Exploring the status of tsunami early warning systems in Samoa

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Abstract
Historical records indicate that a total of sixty tsunami events have impacted the Samoa Islands between the period 1837 to 1980. The majority of these tsunami events were teletsunamis which originated from seismic activity associated with the Pacific Ring of Fire, although local volcanism have also played a role in generating local tsunami events. Relative to the impacts of other natural hazards such as tropical cyclones and flooding, there has been the perception that the magnitude of tsunami impacts in Samoa have been rather moderate. This holds true at least up until the December 26th 2004 Indian Ocean tsunami, which served as a wake up call to Government's around the world to reassess the nature and impacts of tsunamis likely to affect their countries, as well as their respective levels of resilience to such hazards. Samoa has since upgraded the risk of tsunami hazards to extreme based on the unpredictable nature of these events, as well as Samoa's proximity to the Tonga trench region. This change however, has prompted the need to re-evaluate Samoa's existing warning system, as well as identify the loop-holes that need to be strengthened so as to meet public demand for greater service efficiency in the provision of timely public tsunami warnings. This paper takes a generic look at the status of Samoa's tsunami warning system, by exploring the nature of tsunamis that have affected the country, as well as the relative measures Samoa has undertaken in response to tsunami mitigation.

Introduction
Earthquakes, tsunamis, and volcanoes are naturally occurring phenomena which exist within an interlinked geophysical system driven by the earth's internal and crustal processes. Each phenomenon is associated with the other either directly or indirectly, and for the case of tsunamis, the nature of different tsunamis is determined by the magnitude and extent of their source of origin; most commonly shallow submarine earthquakes and volcanoes.

This is not to say that tsunamis are only formed from earthquakes and tsunamis. Tsunamis can also be formed from meteorite impacts, as well as submarine landslides formed from sediment overloading; different from volcanic wall collapses as a result of an erupting submarine volcano. Based on the limitation of detailed information in this area, it is not known whether such sources have ever generated damaging tsunami events in the Samoa Islands, at least with reference to historical evidence.

While the nature of tsunamis in Samoa is relatively known, the levels of national and community preparedness to these hazards are still a working progress. At the national level, two documents which would serve as the framework and mandate for development activities associated with disaster preparedness, response, recovery, and mitigation against all hazards in the country have been tabled to cabinet and parliament for their endorsement; the National Disaster Management Plan (or Plan) and the National Disaster Bill. Stemming from the Plan is the National Tsunami Plan, which lists the risk of tsunamis in Samoa as extreme. This is based primarily on two factors; the non-seasonal nature of tsunamis making them difficult to

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forecast and predict, and, the fact that there exists documented evidence of tsunami impacts in Samoa.

In light of this, the Government of Samoa (GOS) has made and is undertaking current developments to strengthen the existing system, which depends mainly on the continuity of seismic and oceanic data flow from respective seismic and sea level monitoring stations within the region to the Pacific Tsunami Warning Center (PTWC) in Ewa Beach, Hawaii. Although noting the sufficiency of the system in responding to regional or distant tsunamis (teletsunamis), it has become apparent that the system is inefficient in providing timely tsunami advisories or warnings for locally generated tsunamis. Such cases present scenarios where the travel time before impact of a locally generated tsunami (such as along the northern tear-fault region of the Tongan trench) traveling at a speed of more than 700 kilometres per hour could be less than 15 minutes. It is situations such as these that have prompted the GOS to place heavy emphasis on tsunami public education and awareness activities. These activities center on the concept of self-initiative and community collaboration in responding to tsunamis, based on empirical observations of natural fluctuations that are associated with them.

The following Sections of this paper serve to outline the risk and vulnerability that Samoa faces from tsunamis, as well as the national systems in place to monitor them and provide early warning services to the public at large.

Nature and impacts of tsunamis in Samoa

Understanding the nature of tsunamis in Samoa as well as their consequent impacts provides the fundamental basis for understanding the importance of having a tsunami monitoring and warning system in the country. Subsequently, the risk tsunamis impose on the local environment and socioeconomy must also be understood in order to fully realize the need for an efficient early warning system. It is should be noted that approximately 80% of Samoa's population live in coastal areas (that are less than 10 metres in elevation). The central business district of the country is located along the Apia harbour. With the known fact that the majority of population as well as critical infrastructure in Samoa is located in coastal areas, as well as the highly possible rising developments in these areas that are associated with population as well as socioeconomic growth, the risk to tsunamis as well as potential costs to impacts will also increase.

Pararas-Carayannis and Dong in June 1980 compiled a catalogue of tsunamis in the Samoa Islands, and noted that a total of 60 events impacted the Islands' from between November 7th 1837 to June 1980; a period of 143 years. Most of these events were located or identified using qualitative methods, which involved a detailed review of historic periodicals and journals, as well as personal interviews.

One might immediately argue that the findings could equate to a consistent rate of tsunami occurrence in Samoa as 1 event every 2½ years. This assumption however does not hold true, as tsunami occurrence rates must be calculated according to their respective regions of origin. For example, the rate of tsunami occurrences generated from convergence along the Peru-Chile subduction zone are calculated independently of the rate of tsunami occurrences generated from plate convergence in the Japan region. This however, is beyond the scope of this paper, and will not be touched on further. Rather, a generic look at the data will be conveyed in order to establish the importance of having a tsunami monitoring and warning system in the country.

Based on the data, the majority of tsunamis which have impacted Samoa were generated as a result of large earthquakes (magnitudes ≥ 6.5) which occurred, respectively and in different years, along the Pacific Rim of Fire. The most notable of these occurrences in terms of their impacts were in the years 1883, 1906 / 1907, 1917, 1952, 1957 and 1960.

The 1883 event on March 24th was interesting in that the source is unknown. Pararas-Carayannis and Dong argued that it may have been a locally generated tsunami, which caused all houses within a quarter of a mile of the beach on the east end of Savaii to be swept away for a distance of 15 miles along the shore. A likely local source for an event of this magnitude could have been a subsurface eruption of the Mt. Vailuluu submarine volcano, which lies approximately 60 miles east of the island of Tau in the Manua group. An eruption within the hydro-explosive zone may have caused a volcanic wall collapse resulting in the formation of a local tsunami, although it is premature at this stage to make any conclusive assumptions.

The eruption of Mt. Matavanu in Savaii from between 1905 to 1911 was also interesting in that it presented another source for local tsunami generation in the country. A total of 7 local tsunamis were generated as a result of lava coming into contact with the ocean along the coastal area. One of these events occurred on November 28th in 1906, and the latter 6 occurred between the months of June to October, 1907. The impacts were felt along the northwest coast of Savaii, although fortunately they were minimal.

The June 25th 1917 event was significant in terms of the spatial distribution of impacts. A magnitude 8.3 earthquake on the Richter scale which occurred in the Tonga trench region triggered a tsunami which impacted Samoa 10 minutes after the earthquake's origin time. Reports indicated that destructive waves 3 metres in height were experienced at Aleipata, and for the case of Lotofaga, half of the village was submerged and houses destroyed. A bridge was washed away at Palauli and a number of native houses destroyed. In Satupaitea, a copra house was carried down the coast by the wave for about a quarter of a mile, and all native houses were demolished. In Pago Pago, a recession of ocean water was observed a few minutes after the earthquake was felt. Many native houses were destroyed, including partial destruction of a Catholic church in Leone, and a Mormon church in Pago Pago, American Samoa.

Similarly, the 1952, 1957 and 1960 events were significant in terms of their respective spatial distribution of impacts. The actual source for the tsunami on November 4th 1952 is not known, although the major impacts noted was the destruction of a school and some Samoan houses in Fagaloa, particularly Maasina, Sanamea and Taelefaga. The 1957 event originated from a magnitude 8.5 earthquake in the Aleutian Islands, and had a travel time of approximately 9 hours. The impacts of the event were relatively distributed along the north coast of Upolu, Savaii and Tutuila islands, although the most notable were experienced at Fagaloa. Inundation over the lower part of Fagaloa village was approximately 23 metres, causing sea flooding in most of the houses in the area.

In 1960, a magnitude 8.5 earthquake in South Chile generated a Pacific-wide tsunami, which caused devastating impacts in Japan; all the way in the northwest Pacific. This tsunami was undoubtedly one of the largest that has been recorded in the Samoan group. At Lalomanu village (east coast of Upolu Island), two fisherman in canoes near the reef had been picked up by the wave and washed onto the beach by the road. At Fagaloa, the first motion was a recession of the sea beyond the reef. A few minutes later, a crest advanced 82 metres through the village, where the peak water level reached the roof of one of the local Samoan houses.

Fortunately, there were no losses of lives recorded. In Pago Pago, damages amounted to approximately USD$50,000. One house was lifted and moved 3 metres inland, and another was washed into the bay by the outgoing wave.

On a probable though inconclusive note, it is important to bear in mind the possibility of a local tsunami being generated as a result of submarine volcanic activity associated with Mt. Vailuluu; the active hotspot location in the Samoa Islands chain. Volcanic-wall collapse as a result of explosive eruptive activity in the relative future may generate a local tsunami that could propagate west. Theoretically, the islands in the Manu'a group would be most affected, although destructive impacts might still be felt on the islands of Upolu and Savaii (Hart et. al, 2000; Konter et. al, 2004; Staudigel et.al, 2004).

It is clear from the evidence provided above that Samoa is no stranger to tsunamis and their consequent impacts. As a result of this, disaster management authorities have listed tsunamis as one of the highest risk natural hazards in the country (GOS, 2006b). This is based primarily on the fact that more than 80% of our local population reside in coastal areas that are less than 10 metres in elevation, as well as the non-seasonal nature of tsunamis, making them more complicated to predict than geohazards of atmospheric nature. These combined factors indicate that the risk of tsunamis is high, and that communities residing in exposed coastal areas that are less than 10 metres in elevation are vulnerable to the impacts of such hazards.

Existing monitoring and warning system

Samoa, like most island-countries in the Pacific, relies on the PTWC for the issuance of tsunami warnings. The only real-time auxiliary seismic station (AFI AS095) in the country, which is located at Afiamalu (13.9 S, 171.8 W), transmits seismic data to PTWC among other organizations such as the Comprehensive Nuclear Test-Ban Treaty Organization (CTBTO), and the Albuquerque Seismological Laboratory (ASL).

Prior to February 2006, the primary method for the receival of data from the station at PTWC was through the internet. Data was transmitted via VSAT to Vienna (the headquarters of CTBTO), and then onto ASL in Albuquerque also via VSAT. It was ASL that was then responsible for transmitting the data to other relevant organizations including PTWC via the internet. This method, while effective, possessed an element of vulnerability in terms of data transmission in that the system was reliant on local telecommunications organizations in Hawaii. If problems arose within the local telecommunications system, the possibility of disruption to data transmission was very high.

The recent installation of the new VSAT at the station site in February 2006 established the enabling mechanism for the direct transmission of data to PTWC. Now, the primary method for transmitting the data to PTWC is through the new VSAT, with the former method serving as the backup. This new shift has served to boost the reliability of data transmission, while also serving to increase the efficiency and effectiveness of data analytical time with respect to tsunami response.

Samoa also has one tide gauge installed at the Apia wharf, which was installed under the South Pacific Sea Level and Climate Monitoring Project. The data, which is also used to verify tsunami events, is transmitted to the National Tidal Center of the Bureau of Meteorology, Australia.

The system, which is comprised of a network of seismic, sea level, and ocean buoy monitoring stations around the region, is based on the acquisition of this integrated data for analysis and interpretation at PTWC. The seismic data is used to verify the details of an earthquake with potential tsunamigenic properties; the PTWC earthquake magnitude threshold for the formation of a tsunami is greater than or equal to 6.5 on the Richter scale. Ocean and sea level monitoring stations are important for verifying the generation of a tsunami, although they are used in slightly different ways. The ocean buoys have the ability to detect a tsunami while it is still offshore (before impacting land), while the sea level stations can verify the height of a tsunami wave upon impact.

All of these parameters are factored into the PTWS, which currently occupies the role of issuing tsunami information bulletins to PTWS member states, which includes Samoa. After an earthquake has been located and magnitude determined, a decision is made concerning further action. If the earthquake is within or near the Pacific Ocean basin and its magnitude is 6.5 or greater, but less than or equal to 7.5 (less than or equal to 7.0 in the Aleutian Islands), then a Tsunami Information Bulletin is issued to the Warning System member states. Tsunami Warning/Watch Bulletins are issued to the dissemination agencies (Meteorology Division in Samoa) for earthquakes of magnitude greater than 7.5 (greater than 7.0 in the Aleutian Island region), alerting them to the possibility that a tsunami has been generated and providing data that can be relayed to the public so that necessary preliminary precautions can be taken. It should be noted that any decision to issue national public-wide tsunami warning or watch bulletins is made by respective member states' authorities. For Samoa's case, the overall decision comes from the Prime Minister, in his or her role as the Chair of the National Disaster Committee.

It is the Meteorology Division of the Ministry of Natural resources & Environment that holds the responsibility of monitoring and issuing warnings against most, if not all, natural hazards in the country, including tsunamis. More specifically, it is the Geophysics Section of the Division that monitors earthquakes, tsunamis and volcanoes, as well as issues national warnings against these hazards when relevant. The overall decision to issue a national tsunami warning or watch is made by the Prime Minister, based on information received from PTWC. The primary means by which the information is disseminated to the public is through radio and television media outlets, as well as informing the Fire Department who have the responsibility for coordinating urban evacuations. Plans are in place to utilize cellular phones and landlines as another possible means of receiving pre-recorded tsunami early warnings, via audio and text means (GOS, 2006a; GOS, 2006b).

With respect to local tsunamigenic earthquakes, the primary method in place is public education and awareness on the nature of tsunami hazards in the country. The Disaster Management Office as well as the Red Cross Society of Samoa implement public and community awareness programs, which include a wide range of different hazards and disasters, both natural and human-induced. Included within these programs are public information kits on the nature of tsunamis, as well as the means to recognize the signs in nature of an approaching local tsunami.

Although this has all been expressed in corporate and management plans of the Ministry and Meteorology Division respectively, there are still a lot of loop-holes which exist within the operational framework of the system. On the technical front, local geophysical hazard monitoring is limited due to the absence of a national geophysical hazard monitoring network; a challenge that will be discussed further in the following Section of this paper.

Seismic monitoring in the country relies heavily on external sources of information; primarily information issued by the National Earthquake Information Center in Denver, Colorado. With reference to Samoa however, this mechanism is useful only for recording earthquakes with magnitudes larger than 5.0 on the Richter scale. As a result, detailed seismic and integrated geophysical hazard monitoring at the national level is limited.

On the anthropological front capability within the Geophysics Section is limited due to ongoing challenges associated with local budgetary restrictions, as well as bilateral collaborative partners. It cannot be overstated that development in any form depends heavily on the availability of resources, and of high importance within this category is the availability of financial resources. With adequate financial resources in hand, the implementation of technical developments that parallel institutional and human resource strengthening can be undertaken.

In the meantime however, the Geophysics Section is comprised of 7 personnel positions. Institutionally it falls under the Geoscience Section of the Meteorology Division, forming one of two units within this Section. It is headed by a Senior Officer position supervising the duties of 6 subordinate staff positions. Of this 6, 3 positions are delegated to the geophysical hazards program, and 3 to the geomagnetic program.

General technical capability within the Section needs to be strengthened through bilateral assistance, while continuing to support regional and international efforts. This would involve the utilization of financial aid to implement technological developments at the national level, as well as institutional strengthening and public capacity building programs. This would serve to emphasize the importance of the role geophysical monitoring has in the provision of early warnings to geophysical hazards. It would also have a pronounced influence on strengthening emergency response to geophysical hazards at the national level within Samoa.

Conclusion

It is clear from the evidence provided that Samoa is no stranger to tsunamis, both distant and local. The tsunami impacts discussed as a result of the respective tsunami events which occurred over the last 169 years clearly demonstrate that the Samoa islands are not immune to the impacts of tsunamis. While acknowledging the relative difference in scale between the known impacts of tsunamis compared to tropical cyclones, the inevitable fact is that there still exists a wide information-gap on the nature of tsunamis in Samoa, making it difficult to plan effectively. Subsequently, the timeframe in which these events occur or are generated limits prediction and forecast capability considerably. Tropical cyclones, droughts, and flooding, which are seasonal nature, can be forecasted with ample time left to undertake emergency response measures, at least in most cases. Tsunamis on the other hand, follow the non-seasonal nature of earthquakes; which are still complicated to forecast and let alone predict. These combined parameters mean that one living in coastal areas will need to be prepared at all times for the possibility of a tsunami.

With respect to PTWC, the system is very useful in the provision of information which local authorities may utilize to make emergency response decisions against distant tsunamis; tsunamis with an estimated time of impact of more than 2 ½ hours. This window of 2 ½ hours provides sufficient time for emergency officials to implement necessary emergency measures, which may include evacuation to higher ground or vertical evacuation (moving to the top floor of multi-storey buildings). For local tsunamis however, PTWC's response time may not prove sufficient, as the travel time for tsunamis before impacting land could be as little as 5 to 10 minutes. Inevitably, this would mean that the only early warning would be the occurrence of the earthquake itself. Once a strong earthquake is felt, one should assume that it occurred within close proximity to the Samoa islands. For residents inhabiting coastal areas or areas less than 10 metres above sea level, all precaution should be taken. If a rapid ocean recession occurs within the adjacent lagoon, this would mean that a tsunami is approaching.

While public and community education seems a simplistic attempt to determine an approaching tsunami, it is concluded as being the most effective given the existing local and regional capability to respond to local tsunamis. While it is relatively conclusive that the development of a national seismic monitoring network will contribute to strengthening Meteorology Division's ability to monitor and provide local tsunami early warnings, the fact remains that the timeframe for issuing this information as well as the means by which the public receive it may prove insufficient. At present, the primary method for disseminating information to the public is via radio and television media outlets. This in itself presents limitations, as not all media and radio networks operate on a 24/7 basis. Moreso, the majority of people living in Samoa are usually asleep during the early hours of the morning, should an event occur during this time. These factors lead to the conclusion that the existing mechanisms in place to inform or warn people of an approaching tsunami are limited in their effectiveness. Further concluding that public education and local community response systems need to remain a priority, especially in the case of responding to locally generated tsunamis.

It thus becomes articulately clear that tsunami early warning and mitigation systems in Samoa, while existent, need to be strengthened in a manner that complements inter-related development programs. This would involve the incorporation of new systems with existing ones in an all-natural hazards context, whereby technology may be used in an integrated manner to monitor multiple natural hazard events as opposed to a single event. Existing weather, climate, hydrological, earthquake and volcano monitoring technology could be integrated with new technology to form a multi-natural hazards monitoring network at the national level within Samoa. Institutionally, this could be enabled as all of these services fall under the mandate of Meteorology Division. Regardless of which, the primary facts remain that collaboration at all levels, nationally, regionally and internationally is essential to any form of achievement in Samoa's quest to strengthen its tsunami warning systems capability to both local and distant generated tsunamis.

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