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Earth Sciences

The Science and Mitigation Efforts of the Tohoku Earthquake

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Introduction

On March 11th, 2011, the "Tohoku" earthquake occurred with magnitude of 9.0 near the northeast coast of Japan. It struck in the afternoon at 2:46:23 PM (USGS, 2016). Since Japan is geographically near a plate boundary, more precisely a tectonic subduction zone, it is greatly prone to many earthquakes and tsunamis. Adding to that, Japan is also near two tectonic plate triple junctions (one of them being the Boso Triple Junction). Regardless of Japan's world-renowned preventive measures against natural disasters such as those caused by seismic activity, the "Tohoku" earthquake has been one of the worst it has ever faced. It was a major triple-event tragedy, one lead to the next: an earthquake, a tsunami, and finally a nuclear threat. The earthquake triggered a massive tsunami that reached the coast in less than 20 minutes. It has been reported that the tsunami had reached a maximum wave height of up to almost 40 meters, and a stretch measuring more than 500 km of the coast was directly impacted touching regions from Tohoku to Kanto (WHO, 2012). Not long after, it caused 3 nuclear power plants from the Fukushima and Onagawa regions to automatically shut down. Subsequently, this lead to major contamination concerns such as food safety, drinking-water quality and naturally environmental issues. Over 440,000 individuals were evacuated from their homes due to the many concerns. (Davis, C. *et al.*, 2012) Although the earthquake caused a great disturbance, it was the tsunami that claimed more than 90% of the lives lost on that day. Finally, the aftermath lead to 15 894 confirmed deaths, 2 563 individuals gone missing and 6 152 people injured (NOAA, as of January 8th, 2016).

The Earthquake

Annually, the Pacific plate moves westward at an approximate rate of 83 to 90 mm per year, and subducts below the North American plate (USGS, 2016). The Tohoku M9.0 earthquake resulted from "megathrust" faulting near the subduction zone between the Pacific and North America plates (more generally known as the Japan Trench). During this event, many foreshocks occurred including one of a magnitude of 7.2 on March 9th. It was approximately 40 km away from the Tohoku earthquake epicentre. Afterwards, 3 more major ones exceeding M6 followed on that same day (NOAA, 2016). And finally, up to 647 aftershocks were triggered (as of August 4th, 2011) of which 120 of them had a magnitude of 6.0 or more (WHO, 2012). The first major foreshock (M7.2) was not originally regarded as a foreshock per se, but rather as a main earthquake event. The main reason was because of its sheer magnitude. Little notice was given to it considering it was not dangerous to the population: it did not cause any severe damage or tsunamis, and was relatively far from the coast and deep under the sea. Had it been recognized as a foreshock and not as a principal earthquake prior to the M9 event, there would have been a greater emphasis on the importance of hazard mitigation.

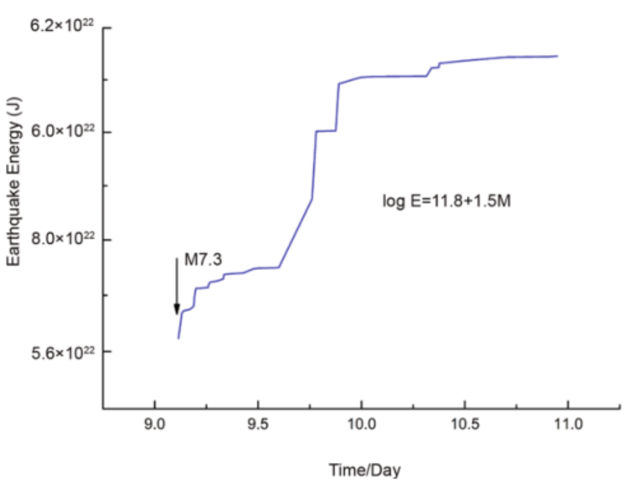

Figure 1 (Liu *et al.*, 2012)

If we observe the energy release of the foreshock sequence along with the main shock, we can observe that there is a gradual increasing pattern indicating that there is an imminent major earthquake event (Liu *et al.*, 2012).

The M9 earthquake's epicentre was located at a depth of 24.4 km (i.e. seafloor) approximately 130 km (WHO, 2012) off the east shore of Sendai city (38.322 N, 142.369 E, from NOAA, 2016). The actual origin or hypocentre (focus) was at a depth of 32 km. The megathrust caused the fault to slip upwards by 30 to 40 meters across an area of around 300 km long by 150 km wide (along-strike and down-dip direction,

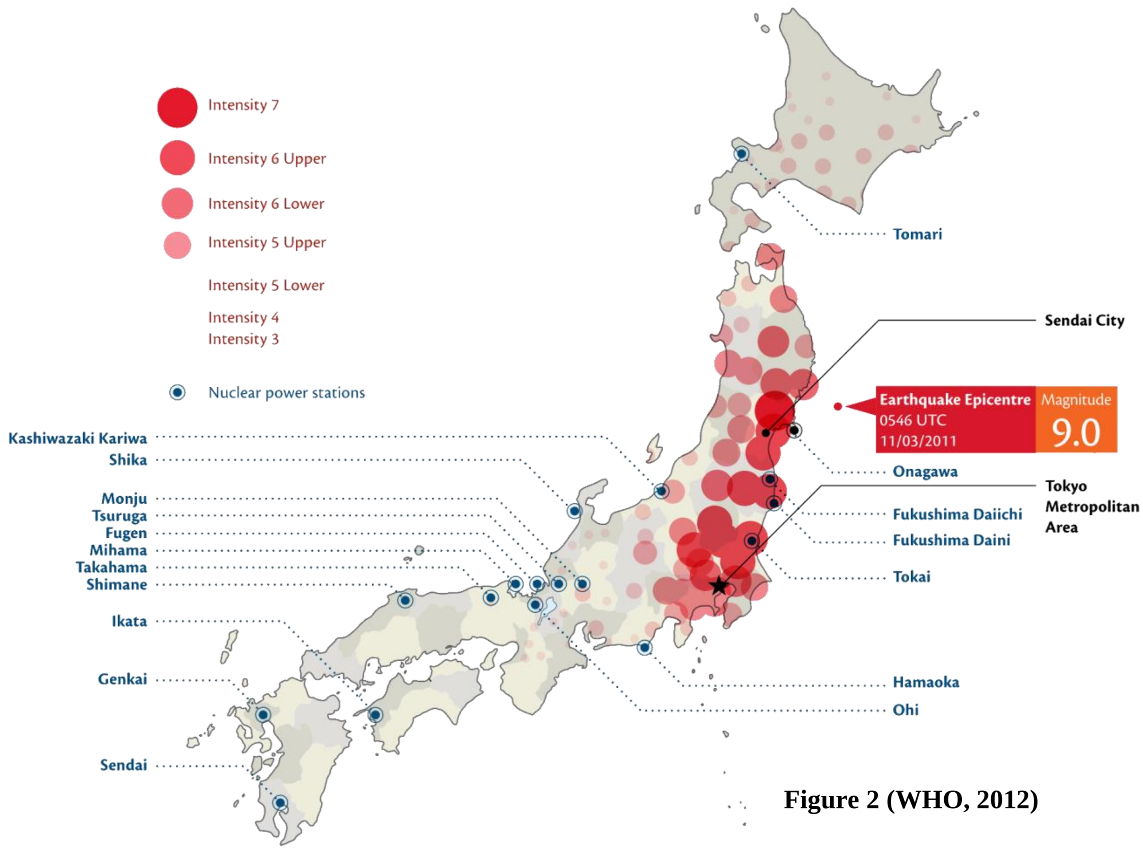

Figure 2 (WHO, 2012)

respectively). The rupture caused the seafloor to be lifted up by as much as 9 meters (Davis, C. *et al.*, 2012). The earthquake lasted roughly six minutes and was powerful enough to move Japan's largest island, Honshu (literally meaning "Main Island"), 2.4 meters eastward (WHO, 2012). Peak ground acceleration (PGA) is the maximum ground acceleration caused by seismic activity experienced at a given time and place. In other words, it is the actual force or shaking of the ground (how hard the ground shakes) expressed in units relative to gravity. The PGA measured directly in the Miyagi prefecture was 2.7 *g*. Point in fact, 2.7 times the gravitational acceleration of Earth (~9.80 m/s^2). It is one of the highest ever to be recorded (Davis, C. *et al.*, 2012). Additionally, it managed to shift the Earth on its figure axis (on which Earth's mass is balanced) by an estimated distance of 17 cm (NASA, 2011). In other words, it changed Earth's distribution of its mass. According to NASA's Jet Propulsion Laboratory, this should have caused the Earth to rotate slightly faster, shortening its day length by approximately 1.8 microseconds. In conclusion, despite M9.0 being the strongest Japan has ever faced, the earthquake in itself was the most devastating part of the March 2011 tragedy. It was only the beginning.

The Tsunami

The earthquake triggered a large tsunami which took only 15 minutes for the wave to reach the coast (WHO, 2012). The rupture from reverse fault caused the seafloor (hanging wall) to move upwards. Subsequently, this caused a massive tsunami wave (15 to 20 m high) to propagate throughout the Pacific Ocean. It was so powerful that it travelled up to 10 km inland and affected more than 2100 km of the eastern coastline of Japan (Davis, C. *et al.*, 2012). Reported by 2011 Tohoku Earthquake Tsunami Joint Survey Group, the highest tsunami wave reached 38.9 masl (meters above sea level) in the Iwate Prefecture (NOAA, 2016). Unfortunately, even the world’s largest tsunami protection wall (located at Kamaishi Bay) measuring 8 meters above sea level was bested by a wave measuring 14 meters in height (Davis, C. *et al.*, 2012). Tsunami wave amplitudes increase as the water gets shallower. On the other hand, the flow speed decreases. In other words, the water is compressed. The total energy of the wave remains constant due to the principal of conservation. However, they will relatively be more deadly than waves that are rather short and fast, because tsunami protection walls can only go so high. Approximately 1 km off the shore of the Sendai coast, the waves have been estimated to reach velocities up to 14 m/s (Goto *et al.*, 2012). Other than the fact that shallower waters can cause deadlier tsunami waves, the topography and ground surface conditions of the local area can increase flow speeds. For example, sand layers or smooth flat surfaces rather than uneven and rocky surface have reduced friction causing the waves to flow with greater ease. This was the case with the runway of the Sendai Airport. It was due to the relatively lower friction of the paved surface (Goto *et al.*, 2012). Following this principle, it means that the tsunami wave slowed but reached higher altitudes enabling them to go over the protection walls, they then would increase in speed again due civilization such as urban environments and surfaces: for example, paved roads, parking lots, etc. Wave velocities approaching 32 m/s (115 km/h) occurred near Miyako city (Goto *et al.*, 2012). It was actually the tsunami, not the actual earthquake that was much more deadly and destructive. The Tohoku event caused a total of 12 143 individuals to drown to death, that's over 90% of the deaths accounted for the entire March 2011 event (NOAA, 2016). It was a disaster. Over a million buildings (mostly residential) were either damaged or totally destroyed. The aftermath devastated entire communities, 127 197 buildings were completely destroyed, 232 083 partially-collapsed, because of the tsunami, the ground shaking and local fires started by the event itself (Davis, C. *et al.*, 2012). At least 345 fires occurred in 12 different prefectures of which more than 40% of those fires were spawned due to the massive tsunami (NOAA, 2016). The event caused oil leakages that result in fires covering many square kilometres.

In a particular event, an explosion occurred at the Cosmo Oil refinery resulting in a fire that burned for two days (Davis, C. *et al.*, 2012). In in the town of Taro (near where the tallest tsunami wave was recorded, ~38 m), the successive massive waves caused the destruction of the town's only health facility. However, due to well-preparedness, knowledge of evacuation routes and a timely alert, all inpatients were evacuated successfully. The health staff then established a temporary clinic on an unaffected area on a hill (WHO, 2012). Had it not been for the measures and plans that were put into in advance, the town of Taro would have been left with no health care centre until the main public health response. About half a million people lost their homes: around 7 600 houses were destroyed due to ground shaking, 19 000 damaged due to liquefaction. The tsunami's inundation total surface area was estimated to be 561 km^2 (NOAA, 2016). In total, it was estimated that the earthquake and tsunami created 25 million tons of debris (Davis, C. *et al.*, 2012). Entire ships were overturned and brought on land, vehicles were crumpled and the roads were completely flooded (The Economist, 2012).

Prevalence of Diseases

After the tsunami and the earthquake, power was out, roads were flooded, gas lines were interrupted and debris was everywhere. On March 16th, 1 794 964 households in 12 prefectures had no running water (WHO, 2012). The water and soil from the tsunami may have been contaminated and contain microbes such as Escherichia coli and Legionella species (incubation period of 2-10 days) that can lead to legionellosis: a form on pneumonia (Takashi, T. *et al.*, 2012). In addition to legionellosis, several other cases of diseases were reported after the event: influenza A(H3N2), pandemic influenza A(H1N1), gastroenteritis, tetanus, and measles. It was mainly small cases or clusters that would contract legionella-associated diseases (such as pneumonia, tuberculosis, tetanus or chicken pox) (WHO, 2012). Although these commutable diseases did not have huge outbreaks, many evacuees were exposed to cold and unhygienic conditions. Malnutrition, insufficient food provision, and lack of running water were other factors that contributed to this negative effect.

The Nuclear Threat

The great eastern Japan earthquake caused 3 nuclear power stations to automatically shut down: a total of 10 nuclear reactors from Fukushima Daiichi, Fukushima Daini and Onagawa power stations. The tsunami had damaged the Fukushima nuclear facilities' backup diesel power generators which are needed for the emergency core cooling systems. Mainly, it affected three units of the Fukushima Daiichi power plant (WHO, 2012). The tsunami, having surpassed the seawalls, lead to other serious problems at Fukushima: 3 large explosions and radioactive leakage. With over 200 000 people being evacuated from the surrounding area, the damage to the Fukushima nuclear power plants resulted in being considered the worst nuclear accident in history after Chernobyl 1986 (Davis, C. *et al.*, 2012). On March 13th 2011, the Onagawa nuclear power was declared to be a Level 2 ("Incident") on the International Nuclear and Radiological Event Scale (INES) due radiation levels higher-than-permitted were measured. It was on March 15th that almost 270000 individuals were evacuated: 20 km away from the Fukushima Daiichi power plant and 10 km away from the Fukushima Daini power plant. Eventually, the Onagawa and Fukushima Daini were contained. However, the Fukushima Daiichi continued to experience major cooling problems with radiation levels on the rise. Cooling efforts followed on March 18th such as spraying water on the affected areas from helicopter and fire trucks. Finally, the government of Japan raised the event of the three nuclear units to Level 5 ("Accident with wider consequences") on the INES. Despite Japan's cooling operations, the situation remained serious until finally, because of the release of a significant amount of radioactive material, the INES rating was upped to a Level 7 ("Major accident"), the same rating as Chernobyl 1986. On April 22nd 2011, a 20 km radius zone around the Fukushima Daiichi power plant was officially declared a No-entry Zone (a nuclear "dead zone"). Furthermore, the radius zone between 20 km to 30 km was officially declared as Planned Evacuation Zones and Emergency Evacuation Preparation Zones based on radiation exposure estimates. In these zones, the annual exposure estimate was 20 mSv. It equates to spending eight hours a day for 365 days outdoors with a dose rate of 3.8 μSv/h and staying indoors for 16 hours with a dose rate not exceeding 1.52 μSv/h. Consequently, on April 30th, the Chief Cabinet Secretary announced that the Government will adopt an "Interim policy" that elementary school grounds are to be restricted if the outside radiation dose rate exceeded 3.8 μSv/h. On June 16th, the national Government announced that it would conduct monthly radiation measurements and if the cumulative annual result did not exceed 20 mSv, the Planned Evacuation Zone designation would be lifted (WHO, 2012). The aftermath of this nuclear threat effectively lead to the radioactive contamination in food, drinking-water and the environment.

Food Concerns

Since humans and animals in general are not primary producers, our food must come from other organisms: we require organic compounds that we cannot synthesize ourselves. This means that "our" food comes from the "environment", and what affects the environment (such as effects on air, soil, rain) will consequently affect "our" food. Once radioactive contaminants (or any other type in general) enter an ecosystem, they can be absorbed by plants or ingested by animals and they will forever remain in the environment unless it is biodegradable. That being said, radioactive contaminants found in food in Japan was first reported on March 19th 2011. The government announced that milk from the Fukushima Prefecture and spinach from the Ibaraki Prefecture had radiation levels exceeding government safety. By July 2011, over 6500 food samples tests were conducted by the Ministry of Health, Labour and Welfare. The samples were tested for radioactive iodine and caesium (WHO, 2012). Currently, they still continue to their tests to this day. The food samples tested include agricultural products, vegetables, fruits, meats, milk, fish and edible fungi. Radioactivity violation rates in food are found to be extremely low and are constantly decreasing, now less than 1% of 1 mSv/year. In a report they issued for February 8th-14th 2016, out of 4191 samples tested only 1 sample had radionuclides exceeding the standard limit (Ministry of Health, Labour and Welfare, 2016).

Drinking-water Concerns

The Ministry of Health, Labour and Welfare collected data on presence of radionuclide (I-131, Cs-134 and Cs-137) in the drinking water mainly from the Fukushima Prefecture and some from the Ibaraki Prefecture. Eventually, the Ministry released a notice on the provisional regulation of the drinking water: a maximum of 300 Bq/kg for iodine and 200 Bq/kg for caesium. Two days later (March 21st, 2011), it released an additional notice that there should be a maximum dosage of 100 Bq/kg of Iodine for infants in the drinking tap water. By April 1st, the restriction on tap water consumption for the general public had been lifted. On 10 May, the remaining restriction for infants was lifted after regular monitoring showed radioactivity levels to be lower than the maximum permissible limits (WHO, 2012).

Environmental Concerns

The Earth system is very dynamic and can be extremely complex. Its subsystems are all intertwined and connected. Its main components are: the atmosphere, the hydrosphere, the lithosphere and finally the ecosphere. Humans find themselves in the ecosphere which is the most impacted of all.

Air

In a radius from 20 km to 60 km around the Fukushima power plant and other nearby prefectures, the radiation levels were being constantly monitored. As of early July 2011, radiation levels seem to have remained stable. Naturally in the area around the north-western part of the power plant, clusters of higher levels were still being measured. Only a few cases were reported to higher than background radiation levels. However, they were considered low in terms of risk to human health (WHO, 2012).

Seawater

Adding on to the previously discussed drinking-water concerns, the Ministry of Education, Culture, Sport, Science and Technology (MEXT) began monitoring seawater from offshore sampling stations. On 23 March, the Tokyo Electric Power Company (TEPCO) also began its surveillance of radiation levels around its Fukushima power plants (WHO, 2012). Not long after, radioactive Iodine (I-131) was found in later samples around the Fukushima Daiichi nuclear plant that had levels exceeding 1,850 times the legal limit. Consequently, TEPCO has faced growing criticism for its handling of the situation, despite their efforts (The Telegraph, 2011).

Soil & Long-term Concerns

As soon as March 18th 2011, MEXT began publishing its results on the radioactivity levels of the soil in the surrounding areas of the Fukushima Daiichi nuclear power plant. Their samples come from 36 different study points within a 20 km to 55 km radius. Since long-term epidemiologic effects are still unclear, WHO’s International Agency for Research on Cancer (IARC) called for long-term support for research for this event and the event of Chernobyl 1986 (WHO, 2012). Effects vary greatly on dosage and dose rate. For example, high level radiation exposure in a short period of time versus low levels for a longer period on individuals (public and plant workers): it is not known whether or not they will contract some form of cancer.

Conclusion

The great Tohoku-oki earthquake of March 11th 2011 was a triple-event that devastated Japan. In total, over 15 000 people were deceased. A magnitude 9.0 earthquake occurred due to a rupture in the Japan Trench approximately 130 km of the shore of Sendai city. The reserve fault slipped causing the seafloor (hanging wall) to move upwards by 30 to 40 meters. Consequently, it triggered a massive tsunami that drowned more than 12 000 people. Within those that survived some were left wounded and others sick from legionella-associated diseases such as pneumonia and tetanus. The tsunami and earthquake caused ships to be overturned and washed up ashore, entire areas to be completely flattened, and the event started over 640 local fires. Subsequently, it lead to a serious nuclear threat. The radiation leakage at the Fukushima nuclear power plant contaminated Japan's food, drinking water and soil within a radius larger than 20 km. Japan considered themselves to be fortunate that the situation did not get any worse.

References

Buis, A. (NASA/JPL), 2011, "Japan Quake May Have Shortened Earth Days, Moved Axis", http://www.nasa.gov/topics/earth/features/japanquake/earth20110314.html , Retrieved February 2016

Davis, C. *et al.*, 2012, Advance prediction of the March 11, 2011 Great East Japan Earthquake: A missed opportunity for disaster preparedness. International Journal of Disaster Risk Reduction, v. 1, pp. 17-32.

Demetriou, D. (The Telegraph), 2011, Japan nuclear crisis: radiation levels in seawater jump, http://www.telegraph.co.uk/news/worldnews/asia/japan/8415260/Japan-nuclear-crisis-radiation-levels-in-seawater-jump.html , Retrieved February 2016

The Economist, 2012, Japan after the 3/11 disaster: The death of trust, "Nuclear energy: The dream that failed" (Print Edition), http://www.economist.com/node/21549917 , Retrieved February 2016

Goto, K. *et al.*, 2012, The future of tsunami research following the 2011 Tohoku-oki event, Sedimentary Geology, v. 282, pp. 1-13, doi:10.1016/j.sedgeo.2012.08.003

Liu, J., and Zhou, Y., 2012, Predicting earthquakes: The Mw9.0 Tohoku Earthquake and historical earthquakes in northeastern Japan: International Journal of Disaster Risk Science, v. 3, p. 155–162, doi:10.1007/s13753-012-0016-0

Ministry of Health, Labour and Welfare, 2016, Information on the Great East Japan Earthquake: Food, http://www.mhlw.go.jp/english/topics/2011eq/index_food.html , Retrieved February 2016

National Oceanic & Atmospheric Administration: National Centers for Environmental Information (NOAA/NCEI), 2015, "Great Tohoku, Japan Earthquake and Tsunami, 11 March 2011", http://www.ngdc.noaa.gov/hazard/11mar2011.html , Retrieved February 2016

Takahashi, T. *et al.*, 2012, Infectious Diseases after the 2011 Great East Japan Earthquake, Journal of Experimental and Clinical Medicine, v. 4, Issue 1, p. 20-23, doi:10.1016/j.jecm.2011.11.013

United States Geological Survey (USGS), 2012, M9.0 - near the east coast of Honshu, Japan, http://earthquake.usgs.gov/earthquakes/eventpage/usp000hvnu , Viewed Feb.2016

World Health Organization: Western Pacific Region (WHO/WPRO), 2012, The Great East Japan Earthquake: A story of a devastating natural disaster, a tale of human compassion, ISBN 978 92 9061 568 2