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Agenda Item 3 **Specific Air Navigation Activities and Developments**
3.3 Search and Rescue (SAR)

THE UNITED STATES' TSUNAMI WARNING SYSTEM IN THE CARIBBEAN AND EAST COAST

(Presented by the Secretariat)

SUMMARY

The information contained in this paper was discussed during the CAR Region Search and Rescue (SAR) Meeting/Workshop that was held in Santo Domingo, Dominican Republic from 28 March-01 April 2005 and it is presented for the consideration of the 29 E/CAR WG Meeting.

References:

- CAR/SAR IP/01, dated 23/03/05

1. Caribbean

1.1 The focus of this paper is on Puerto Rico and the U.S. Virgin Islands. Much of the content derives from a 1999 USGS sponsored workshop on "Seismic and Tsunami Hazard in Puerto Rico and the Virgin Islands" attended by international academic, local academic and governmental, and federal agency experts on seismic and tsunami hazard research, engineering, and mitigation. Complete workshop proceedings are available at http://pubs.usgs.gov/of/of99-353/tsunamigrp.html. The regional hazard potential and the identified needs for upgrading of knowledge and systems are relevant broadly to the Northern Caribbean. While much of the identified needs are targeted at U.S. Caribbean territories the broad expansion of seismic monitoring and development of warning systems are intended to encompass the Caribbean basin. Providing regional monitoring and warning systems should be a collaborative effort with regional governments, similar to the International Coordination Group for Tsunami Warning in the Pacific (http://ioc.unesco.org/itsu/), but should draw on the technological and operational facilities in place in existing federal earthquake and tsunami centers.

1.1.1 Introduction and State of Knowledge

1.1.1.1 Practically all known sources for tsunamis occur in the Caribbean, presenting unique challenges for mitigating tsunami hazards in Puerto Rico and the Virgin Islands. These include earthquakes, primarily, but also submarine landslides (north of Puerto Rico), submarine volcanic eruptions, catastrophic edifice collapse, and teletsunamis (tsunamis from distant sources). Recent modeling studies of the 1918 earthquake and tsunami in Puerto Rico that killed 116 people and the compilation of a tsunami catalog over the last 500 years has highlighted the significant hazard in the

Caribbean. Earthquake and tsunami hazards are a real threat in the region and adequate warning and mitigation measures are required to reduce the risk to human lives and damage to property, infrastructure, and commercial interests. An effective response will require coordinated federal action with local and regional participation.

1.1.2 Past Earthquake and Tsunami Events

1.1.2.1 The Puerto Rico region is an area of high regional seismicity and large earthquakes. Examples include the 1918 magnitude 7.5 earthquake in Mona Passage, a magnitude 7.5 earthquake centered northeast of Puerto Rico in 1943, and magnitude 8.1 and 6.9 earthquakes north of the Dominican Republic in 1946 and 1953 respectively. Other large earthquakes include the 1787 magnitude 8.1 earthquake in the Puerto Rico trench and the 1867 magnitude 7.5 earthquake between Puerto Rico and the Virgin Islands. Newly discovered active onshore faults in western Puerto Rico have increased earthquake hazard estimates there and current USGS hazard maps place equal probability for damaging earthquake ground shaking for the city of Mayagüez as for Seattle. Because of great and increasing population density and extensive construction near the coast a perilous earthquake/tsunami risk exists in Puerto Rico and elsewhere in the region.

1.1.2.2 Thirty-eight tsunamis have been reported for the entire Caribbean region in the past 500 years, including 14 tsunamis reported from Puerto Rico and the Virgin Islands. 30 tsunamis caused significant damage, including reports of as many as 9600 fatalities, which can be attributed to tsunamigenic earthquakes and tsunamis combined. 1922 deaths are confirmed as being specifically related to tsunamis during the last 150 years. A 1918 M7.5 earthquake resulted in a tsunami, which together killed at least 116 people in Puerto Rico. A run up of about 6m (20 feet) has been documented by mapping, and sedimentary evidence for at least two earlier tsunamis in the area has been cited. Eyewitness reports of a 1867 Virgin Islands tsunami give a maximum wave height of more than 7 meters (23 feet) in Frederiksted, St. Croix. A U.S. Naval ship was lifted by the wave and placed on the pier. This event, with a nearby earthquake source, a large nearly instantaneous tsunami, a travel time in minutes, a dense coastal population, and an unprepared populace is the archetype for potential seismic/tsunami disasters in the region. Current population growth and development greatly increase the potential damage associated with future tsunami events.

1.1.3 Current capacity for developing hazard assessment and warning systems

1.1.3.1 Regional seismicity and the historical record indicate that the hazard potential throughout the Caribbean region is significant. Accurate hazard assessments require an improved knowledge of the regional seismology and geology of this region – which is extremely complex and not well defined relative to other seismically active regions. To systematically assess the earthquake and tsunami hazards in the region, the entire spectrum of sources must be considered, placing special emphasis on those sources most likely to occur and those that cause the largest hazard (severity and extent). Hazard assessments, and ultimately warning systems, must acknowledge the differences between earthquake (ground shaking) and tsunami (run-up) responses. In particular, a potential interplate earthquake located in deep water (such as occurred in 1946 and 1787) will dominate the tsunami hazard potential relative to all other earthquake sources. Monitoring and geologic investigations and reconstructions are required to identify seismic activity and understand tsunami potential.

1.1.3.2 A seismic network was established in Puerto Rico in 1979 (the Puerto Rico Seismic Network, PRSN) and is currently operated by the University of Puerto Rico, Mayagüez. A sparse strong motion instrument network has operated in Puerto Rico since the 1970's. The network has been subsequently modernized and densified and since 1998 the PRSN has operated the data center for the Middle-America Seismograph Consortium (MIDAS). A protocol has been established for participating

seismic networks of the Caribbean, North America, Central America, and South America to submit data on significant events in near real time. While the current PRSN network is connected to the National Earthquake Information Center (NEIC) the existing operations are constrained (unmanned during non-business hours) and modernization and expansion of regional networks within the Global Seismographic Network are required.

1.1.3.3 Existing earthquake hazard maps for Puerto Rico are based mainly on regional sources; the risk associated with rupture of specific faults has not yet been assessed because of a lack of adequate geological and geophysical knowledge. Geophysical surveys and offshore seismic studies for the northeastern Caribbean are sparse, limiting our current ability to identify geologic structures relevant to seismic and tsunami hazard potential. Shallow seismic reflection data is required to determine the geology of slope failures and their debris field.

1.1.3.4 Global Positioning System (GPS) geodesy is an essential technique to constrain the complex strain within the Caribbean-North American plate boundary zone. GPS studies in the eastern Greater Antilles and the Virgin Islands. Since 1994 the regional network has been steadily improved and provide relatively well constrained regional velocity fields – however additional sites and longer-term monitoring is required to constrain velocities along potentially seismogenic structures both onshore and offshore.

1.1.3.5 Detailed high-resolution elevation data (bathymetry and topography) is required for fault and landslide identification, modeling of tsunami run-up, and assessment of coastal hazards. Recently collected laser altimetry and IFSAR surveys are available for the development of improved digital elevation models for the eastern Greater Antilles (Dominican Republic, Puerto Rico, Virgin Islands).

1.1.3.6 Analysis of tsunami deposits yields critical information on both tsunami and generating earthquakes. The potential to extract this information from geologic field studies, particularly by discriminating tsunami and storm deposits, is largely untapped in this region. Age dating of these deposits also yields critical information on the recurrence of tsunami hazards.

1.1.3.7 Existing knowledge and information is applied by the Puerto Rico Tsunami Warning and Mitigation Program, cooperatively sponsored by the Federal Emergency Management Agency and the University of Puerto Rico. The PRSN has developed a tsunami warning and alert protocol to be followed between the PRSN and the San Juan office of the National Weather Service (NWS). The PRSN has no dedicated and assured communications lines, however. Additionally, due to a lack of offshore buoys and coastal tide gauges there is no means to confirm whether seismic activity has resulted in a tsunami. Over the past year U.S. academics have cooperated in efforts to set up a tsunami warning system in the wider Caribbean region. Connections have been established and maintained between the PRSN and the Pacific Tsunami Warning Center (PTWC). However, operational systems at the PRSN need to be upgraded to the same level as at the two other regional U.S. tsunami warning centers (PTWC and the West Coast/Alaska Tsunami Warning Center).

1.2. What needs to be done (a USGS perspective)

a. Tsunami and Earthquake Sources & Monitoring

i. Expand and modernize the GSN network with the addition of 9 GSN stations (Puerto Rico, Hispaniola, Antilles (2), Venezuela (2), Cuba, Jamaica and E. Honduras) around the Caribbean basin. Upgrade of 4 existing stations and associated telemetry. Data will be routed through the NEIC and shared with the Puerto Rico and the Pacific Tsunami Warning Center (PTWC).

ii. Assessment of regional sources in the Puerto Rico trench. Synthesis of existing seismic, bathymetric, geophysical and geological information.
iii. Collection of detailed bathymetric and shallow seismic reflection data in the Mona Passage (source of the 1918 tsunami) and the Anegada Trough/Virgin Islands Basin (source of the 1867 tsunami) to understand the failure structures and mechanisms of tsunami generation.
iv. Assistance to regional governments in the evaluation of seismic and tsunami hazards (particularly the Dominican Republic which as well as being a major tourist destination effects the hazard potential in western Puerto Rico and has an overall greater hazard potential than Puerto Rico and the Virgin Islands.)

b. Updated hazard assessments and maps.

i. Development of high-resolution nearshore bathymetry and topography for inundation mapping.
ii. Modeling of tsunami inundation potential (constrained by geologic reconstructions).
iii. Identify and analyze tsunami deposits to establish recurrence intervals for major earthquake and tsunami events throughout the region. Develop criteria for discrimination of tsunami, storm and hurricane deposits.
iv. Assess the seismogenic potential of major onshore faults for their contribution to regional earthquake hazard.
v. Development of up-to-date seismic and tsunami hazard maps including ground-shaking and inundation hazards.

c. Education, Outreach, and a Caribbean Tsunami Warning System

In the last 150 years tsunami-related fatalities in the Caribbean were nearly 5 times greater than in Hawaii, Alaska, and the U.S. West Coast combined. It is important that, as soon as possible, a tsunami-warning program be implemented in the U.S. Caribbean possessions and throughout the basin.

2. East Coast

2.1 Introduction

2.1.1 Earthquake-generated tsunamis represent a much smaller hazard along the U.S. east coast than in the Pacific and Indian Oceans and throughout the Caribbean because of the relative lack of subduction zones and associated earthquakes. An exception is the 1755 Lisbon earthquake that occurred along the Africa/Eurasia plate boundary and produced a tsunami (50,000-70,000 people were killed by the tsunami and earthquake in Lisbon alone). The collapse of volcanic edifices (such as the Canary Islands) has the potential to create large tsunami events but such events are extremely rare and the tsunami potential is poorly known (depending on the velocity and duration of acceleration of the collapse). Volcanic eruptions, for instance in the Azores, have the potential to generate tsunami, though this is again a rare occurrence.

2.1.2 Submarine landslide-generated tsunami hazard must be evaluated for the east coast of the United States. The pre-historic Storega slide in Norway produced a tsunami in excess of 20m in Scotland. USGS surveys off the East Coast of the U.S. show many submarine failure scarps, including the 250-km long Cape Fear landslide and the 150 km-long Cape Lookout landslide. Most of the identified slope failures originated at the top of the gas hydrate stability zone. Several large failures such as the 1929 Grand Banks tsunami resulting from a magnitude 7.2 earthquake on the continental slope resulted in significant but localized tsunami damage. In comparison to more really extensive earthquake sources,

landslide-generated tsunamis can result in high runups in a localized region near the source and dissipate rapidly outward from the source region. From the 1929 tsunami it seems clear that:

a) It is very difficult to provide warnings because of the relatively short propagation times.

b) Public education is critical as most landslide-generated tsunami are preceded by a recession of water levels – which should be recognized and followed by evacuation to higher ground.

2.2 What needs to be done (a USGS perspective)

2.2.1 The tsunami hazard along the U.S. East Coast is relatively modest, but not negligible. Prudent approaches consistent with the hazard would include the following aimed at assessing the hazard potential and identifying areas most susceptible. The activities described have broader relevance beyond tsunami hazards.

1) Assessment of the landslide potential and dynamics along the eastern United States continental slope. Geologic and geophysical evaluations of the frequency, causes, and susceptibility to massive slope failures should be developed. Should the U.S. become a signatory to the Law of the Sea treaty, the provisions for expansion of the continental shelf will necessitate geophysical surveys along much of the U.S. Atlantic margin. These should be leveraged to result in an initial assessment of landslide potential and identification of those areas of greatest hazard potential.

2) Research into the potential linkage between gas hydrate accumulations and slope stability. Understanding the potential for methane-hydrate release to generate tsunamigenic landslides is required for hazard assessments and has application to offshore operations in the Gulf of Mexico. Broader efforts to understand the response of slope deposits to seismic shaking are needed, but should focus on the Pacific coast including Alaska.

3) Modeling of tsunami generation and propagation resultant from geologically-constrained landslide scenarios leading to inundation maps.

4) Development of earthquake-induced ground-shaking potential maps on the outer continental shelf and slope to assess potential landslide initiation.

2.2.2 The efficacy of these efforts, and mitigation of the hazard potential, depends on the availability of high-resolution elevation data (topography and bathymetry) for the nearshore and coastal regions. This has broader application for assessing vulnerability, guiding development, and designing evacuation plans related to coastal storm and flood hazards.

2.2.3 Landslides generated by volcanic activity, or collapse of volcanic structures, are infrequent but could have large consequences. The most prudent course of action is to support long-term monitoring of volcanic systems, including monitoring to identify incipient slope failures.

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