SUMMARY REPORT
15 April 2006

ICG/PTWS Working Group One on Seismic Measurements, Data Collection and Exchange Intersessional Meeting, 15-16 March 2006 Honolulu, Hawaii USA

INTRODUCTION

Working Group (WG) 1 Seismic Measurements, Data Collection and Exchange met on 15-16 March 2006 in Honolulu, Hawaii, USA to build upon the recommendations made in Chile and evaluate the strengths, weaknesses, potential threats, and solutions to improve the seismic monitoring and evaluation capabilities of Pacific Tsunami Warning and Mitigation System (PTWS). Through the course of several presentations and much discussion, the WG made several recommendations for PTWS. Naturally, many if not most, of the Recommendations have application for the tsunami warning centres of other ocean basins. The WG also identified promising new technologies that should be incorporated into the warning system as these data become available.

The WG was chaired by Dr. Stuart Weinstein of the Pacific Tsunami Warning Center (PTWC), and attended by 14 participants. These were:

Dr. Stuart Weinstein, PTWC
Dr. Charles McCreery, PTWC Director
Dr. Osamu Kamigaichi, Japan Meteorological Agency (JMA)
Yuji Nishimae, JMA
Dr. Rhett Butler, IRIS GSN Program Manager
Dr. Stuart Sipkin, US Geological Survey
Dr. Gerard Fryer, PTWC
Dr. Vindell Hsu, PTWC
Dr. Stuart Koyanagi, PTWC
Barry Hirshorn, PTWC
Dr. Benjamin Brooks, University of Hawaii
Dr. Cecily Wolfe, University of Hawaii
Masahiro Yamamoto, IOC
Dr. Laura Kong, IOC ITIC Director
Brian Yanagi, IOC ITIC

OPENING REMARKS

The Chair of Working Group opened the meeting by providing opening remarks, noting that in the Pacific there has been a well-established international system since the 1960s. He further noted that since the 2004 Indian Ocean tsunami, both the PTWC, JMA, and the WC/ATWC have increased their warning and advisory services to beyond the Pacific. He also recalled that the Japan recent inauguration of the Northwest Pacific Tsunami Advisory Center now provides sub-regions of the Pacific (northwest Pacific and starting 1 April 2006 the South China Sea) with focused tsunami warning coverage. The Chair also stated the importance of real-time sharing on seismic waveform data and other parametric information from regional and local networks as critical for realizing and issuing the earliest tsunami warning. In this respect, the Pacific

continues to be the leader in promoting and implementing a range of tsunami warning and mitigation services. In convening this Working Group, he asked all participants to actively participate in the discussions with the goals of acknowledging the present state of seismology an seismometry supporting tsunami warning, identifying gaps and needs to improve the quality and response time for the evaluation of large earthquakes for tsunamigenesis, and recommending initiatives for action.

The IOC provide opening remarks by recognizing the leadership role that the Pacific can play in the implementation of tsunami warning systems in other oceans and seas, and in the development and recommendations of earthquake detection and analysis methods for tsunamigenic potential. The ITIC Director provided some guidance to the Group and asked participants to review the Recommendations and Report from the same Indian Ocean Working Group as background to the formulation of Pacific recommendations. She indicated that the Summary Report will be presented to the ICG/PTWS-XXI in Melbourne, Australia 1-5 May 2006, and that the ICG/IOTWS, ICG/CARIBE-EWS, and the ICG/NEAMTWS would also receive copies of the Recommendations and the Report.

The IOC Senior Tsunami Advisor asked to Group to consider how to best formulate an Action Plan for the enhancement of the Pacific. He referred to a similar effort that is now taking place for the Indian Ocean in which a step-by-step process is being undertaken that has milestones in June 2006, one year later, three years later, and beyond.

The IRIS Global Seismographic Network Program Manager recalled the enormity of the 2004 Indian Ocean earthquake, in terms of magnitude, rupture length and tsunami, and challenged the Working Group to consider how well the Pacific would have done if a M9+ shallow earthquake had occurred along the Pacific Ring of Fire, and given this background, then how the Pacific can do better in source characterization in real or near-real time.

PRESENTATIONS

The Working Group heard presentations from participants. General summaries are provided below, and copies of the presentations can be downloaded from the PTWS Web Site at http://ioc3.unesco.org/ptws/pre_post_meetings.htm

1. *Dr. Gerard Fryer, PTWC*
   Development of Hawaiian Islands Seismographic Network for Local Tsunami Warning
   His presentation discussed the factors leading to the design and planned upgrade of PTWC's seismic monitoring system in the Hawaiian islands. For large earthquakes, PTWC will use the Mwp method. A magnitude method making use of the large number of accelerometers is also desirable, as confirmed by the JMA.

2. *Dr. Benjamin Brook, University of Hawaii*
   Space- and Seafloor-Geodesy and Tsunami Warning in Hawaii
   His presentation showed how GPS could play a role in the tsunami warning system by providing a real time measure of surface displacements during an earthquake. While geodetic grade sensors are expensive, it is suggested that cheaper sensors deployed in dense configurations would be more than adequate to detect rapid relative displacements on the order of a few meters; he stated that in the future, that 1 meter of relative displacement could be rapidly detected from data in about 10 seconds after transmission. A local strategy for detection and processing is desirable, rather than a global monitoring system. The processing times required for absolute displacement measurements are presently too long to support

initial tsunami warning bulletins, but could be useful for later bulletins for the case of distant tsunamis.

3. *Dr. Stuart Sipkin, USGS NEIC*
   Status of Seismic Monitoring at the USGS National Earthquake Information Center, Hydra system
   His presentation centered on "Hydra", the newly developed and deployed USGS operations software package used by the National Earthquake Information Center (NEIC) for the identification and analysis of earthquakes. The new philosophy for earthquake operations emphasizes speed over accuracy, wherein earthquake solutions will be reported out as soon as minimum criteria are satisfied rather than waiting for all the seismic data to be received completely. Revised, more accurate solutions are then issued as more data is received. Both body-wave Moment Tensor, and surface wave Centroid Moment Tensor solutions are computed in near-real time using global and regional network data. Dr. Sipkin also talked about the progress underway in deploying nine additional high quality broadband stations in the Caribbean. These instruments will form the backbone of the seismic network in that region and will well-serve the regional tsunami warning centre for that region. He also discussed NEIC's highly successful programme of providing external grants to researchers to develop operational analysis tools for use by NEIC. He noted several recent grantees are helping to develop software that will improve NEIC operations, including techniques for source imaging of rupture using arrays, finite fault modeling, techniques for depth estimation, and event detection and location using surface waves. WG participants saw high value in the programme, and inquired to PTWC if this was also available to them. The PTWC replied that presently no such grant programme is available, and that present development is dependent on the NOAA Pacific Marine Environmental Laboratory for tsunami modeling only.

4. *Yuji Nishimae, JMA*
   Acquisition of Seismic Data from Global Network
   His presentation showed how JMA is now incorporating GSN data into their warning system. They are having latency issues due to the particular IRIS server they were using. This provided an impetus for general discussion of the meaning of "data latency", and was followed upon later by Dr. Butler's presentation that proposed a definition of Latency. The JMA reported that seven JMA seismic stations are planned for sharing and distribution through the IRIS Data Management Center in the near future.

5. *Dr. Osamu Kamigaichi, JMA*
   Dr. Kamigaichi introduced the present status and future plans for GPS network in Japan in view of tsunami warning. About 1000 GPS stations are operated by Geographical Survey Institute (GSI) of Japan. Data are collected online, and GSI is upgrading data collection system so that all data can be collected in every one second in a real-time basis. The goal is an automatic estimation of hypocentral fault parameters in 10 minutes after an earthquake occurrence, but it is in a research stage as of now. A priori information would be necessary to get a stable estimation especially for an offshore event. GSI is planning to send this estimation to JMA to be taken into account to the update of tsunami warning in future.

6. *Dr. Rhett Butler*
   GSN, Data Latency and Completeness
   His presentation highlighted the success of the GSN (now with data availability running at 90%), what it takes to maintain the GSN, and how it leverages resources of other network operators like the CTBTO. The extensive coverage of the FDSN was emphasized, as well and

the valuable contribution these stations offer for global, regional, and local tsunami warning systems. Dr. Butler also introduced a discussion of "Latency" and completeness of seismic data streams as quality measures. He noted that Latency is comprised of transmission latency, buffer latency, and data (re)formatting latency, and that each should be minimized for real-time monitoring. Recently, JMA experience with excessive data latency from the IRIS BUD server was due to data (re)formatting latency, which has been corrected. Data must also be complete with no data gaps in order to be able to use the data stream reliably. Dr. Butler also made the point that because virtually all seismometry is land based, the need for oceanic coverage is paramount, not just for researchers, but for the tsunami warning system as well.

7. *Dr. Vindell Hsu, PTWC*
   Array processing – Example of Korea array for 2004 Sumatra earthquake
   His presentation showed how teleseismic P-wave data from seismic arrays can be quickly analyzed to show the extent and time history of an earthquake rupture. By example, Dr. Hsu showed the results of array processing analysis of the 2004 Sumatra earthquake using data from the Korea KSRS arrays. The long period array consists of seven KS54000 sensors with 10 km element spacing and the short period array contains 19 23900 sensors at 2 km element spacing. The PTWC is working to evaluate various methodologies with the intent of implementing additional analysis methods to support tsunami warnings. Challenges are to develop ways in which to characterize rapidly rupture size, direction, and velocity as these are valuable indications of tsunamigenesis. He also made reference to the importance of considering how to best detect tsunamis from other sources, such as volcanic eruptions, meteorites, and landslides using other types of data such as hydro-acoustic, infrasound and space sensors.

8. *Barry Hirshorn, PTWC*
   Mwp
   His presentation focused on how the use of Mwp has reduced the time for PTWC to issue its first bulletin. He recalled that S. Tsuboi of JAMSTEC first published the research method for regional deep earthquakes in 1995, but that in recent years, the warning centers in Hawaii and Alaska have studied and implemented real-time algorithms to support tsunami warning. Hirshorn discussed preliminary results for the application of Mwp for evaluating earthquake size in the near field noting that interference with other arriving waves may result in limits to the use of Mwp on great earthquakes (M8.5 or greater). He stated that estimates using STS-1 sensors (response flat to 350 s) provided better estimates than data from STS-2 sensors (response flat to 130 s), and specifically that Mwp estimates using STS-2 sensors may be reliable only to about magnitude 7. He noted that the mantle magnitude Mm using the later arriving surface waves was more suited for the accurate estimation of great earthquakes.. In addition, he also mentioned the recommendation of Professor Hiroo Kanamori to use the W-phase, and indicated that the phase could and should be incorporated into the warning system. Finally, he stated the importance of conducting sensitivity and calibration studies using the current network geometry and historical data to determine the magnitude accuracy range and any corrections factors that may be required.

   Japan indicated that it also uses Mwp to rapidly estimate earthquake magnitude. In general, the JMA uses the M_{JMA} magnitude scale using accelerometers and reported that estimated magnitudes were reliable up to M8.2. The JMA further indicated that it was planning to investigate the use of period-independent strain-meters and reported that preliminary analyses of the 26 December 2004 Sumatra and 28 March 2005 Nias earthquakes resulted in estimates of M9.2 and M8.7, respectively.

Hirshorn also highlighted PTWC's inability to cover the local tsunami problem outside of Hawaii, and that many nations with an elevated local tsunami hazard are in danger of 'falling though the cracks' in the PTWS.

9. *Dr. Stuart Weinstein, PTWC*
Mm, Theta, and All That
His presentation showed how use of the Mantle magnitude Mm can overcomes the saturation problem associated with Ms (variable period magnitudes) and is less affected by earthquake rupture slowness, complexity and duration. He also described the use of an energy discriminant Theta Θ as an indicator of the long source duration of large earthquakes and an indicator for slow earthquakes. An analysis of thousands of Mm measurements highlighted the superiority of the STS-1 seismometer. He also provided preliminary work in developing near-real time algorithms to estimate finite fault ruptures of earthquakes which provide information on the spatial and temporal distribution of energy release of large earthquakes; additionally, Dr. Weinstein reported that the method using up to 15 waveforms required less than three minutes to compute, thus making it useful for rapid earthquake analysis.

   Dr. Weinstein highlighted the fact, that as the STS-1 seismometer is the best instrument for magnitude estimation of great earthquakes and recording seismic waves in general, the PTWS could be in serious jeopardy if no successor is found to the STS-1 before the current deployments of STS-1 age and fail.

RECOMMENDATIONS

Throughout the meeting, the Working Group vigorously deliberated on the information presented, asking questions and discussing the merits and limitations of the many standards, techniques, and processing methodologies available for real-time earthquake source characterization to support tsunami warnings.

Through collective discussion and agreement on the afternoon of the 16th, in which all of the WG participants made valuable comments and suggestions, the WG concluded with the following Recommendations:

1. The WG highly recommended that regular scientific symposia are convened to focus on improving tsunami warning systems and their operational procedures. The WG noted that the IUGG Tsunami Commission has convened such meetings on tsunami research, but not on operational systems, and further noted the need and high value for such symposia on real-time seismology.

2. The WG recognized that the international tsunami warning system depends largely upon the real-time seismic waveforms made available by the Global Seismographic Network (GSN), and noted that this scientific network is funded largely by the US National Science Foundation and the US Geological Survey. The WG also recognized the important contributions made by international and Member State organizations toward this Network. However, the WG noted that the function of these organizations is primarily for earthquake monitoring and research, and not tsunami warning. The WG thus strongly stated that it is essential that the GSN and other contributing networks should be sustained at high levels of operational reliability for tsunami warning.

3. The WG stated that open and unrestricted access to real-time data is essential for both research and operations. These data include seismic and sea level time series.

4. The CTBTO presently provides its primary station and hydro-acoustic data to tsunami warning centres. The WG noted its high value as presented by the JMA and PTWC, and recommended that this data flow be continued. The WG also recognized the importance of auxiliary station data for tsunami warning, and recommended that these be also made available in real time.

5. The CTBTO shares its Global Communications Infrastructure (GCI) with the GSN, and this telemetry is vital for tsunami warning systems. The WG recommended that the IOC recognize and encourage that this important cooperation with CTBTO continue.

6. The WG recognized the world wide coverage and open data availability of stations of the International Federation of Digital Seismograph Networks (FDSN), and recommended that global, regional, and local Tsunami Warning Systems work with FDSN and its member networks to incorporate real-time data from available FDSN stations.

7. The WG recognized that there currently are significant Internet and telemetry bandwidth limitations into PTWC which restricts bringing available, high-quality seismic, hydroacoustic, GPS and other relevant real-time continuous data for tsunami warning operations. The WG recommends that these limitations be reviewed and rectified at PTWC and at other TWS to assure adequate, dedicated bandwidth for available data flow.

8. The WG recognized and recommended that the GSN constitute the basis for the Pacific Core Network, encouraged the designation of additional real-time FDSN stations in the Core Network, and agreed that additional stations to densify the network, such as in the Southwest Pacific, South China Sea, and seaward of major seismogenic zones, will be very valuable.

9. The WG recognized that the best seismometers for determining the tsunamigenic potential of an earthquake are Streckeisen STS-1. Therefore, the WG stated that is incumbent for Member States with STS-1 sensors to share the data in real time.

10. The WG was concerned that STS-1 sensors are no longer being manufactured, and that no adequate replacement is in sight. Furthermore, existing deployed sensors are aging. The WG stated that it is necessary for the continued integrity of the tsunami warning system that a successor be developed as soon as possible.

11. The WG recognized that research plays a fundamental role in developing better ways of characterizing earthquakes and their potential for tsunamigenesis, and that it is critical that this research be developed into operational tools. The WG recommended that these tools should be openly shared with earthquake monitoring centres and tsunami warning centres.

12. The Pacific Tsunami Warning Center provides timely international tsunami warnings for tele- and regional tsunamis. However, the WG recognized the limitations of the PTWC to provide local tsunami warnings, and recommended each Member State to consider national or coordinated sub-regional tsunami warning centres to address local tsunami hazards. The WG encourages Member States with local capabilities to share their know-how and experience.

13. The WG recognized the high value of providing guidance on the establishment of local warning capabilities, and recommended this issue be addressed by the Working Group on the Medium-Term Strategy for the Pacific Tsunami Warning and Mitigation System.

14. The WG recognized that all seismic coverage is from land-based seismic stations, and that almost no coverage is available seaward from the major seismogenic zones around the Pacific. The WG noted that this is a fundamental gap in the PTWS' ability and speed to characterize the earthquake source in near real-time. It was recognized that extensive deep-ocean tsunami infrastructure is being developed and deployed to monitor sea levels in real time. The WG recommended that enhancing these systems with seafloor seismic and acoustic sensors should be explored and developed.

15. The Southwest Pacific faces a significant threat from locally-generated tsunamis that is not currently addressed by any local warning system. The WG reaffirmed the Action Plan developed by eight SOPAC Member States during the South Pacific Tsunami Awareness Workshop in July 2004.

16. Countries along the Middle America Trench face a significant threat from locally-generated tsunamis that is not currently addressed by any local warning system. The WG encouraged the Working Group for the Central America – Pacific Coast Tsunami Warning System to actively continue its activities to enable the timely dissemination of local warnings to coastal populations.

17. The WG discussed the requirements for high-quality real-time seismic waveforms. For this, the concepts of waveform completeness and timeliness of receipt were agreed to be the most important metrics. Complete data must have little or no gaps. Latency should be as small as reasonable. The WG recommended definitions of Completeness and Latency to facilitate the discussion of seismic transmission standards. It was recognized that Latency is comprised of several components; data record size, telemetry (including internet) latency, data reformatting and server latency. The WG recommended that transmission latency should be defined as the difference between current time and the time of the last datum received in the most recent packet, emphasizing the vertical 20sps channel. Networks should note the respective data record size for channels. Measures of latency should include median statistics to avoid effects of large outliers. Data servers should measure and note server latency due to data reformatting or internal buffers.

18. The WG identified the strong need for synergy between other ICG Seismic Working Groups in the Indian Ocean, Caribbean and Adjacent Regions, and the North-eastern Atlantic, Mediterranean, and Connected Seas, and called for the IOC to take a leadership role in integrating and coordinating common activities.

19. The WG recognized GPS to be a promising technology for quickly measuring displacements resulting from earthquakes in real time. Such technology is potentially very useful to address the local tsunami warning problem and great global earthquakes. The WG recommended that further research was needed to evaluate the use of GPS for tsunami warning methodologies.

20. The WG recognized that additional threats from tsunamis are generated by landslides, volcanic explosions, and meteorite impacts, but noted that current tsunami warning systems cannot adequately warn for these events. The WG recommended that further evaluation of these threats is merited.