CRITICAL ASSESSMENT OF GLOBAL AND REGIONAL DISASTER VULNERABILITIES STRATEGIES FOR MITIGATING IMPACTS

George Pararas-Carayannis
President, Tsunami Society

ABSTRACT

Global population expansion, technological improvements and economic growth have made the use of the world's coastal zones more necessary than before. However, the same developments and advanced industries, which are the basis of socioeconomic improvements of human living standards, are also contributing to an increased impact from natural, terrestrial and marine disasters around the globe. The combination of social and economic factors in the development of coastal regions – without proper planning - makes a number of developed and developing countries particularly vulnerable to natural disasters. Also in recent years, man-made disasters such as chemical, industrial, nuclear and transportation accidents and wars, are creating havoc on terrestrial and marine environments, resources and cultural sites. Slower term environmental disasters, with readily identified anthropogenic input, are also creating water and climate related hazards that will have a severe impact on humanity in the future. Equally threatening are future biological disasters and epidemics.

As the earth's population continues to grow and demands for energy and other resources increase, future natural disasters, such as earthquakes, tsunamis, hurricanes, volcanic eruptions, floods and droughts will continue to take an heavier toll on human life and resources globally, particularly along the densely populated coastal regions of the world. The Great Earthquake and Tsunami of 26 December 2004 in the Indian Ocean and the extensive destruction of New Orleans by Hurricane Katrina in 2005 should not have surprised anyone. They were disasters-in-the-making. Their severe impact is an example of the lack of proper disaster assessment and proper preparedness. The tsunami vulnerabilities of countries surrounding the Indian Ocean had been ignored. The vulnerability of New Orleans to severe hurricanes was ignored. The lessons learned from past disasters were forgotten. To this day, and for most regions of the world, the potential impacts of future marine or terrestrial disasters have not been properly assessed. To mitigate future impact of natural and man-made marine disasters around the globe, a more critical and comprehensive approach must be taken in assessing the specific vulnerabilities of each region. New strategies need to be devised and implemented to avoid repeats of the tragedies like those of the Indian Ocean Tsunami or Hurricane Katrina.

The present paper presents a general overview of global and regional vulnerabilities to different disasters, recommends the adaptation of needed strategies, and provides guidelines for effective disaster preparedness and mitigation.

1. INTRODUCTION

In the last 30-40 years there has been tremendous population growth and significant development of coastal areas in most of the developed or developing nations of the world (Fig. 1). However, the same developments and advanced industries, which have been the basis of socio-economic improvements of human living standards, also have increased exposure to both natural and man-made disasters. The combination of social and economic factors, development, population growth and the urbanization of coastal regions have increased vulnerabilities. The population explosion by itself may be also a disaster of major proportions, as it will impact on the earth's limited resources and sensitive environment. According to statistical reports published by the United Nations, the human population is now more than 6.5 million and is increasing at the rate of 210,000 per day or about 76 million per year. There are speculative projections that the world population may even reach 30 billion by the end of the millennium. Given these statistics of growth, there is little doubt that the impact of natural and man-made disasters will be significantly greater in the future.

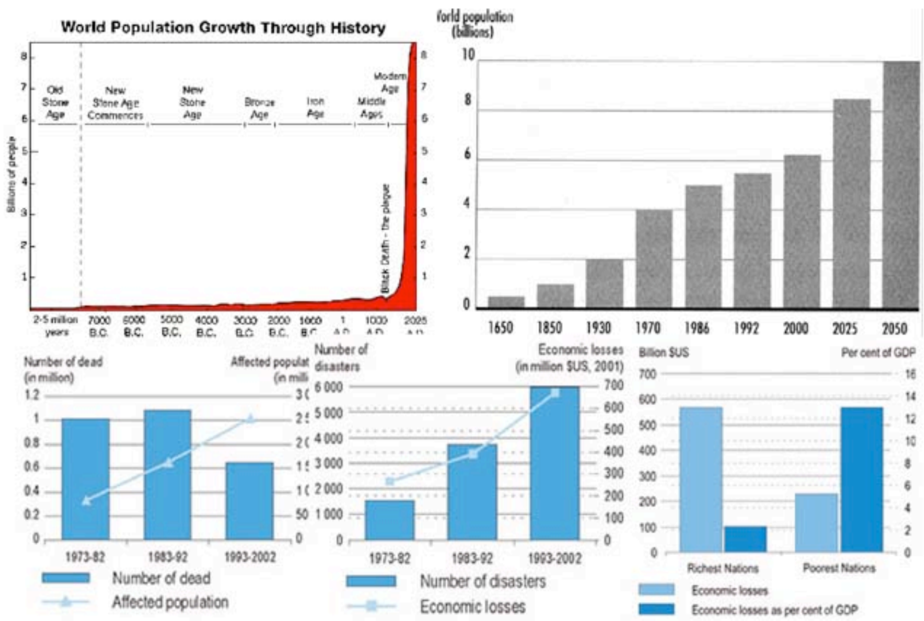

Fig. 1 Past and projected population growth – Losses of life and effect on Economic Resources (Losses related to the 2004 tsunami in the Indian Ocean, the 2005 earthquakes in Indonesia and the 2005 Hurricane Katrina – if included - would show a much greater losses)

Already, globally and regionally, there appears to be an alarming increase in losses from geological and weather-related disasters. The costs of these disasters in terms of lives lost, homes destroyed and economies disrupted, have skyrocketed in recent years, as the world's population has grown and has moved onto areas that are vulnerable. The geologic disasters include earthquakes, volcanic eruptions and tsunamis. The weather-related disasters include hurricanes (typhoons, cyclones) and associated surge flooding, tornadoes, heavy thunder storms, flash flooding, floods, mud and rock slides, high winds, hail, severe winter weather, avalanches, extreme high temperatures, drought and wildfires. Longer term, environmental disasters, with considerable anthropogenic input, are already contributing to global warming, sea level rise, climate change and to more frequent and intense weather-related hazards.

Man-made disasters, such as chemical, industrial, nuclear and transportation accidents, which created havoc in the past, could do even more harm in the future. Biological disasters and epidemics will greatly threaten humanity as the world population continues to grow. Finally, one of the greatest threats to the sustainable development of our planet and its hydrosphere are those of armed conflicts.

Excluding such pessimistic outcomes that reflect on human nature's apparent propensity for self–destruction – made further possible by our advancing technological developments – there is a moral, as well as scientific need to address current trends on how marine and terrestrial resources on this planet can be sustained and adverse trends be reversed or mitigated. Undoubtedly, with the projected population growth and the continuing increases in the use of coastal areas, this becomes a greater challenge. While disaster awareness and preparedness are two important parameters that can help mitigate the impact of future disasters, more comprehensive strategies must be adopted to offset the increasing threats. Since different areas of the world are vulnerable to various disasters, each coastal community must assess its own vulnerability and risks and develop specific regional strategies.

Effective disaster mitigation requires the assumption of greater responsibility by individuals, groups, organizations and government agencies. Global efforts and strategies can only be successfully implemented if there are supporting grass-root efforts at local levels.

In recent years, earthquakes, tsunamis, hurricanes, volcanic eruptions and other natural disasters have taken a greater toll on humanity. Regrettably, these disasters occurred in regions known to be vulnerable but where proper risk assessment studies had not been made and no adequate plans for preparedness or mitigation existed. Such lack of preparedness resulted in the destruction of the city of New Orleans and of other well-developed communities in the Gulf of Texas when Hurricane Katrina struck in August 2005. If proper plans were in place, the death toll and destruction would have been minimized. This is also true for other regions where other types of disasters struck recently. The following review provides a few examples of the vulnerabilities of certain regions to specific disasters in order to demonstrate how scientific and technical assessments can be integrated into strategies of evaluation and preparedness that can save lives, preserve property, and also assure social sustainability after a disaster strikes.

1. EARTHQUAKE AND TSUNAMI DISASTERS

As recent earthquakes and tsunamis have demonstrated, huge losses of life and property are becoming increasingly common. The tsunami of 26 December 2004 in the Indian Ocean tsunami left irreparable losses (Fig. 2). It affected 13 countries and was responsible for the deaths of more than 250,000 people. Another great earthquake on 28 March 2005, in the same general area, caused additional devastation. The great earthquake of October 8, 2005 in Northern Pakistan and Kashmir killed over 80,000 people and left over 3.3 million homeless (Pararas-Carayannis, 2004, 2005, http://drgeorgepc.com).

2.1 Earthquake and Tsunami Vulnerabilities – Critical Assessment of Future Impact

The global and regional vulnerabilities for large earthquake and tsunamis generated along zones of tectonic subduction are well documented (Brooks, 1965; Denham 1969, Byrne et al. 1992; Pararas-Carayannis, 1978, 1985, 1992, 2001a, 2005a,b, c, d, e, 2006a, 2007). In the Pacific Ocean, hundreds of thousands of people have been killed by tsunamis in Japan, Chile, Indonesia, Philippines, Central America and elsewhere (Fig. 3). Since 1900 (the beginning of instrumentally located earthquakes), most of the documented tsunamis were generated in Japan, Russia, Peru, Chile, Alaska, Papua New Guinea and the Solomon Islands. However, the only regions that generated remote-source tsunamis affecting the entire Pacific Basin are the Kamchatka Peninsula, the Aleutian Islands, the Gulf of Alaska, and the coast of South America. The Hawaiian Islands, because of their location in the center of the Pacific Basin, have experienced tsunamis generated in all parts of the Pacific. Numerous other locally generated tsunamis have caused extensive destruction in the Philippines, Indonesia, Colombia, Mexico, Nicaragua, Costa Rica and elsewhere in the Pacific.

Fig. 2. Satellite and ground images of Banda Aceh, in Sumatra, showing the extent of inundation and destruction from the tsunami of December 26, 2004

In the Atlantic Ocean, the frequency of earthquakes and tsunamis has not been very high. There are no major subduction zones at the edges of plate boundaries as in the Pacific and the Indian Ocean to spawn destructive tsunamis. However near the Caribbean and Scotia arcs, large earthquakes can occur and destructive tsunamis can be generated. Examples of these would be the 1867 earthquake at Mona Pass near the Puerto Rico Trench and the 1929 Grand Banks earthquake in Nova Scotia. Both of these earthquakes generated destructive tsunamis. Also, the Azores-Gibraltar boundary of continent-continent tectonic collision, which caused the 1755 Lisbon earthquake and tsunami, is a region that is potentially dangerous (Pararas-Carayannis, 1997). A large earthquake along this boundary could be very destructive in Portugal and Morocco and could generate a tsunami that would be devastating on both sides of the Atlantic.

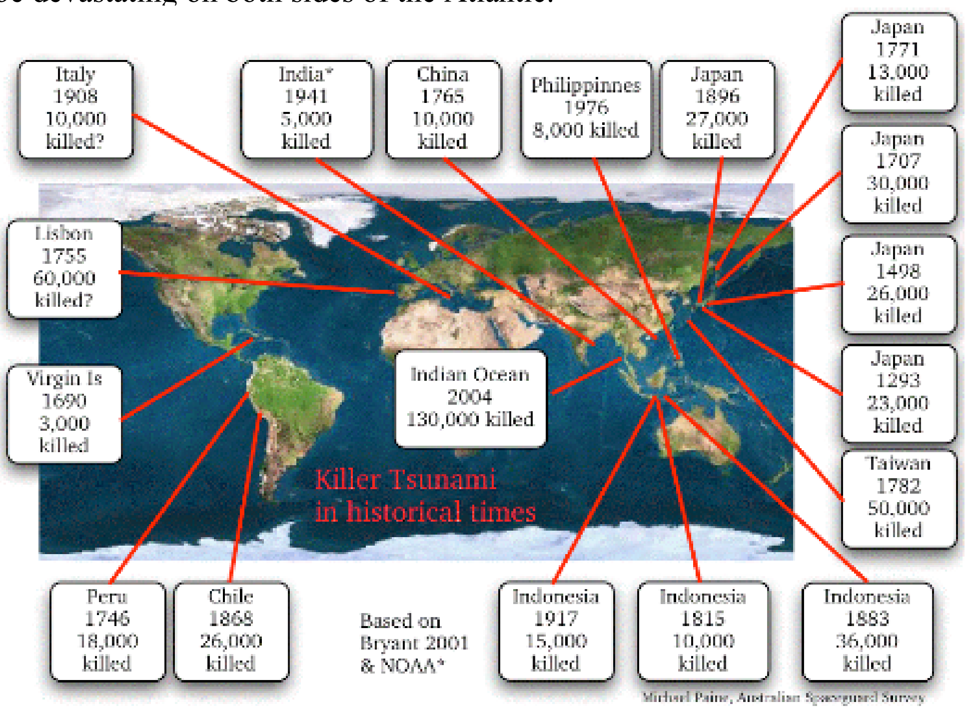

Fig. 3. Global vulnerabilities of earthquake and tsunami disasters – Death tolls

Additionally, the Mediterranean and Caribbean Seas, both have extensive seismicity along small subduction zones, and have histories of locally destructive tsunamis.

In the Indian Ocean the frequency of tsunamis has not been as high, but the tsunami of 26 December 2004, as well as previous and subsequent events illustrate the extreme vulnerability of this region (Pararas-Carayannis 1978, 2005a,b, c, d). Continuous and active subduction of the Indo-Australian plate beneath the Eurasian plate at its east margin presents the highest danger and creates high vulnerability for Indonesia and other countries bordering the Indian Ocean.

The specific methodology for assessing earthquake and tsunami vulnerabilities has been described adequately in the scientific literature (Pararas-Carayannis, 1986, 1988, 2006b). Each earthquake and each tsunamigenic region in the world has its own characteristic mechanisms that need to be evaluated independently for proper risk assessment. Although not all earthquakes generate tsunamis, and tsunamis can be generated by other sources, the following example on the earthquake and tsunami of April 1, 2007 summarizes the combined earthquake and tsunami vulnerabilities of a unique region of tectonic subduction in the New Georgia Group of Islands in the Solomons. This event was chosen as an example, not because it generated a great catastrophic tsunami as the 2004 event did, but because of the uniqueness of this region and the useful information that resulted from its study. Analysis of the seimotectonic characteristics of this particular region of subduction can help assess the impact of future earthquake and tsunami disasters, develop realistic scenarios of local and far field vulnerabilities, and adopt more effective strategies for informed tsunami warnings and disaster mitigation. Such informed understanding is now lacking. Decisions on issuing tsunami warnings are based on mere earthquake magnitude thresholds without any analysis or evaluation of the geodynamic characteristics of each tsunamigenic region. Including proper evaluation of other geotectonic parameters would result in a more effective decision-making process on whether to issue a local warning for a region, or whether to expand the warning to larger geographical areas. Such understanding and analysis would also result in developing better strategies for zoning the risks and overall disaster mitigation.

2.1.1 The Great Earthquake and Tsunami of April 1, 2007 in the Solomon Islands – This great earthquake – much like the catastrophic event of 26 December 2004 in Sumatra – occurred along a very complex oceanic region where tsunami hazards had not been properly assessed as to their potential destructiveness (Fig. 4). Extreme measures were taken in Australia and elsewhere on the belief that this event in the Solomons could generate a tsunami that could be equally catastrophic as the 2004 event to the countries bordering the Indian Ocean. The concern was based on the large magnitude of the earthquake and inadequate understanding of the geodynamics of the region.

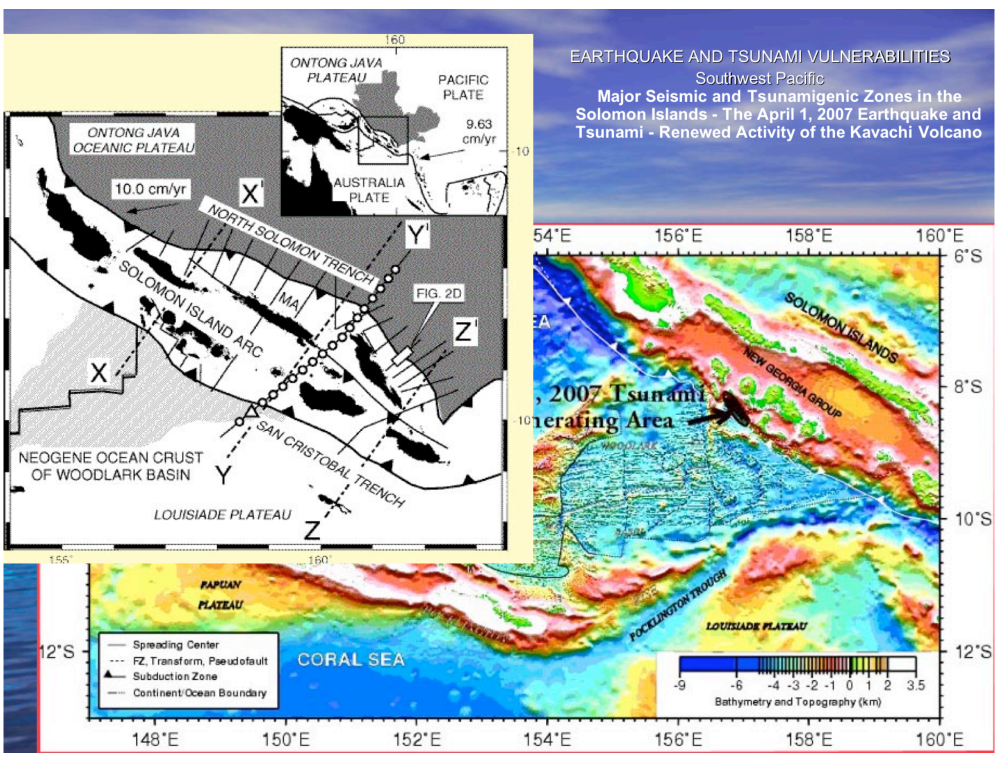

Fig. 4. Earthquake and tsunami vulnerabilities in the Solomon Island Region. The Earthquake and Tsunami of April 1, 2007 (http://drgeorgepc.com/Tsunami2007Solomons.html)

Indeed this great earthquake generated a destructive local tsunami in the New Georgia Group of the Northwest Solomon Islands and in Southeast Papua New Guinea. Although the tsunami was not particularly damaging elsewhere in the Solomon Islands or in Australia, examining its source mechanism characteristics more carefully can lead to better understanding about the spatial distribution of earthquakes on both sides of the Solomon Island Volcanic Arc, the regional characteristics of tsunami generation along active boundaries of young, marginal sea basins and spreading oceanic ridges, and what can be expected in the future (Pararas-Carayannis, 2007)

Briefly and simply stated, the distribution of earthquakes and aftershocks in this region supports the existence of several subduction zones where major and great tsunamigenic earthquakes can be expected in the future. However, the geometries of subduction differ for different segments along the entire Papua-New Guinea and Solomon Islands region, so one has to analyze each specific segment separately. What complicates the analysis is that along the entire plate margin, there is not one simple plate boundary but a cluster of small plate boundaries, which accommodate the mechanisms of the total interaction in the region (Brooks, 1965; Denham, 1969). Therefore, one has to look at the geologic history of the entire Southwest Pacific to understand the complex evolutional dynamics that control the Solomon Island Arc migratory arc system and the present seismicity (and tsunami generation potential) on either side of the Solomon Island Volcanic Arc.

For example, on the northeast side of the Solomon Arc, larger ruptures of adjacent slabs are possible which could involve the New Ireland segment or the North Solomon Trench. The most significant earthquake that could occur in this area that could approach an earthquake with a Moment Magnitude Mw-9 would be expected near the Solomon Sea-Bismarck Sea triple junction, where three tectonic plates meet (Pararas-Carayannis, 2007). Any large earthquake in this region could be extremely damaging and could generate a destructive local tsunami. Good understanding of the overall geodynamics of the region, as well as knowing the epicenter and magnitude of a future earthquake can help assess specifically the tsunami vulnerability from that event and decide whether the tsunami threat is localized or whether it will have far reaching impacts - thus warn accordingly. In the case of the April 1, 2007 tsunami, there was unwarranted concern that it would be destructive in Australia – when no such danger existed in spite of the earthquake's large magnitude.

2.2 Strategies for Mitigating Impact of Future Earthquake and Tsunami Disasters

The significance of the above-described geophysical evaluation and how it can be incorporated into disaster mitigation may be questioned. However, the answer is really simple. Such scientific understanding is essential in assessing the vulnerabilities of a region to earthquake and tsunami hazards and in devising strategies for mitigation. Knowing the types and magnitudes of earthquakes, the source mechanisms, and where the potential impact of future disasters will be, is fundamental data that must be incorporated into early warning system evaluation and long-term disaster plans for coastal evacuation, land use, or the designation of building codes. With reliable scientific data and good planning, lives would be saved, the damage to critical structures would be minimized, and communities could recover quickly in the post-disaster period. The methodology for implementing such strategies is briefly outlined in a subsequent section.

2. VOLCANIC DISASTERS

The historic record indicates that volcanic eruptions pose a serious threat to many regions of the world (Pararas-Carayannis, 2003) and have been responsible for great loss of life (Fig. 5). For example, following the December 26, 2004 and the March 28, 2005 earthquakes in Indonesia, Mt. Talang became very active and required massive evacuations from Padang and elsewhere on Sumatra. Anak Krakatau in the Sunda Strait showed signs of renewed activity. Also Merapi, Gedek and other volcanoes on the island of Java became very active and required massive evacuations. There is a good probability that Mt. Talang and Merapi will have major destructive eruptions in the near future. Other volcanoes in Sumatra, Java, the Lesser Sunda Islands (Sumba and Sumbawa), Japan, Philippines, Alaska, the Pacific Northwest, Mexico, Central America and Colombia, could become active again.

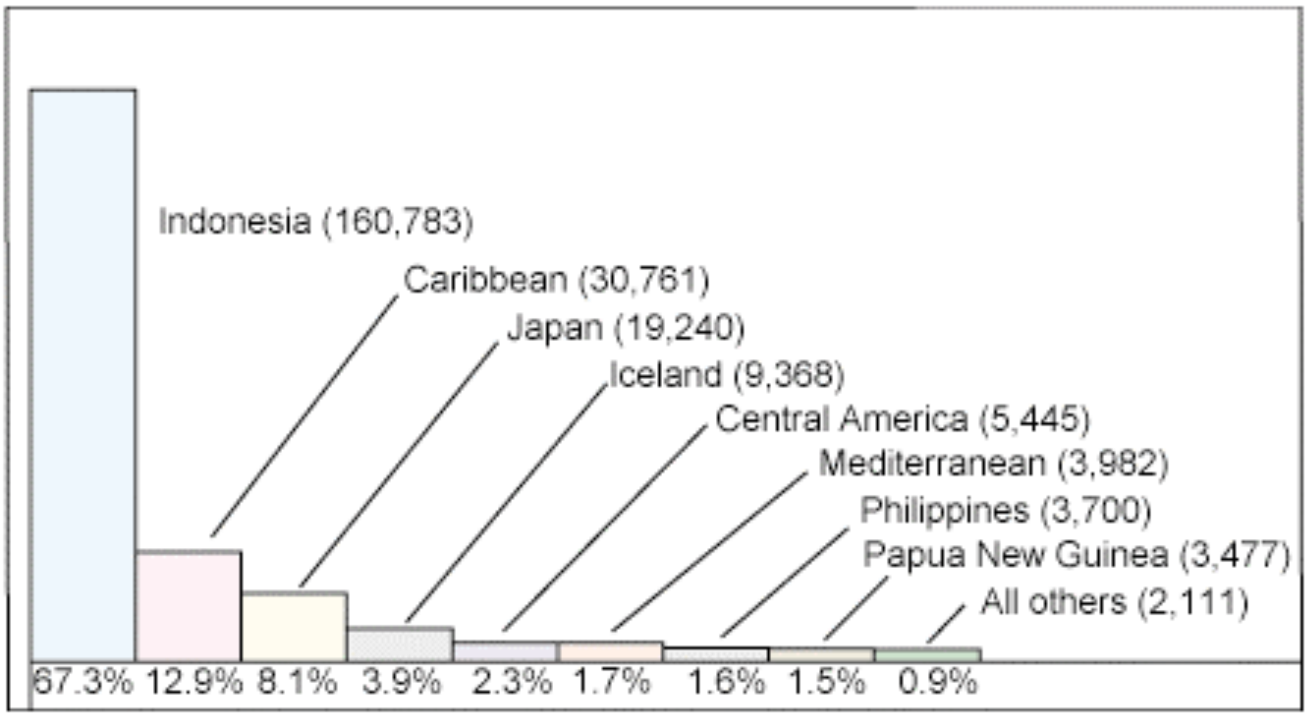

Fig. 5. Graph illustrating the number of deaths in each volcanic region from 1600 to 1982. The total number of deaths was 238,867 (After Blong, 1984)

Caribbean volcanoes pose a serious threat for several islands in the region (Shepherd, 1989; Fiske & Shepherd, 1990; Robertson1992, 1995; Young, 2004; Pararas-Carayannis, 2006a). Mt Pelée on Martinique, La Soufrière on St Vincent, Soufrière Hills on Montserrat, and Kick'em Jenny near Grenada are the most active volcanoes in the Lesser Antilles in the Caribbean region that have caused destruction and even generated local tsunamis by their associated pyroclastic flows, flank failures and landslides (Fig. 6). They will erupt again in the future as well as volcanoes in the Mediterranean, the Red Sea and along the Great African Rift.

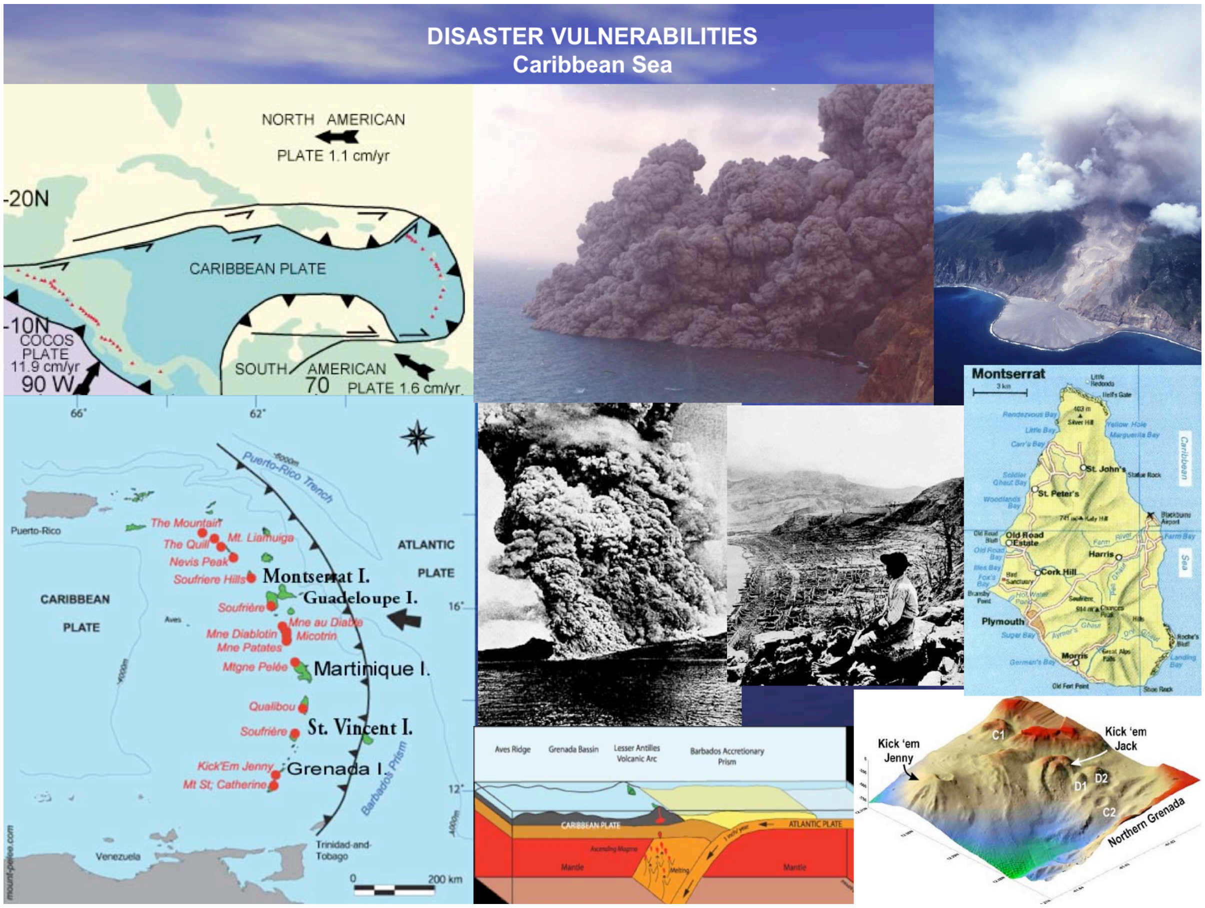

Fig. 6. Composite diagram of volcanic and tsunami hazards in the Caribbean Sea; Active volcanoes and eruptions (1902 Mont Pelée Eruption on Martinique Island; 2003 eruption of Soufrière Hills on the Island of Montserrat; Pending eruption of Kick'em Jenny Submarine Volcano; Debris avalanches and pyroclastic (lava) flows associated with the 1999 eruption of the Soufrière Hills volcano on the island of Montserrat (Photos of Soufrière Hills pyroclastic flows: Montserrat Volcanic Observatory)

A recent example of volcanic disaster was the eruption of Soufrière Hills volcano on the Island of Montserrat (Fig. 7). The capital city of Plymouth was incinerated by nuee ardentes and other cascading pyroclastic flows. A series of subsequent eruptions and another episode in 2003 resulted in flank failures and pyroclastic flows that reached the sea and generated a local tsunami.

3.1 Volcanic Vulnerabilities – Future Impact

There have been several destructive volcanic eruptions around the globe in recent years. Contributing tectonic factors include island arc volcanism that overlies a subduction zone and which can result in the most catastrophic types of eruptions. Many additional specific factors determine the eruption style, higher explosivity, the generation of pyroclastic flows, the structural flank instabilities, the slope failures and the debris avalanches that characterize the mainly andesitic volcanoes such as those encountered in the Caribbean region (Pararas-Carayannis, 2006a). However the same factors apply to all basaltic/andesitic volcanoes around the world that border tectonic boundaries.

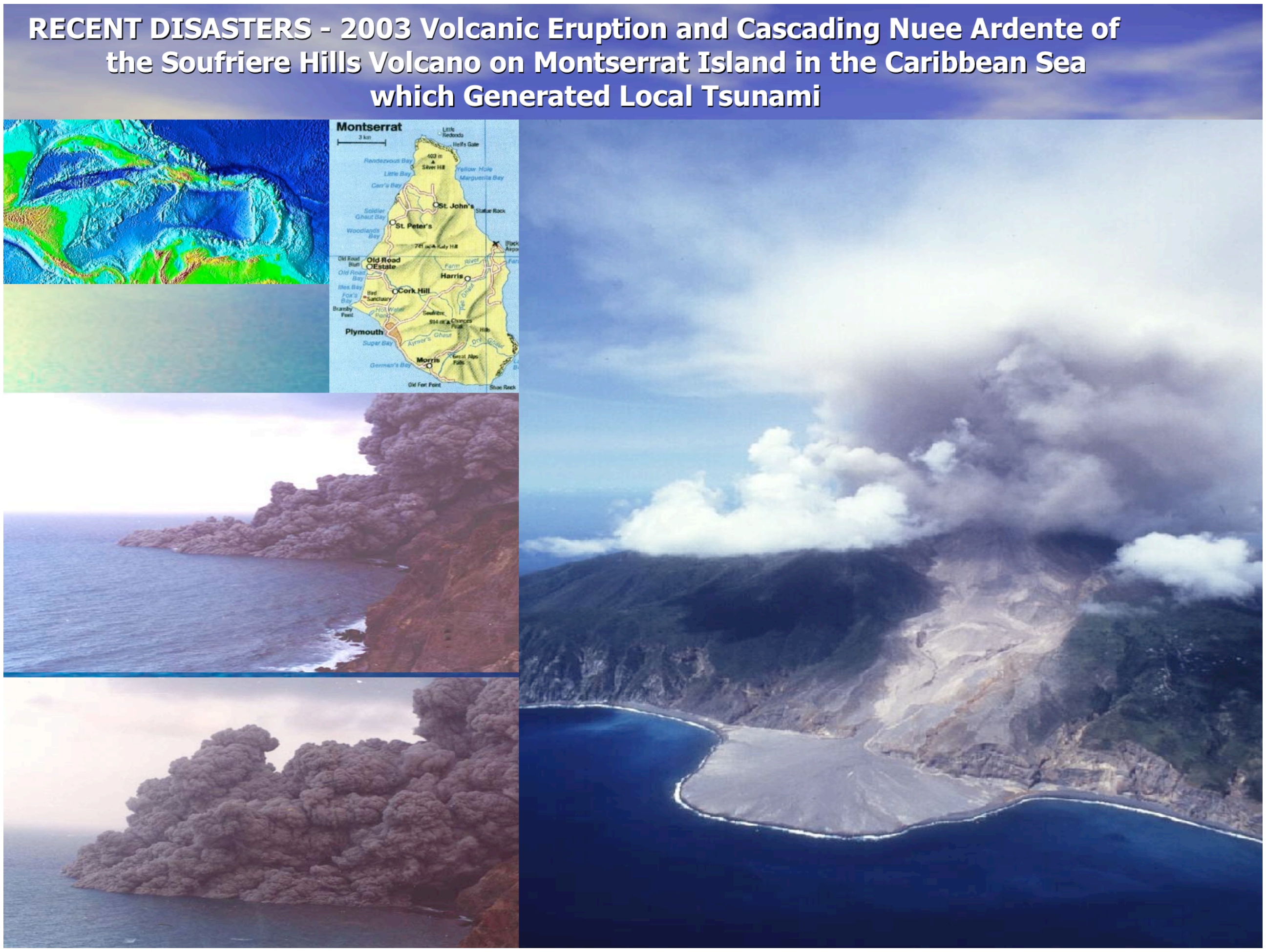

Fig. 7. Recent Volcanic Disasters – 2003 eruption and cascading Nuee Ardente of the Soufriere Hills Volcano on Montserrat Island in the Caribbean Sea which generated a local tsunami. The city of Plymouth was completely incinerated and abandoned after earlier eruptions in the 1990's.

Volcanic eruptions are often associated with numerous other collateral disasters, which may have an immediate impact or a long-term environmental effect on climate and weather-related hazards. The vulnerabilities are too numerous to include in this overview. For example, tsunamis can be generated by volcanic caldera and lava dome collapses, by vertical, lateral or channelized explosive activity, and by the associated atmospheric pressure perturbations, pyroclastic flows, lahars, debris avalanches or massive volcanic edifice failures. Whether a volcano will have effusive eruptive activity or explosive type of bursts will depend primarily on geochemical factors. The build up of pressure of volatile gases within the magmatic chambers determines a volcano's eruption style, explosivity and flank instability. The mechanisms and explosivity factors have been thoroughly analyzed and presented in the scientific literature (Pararas-Carayannis, 2006a).

The following is only a brief overview of the recent eruptions of the Soufrière Hills volcano on Montserrat Island, which demonstrate the multiple hazards associated with volcanic eruptions. Such information is needed in order to develop scenarios of local and far field vulnerabilities, and plan for disaster mitigation in regions similarly threatened by volcanic hazards.

3.1.2 Recent Eruptions of the Soufrière Hills Volcano on Montserrat Island – The Soufrière Hills, located on the southern part of Montserrat Island, is a very active, primarily andesitic stratovolcano (Rowley1978) - which is the predominant type of explosive volcano in the world. The first known historical eruption was in 1995. Since then there have been several more eruptions in the late 1990s (Hooper and Mattioli, 2001). All of its eruptions have been associated with earthquake swarms, lava dome collapses, steam explosions, ash falls, pyroclastic flows and debris avalanches. The volcano's flank instability and its potential for landslides result from the composition of its magma, which is very sticky and has a high content of dissolved water (Pararas-Carayannis, 2006a). In fact, eruptions appear to be linked with rainstorms and high earth tides. When the volcano erupts it tends to form a steeply sloped peak made of alternating layers of lava, block, and ash. Thus, the slopes of the volcano become unstable and susceptible to massive landslides and debris avalanches, some of which can reach the sea and generate local tsunamis. In fact several have occurred in the last few years, the latest in 2003.

3.1.3 The Eruptions and Tsunamis of 26 December 1997 and 1999 and 2003 – The Soufrière Hills volcano either erupts by exploding and expelling lava or by dome collapse. Both types of eruption can be destructive as they can produce dangerous ash hurricanes and pyroclastic flows, trigger landslides and debris avalanches and thus, also generate tsunamis. The weakness of Soufrière Hills' flanks following the 1995 eruption contributed to subsequent volcanic flank failures associated with the eruptions of 1997, 1999 and 2003, which generated tsunamis (Heinrich et al., 1998, 1999ab, 2001). Specifically, on June 25, 1997, after two years of precursory swelling and micro earthquake activity, the Soufrière Hills volcano erupted again. A damaging pyroclastic flow of ash, gas, and rock killed at least ten people and destroyed nine villages. A lava dome was subsequently observed which built up steadily in the volcano's crater for over two months. On 26 December 1997, following the collapse of this lava dome, a major eruption occurred. The eruption generated ash hurricanes, which destroyed the city of Plymouth. Both the ash hurricanes and a landslide - possibly assisted by pyroclastic flows triggered by the dome-collapse - reached the sea, along the southwestern coast of the island and generated significant tsunami waves. (Heinrich et al., 1998, 1999a,b, 2001). The maximum run-up of the tsunami waves was about 3m. about ten kilometers away from the source region, with inland penetration of about 80 meters. The volume of the landslide debris, which generated this tsunami, was estimated to be about 60 million cubic meters (Lander et al., 2003).

Similar debris avalanches and pyroclastic flows associated with the1999 eruption of Soufrière Hills reached the sea and generated another local tsunami. The height of the waves in the immediate area ranged from 1-2m but attenuated rapidly. By the time the waves reached the islands of Guadeloupe and Antigua their heights had attenuated considerably. Maximum run-up heights were only about 50 cm. The most recent tsunami was produced by the eruption of July 12, 2003 (local date) following a major collapse of a lava dome (Pelinovsky et al 2004; Young 2004). Pyroclastic flows and a debris avalanche reached the sea at the end of Tar River Valley on the east coast and generated this tsunami, which was reported to be about 4 meters at Spanish Point on Montserrat Island and about 0.5-1 m at Deshaies and near Plage de la Perle on Guadeloupe where it caused some damage to fishing boats (Pararas-Carayannis, 2006c).

3.2 Strategies for Mitigating Impact of Future Volcanic Eruptions and Associated Disasters

Each region of the world that faces the prospect of volcanic disasters should prepare so that loss of life and damage to property can be minimized. There is no excuse for the loss of life (25,000+) that was caused by the 1985 lahar from the Nevado Ruiz volcano in Colombia. The village of Armero was located in a high-risk area and no risk assessment study had been undertaken.

Strategies for mitigating future impact of volcanic disasters should include the monitoring of precursory eruptive processes as what is ongoing presently (Sigurdsson 1981; Shepherd and Aspinall 1982; Shepherd 1989). Additionally, strategies must include studies of geomorphologies and flank instabilities of each individual volcano and the mapping of risk areas that can contribute to massive volcanic edifice failures - with or without a volcanic triggering event. Already, as a result of greater awareness and concerns about the threat of volcanic hazards in the Caribbean region, several scientific organizations established monitoring stations on several islands and begun monitoring shallow seismic activity (Hirn et al., 1987). For example, as early as 1902, following the devastating 1902 eruption of La Soufrière volcano on St. Vincent Island, a surveillance program was initiated and studies of stratigraphy and geochemistry were completed (Rowley, 1978) as well as risk assessment for future eruptions (Robertson, 1992, 1995). In 1952, a Seismic Research Unit was established on the island and a sustained program of volcano monitoring was undertaken (Shepherd & Apinall, 1982; Fiske and Shepherd. 1990). Similarly, following the 1995 eruption of the Soufrière Hills volcano on the island of Montserrat, a monitoring program was established. Additionally, the Universities of Puerto Rico and of the West Indies have undertaken extensive monitoring functions and programs.

Present volcano monitoring operations include routine measurements of geological, geophysical and geochemical parameters and assessments of precursory-to-an-eruption phenomena. With some small additional effort, these existing volcano-monitoring programs in the Caribbean region can easily assess future risks. Such efforts must include routine monitoring of micro-earthquake activity to help forecast eruptions (Hirn et al. 1987), monitoring lava dome formation and rate of growth as well as evaluation of potential lava dome collapses as thoroughly outlined in the literature (Pararas Carayannis, 2003, 2004, 2005, 2006a). Furthermore, since lava dome collapses, particularly near a volcanic summit may be followed by violent eruptions, pyroclastic flows and debris avalanches, the expected path of destruction and potential flank failure sites can be determined by careful evaluation of the local topography and geomorphology. Based on such assessments, coastal areas subject to the hazard could be identified, microzonation maps can be drawn, and appropriate warning signs be posted for the protection of the public. In brief, volcanic eruptions can be predicted if there is sufficient data on a volcano's eruptive history and if appropriate instrumentation has been installed to monitor precursory events and changes that take place.

4. MASS EDIFICE FAILURES – COLLAPSES OF VOLCANIC ISLAND FLANKS

Inappropriate media publicity has been given recently to postulated massive flank failures of island volcanoes such as Cumbre Vieja in La Palma, Canary Islands, and Kilauea, in Hawaii, claiming that such collapses would generate mega tsunamis with devastating impact on densely populated coastlines in both the Atlantic and Pacific Oceans. Although interesting and well choreographed, these media presentations have created unnecessary public anxiety. Forecasts of mega tsunami generation from massive slope failures have been based on incorrect assumptions of volcanic island slope instability, source dimensions, speed of failure, and tsunami coupling mechanisms. Incorrect input parameters and treatment of wave energy propagation and dispersion, have led to overestimates of tsunami far field effects.

4.1 Vulnerabilities from Mass Edifice Failures - Future Impact

Massive flank failures of volcanoes can occur but they are extremely rare phenomena and none have occurred within recorded history. However, smaller-scale flank collapses occur more frequently and can create a great deal of destruction along coastal areas. Also, they can generate destructive local tsunamis.

Massive flank collapses of Cumbre Vieja or Kilauea volcanoes – as recently postulated - are extremely unlikely to occur in the near geologic future (Fig. 8). The flanks of these island volcanoes will continue to slip seismically, as in the past. Also, sudden slope failures can be expected to occur along faults paralleling rift zones, but these will occur in phases, over a period of time, and not necessarily as single, sudden, large-scale, massive collapses. Most of the failures will occur in the upper flanks of the volcanoes, above and below sea level, rather than at the basal decollement region on the ocean floor (Pararas-Carayannis, 2002).

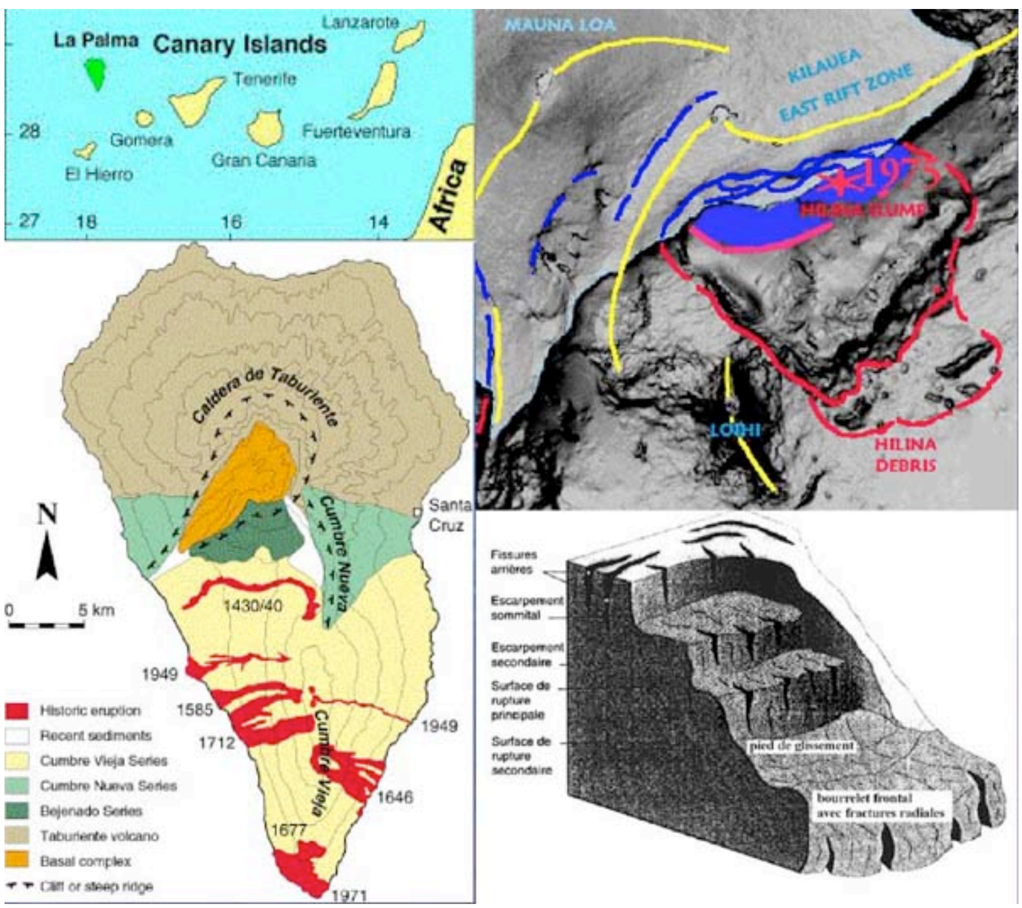

Fig. 8. Composite diagram of postulated mass edifice failure of the Cumbre Vieja volcano on the Island of La Palma; Gradual collapses of unstable flanks of Kilauea volcano in Hawaii; Step-like failures of the Piton De La Fournaise volcano on Reunion Island, Indian Ocean.

The sudden flank failures of the volcanoes of Mauna Loa and Kilauea in 1868 and 1975 and the resulting earthquakes generated only destructive local tsunamis with insignificant far field effects. Caldera collapses and large slope failures associated with volcanic explosions of Krakatau in 1883 and of Santorini in 1490 B.C. generated catastrophic local tsunamis, but no waves of significance at distant locations (Pararas-Carayannis, 1992). Mega tsunami generation, even from the larger slope failures of island stratovolcanoes, is extremely unlikely to occur. Greater source dimensions and longer wave periods are required to generate tsunamis that can have significant, far field effects.

4.2 Strategies for Mitigating Impact of Future Mass Edifice Failure and Associated Disasters

Therefore, the threat of mega tsunami generation from massive flank failures of island volcanoes has been greatly overstated. However, the threat should not be overlooked. Locally catastrophic collapses will occur along unstable volcanic flanks. The best strategy for the mitigation of this type of disaster is to properly monitor unstable flanks of volcanoes and mountains and to legislate for appropriate land use that would not allow development of such risk areas.

5. WEATHER RELATED DISASTERS

Hurricanes (typhoons, cyclones) are severe tropical storms that form in the southern Atlantic Ocean, Caribbean Sea, Gulf of Mexico, in the eastern and Western Pacific Ocean and in the Indian Ocean. The disastrous effects of their winds and of the flooding surges are well known. Their paths and vulnerable regions of the world are well established. Intense weather related disasters have resulted recently in an increase of the human death toll. Global warming appears to be a contributing factor. The following are only a few examples of recent catastrophes.

According to the World Disasters Report, weather-related disasters in 1998 resulted in the deaths of thousands. Hurricane Mich killed 10,000 in Central America. Indonesia experienced the worst drought in 50 years. Floods in China affected 180 million people. Fires, droughts and floods - blamed on the El Nino weather phenomenon - claimed a total of 21,000 lives and caused more than $90 billion in damages.

In 2005, extreme droughts resulted in failed maize harvest, followed by famine in Malawi, Southeast Africa. In June 2005, severe monsoon rains in Gujarat, India, caused floods, resulting in 123 deaths, and about 250,000 evacuees. In July 2005, Typhoon Haitang struck Taiwan and China causing many casualties and injuries. In July 2005, large parts of Bombay, India, experienced severe floods that resulted in more than 1,000 casualties. In August 2005, Hurricane Katrina caused devastation in the American city of New Orleans, in Louisiana. More than 1,600 people died from this disaster and the destruction was in the billions of dollars. In September 2005, Hurricane Rita struck again Louisiana, killed seven people directly, and caused many more casualties during evacuations and from indirect collateral consequences (fires, car crashes, illness, poisoning). Eventually, the official death toll from this disaster was set on 120. In October 2005 Hurricane Wilma hit parts of Mexico, Cuba and Florida, killing many people and causing extensive damage. In September 2005, Typhoon Longwang killed 96 people along the coasts of Japan.

More recent examples of severe weather-related disasters in June of 2006 was Typhoon Ewiniar which struck China, Korea and the Japanese islands, destroying many homes killing many people and requiring the evacuation of thousands. More recently, in October 2007, extended drought conditions contributed to large wildfires in southern California (US), which destroyed thousands of square kilometers of forests, burned thousands of homes and forced the evacuation of over 1 million people.

Bangladesh is another country which is extremely susceptible to weather related disasters. Because of its low-lying terrain and isolated villages the country has a long history of destruction by deadly cyclones. In, 1970, Cyclone Bhola struck Bangladesh -- then East Pakistan -- killing 500,000 people. Subsequently in 1974, nearly a million people died after massive floods wiped out the country's rice production. In 1991, the country was hit again by a devastating cyclone that killed at least 140,000 people.

As recently as August 2007 flooding in India, Nepal and Bangladesh resulted in what was called by the United Nations as "the worst flooding in living memory." After months of heavy monsoon rains that brought misery across the entire region, another cyclone struck again. In November 2007, Cyclone Sidr, a powerful Category 4 tropical cyclone, made landfall along the India-Bangladesh border. The cyclone and its surges raked Bangladesh's southwest coast with maximum sustained winds of 150 mph (241 kms), destroying fishermen's hamlets and villages, uprooting trees, destroying power and telephone line, homes and even damaging buildings where people had sought shelters. A storm surge of 15 to 20 feet above normal tides flooded the low-lying coastal areas. There was no warning system in place and no means for effective evacuation. Volunteers banged on drums in trying to get people in low coastal areas in Bangladesh to evacuate.

As of November 15, 2007, about 10,000 people had lost their lives and about 280,000 people were left homeless - with thousands more missing. The flooding wiped out the country's yearly rice production - a major food staple for the impoverished country. Nearly a third of Bangladesh's 64 districts were affected by the cyclone, most of those along the southern coast. The scope of the destruction by this cyclone may be much more extensive than what was reported since there are remote areas where conditions could not yet be determined.

5.1 Hurricane (Cyclone and Typhoon) and Surge Vulnerabilities – Future Impact

Many regions of the world in the Atlantic Ocean, the Caribbean Sea the Gulfs of Mexico and the Pacific and Indian Oceans remain extremely vulnerable to severe storm systems. Fig. 9 shows the numerous storm systems that developed in the Eastern Pacific in 1992 – an El Nino year. One of these systems developed into a Category 4 hurricane that devastated the island of Kauai, in Hawaii.

Most storm systems do not even have to be very intense to cause severe destruction or to disrupt the lives millions of people living in coastal communities. When Typhoon Whipa slammed recently into China’s heavily populated east coast with winds of up to 100 kilometers per hour, close to 2 million people had to be evacuated. The threat of Whipa created chaos in Shanghai one of the country’s most significant economic centers. Not only hundreds of thousands had to be evacuated from low-lying coastal areas, but also ships and ferries had to leave the ports.

The most recent example of extreme hurricane and hurricane surge vulnerability is that of the city of New Orleans and of adjacent areas in the Gulf of Texas. Other coastal regions in Florida, Mexico, Central America and the Caribbean region are equally vulnerable (Fig. 10). When Hurricane Katrina made landfall on August 29, 2005; it was only a Category 3 storm, yet its impact on the city of New Orleans was catastrophic. This impact should not have been a surprise. It was only a question of time before a storm of such magnitude or greater struck the city.

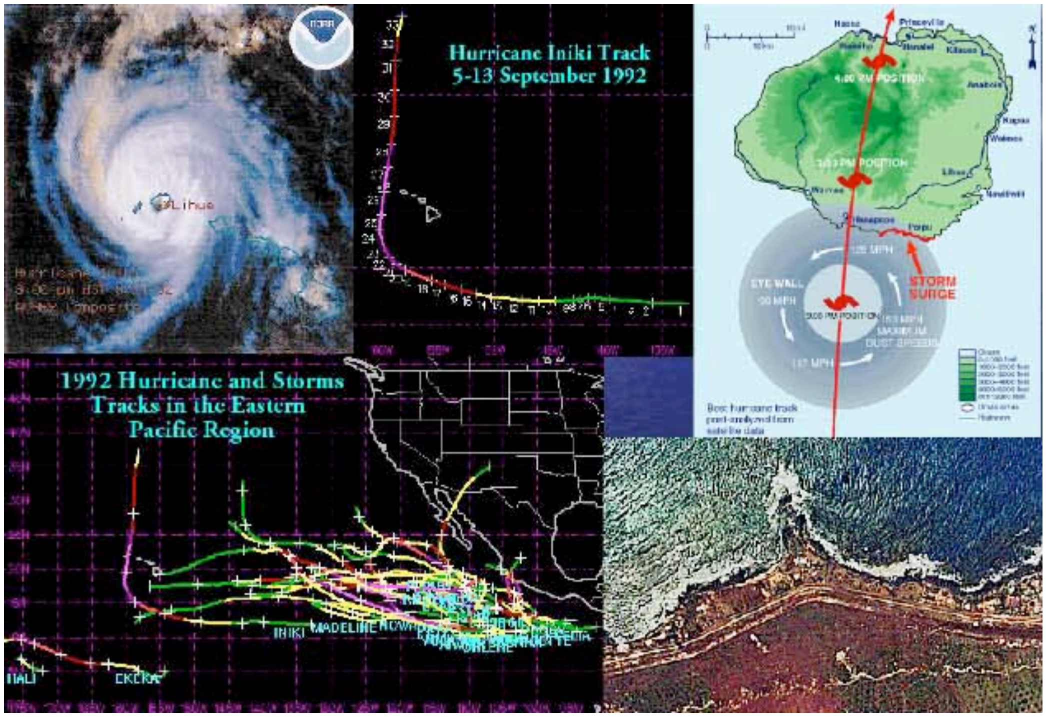

Fig. 9. Composite diagram of Eastern Pacific 1992 hurricanes; Track of Hurricane Iniki in 1992 near the Hawaiian Islands and landfall with 27 ft. surge inundation on the Island of Kauai (Pararas-Carayannis, 1993).

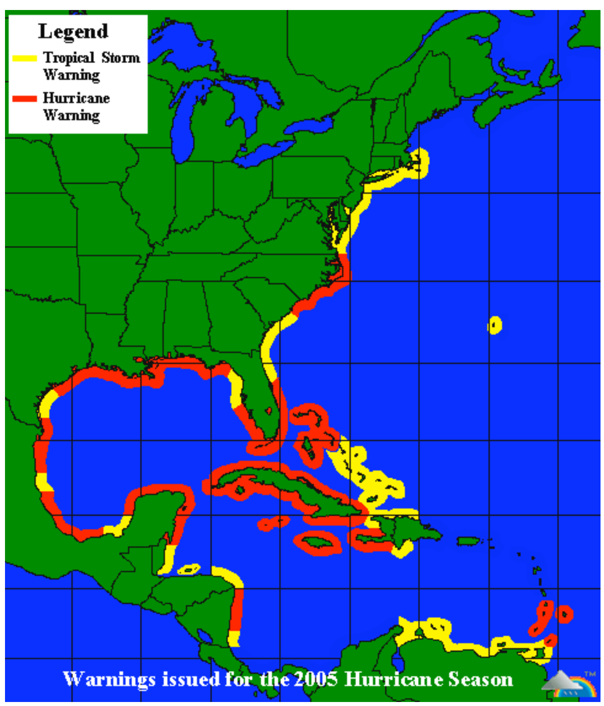

Fig. 10. Atlantic hurricanes and vulnerable regions. Warnings issued for 2005 Hurricane Season.

Numerous hurricanes have made landfall near the city of New Orleans in the past. The historic record shows that Hurricane Betsy had flooded part of New Orleans in 1965. In 1969, Hurricane Camille passed barely east of New Orleans (Pararas-Carayannis, 1975). Therefore a hurricane striking New Orleans should not have been a surprise (Fig 11). What really made the impact of Hurricane Katrina so severe in New Orleans was the lack of planning. Social, economic and political forces, as well as lack of preparedness, played the key roles in setting the stage for the hurricane's severe impact on the communities of the region. A clustering of vulnerability factors and unequal exposure to risk - coupled with unequal access to resources – is what contributed to the devastation.

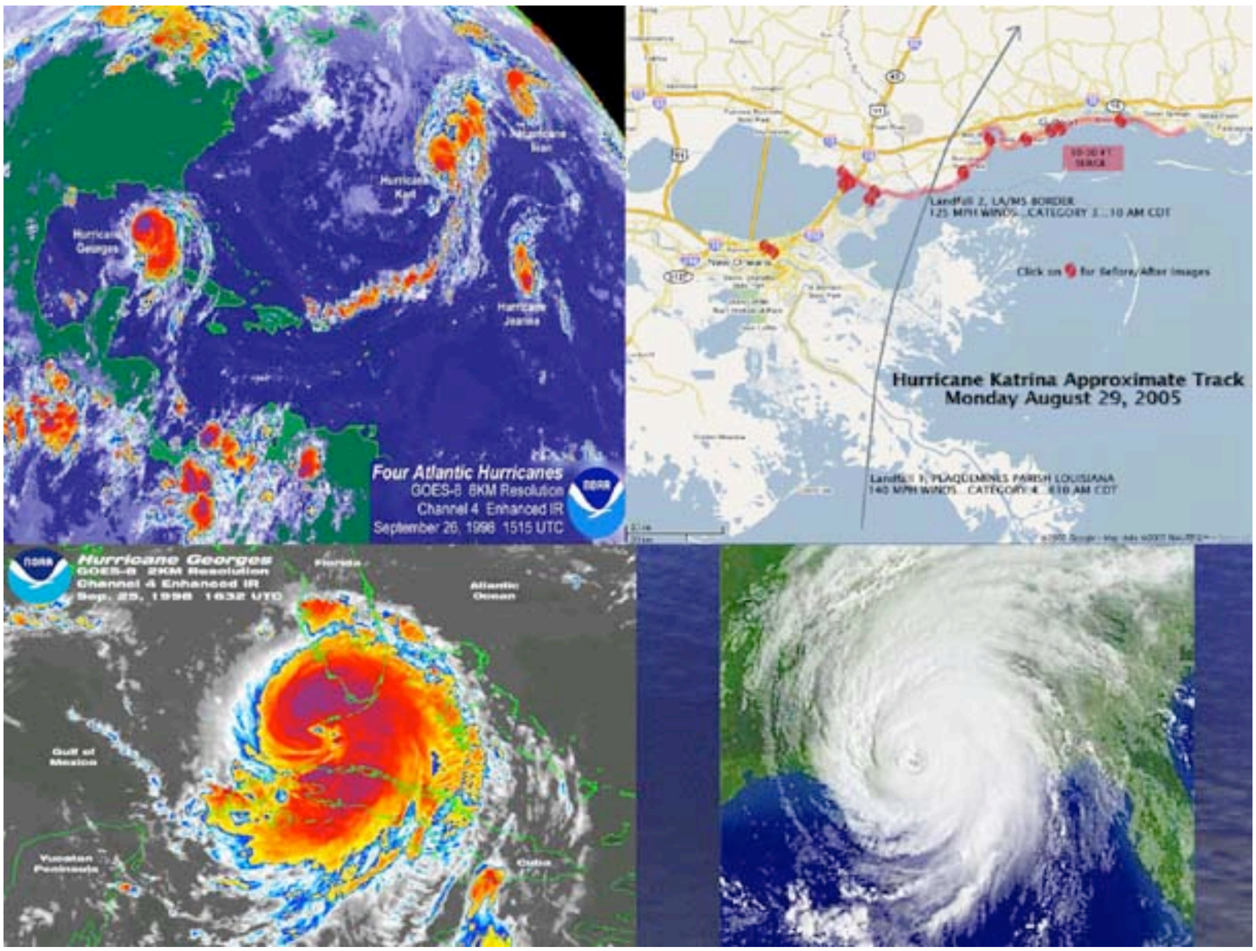

Fig. 11. Composite diagram of NOAA images of 5 concurrent hurricanes in the Northern Atlantic in September of 1998; track of the 2005 Hurricane Katrina over New Orleans.

The greatest impact and damage of hurricanes (typhoons, cyclones) along a coast are usually caused by surges that raise sea level and flood the land. Superimposed on the hurricane surge are storm waves that add to the height of inundation and degree of destruction. However, coastal morphology may also affect the extent of rise of water. This probably occurred with hurricane Katrina when the New Orleans levees were overtopped and failed from higher surge approaching from the direction of Lake Pontchartrain from the north of the city as shown in the Quick Bird satellite Infrared image below (Fig 12).

Fig. 12. Quick Bird satellite Infrared image of New Orleans showing extent of flooded areas.

5.2 Strategies for Mitigating the Impact of Future Weather-related Disasters

Strategies for mitigating the impact of weather-related disasters such as hurricanes (typhoons, cyclones) and associated surge flooding, tornadoes, heavy thunder storms, flash flooding, floods, mud and rock slides, high winds, hail, severe winter weather, avalanches, extreme high temperatures, drought and wildfires must be based on good understanding of what has happened in the past and what can happen in the future. Thus, proper assessment of the potential risks is the first essential step in the planning process and in designating susceptible areas. Establishing more effective early warning systems and building shelters in safe areas can help mitigate the impact of storm disasters in low-lying coastal regions such as Bangladesh or New Orleans. In addition, planning for quick post-disaster recovery is essential in keeping the death toll low. For example the number of deaths due to 2007 Cyclone Sidr was far lower in Bangladesh than previous disastrous cyclones in the region of 1970 and 1991, when the tolls were in the hundreds of thousands. Poor construction practices usually contribute to the severe impact of disasters in the region. Most houses are built with flimsy materials such as bamboo and corrugated iron. Thus imposing higher building standards and adopting better land use policies are an effective strategy in mitigating the impact of a similar disaster.

Better strategies must be implemented in vulnerable areas. For example, and in spite of post-disaster preparations in New Orleans, it is still doubtful whether this city will be able to survive another hurricane similar to Katrina - if one occurs very soon. Because of the geographical location and the geomorphology of the region, New Orleans, like many other coastal metropolitan areas, remains extremely vulnerable to hurricanes and flooding by storm surges. Unfortunately, as hurricane Katrina demonstrated, some of the protective defense structures in New Orleans - the levees – were not adequately designed and were breached or failed with only a Category 3 hurricane (Fig. 13). The same thing can happen again in the future.

Fig 13. Example of inadequate design. Hurricane Katrina surge flooded New Orleans when protective hurricane levees failed or were overtopped. The levees were designed for a Category 3 hurricane.

Whether a city like New Orleans can quickly recover from the impact of another major hurricane in the future will depend in large part on whether the effects of social vulnerability have been sufficiently addressed and mitigated. And the question arises as to what will happen if a Category 4 or 5 strikes next time. Of course for low-lying coastal mega-cities like New Orleans, there is also the longer-term threat of submergence by the rising sea level, mainly caused by global warming. For such low-lying regions of the world, a relocation strategy may be the more viable solution. Protective coastal defenses may provide temporary security but at a very high economic cost.

Finally, strategies for hurricane disaster mitigation must include reliable early warning systems that use remote sensing, satellite photography and other types of imaging techniques that can successfully estimate storm tracks, wind velocities and landfalls. Additionally, increased development of critical coastal installations, such as power plants and super port terminals, require accurate estimates of storm surges resulting from an intense storm's atmospheric pressure field and wind stresses on the water surface. The use of numerical models for such assessments is essential. A brief summary of such modeling techniques is described in the following section.

5.2.1 Mathematical Modeling for Hurricanes and Flooding Evaluation - The capability to predict hurricane (typhoon, cyclone) surges is based primarily on the use of analytic and mathematical models, which estimate the interactions between winds and ocean. The prediction of sea surges resulting from the combined meteorological, oceanic and astronomic effects coincident with the arrival of a hurricane at the coast is more difficult problem to solve. The reason is that a hurricane is a three-dimensional, weather system with ever changing dynamic conditions of wind speeds, directions and atmospheric pressures. The nonlinear storm surge can be computed along the coast by integrating numerically the hydrodynamic equations of motion and continuity (Pararas-Carayannis, 1975). To estimate mathematically the potential impact of the hurricane and the maximum height of its surges, there is a need to collect accurate data on the storm system. It will not be attempted here to explain exactly how the problem is solved. Only some of the basic concepts and components - which cumulatively contribute to hurricane surge - will be briefly explained. Fig. 14 portrays graphically the various components, which contribute to the cumulative total of hurricane surge on an open open-ocean coast (Pararas-Carayannis 1975), which can be calculated for sites where critical infrastructure coastal facilities are planned.

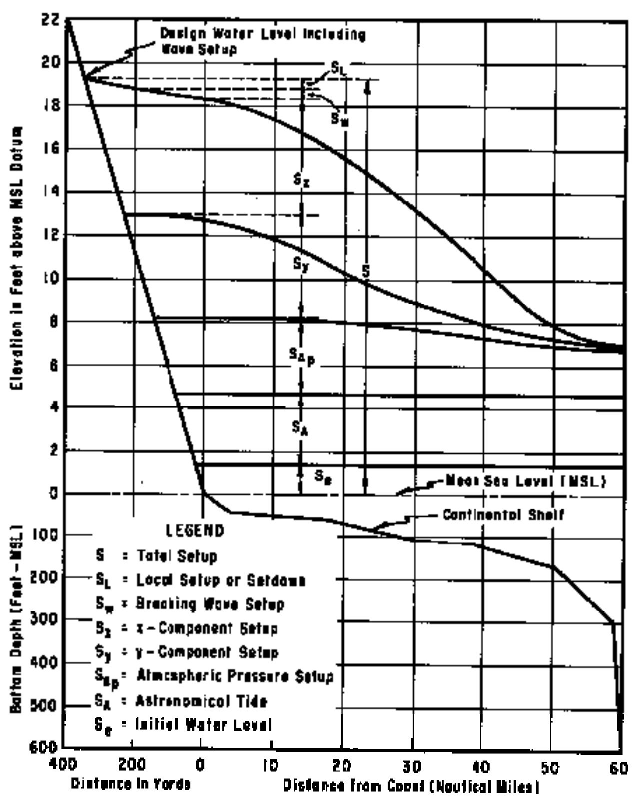

Fig. 14. Components of Bathystrophic Storm and Hurricane (typhoon, cyclone) Surges. The storm surge is a composite of water elevation obtained from components of astronomical tide, atmospheric pressure, initial rise, rises due to wind and bottom friction stresses, and wave setup. (Pararas-Carayannis, 1975)

Many sophisticated mathematical models have been developed in recent years to provide accurate three-dimensional estimates of energy flux and flooding that can be caused by a passing storm system. All models, regardless of sophistication of methodology, must use the Bathystrophic Storm Tide Theory to estimate the rise of water on the open coast - taking into account the combined effects of direct onshore and along shore wind-stress components on the surface of the water, the effect of the earth's rotation – known as the bathystrophic effect - and the different pressure and frictional effects on the ocean surface and on the ocean floor (Pararas- Carayannis, 1975, 1993, 2004).

To model a hurricane and calculate its maximum surge heights, the following meteorological parameters must be first determined. These are the hurricane's central pressure index, its peripheral pressure, the radius to maximum winds, the maximum gradient wind speed, and the maximum wind Speed, and the speed of hurricane translation (overall speed of the system). The models of oceanic/atmospheric interactions also take into account numerous other factors, such as astronomical tide, existing ambient wave conditions, surface and bottom friction and coastal topography. Only then one can proceed with the solution of the complex hydrodynamic equations of motion and continuity that will allow determination of the time history of expected changes in sea level associated with the hurricane (typhoon, cyclone), at any given point on the shore.

Mathematical models using the Bathystrophic Storm Tide Theory can be quasi-one-dimensional, two dimensional, or three-dimensional numerical schemes. The simplest, which is superficially described here, is a quasi-one-dimensional model which is a steady-state integration of the wind stresses of the hurricane winds on the surface of the water from the edge of the Continental Shelf to the shore, taking into consideration some of the effects of bottom friction and the alongshore flow caused by the earth's rotation. This bathystrophic contribution is an important parameter of the hurricane's surge and must be further explained.

In the northern hemisphere hurricane winds approaching the coast have a counterclockwise motion. Because of the Coriolis effect due to the earth's rotation, the flow of water induced by the cyclonic winds will deflect to the right (the Eckman Effect), causing a rise in the water level. The bathystrophic storm tide, therefore, is important in producing maximum surge even when the winds blow parallel to the coast. Coastal morphology and direction of approach also affect the extent of rise of water. Onshore and along shore wind-stress components of the moving wind field over the continental shelf and the frictional component of bottom stress, affect the extent of water rise (Pararas-Carayannis, 1975, 1993). In brief, effective strategies for the evaluation of storm systems and collateral effects on critical structures must include such modeling studies.

6. GLOBAL WARMING AND CLIMATE CHANGE DISASTERS

The on going climate change and the accelerated global warming that our planet has been experiencing for the last few decades, represent the greatest long term disasters that threaten present and future generations (Pararas-Carayannis, 2003). Unfortunately, these slow, global changes cannot be easily quantified or mitigated. In spite of international treaties, such as the Kyoto Protocol for reduction of greenhouse gases, there has been no significant change in atmospheric concentrations. In fact, the world population increases have placed higher demands for the use of fossil fuels, thus contributing to increases in the amounts of greenhouse gases.

The slower developing man-made disasters include pollution of the atmosphere and of the seas, destruction of the rain forests, alterations of sensitive ecosystems and destruction of the ozone layer.

Also, in the last two decades there has been a remarkable increase in the frequency and severity of weather-related disasters such as hurricanes, tornadoes, floods, wildfires, and droughts. Although these are considered to be natural disasters, anthropogenic input in the form of greenhouse gases emitted by industries into our planet's atmosphere, has been blamed for their higher frequencies and intensities. It appears that a new era of weather-related super-disasters has made its ugly appearance. In 2005 there was a record of 26 storm systems in the Atlantic and most of them reached hurricane intensities. Nothing similar has occurred in the past. The contributing human factors can no longer be ignored. Global warming due to increased greenhouse gases and ozone depletion are already affecting the earth's climate in ways that are not fully understood, but appear ominous for humanity. Global warming and sea level rise are slow disasters in the making that will have a long-term adverse impact on the planet and will affect seriously human safety, health and marine resources.

6.1 Global Warming

The consensus among the majority of scientists is that greenhouse gases are the chief cause of global warming. This is supported by the fact that there has been a remarkable and measurable increase in the concentrations of greenhouse gases in the atmosphere in recent years. For example, through monitoring the changing ice sheet in the Arctic Circle since the mid-1990s with a network of global positioning systems and weather stations, a dramatic rise in temperatures has been recorded. Specifically since 1994, a steady increase of 4.5 degrees centigrade (8.1 degrees Fahrenheit) was recorded during the winter months. The impact of such continuous global warming is already affecting the earth's weather and is resulting in climate change and storms of higher intensity and frequency. Based on NASA satellite data and analysis, it was further estimated that the melt area of over the last 30 years has increased by 30 percent and that Greenland is losing about 100 billion tons of ice each year - more than it is gaining from snowfall in the interior. The current warming trend in Greenland is very extensive and cannot be explained by natural variability alone. Furthermore, the warming is consistent with scientific predictions about the effects of man-made greenhouse gases.

6.2 Sea Level Rise

Global warming appears to cause increased changes in oceanic circulation. Warmer waters moving under the ice shelves in Antarctica have caused an increase in the rate of ice-shelf melting. Satellite observations of the grounded ice sheet in Greenland and on the floating ice shelves of the Amundsen Sea Embayment show considerable thinning of the ice over the last two decades. The ongoing thinning of the ice sheet is already contributing to an accelerated rate of sea-level rise. Since 1993, global sea levels have been rising at the rate of about three millimeters per year.

A recent report from the U.N.'s Intergovernmental Panel on Climate Change, estimates the sea level rise by 2100 to be as much as 1½ foot. However, this sea level rise may be underestimated because it is only based on melting from ice sheets and does not include the new fast flow of ice that has been detected in Greenland. Over the next century, sea levels could rise by three feet or more and such rise could wreak havoc around the world. Furthermore, Greenland alone holds enough ice to cause sea levels to rise by 23 feet - if this entire ice sheet melted. This is a possibility, which cannot be overlooked, given the accelerated rates of ice melting.

Sea level rise caused by global warming is threatening to submerge many coastal mega cities and destroy their economies. The Intergovernmental Panel on Climate Change warns that at least 20 of the world's largest cities are at risk of being swamped as sea levels rise in the coming decades. If the melting of ice continues as predicted, sea levels can be expected to rise enough to flood low-lying cities, such as Shanghai, China, and New York City, and to displace millions of people in the process.

For example Bangkok, a city of more than 10 million people, is one of the major coastal cities that are threatened. Its loss would destroy Thailand's economic engine. Projected sea level rise in the next 15-20 years is too rapid to permit moving this mega city to a safer location. The still expanding mega polis rests about 3 ½ to 5 feet above the nearby gulf, although some areas already lie below sea level. The gulf's waters have been rising by about 3 m), about the same as the world average. However, the city is built on clay of a swampy floodplain along the Chao Phraya River rather than on bedrock. Extraction of fresh water out of the city's aquifers has compacted the layers of clay, thus causing the land to sink at a rate of up to 10 cm annually. It is projected that with the ground sinking and the seawater rising, a good portion of Bangkok will be submerged under seawater in the next 15 to 20 years and will be submerged totally before the end of the century. Annual monsoon season flooding and surges will contribute to the erosion of the land and accelerate the process.

6.3 Strategies for Mitigating the Long Term Impact of Global Warming and Sea Level Rise

It will be very difficult to reverse the damage that has been done already to our planet by global warming. Mitigating the long term effects of global warming and the associated hazards will require more than firm commitments or simple adherence to international treaties for greenhouse emission standards. It will require responsible decisions and many sacrifices. Slowing down and hopefully reversing the ongoing trends will be a long and arduous process. Reaching a level of sustainability may or may never be achieved and the human race may have to adopt in the future to deal with higher temperatures and severe weather-related environmental conditions and disasters.

Existing technologies and forward-thinking policies and strategies offer practical and affordable solutions to reduce our dependence on the fossil fuels that currently dominate the world's electricity production systems. In the way they operate presently, these systems threaten the health of our communities by polluting the air and contributing to global warming. If left unchecked, heat-trapping emissions, such as carbon dioxide (CO_2), are expected to cause irreversible damage to communities throughout the world.

To arrest the process of global warming will require the commitments of all nations and strict enforcement of treaties. It will require drastic reduction of greenhouse gases, particularly carbon dioxide. New strategies must be adopted and new technologies must be encouraged to develop the means by which to sequester the excessive amount of carbon dioxide from the atmosphere. Reduction in the use of fossil fuels may be one of the ways of dealing partially with the problems of global warming. More importantly, new technologies must be developed to use fossil fuels more efficiently, and to decarbonize them by sequestering and removing the carbon dioxide from closed systems, following combustion. The carbon dioxide could be removed by chemical means from such closed systems, disposed safely, and thus prevented from going into the atmosphere. Such technologies can be developed for electric power plants and other industrial complexes that use large quantities of fossil fuels.

Researchers at Harvard University have suggested new technologies. They propose to electrochemically remove hydrochloric acid from the ocean and then neutralize the acid by reaction with silicate (volcanic) rocks and accelerate natural chemical weathering - thus permanently transferring CO_2 from the atmosphere to the ocean. Unlike other ocean sequestration processes that have been suggested, this proposed new technology does not further acidify the ocean and may be beneficial to coral reefs.

In addition, other practical solutions exist. For example, renewable electricity standards and policies can be adopted that require electricity suppliers to gradually increase their use of renewable energy such as wind, solar, geothermal, and bioenergy. Renewable standards are an affordable solution to reduce CO_2 and other unhealthy air emissions, while alleviating the harmful impact that fossil fuel extraction, transport, and use have on land and water resources.

These strategies are aimed at long-term solutions to obtain sustainability for the planet and its ecosystems. Whether sustainability can be achieved will not be known for a long time. Already many regions of the world – particularly low lying coastal areas and islands - face the direct and indirect threats of multiple disasters associated with climate change due to global warming and rising sea level. Unfortunately there are no easy solutions to mitigate effectively the impact of such long-term disasters. As mentioned already, Bangkok, is threatened by monsoon surges, a sinking land mass and the rising sea level. In the last thirty years the city has lost about half of its shoreline. This loss was accelerated by the destruction of vast mangrove forests that once protected the shoreline from erosion. Other regions around the world face similar problems. To alleviate the potential future loss of Bangkok and other threatened coastal cities, drastic remedial actions must be taken. To mitigate Bangkok's problems for example, proposals have been made for the construction of water diversion channels and up river inland dams to divert the flow of fresh water into reservoirs and, thus, help control the yearly flooding and minimize near shore land sinking. Also, a dike system has been proposed to channel the flow of Chao Phraya River and to offer a degree of protection to the city. Protective walls with gates have been recommended to provide protection from surges during the monsoon season. Restoring the mangrove trees may be an effective solution in halting or slowing down the shoreline erosion, but even this may be a temporary solution. Indeed all these measures may provide a form of protection in the short term, but not much protection in the future if the sea continues to rise at the present or greater rate. Many other coastal regions face similar problems.

In brief, decisions about climate change must be made in spite of considerable uncertainties as those related to sea level rise. In spite of uncertainties, governments must urgently initiate mitigation actions for both short and long term threats. Policies will need to be adaptive on climate change and sea level rise as new data is collected. Mitigation and adaptation policies should occur in parallel and in a synchronous manner. There is no time for political games or delays. Indeed the planet is already in great danger.

7. MAN-MADE DISASTERS

Man-made disasters are events, which are caused, either intentionally or by accident, which can directly or indirectly cause severe threats, either directly or indirectly, to public health and the well being of entire communities. As the world population continues to grow at a fast rate, man-made disasters will have an even greater impact. Major chemical, industrial and nuclear related disasters can be expected. Additionally, the economic development of coastal mega cities and associated industries will enhance the air and water quality problems. Air and water pollution are associated with unregulated population growth that outpaces predictions and control measures. Countries such as China have fast-growing economies, but its cities pay for it with choking pollution. Extensive use of coal, geographical location and growing number of motor vehicles result in deteriorating air quality. Fine particles of pollution that are harmful to human health are particularly worrying. Under present conditions human health is already affected. For example, mega cities like Beijing or coastal cities like Sanghai, are often blanketed by a gray haze, some originating from coal-fired industries, and other from the high numbers of cars. A U.N. report on air quality found that the average level of small particulate matter in Beijing's air in 2006 was eight times higher than the level recommended by WHO.

Finally, warfare is a man-made disaster that results in the destruction of important infrastructure facilities and human resources that sustain the social fabric of communities. The application of weapons often destroys cultural sites, which are the common heritage of all mankind on this planet. Burning oil fields, starting fires and releasing chemicals associated with the application of weapons, have severe impacts on air, water and soil qualities and ultimately affect human health throughout the world. Warfare and use of weapons of mass destruction may be the ultimate threat on our planet.

7.1 Chemical, Industrial, Nuclear and Other Man-Made Disaster Vulnerabilities – Critical Assessment of Future Impacts

Man-made disasters took a heavy toll on humanity and marine resources in recent years. For example, in September 2006, the disposal of waste containing toxic substances from an oil tanker caused an environmental disaster along the Ivory Coast, killing people and inducing illness to 40,000 more. In January 2006 six tons of diesel oil leaked into the Yellow River in the province of Henan, China from a power plant and spread towards the Bohai Sea causing damage to ecosystems and fisheries. In December 2005, a Slovakian oil tanker containing 42 tons of crude oil caught fire and sank near Bulgaria in the Danube River. Finally, the bombing of an electricity plant during the Lebanon war, in July 2006 caused the leakage of 25,000 tons of crude oil from the Lebanese coast to the Mediterranean Sea.

7.2 Strategies for mitigating man-made environmental disasters

Because of their unpredictability, man-made disasters cause an especially challenging threat, which must be dealt with through watchfulness, and proper preparedness and response. Increased efforts in improving waste management, transportation and water treatment could mitigate potential hazards to health. Also, contingency measures must be adopted that include policies that regulate the use of fossil fuels, the emission controls for factories or even limit or selectively ban the use of cars. The use of solar power and electric or hybrid cars should be encouraged. Forbidding the use of chemicals that damage the ozone layer must become mandatory.

To mitigate effectively the impact of man-made environmental hazards and disasters, governments must adapt appropriate legislation that is vigorously and continuously implemented and enforced. Emergency plans must exist for all industrial installations to prevent major accidents involving dangerous substances. The internal plans should be effectively supervised by appropriate regulating agencies. In addition, governments should also develop external emergency plans to cover measures to be taken outside these installations if a major accident occurs. Such measure must include on-site and off-site mitigation actions and also provide the public with specific information relating to the accident and how to minimize its adverse impacts.

8. SPECIFIC STRATEGIES FOR MITIGATING DISASTER IMPACTS

Natural and man-made disasters differ from region to region and often affect directly or indirectly large geographical areas. Although each disaster for each geographical region often requires a different methodology in developing a valid risk assessment plan, some basic principles apply to all Similarly, effective strategies for mitigating the impact of different disasters have common elements. All require proper assessment of vulnerability, proper planning, land utilization, civil defense preparedness, public education, implementation of early warning systems and proper engineering methods for construction of critical infrastructure facilities (Pararas-Carayannis, 2006a). For better understanding and easier land use designation, the assessments of different disaster vulnerabilities are often summarized into hazard microzonation maps (Fig. 15) that show the geographical distribution and intensities of hazards.

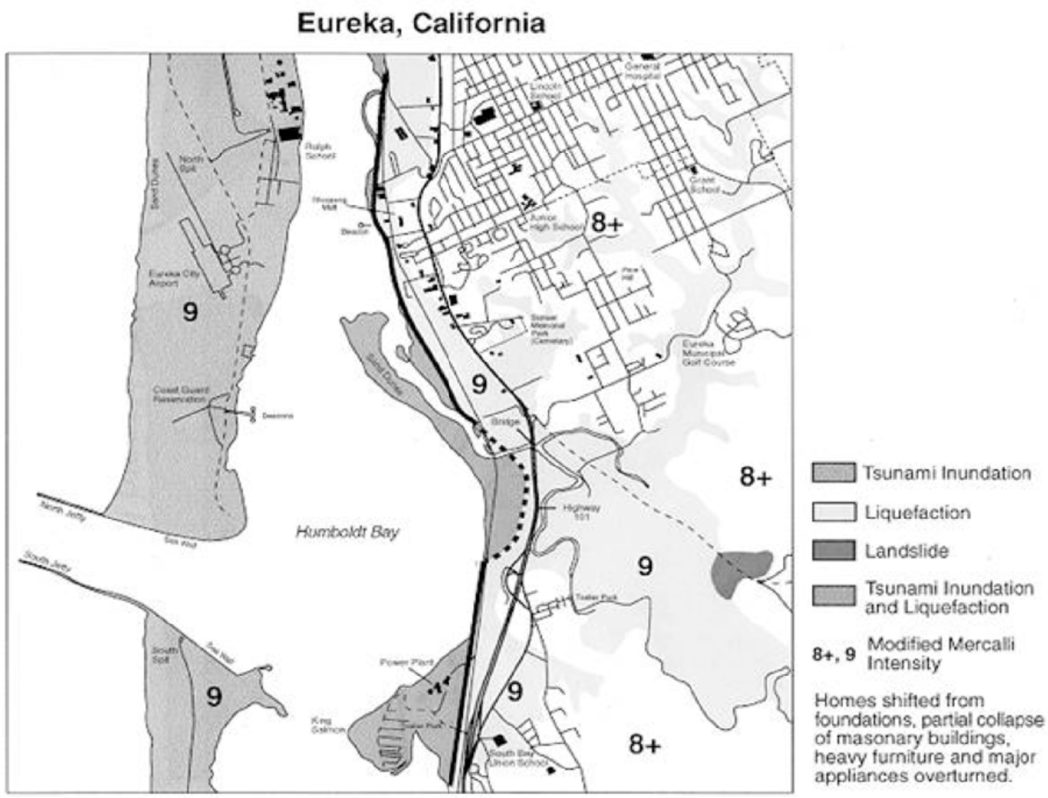

Fig. 15. Example of Multi-Hazard Zonation at Eureka, California, showing areas vulnerable to tsunami inundation, ground liquefaction, landslides and higher seismic intensities.

8.1 Land Use and Engineering Considerations in Mitigating the Impact of Future Geological and Marine Disasters

Proper land use is critical in planning for the reduction of the impact of disasters on resources located in coastal areas. Such planning must resolve - ahead of time - land use conflicts and provide for management systems that can allow for continuous functioning and operation of critical infrastructure facilities in the post-disaster period.

Architects and engineers involved in the design and construction of critical infrastructure facilities usually design and build in accordance to codes that provide adequately for static loads. Often, however, the structural vulnerabilities of critical structures to extreme loading of dynamic forces associated with natural disasters are overlooked or underestimated. Even if the critical structures survive the initial dynamic forces associated with a disaster, often-progressive collapse can occur from loss in strength of materials, when repeated cycles of dynamic forces continue. An example is the destruction to buildings in the coastal area of the Sea of Marmara from the 1999 earthquake in Turkey. Although well designed for static loads, most of the buildings that were destroyed were located in coastal areas, reclaimed land, and areas underlain with unconsolidated sediments. The strong earthquake motions caused liquefaction of the foundations and the buildings collapsed or sank in the sea. The subsequent tsunami completed the destruction.

8.2 Engineering Considerations

Each disaster requires a different type of extensive engineering analysis for calculating the impact on structures or on resources. In this section, and as an example only, we will address briefly some of the engineering considerations of potential seismic impacts.

Earthquakes generate many different waves. The most destructive of the seismic waves are those that travel on the surface and induce dynamic vertical and lateral accelerations on structures. These forces often result in ground liquifaction particularly in areas that are underlain by unconsolidated sediments. Liquefaction may result in the settling/sinking/tilting/cracking of the entire structure or the separation from the superstructure from the foundations. Damage to structures is not limited to the effects of liquefaction. Damage could occur with full liquefaction, partial liquefaction or no liquefaction at all. Damage could occur simply from strong ground motions. Enhancement of ground motions could occur in alluvial deposits even in the absence of liquefaction. It is not liquefaction that causes strong motions. The rupture geometry of the seismic source region can affect the directivity and frequency of the surface seismic waves. Furthermore the surface waves could separate into trains of certain periods. Waves of certain periods could enhance the ground accelerations (vertical and horizontal) particularly in alluvial sediments. For example, most of the damage at the Mexico City earthquake resulted from maximum ground accelerations caused by a single monochromatic surface seismic wave traveling within a 30 ft. layer of sediments (Pararas-Carayannis, 1985). Downtown Mexico City has been built on sediments of a dry lake (which existed when Cortez and the Spaniards arrived in 1541). The Aztecs lived on an island on that lake.

It is outside the scope of the present report to comment on specific engineering guidelines. It will suffice to state that the structural failures of critical structures from the dynamic forces of disasters can be prevented with proper analysis and performance studies, proper retrofitting of buildings and proper land use. Thus, specific design and construction strategies are essential in minimizing the impact of disasters on critical infrastructures facilities and in assuring continuity of operations in the post disaster period.

8.3 Early Warning Systems

Finally, early warning systems for natural and manmade disasters provide the best means for mitigating losses of human lives. Usually, an early warning system detects the disaster in real time and determines the type, magnitude, speed, direction, and the expected geographic area that will be impacted. When necessary, this information is transmitted in the form of a warning or advisory for evacuation or for other response action by the public that will help save lives and property.

Each type of disaster requires an early warning system that operates under various time constraints. For example there is no real-time early earthquake warning system because these disasters are sudden and unexpected. Tsunami warning systems may have a window of time for communicating a warning or an advisory to the public that may vary from a few minutes to several hours. Hurricane warning systems may be able to provide a warning a few days before the disaster strikes. Usually, for man-made accidents there is no warning.

9. APPLICATION OF DISASTER INFORMATION IN MITIGATING FUTURE LOSSES - A SUMMATION

The global and regional vulnerabilities to disasters are enormous and need to be assessed individually. Disaster mitigation requires accurate and expeditious assessment of all potential risks, the issuance of prompt warnings, and programs of preparedness and education that will assure warning effectiveness and public safety. The methodology for assessing the potential risks that threaten each region of the world requires adequate understanding of the physics of each type of disaster, a good and expeditious collection of historical data of past events, and an accurate interpretation of this data as to what the future impact will be.

An effective disaster mitigation strategy must promote the application of appropriate scientific tools for planning and management that raises public awareness of the potential hazards and promotes public participation in mitigating their impact. Thus, the first step is to develop a complete technical database on the threatening disasters, then augment the information with scenarios of potential impacts on communities and facilities in each region. To be effective, the data and information must be summarized and be widely disseminated to other coordinating and cooperating regional or international agencies for wider public dissemination and for early warning. A good public relations program and appropriate funding are prerequisites for the success of such programs. Effective strategies for mitigating the impacts of marine and terrestrial disasters require:

1. Identifying processes, mechanisms and root causes of disasters threatening each geographical region of the planet;

2. Establishing a methodology for natural disaster risk assessment and the adaptation of rational probabilistic models that can estimate disaster recurrence frequencies and intensities, with a reasonably high degree of certainty;

3. Developing guidelines for proper instrumentation that can assist in the prediction, assessment, monitoring and computation of relevant disaster parameters for the purpose of managing resources and reducing future impact and collateral damages;

4. Developing integrated planning for coastal areas through the improvement of scientific tools.

5. Formulating guidelines that can be incorporated in relevant codes that can assist enforcing agencies with appropriate planning, analysis and design methodologies and the implementation of coastal and oceans management programs;

6. Developing environmental and engineering standards and guidelines that can be incorporated in city planning and in the sitting, designing and management of important infrastructure facilities in coastal zones;

7. Establishing programs of effective education and training that involve women and youth groups into grassroots efforts of public disaster awareness and preparedness;

8. Drafting recommendations for a global policy that deals with the mitigation of marine disasters.

10. REFERENCES

Brooks, J. A., 1965, "*Earthquake activity and seismic risk in Papua and New Guinea*" Australian Bureau of Mineral Resources, Geology & Geophysics, Report No. 74.

Denham, D., 1969. "*Distribution of earthquakes in the New Guinea-Solomon Islands region".* J. *Geophys. Res.,* 74: 4290-4299.

Byrne Daniel E., Sykes Lynn R. Davis Dan M., 1992, *"Great thrust earthquakes and aseismic slip along the plate boundary of the Makran subduction zone".* JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 97, NO. B1, PAGES 449–478, 1992

Fiske, R. S., and J. B. Shepherd, 1990, "*12 Years of Ground-Tilt Measurements On the Soufrière of St- Vincent, 1977-1989"*, Bulletin of Volcanology 52 (3):227-241.

Heinrich, F., Mangeney, A., Guibourg, S., and Roche, R. 1998, "*Simulation of water waves generated by a potential debris avalanche in Montserrat, Lesser Antilles"*, Geophys. Res. Lett., 25, 9, 3697-3700,

Heinrich, F., Guibourg, S., Mangeney, A., and Roche, R. 1999a, "*Numerical modelling of a landslide-generated tsunami following a potential explosion of the Montserrat Volcano"*, Phys. Chem. Earth (A), 24, 2, 163-168,

Heinrich, F., Roche, R., Mangeney, A., and Boudon, G. 1999b, *"Modeliser un raz de maree cree par un volcan",* La Recherche, 318, 67-71,

Heinrich, F., Boudon, G., Komorowski, J. C., Sparks, R. S. J., Herd, R., and Voight, B. 2001. "*Numerical simulation of the December 1997 debris avalanche in Montserrat",* Geophys. Res. Lett., 28, 13, 2529-2532.

Hirn, A., Girardin, N., Viode, J.-P., and Eschenbrenner, S., 1987, "*Shallow seismicity at Montagne Pelee volcano, Martinique, Lesser Antilles"*, Bulletin of Volcanology, v. 49, p. 723-728.

Hooper, D. M. and Mattioli, G. S. 2001, "*Kinematic modelling of pyroclastic flows produced by gravitational dome collapse at Soufriere Hills",* Natural Hazards, 23, 65-86.

Lander James F., Whiteside Lowell S., Lockridge P A 2003, "*TWO DECADES OF GLOBAL TSUNAMIS 1982-2002".* Science of Tsunami Hazards, Volume 21, Number 1, page 3.

Pararas-Carayannis, G., 1975, *"Verification Study of a Bathystrophic Storm Surge Model*", U.S. Army, Corps of Engineers - Coastal Engineering Research Center, Washington, D.C., Technical Memorandum No. 50, May 1975.

Pararas-Carayannis, G., 1978, *"The Earthquake and Tsunamis of 19 August 1977 in the Lesser Sunda Islands of Indonesia".* ITIC Progres Reports for 1976-1977 prepared for the 1978 Sixth Session of ITSU in Manila, Philippines. http://drgeorgepc.com/Tsunami1977Indonesia.html

Pararas-Carayannis, G., 1985, "*The Mexican Earthquakes and Tsunami of September 19 and 21, 1985*". Intern. Tsunami Information Center, Tsunami Newsletters, Vol XVIII, No. 2, 1985.

Pararas-Carayannis, G., 1986, 1988. "*Risk Assessment of the Tsunami Hazard",* Proceedings of the International Symposium on Natural and Man-Made Hazards, Rimouski, Canada, August 3-9, 1986. In Natural and Man-Made Hazards, D. Reidal, Netherlands, pp.171-181, 1988.

Pararas-Carayannis, G., 1992, "*The Tsunami Generated from the Eruption of the Volcano of Santorin in the Bronze Age",* Natural Hazards 5:115-123.

Pararas-Carayannis, G., 1992, *"The Earthquake and Tsunami of 2 September 1992 in Nicaragua"* http://drgeorgepc.com/Tsunami1992Nicaragua.html

Pararas-Carayannis, G (1993), "*The Wind and Water Effects from Hurricane Iniki on September 11, 1992,* at Lawai Beach Resort, Poipu, Island of Kauai, Hawaiian Islands", A study prepared for Metropolitan Mortgage & Securities Co., Inc., Spokane, Washington,and the Ritter Group of Companies, Chicago, June, 1993.

Pararas-Carayannis, G., 1997, *"The Great Lisbon Earthquake and Tsunami of 1 November 1755",* http://drgeorgepc.com/Tsunami1755Lisbon.html

Pararas-Carayannis, G., 2001a, *"The Earthquake and Tsunami of 28 November 1945 in Southern Pakistan"* http://drgeorgepc.com/Tsunami1945Pakistan.html

Pararas-Carayannis, G. 2001b, *"The Great Tsunami of August 26, 1883 from the Explosion of the Krakatau Volcano ("Krakatoa") in Indonesia"* http://drgeorgepc.com/Tsunami1883Krakatoa.html

Pararas-Carayannis, G. 2002, "*Evaluation of the threat of mega tsunami generation from postulated massive slope failures of island stratovolcanoes on La Palma, Canary Islands, and on the Island of Hawaii"*, Science of Tsunami Hazards, Vol. 20, 5, 251-277. http://drgeorgepc.com/TsunamiMegaEvaluation.html

Pararas-Carayannis, G., 2003, *"Near and far-field effects of tsunamis generated by the paroxysmal eruptions, explosions, caldera collapses and massive slope failures of the Krakatau volcano in Indonesia on August 26-27, 1883",* Presentation for the International Seminar/Workshop on Tsunami "In Memoriam 120 Years of Krakatau Eruption - Tsunami And Lesson Learned From Large

Tsunami", August 26th - 29th 2003, Jakarta and Anyer, Indonesia; Journal of Tsunami Hazards, Volume 21, Number 4. 2003. Also, Journal of Tsunami Hazards, Vol. 21, Number 4. http://drgeorgepc.com/Tsunami1883Krakatau.html

Pararas-Carayannis, G., 2003, "*Climate Change, Natural and Man-Made Disasters - Assessment of Risks, Preparedness and Mitigation",* 30th Pacem in Maribus, Kiev, Ukraine, October 26-30, 2003 http://drgeorgepc.com/ClimateChange.html

Pararas-Carayannis, G., 2004, "Factors Contributing to Explosivity, Structural Flank Instabilities, Mass Edifice Failures and Debris Avanlanches of Volcanoes - Potential for Tsunami Generation" 2004 National Science Foundation, Tsunami Workshop in San Juan, Puerto Rico, 2004. http://drgeorgepc.com/TsunamiVolcanicFactors.html

Pararas-Carayannis, G., 2005a,*"The Great Earthquake and Tsunami of 26 December 2004 in Southeast Asia and the Indian Ocean",* http://drgeorgepc.com/Tsunami2004Indonesia.html

Pararas-Carayannis, G., 2005b,*"The Earthquake and Tsunami of 26 June 1941 in the Andaman Sea".* http://drgeorgepc.com/Tsunami1941AndamanSea.html

Pararas-Carayannis, G., 2005c,*"The Great Earthquake and Tsunami of 1833 off the coast of Central Sumatra in Indonesia"* http://drgeorgepc.com/Tsunami1833Indonesia.html

Pararas-Carayannis, G., 2005d, *"The Great Earthquake and Tsunami of 28 March 2005 in Sumatra, Indonesia"*, http://drgeorgepc.com/Tsunami2005ndonesia.html

Pararas-Carayannis, G., 2005e, *"The Earthquake of 8 October 2005 in Northern Pakistan"* http://drgeorgepc.com/Earthquake2005Pakistan.html

Pararas-Carayannis, G., (2006a), "*Disaster Risk Assessment - Overview of Basic Principles and Methodology"* "Natural Disaster Risks", Risk Journal pp. 17-73 , March 2006.

Pararas-Carayannis, G., 2006b, "*Potential of tsunami generation along the Makran Subduction Zone in the Northern Arabian Sea – Case Study: The Earthquake and Tsunami of 28 November 1945"*, 3rd Tsunami Symposium of the Tsunami Society May 23-25, 2006, East-West Center, Un. of Hawaii, Honolulu, Hawaii, Science of Tsunami Hazards Vol 24(5), 2006 http://drgeorgepc.com/TsunamiPotentialMakranSZ.html

Pararas-Carayannis, G., 2006c, *"Risk Assessment of Tsunami Generation from Active Volcanic Sources in the Eastern Caribbean Region"*, In "CARIBBEAN TSUNAMI HAZARDS"- Proceedings of National Science Foundation Caribean Tsunami Workshop, March 30-31, 2004, Puerto Rico, Aurelio Mercado-Irizarry - Philip Liu, Editors. ISBN 981-256-545-3, 341 pp. 2006, Hard Cover Book. World Scientific Publishing Co. Pte.Ltd., Singapore

Pararas-Carayannis, G. 2007, *"The Earthquakes and Tsunami of September 12, 2007 in Indonesia"*, http://drgeorgepc.com/Tsunami2007Indonesia.html

Pelinovsky E., Zahibo N., Dunkley P., Edmonds M., Herd R., Talipova T. , Kozelkov A., and I. Nikolkina, 2004, "*Tsunami Generated by the Volcano Eruption on July 12-13, 2003 at Montserrat, Lesser Antilles"*. Sciences of Tsunami Hazard Vol. 22, No. 2, pages 44-57.

Robertson, R.E.A. 1992, "*Volcanic Hazard and Risk Assessment of the Soufrière Volcano, St. Vincent, West Indies",* MPhil, Earth Sciences, The University of Leeds, Leeds.

Robertson, R.E.A. 1995, "*An Assessment of the Risk From Future Eruptions of the Soufrière Volcano of St. Vincent, West Indies*", Natural Hazards 11 (2):163-191.

Rowley, K.C. 1978, "*Stratigraphy and geochemistry of the Soufriere Volcano, St. Vincent, West Indies*", PhD, Seismic Research Unit, University of the West Indies, St. Augustine

Shepherd, J.B., and W.A. Aspinall. 1982, "*Seismological studies of the Soufrière of St. Vincent, 1953-1979: Implications for volcanic surveillance in the Lesser Antilles"*. Journal of Volcanology and Geothermal Research 12:37-55.

Shepherd, J.B. 1989, "*Eruptions, eruption precursors and related phenomena in the Lesser Antilles. In Volcanic hazards:* IAVCEI Proceedings in Volcanology 1, edited by J. H. Latter. Berlin, Heidelbery: Springer-Verlag.

Sigurdsson, H. 1981, *"Geological observations in the crater of Soufriere volcano, St. Vincent":* University of the West Indies.

Young R. S., 2004*, " Small scale edifice collapse and tsunami generation at eastern Caribbean volcanoes; a standard phase of the volcanic cycle"*, NSF Caribbean Tsunami Workshop, Puerto Rico March 30-31, 2004.