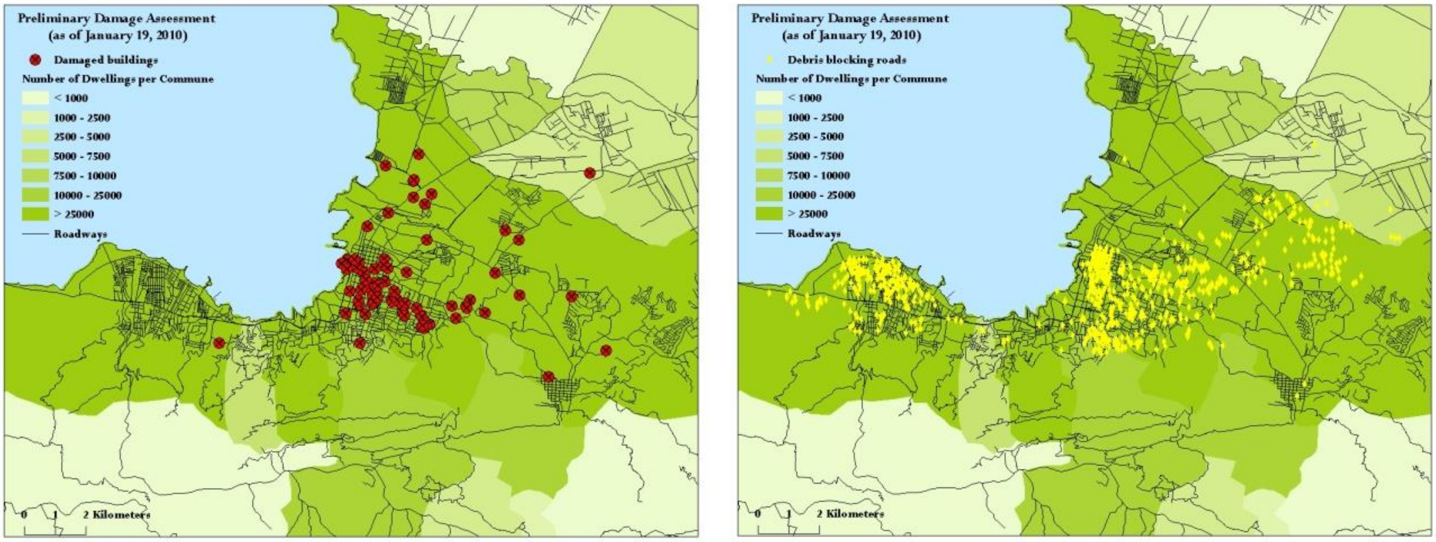
Figure 4: Aerial views of Port-au-Prince before the 2010 earthquake (left) and after the 2010 earthquake (right), illustrating the numerous collapsed buildings (Source: DigitalGlobe).

According to the Institut Haïtien de Statistique et d'Informatique (IHSI or Haitian Institute of Statistics and Informatics) (IHSI, 2010), over 70% of the country's building stock is low rise (i.e., one story in height). L'ajoupas or cottages (translated "country homes") represent over 15% of the country's construction, with much higher concentrations in rural regions (e.g., 92.5% in rural and 7.5% in urban regions). Multi-story buildings represent less than 10% of Haiti's property at risk and are concentrated in urban regions.

Over 90% of the walls of buildings are constructed using one of four material(s): concrete/blocks, earthen materials, clisse (translated "woven wood mats"), or bricks/rocks; with all materials, there is often no reinforcement (e.g., steel rebar). In rural regions, earthen materials are most common; in urban regions, concrete/blocks are utilized for close to 80% of the built walls. Similar patterns are seen in flooring materials, with hard-packed earth in rural regions and concrete in urban regions. Close to 70% of roofs are constructed using light metal (i.e., tin).

These heavy materials used to construct the walls, often with no reinforcement, caused numerous building collapses, resulting in extensive property damage and loss of life. Utilizing aerial satellite imagery, numerous worldwide agencies have begun cataloging the scope of damage. For example, UNOSAT, the UN Institute for Training and Research (UNITAR)

Operational Satellite Applications Programme, developed a preliminary damage assessment map of major buildings and infrastructure in and around Port-au-Prince (UNOSAT, 2010). This assessment (as of January 19, 2010, and illustrated in Figure 5), is somewhat limited in scope, with its focus on non-residential buildings (e.g., schools, hospitals, government buildings). However, this information can be combined with residential building damage assessments and ground reconnaissance to ascertain the full scope of damage.



(a) (b)

Figure 5: Inferred preliminary damage using GeoEye-1 satellite imagery recorded on January 13, 2010, in and around Port-au-Prince, Haiti: (a) locations of 80 damaged buildings consisting of hospitals, government and UN offices, schools, churches and industrial complexes; (b) areas where debris is visible (Source: UNOSAT, 2010); both maps also illustrate the density of residential building stock (in number of dwellings per commune), as estimated from the 2003 Haitian census.

Of particular concern following the 2010 Haiti Earthquake is the damage to informal housing in shanty towns on the outskirts of the city center of Port-au-Prince (Figure 6). Over the past several decades, there has been a global trend toward urbanization, with an exodus of populations from the countryside to major cities. Rural poor in developing countries often head for a better life in the capital cities, which represent the main economic engine of the country.

As rural poor migrate to the major cities, they often take up residence in shanty towns on the city margins, as seen in Port-au-Prince. They live in self-constructed residences, built using available materials. The substandard construction cannot stand up to the natural hazards that are present across so many capital cities—from hurricanes to landslides and earthquakes.[2]

[2] RMS is currently carrying out a new type of collaborative model development effort designed to quantify the economic and humanitarian impacts of future earthquakes on capital cities in developing countries, with South America as an initial test case. For more information, see: http://www.rms.com/AboutRMS/Expertise/RiskReduction_Mitigation/Default.asp

Figure 6: Informal housing destroyed following the 2010 Haiti Earthquake. (Source: UNDP Global; http://www.eqclearinghouse.org/20100112-haiti/)

4. Which secondary hazards contributed to the loss following the 2010 Haiti Earthquake?

While the primary damage from an earthquake is due to ground shaking, secondary hazards are phenomena that can cause additional loss to people and property at risk. The most relevant secondary hazards are liquefaction and landslide—both of which played a role in increasing the damage and loss to the island nation of Haiti.

Liquefaction occurs when poorly-consolidated, water-saturated sediments temporarily lose their bearing capacity (and "liquefy") during strong ground shaking. Much of the flatlands in Port-au-Prince comprise sedimentary materials prone to this phenomenon and aerial images after the January 12 event indicate areas of liquefaction—particularly in and around the port facilities. These show lateral spreading along wharfs, collapsed jetties, and cranes that are now submerged in the bay. Incapacitation of the ports has contributed to the difficulty in transporting aid supplies and personnel to the region.

This is not a unique circumstance, as widespread liquefaction was described in the previous earthquakes of 1751 and 1770 on the island of Hispaniola. Moreover, it is not a surprising circumstance, as port facilities are often built on reclaimed land susceptible to liquefaction. The resultant damage can limit the capacity to bring in the needed heavy equipment to respond to the disaster. The 1999 Kocaeli Earthquake in Turkey generated extensive liquefaction damage that contributed to the destruction of nearly half of the jetties in the Izmit Bay region.

Landslides can occur without the influence of an earthquake, but strong shaking can act as a trigger for multiple slope-driven ground failures that otherwise might not occur simultaneously. The southern parts of Port-au-Prince, as well as the upland region along the Enriquillo-Plantain Garden fault zone, have many areas where steep slopes combined with long-term deforestation have created high landslide susceptibility. Initial reports suggest there have been numerous landslides in the epicentral region, while preliminary assessments in southern Port-au-Prince indicate high concentrations of building damage in these sloping areas where soil failures are likely to have contributed.

The contribution of landslide and liquefaction hazards on the overall damage and loss is not unanticipated. A 2009 UN planning study for Port-au-Prince highlighted that over 90% of the informal settlements were in ravines or on hillsides, with almost 40% in the latter category (UN-HABITAT, 2009). Concentration of informal housing in these susceptible areas is a common theme in many developing countries.

5. What is the RMS estimate of casualties from the 2010 Haiti Earthquake?

RMS estimates approximately 250,000 fatalities as a result of the 2010 Haiti Earthquake. This is a best estimate based on the limited data available within 36 hours of the occurrence of the event and the immediate impacts of the earthquake—primarily building collapse. This preliminary estimate of 250,000 casualties could potentially increase over the coming weeks due to compounding factors, such as the spread of infectious diseases, lack of food and water, and limited access to medical care. On January 20, 2010, a representative of the aid group Partners in Health estimated that up to 20,000 people were dying each day due to the lack of medical care (specifically medical operations).

The initial casualty estimates were developed using publically available information including population data, ground shaking intensities, and Haitian construction materials and practices, as previously summarized. Specifically, casualties were estimated using a 1-km population density grid (based on the 2005 LandScan™ Global Population Database and scaled upward to match the current population projections from the UNDP) in conjunction with the Modified Mercalli Intensity (MMI) estimates from the USGS ShakeMap, published on January 13, 2010 (See Figure 1). The building vulnerability was assumed to map on average to unreinforced masonry construction, which is extremely susceptible to collapse and heavy enough to cause significant casualties to occupants. This is consistent with the prevalent construction type in the urban regions of Haiti (i.e., blocks/concrete), but actual construction practices vary and include reinforced concrete, reinforced masonry, and unreinforced self-constructed buildings. Figure 7 shows the density of fatalities (i.e., number of fatalities per km^2) across the region, highlighting the overwhelming loss of life in Port-au-Prince (shown in red).

There is considerable uncertainty in casualty estimates developed within hours of an earthquake and the lack of recent population data and building inventory data specific to Haiti increases the uncertainty. The actual number of casualties is likely to not be known for some time. On January 14, 2010, the International Red Cross estimated that over 50,000 were killed as a result of the earthquake. On January 19, 2010, representatives from the Pan American Health Organization, who are coordinating response efforts, gave an estimate of 200,000 fatalities as a result of the earthquake. However, even given this uncertainty, the use of rudimentary data to quickly estimate loss of life is extremely useful for real-time estimates, assisting in the response and recovery following an event.

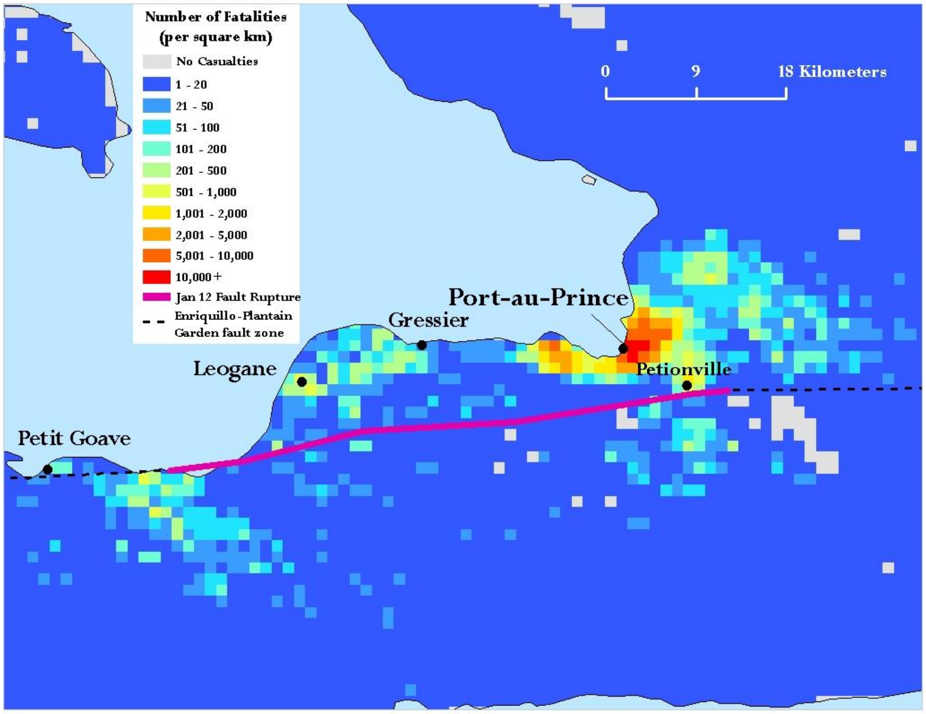


Figure 7: Map of the preliminary number of fatalities (per km^2) as a direct result of the 2010 Haiti Earthquake, developed by RMS within 36 hours of the event. Areas with no reported fatalities (in grey) are regions where the population database indicated the presence of no population.

6. What is the expected impact of the 2010 Haiti Earthquake on the global insurance market?

According to Axco Insurance Information Services, non-life (property/casualty) insurance penetration in Haiti is extremely limited, measuring around 0.28% of its gross domestic product. Therefore, the impacts of the event on the insurance market will be minimal. The ability of Haiti to recover from the January 12 event will not be a function of insurance payments, but due to international post-event funding.

Some funding has already been made available through the triggering of an $8 million payout from the Caribbean Catastrophe Risk Insurance Facility (CCRIF). The CCRIF is not insurance per se, but a program established by the World Bank to provide initial funding to Caribbean governments to pay for initial costs in the aftermath of an event (e.g., wages for government employees and clean up). Unfortunately, this 'risk sharing pool' was developed to assist in moderate-sized disasters and was not intended to provide significant assistance in a massive humanitarian catastrophe like the 2010 Haiti Earthquake.

7. What are the characteristics of the earthquake hazard and risk across the Caribbean?

Many of the islands in the Caribbean are a direct result of the active tectonic forces that generated the January 12 earthquake, lying on the boundary between the Caribbean and North American plates. Virtually all of the islands have experienced moderate to severe earthquakes over the past 300 to 400 years. These plates continue to move relative to one another and will generate earthquakes in the future. The character of seismic hazard across the islands of the Caribbean varies as a function of their location in the region. For example, the Lesser Antilles to the East can experience significant subduction-related earthquakes, which can be much larger than the 2010 Haiti Earthquake, but are generally deeper and offshore. Moreover, the coastlines of the Caribbean islands are at risk from earthquake-induced tsunamis, with numerous damaging events in the historical record. For example, in 1946, a M8.0 earthquake off the northern coast of the Dominican Republic generated a tsunami that killed 1,800 people in the town of Matancitas, which was abandoned as a result. Major tsunamis also struck the west coast of Puerto Rico in 1918 and the Virgin Islands in 1867.

Regions with greater insured exposure that have tectonic features most similar to the 2010 Haiti Earthquake are the Dominican Republic and Jamaica. Both have significant strike-slip faults that accommodate the shifting between the Caribbean and North American plates. As previously mentioned, the northern half of Hispaniola is dominated by the Septentrional fault zone; the Dominican city of Santiago is particularly exposed to this fault zone. On the southern half of Hispaniola, the Enriquillo-Plantain Garden fault zone continues to the west where it intersects Jamaica near the capital city of Kingston. Major earthquakes struck Kingston in 1692 and 1907.

Examining the relative risks of the densely populated cities on Hispaniola, Santiago of the Dominican Republic, situated along the Septentrional fault zone, has the highest risk across the island, as well as the highest seismic risk of any major city in the Caribbean. Santiago is followed by Port-de-Paix of Haiti, also situated along the Septentrional fault zone. Port-au-Prince, Haiti, and Kingston, Jamaica have similar risk levels, primarily due to their proximity to the Enriquillo-Plantain Garden fault zone. The last of the key cities in Hispaniola is Santo Domingo, Dominican Republic, situated in the lowest hazard region of the island, but with a history of damaging earthquakes. The seismic risk to Santo Domingo is still higher than for any city in Puerto Rico.

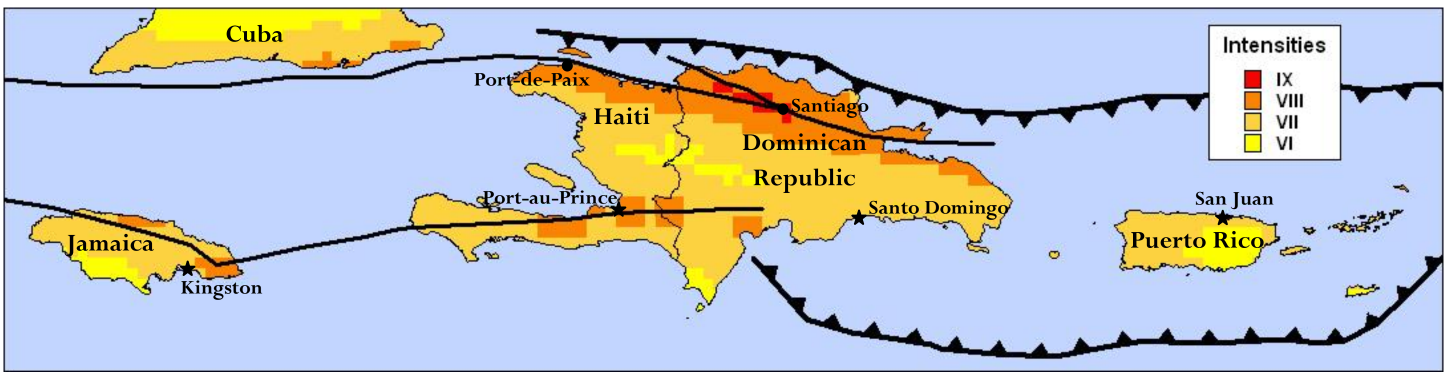


Figure 8: Seismic hazard map of the Caribbean islands of Haiti, the Dominican Republic, Jamaica, Puerto Rico, and southern Cuba, as estimated by the RMS® Caribbean Earthquake Model (475-year MMI).

8. Are there any historical natural disasters comparable to the one developing in Haiti in 2010?

One cannot directly compare the 2010 Haiti Earthquake to a particular historical natural disaster; however, some parallels can be made to historical earthquakes with high casualties or similar damage patterns. For example, the official number of fatalities from the 1976 Tangshan Earthquake in China, which completely destroyed the city of Tangshan, was 242,400—similar to the initial RMS casualty estimate of 250,000 for the 2010 Haiti Earthquake. The 2008 Wenchuan Earthquake killed close to 70,000 people in China, and like China the impacts of landslides in mountainous rural areas may be significant Haiti in 2010.

The 2010 Haiti Earthquake, like all disasters, is unique in its own way. Haiti is a poor, island nation, relying on imports for many goods. The damage to the port facilities of Port-au-Prince is going to severely hamper not only response and recovery but the functioning of the country as it moves forward. As the response to those injured from the earthquake evolves, more individuals could die from wound infections and water borne diseases could potentially resurge. For those displaced from the event, the scavenging of materials to rebuild is concerning, as better construction materials and methods are needed to avoid a repeat of the current disaster.

Once the response and recovery phase of the disaster is complete, ground reconnaissance is needed to assess the full impact of the event on the building stock and infrastructure. RMS is currently evaluating the feasibility of sending a reconnaissance team into Haiti to perform ground reconnaissance, coordinating with other research institutions.

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Appendix

Table: Historical Earthquakes on Hispaniola from 1551 to 1990 with Intensity ≥ VIII (Source: Jimenez, 1989).

Date	Maximum Intensity	Regions and Cities Impacted
1562 December 2	IX	La Vega and Santiago devastated, Puerto Plate suffered damage, 16 people killed. Aftershocks for 30 days
1615 September 8	IX	Santo Domingo devastated, the majority of the buildings were destroyed. Aftershocks for 40 days.
1673 May 9	IX	Santo Domingo devastated, lots of damage, 24 people killed. Aftershocks continued for more than 40 days.
1684	VIII	Azua and Santo Domingo seriously damaged.
1691	IX	Azua destroyed, damage in Santo Domingo.
1751 October 18	X	Destruction of Azua, significant damage in Santo Domingo, El Seybo, felt in Haiti. Tsunami.
1751 November 21	IX	Destruction of Port-au-Prince, considerable damage in Culdesac (aftershock).
1751 November 23	VIII	Earthquake of similar strength to the previous, damage in Port-au-Prince, (aftershock).
1761 October 28	VIII	In Santo Domingo almost all of the buildings suffered damage, especially the churches, monasteries and hospitals, aftershocks for almost 30 days.
1761 November 21	IX	Azua destroyed, ground deformation in Azua and San Juan, felt in Santiago, La Vega and Cotui.
1770 June 3	VIII	Catastrophe in Port-au-Prince and Petit-Goave, felt in Santo Domingo, Port-de-Paix, and Cap-Haitien.
1842 May 7	X	Damage on the entire island, destruction in Port-de-Paix, Morel Saint Nicolas and Santiago, 5000-6000 killed, tsunami.
1842 May 8	VIII	Affected the same regions as the May 7 event. (Aftershock)
1860 April 8	VIII	Considerable damage in Petit-Goave, Anse-A-Veau, very strong event.
1887 September 23	VIII	Disaster in Moles Saint Nicolas, Port-de-Paix and Cap-Haitien, felt in all of Haiti, tsunami along northern coasts.
1897 December 29	IX	Damage in Santiago, Cathedral, churches and the Palace of the governor in ruins, felt in Guayabin, Guanabano-Abajo, Altamira and Navarrete.