Scientific meeting of experts for coordinated scenario analysis of future tsunami events and hazard mitigation schemes for the South China sea region

Meeting of Experts
Xiamen, China
16 - 18 November 2015
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Executive Summary

The South China Sea region, which covers the South China Sea and its adjoining basins including Sulu Sea and Celebes Sea, is identified as one of the most vulnerable regions to major tsunamigenic earthquakes due to the high seismicity of the Manila Trench, Cotabato and Negros Trench and Sulawesi Trench. According to historical records, a number of devastating tsunamis have occurred in the region.

To tackle tsunami risk in the region, the international community has launched a coordinated plan of action. The Twenty-third Session of the Intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System (ICG/PTWS-23, 16-18 February 2009, Samoa) formed a Working Group on Tsunami Warning and Mitigation System in the region to, among other functions, promote and facilitate tsunami hazard and risk studies in the region.

During this workshop the major topics for discussion were paleoseismology and historic events in the South China Sea region and Philippines Trench, seismic studies and potential tsunamigenic sources in the South China Sea region and technical/scientific development of tsunami modelling for the South China Sea region, including key parameters.

The workshop resulted in a better understanding of the tsunami hazard and risk in the South China Sea region, which would be useful for the planning for the establishment of the sub-regional Tsunami advisory centre, as well as allow Member States to better understand their level of tsunami exposure.

Based on previous reports of earthquake sources, the following are identified as possible generators of tsunami events, capable of generating surface-rupturing events (>M6.5) that may generate and propagate tsunami waves within the South China Sea region and affect the countries within:

Regional Source: Manila Trench, Negros Trench, Sulu Trench, Cotabato Trench, Sulawesi Trench, Ryukyu Trench

Local Source: 1781-82 Taiwan Tsunami Source, Aglubang River Fault in Mindoro Island, Chinese Mainland Coastal Faults

Transoceanic: Pacific Sources (Yap, Chile)

The participants further recommended:

- A search for tsunami deposits along the shores of the South China Sea should be initiated. This should be coordinated on a regional level by a group of experts, to be identified.

- A baseline bathymetric database be developed for all modellers to use. 30 arcsecs in deep water, 500m + interpolation techniques on the continental shelf. The common shared database should be derived from publicly available data, where available.

- There is a need to look at historical literature to find ancient records of tsunamis

- The SCS-WG should look at operational capability gaps in Member States and find ways of filing them.

- NOAA/PMEL is asked to integrate Negros, Sulu, Cotabatos y Sulawesi in ComMIT/MOST
1. BACKGROUND AND OBJECTIVES

The South China Sea region, which covers the South China Sea and its adjoining basins including Sulu Sea and Celebes Sea, is identified as one of the most vulnerable regions to major tsunamigenic earthquakes due to the high seismicity of the Manila Trench, Cotabato and Negros Trench and Sulawesi Trench. According to historical records, a number of devastating tsunamis have occurred in the region. For example, the tsunami which hit Keelung in 1867 is believed to have resulted in the loss of several hundred lives. More recently, the tsunami generated by the M8.1 earthquake which hit Moro Gulf of the Celebes Sea in 1976 resulted in over 8,000 dead or missing, 10,000 injured and 90,000 homeless. The recent Mw 7.0 earthquake in 2006 off Taiwan once again raised attention and awareness of tsunami hazard of the region.

To tackle tsunami risk in the region, the international community has launched a coordinated plan of action. The Twenty-third Session of the Intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System (ICG/PTWS-23, 16-18 February 2009, Samoa) formed a Working Group on Tsunami Warning and Mitigation System in the region to, among other functions, promote and facilitate tsunami hazard and risk studies in the region.

There are already a significant number of studies on the tectonic, seismicity, historical earthquakes, tsunami records as well as tsunami risk assessments of the South China Sea region with results published in peer-reviewed journals. The results of those studies will form a good basis for further tsunami hazard and risk assessment in the region.

The historical tsunami events discussed above had mainly local impacts and there is very little historical information on events affecting a large region of the South China Sea. Considering these information gaps, some relevant questions on tsunami hazard in the South China Sea region are:

- Is the Manila Trench the only structure capable of producing a South China Sea wide tsunami?
- What is a comprehensive list of possible tsunami sources in the South China Sea region (local, regional, distant)?
- Are any sources outside the region a potential hazard for the South China Sea region?
- How large an earthquake can be produced by the Manila Trench and other potential sources within the South China Sea region?
- What is the return period for Manila Trench and other main source events?

In addition to the listed topics, there is evidence of past/potential submarine landslides in the South China Sea region, especially in the relatively steep slope transition zones from continental shelf to deep South China Sea basin, e.g., those in Northern South China Sea and offshore Vietnam among other areas (ref. Huang et al., 2010; Sun et al., 2014; Su et al., 2015; Wu et al.). These sources may be able to pose significant tsunami threat to the surrounding areas, especially to those within their close proximity.

In view of the large volume of knowledge in the studies discussed above, and the diversity of some of the study results, the IOC organized a three-days scientific meeting of relevant experts to review historical records, discuss the most likely sources and probability of occurrence of earthquakes and tsunamis for coordinated scenario analysis of future events and hazard mitigation schemes for the South China Sea region.
The workshop resulted in a better understanding of the tsunami hazard and risk in the South China Sea region, which would be useful for the planning for the establishment of the sub-regional Tsunami advisory centre, as well as allow Member States to better understand their level of tsunami exposure.

The major topics for discussion at the workshop were paleoseismology and historic events in the South China Sea region and Philippines Trench, seismic studies and potential tsunamigenic sources in the South China Sea region and technical/scientific development of tsunami modelling for the South China Sea region, including key parameters.

More information about the meeting, including the presentations is available from: http://www.ioc-tsunami.org/index.php?option=com_oe&task=viewEventRecord&eventID=1707

2. SEISMIC ZONES IN THE SOUTH CHINA SEA AND POSSIBLE SOURCES OF TSUNAMI AFFECTING THE SOUTH CHINA SEA REGION

The following image (Image 1) composed by Dr. Ishmael Narag shows the seismic zones in the South China Sea.

![Seismic Zones in The Study Area](image)

Based on previous reports of earthquake sources, the following are identified as possible generators of tsunami events, capable of generating surface-rupturing events (>M6.5) that may generate and propagate tsunami waves within the South China Sea region and affect the countries within.

**Regional Source**

- Manila Trench
- Negros Trench
- Sulu Trench
Regional earthquake sources are capable of generating tsunamis affecting coastal areas with waves greater than 0.3 m in at least two countries. Local sources are those that would only affect one country while transoceanic sources may generate mega-thrust events that may spawn large Pacific tsunami waves that may enter and leak into the South China Sea region (e.g. 1960 Chilean tsunami).

3. PARAMETERS FOR OTHER REGIONAL SOURCES

There was consensus in the group that the current status of knowledge for the below listed potential tsunamigenic sources (Table 1) is very limited. The group does not caution the proposed Mmax for its use for tsunami warning or for hazard assessment purposes.

<table>
<thead>
<tr>
<th>Source</th>
<th>Length (km)</th>
<th>Width (km)</th>
<th>Area (km²)</th>
<th>Coupling Rate (mm/yr)</th>
<th>Mw (Wells&amp;Coppersmith)</th>
<th>Mmax (manual)</th>
<th>Mmax (Observed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negros</td>
<td>314</td>
<td>52</td>
<td>16328</td>
<td>0.5</td>
<td>19,1</td>
<td>8,1</td>
<td>8,3</td>
</tr>
<tr>
<td>Cotabato</td>
<td>250</td>
<td>52</td>
<td>13000</td>
<td>0.5</td>
<td>18,5</td>
<td>8,0</td>
<td>8,3</td>
</tr>
<tr>
<td>Sulawesi</td>
<td>300</td>
<td>62</td>
<td>18600</td>
<td>0.5</td>
<td>35</td>
<td>8,2</td>
<td>8,8</td>
</tr>
<tr>
<td>Sulu</td>
<td>445</td>
<td>100</td>
<td>44500</td>
<td>0.5</td>
<td>18,2</td>
<td>8,5</td>
<td>8,7</td>
</tr>
<tr>
<td>Molucca</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taiwan Strait</td>
<td>127</td>
<td>63</td>
<td>8001</td>
<td></td>
<td>7,8</td>
<td>8,1</td>
<td>?</td>
</tr>
</tbody>
</table>

Table 1. Parameters for South China Sea tsunami sources other than the Philippines Trench
4. RECOMMENDATIONS ON OTHER CONSIDERATIONS FOR TSUNAMI MODELLING

EQ Parameters:

- The SCS modelling region should be different from the warning region. The modelling region should be larger than the warning region to cover features outside the domain and sources outside the domain.

- GEM has already established earthquake source parameters. The SCS-WG should re-examine these parameters including slip heterogeneity and report back to GEM.

Landslides:

- It is recognised that historically there have been landslides in several regions but the challenge is how to identify the regions most susceptible to landslides. Landslides are localised events that can generate large tsunamis. We need to identify potential landslides regions by examining pertinent databases. However for the SCS early warning system, landslide generated tsunamis is primarily a local concern.

Tsunami Deposits:

- A search for tsunami deposits along the shores of the SCS should be initiated. This should be coordinated on a regional level by a group of experts, to be identified.

- Need to also improve the modelling of the processes for transporting sediment and boulders to the deposition zone and processes for reworking of sediments.

Tsunami Modelling and Bathymetry:

- Grid of 30 arc seconds in open ocean is adequate but near the coastline higher resolution is required.

- On the continental shelf, 500m or finer spatial resolution is recommended.

- Recommended that a baseline bathymetric database be developed for all modellers to use. 30 arcsecs in deep water, 500m + interpolation techniques on the continental shelf. The common shared database should be derived from publicly available data, where available.

- Frictional coefficient will be model dependent. Recommended that it should be kept as small as practical

- Tidal variations can be decoupled from the propagation model but needs to be considered for inundation models

- Numerical dispersion must be checked and minimised, whatever model is used.
• Linear-Shallow Water models to be used for propagation in deep ocean. In the Near shore region nonlinear shallow water equation models are suitable for estimating runup heights and inundation area. However, for calculating tsunami forces on structures and sediment transport non-Linear, non-hydrostatic and/or 3D models should be used.

• All models should be validated with established benchmark procedures.

Other recommendations:
- There is a need to look at historical literature to find ancient records of tsunamis
- The SCS-WG should look at operational capability gaps in Member States and find ways of filling them.
- NOAA/PMEL is asked to integrate Negros, Sulu, Cotabatos y Sulawesi in ComMIT/MOST

5. PARAMETERS FOR EARTHQUAKE AND TSUNAMI MODELLING FOR THE PHILIPPINES TRENCH

In light of the abundant literature and the importance of this potential tsunamigenic zone in terms of risk for the entire basin, the group concentrated in comparing the table of parameters in use by the model ComMIT/MOST as provided by Dr. Yong Wei and the table provided by ZHOU Bengang, HE Honglin, AN Yanfen, et al. “Report of the evaluation of the seismotectonic background and source parameters in the Ryukyu Trench and Manila Trench. Institute of Geology, Institute of Geophysics, Institute of Earthquake Science, China Earthquake Administration, 2011. (in Chinese) hereunder as Table 2.

<table>
<thead>
<tr>
<th>Manila</th>
<th>location</th>
<th>length (km)</th>
<th>width (km)</th>
<th>depth (km)</th>
<th>strike (°)</th>
<th>dip (°)</th>
<th>rake (°)</th>
<th>$M_u$</th>
<th>slip (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM 1</td>
<td>longitude: 119°51′, latitude: 21°58′</td>
<td>210</td>
<td>82</td>
<td>20</td>
<td>350</td>
<td>14</td>
<td>110</td>
<td>8.2</td>
<td>2.94</td>
</tr>
<tr>
<td>RM 2</td>
<td>longitude: 120°21′, latitude: 20°06′</td>
<td>310</td>
<td>109</td>
<td>20</td>
<td>29</td>
<td>20</td>
<td>110</td>
<td>8.6</td>
<td>5.3</td>
</tr>
<tr>
<td>RM 3</td>
<td>longitude: 118°56′, latitude: 17°40′</td>
<td>135</td>
<td>66</td>
<td>20</td>
<td>3</td>
<td>20</td>
<td>90</td>
<td>7.9</td>
<td>1.89</td>
</tr>
<tr>
<td>RM 4</td>
<td>longitude: 119°09′, latitude: 16°24′</td>
<td>140</td>
<td>66</td>
<td>20</td>
<td>351</td>
<td>20</td>
<td>90</td>
<td>7.9</td>
<td>1.89</td>
</tr>
<tr>
<td>RM 5</td>
<td>longitude: 119°05′, latitude: 15°12′</td>
<td>166</td>
<td>71</td>
<td>20</td>
<td>353</td>
<td>30</td>
<td>50</td>
<td>8</td>
<td>2.19</td>
</tr>
<tr>
<td>RM 6</td>
<td>longitude: 119°16′, latitude: 13°44′</td>
<td>142</td>
<td>66</td>
<td>20</td>
<td>308</td>
<td>30</td>
<td>50</td>
<td>7.9</td>
<td>1.89</td>
</tr>
</tbody>
</table>
Table 2: ZHOU Bengang et al, 2011, Institute of Geology, Institute of Geophysics, Institute of Earthquake Science, China Earthquake Administration

The group agreed that Table 2 is representative of the current knowledge about the geology and tectonics of the region but did not agree on endorsing the two scenarios identified in Table 2 as RM (2+3) and RM (4+5+6).

The group also looked at the information compiled by a group of seismologists of the University of Taiwan, China as indicated in Image 2 below which identifies 4 potential tsunami scenarios (indicated as segments 2, 3, 4, and 5).

Image 2. Caption to be provided by Dr WU

The seismologist that developed the scenarios described in Image 2 considered the following elements in defining the two key scenarios:

Length: We consider the topography and geological conditions of trenches and faults, and determine the maximum length based on the uniformity of the geological structure.

Width: Reference to the world-class mega-earthquakes, the width is determined.

Mw and slip: After obtaining the length and width of the mega-thrust, the area can be determined. Based on the seismic scaling law (Yen and Ma, 2011), the earthquake magnitude (Mw) and slip can be determined.
Adopting the half-space homogenous elastic mode (Okada, 1986) to estimate the vertical displacement of the seafloor deformation and the tsunami initial profile.

The group agreed that the considerations and information that supports the parameters indicated in Image 2 are also reasonable in light of the current knowledge of the geology and tectonics of the region but did not agree on endorsing the four scenarios identified in Image 2 as segments 2, 3, 4, and 5.
## ANNEX I

### AGENDA

<table>
<thead>
<tr>
<th>DAY 1</th>
<th>16 NOVEMBER 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:00-09:00</td>
<td>REGISTRATION</td>
</tr>
<tr>
<td>09:00-10:00</td>
<td>OPENING</td>
</tr>
<tr>
<td>10:00-10:30</td>
<td>COFFEE BREAK</td>
</tr>
<tr>
<td>10:30-12:30</td>
<td>1. Paleoseismology and historic events in the South China Sea region and Philippines Trench [Moderator: Ishmael C. NARAG]</td>
</tr>
<tr>
<td>10:30-11:00</td>
<td>1.1. Seismicity characteristics in the South China Sea region and its tectonic significances, Zhiguo Xu</td>
</tr>
<tr>
<td>11:00-11:30</td>
<td>1.2. Tsunami events recorded in China historical document and the field investigation of possible paleo-tsunami in South China Sea, Honglin He &amp; Shi Feng</td>
</tr>
<tr>
<td>11:30-12:00</td>
<td>1.3. What caused the mysterious eighteenth century tsunami that struck the southwest Taiwan coast? Linlin Li, Adam D. Switzer, Yu Wang, Robert Weiss, Qiang Qiu, Chung-Han Chan, and Paul Tapponnier</td>
</tr>
<tr>
<td>12:00-12:30</td>
<td>1.4. Realistic scenarios for tsunami risk in the South China Sea, Emile Okal</td>
</tr>
<tr>
<td>12:30-13:30</td>
<td>LUNCH</td>
</tr>
<tr>
<td>13:30-15:00</td>
<td>2. Seismic studies and potential tsunamigenic sources in the South China Sea region [Moderator: Dr. Ken Gledhill]</td>
</tr>
<tr>
<td>13:30-14:00</td>
<td>2.1. GEM global faulted earth database, Ken Gledhill (on behalf of GEM)</td>
</tr>
<tr>
<td>14:00-14:30</td>
<td>2.2. Probabilistic Tsunami Hazard Assessment in the SCS region, Ye Yuan, Hongwei Li</td>
</tr>
<tr>
<td>14:30-15:00</td>
<td>2.3. Estimation of hazard parameters for potential tsunamigenic sources in the South China Sea region, Nguyen Hong Phuong</td>
</tr>
<tr>
<td>15:00-15:30</td>
<td>COFFEE BREAK</td>
</tr>
<tr>
<td>15:30-17:00</td>
<td>3. Technical/Scientific development of tsunami modelling for the South China Sea region, including key parameters, [Moderator: Dr. Philip Liu]</td>
</tr>
<tr>
<td>15:30-16:00</td>
<td>3.1. Probabilistic tsunami hazard zonation in the coastal area of China, Ruizhi Wen &amp; Yefei Ren</td>
</tr>
<tr>
<td>16:00-16:30</td>
<td>3.2. Dispersion effects on tsunami propagation in the South China Sea region, Hua Liu</td>
</tr>
<tr>
<td>16:30-17:00</td>
<td>3.3. Recent research results on tsunami hazard associated with the scenario earthquakes along the Manila trench, Philip L-F. Liu, Tso-Ren Wu</td>
</tr>
<tr>
<td>17:00-17:30</td>
<td>3.4. Modeling of Tsunami Generation, Propagation, and Inundation with a Non-hydrostatic Model, Kwok Fai Cheung</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DAY 2</th>
<th>17 NOVEMBER 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:00-09:30</td>
<td>3.5. American Society of Civil Engineers approach for the probabilistic tsunami assessment and implications for the South China Sea, Yong Wei</td>
</tr>
<tr>
<td>09:30-10:00</td>
<td>3.6. Real time tsunami warning skills in the South China Sea region, Fujiang Yu, Peitao Wang</td>
</tr>
<tr>
<td>10:00-10:30</td>
<td>3.7. Effect of fault slip heterogeneity on the coastal impact of tsunami and</td>
</tr>
<tr>
<td>Time</td>
<td>Activity</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>10:30-11:00</td>
<td>3.8. Reviewing tsunami fragility curves and its application for the South China Sea countries, Anawat Suppasri</td>
</tr>
<tr>
<td>11:00-11:30</td>
<td>COFFEE BREAK</td>
</tr>
<tr>
<td>11:30-12:30</td>
<td>4. Break-out Groups – each group discuss the three subjects</td>
</tr>
<tr>
<td>11:30-12:00</td>
<td>Round-up of the three sessions and general guidance discussion chaired by moderators before breaking groups start working [Ishmael C. NARAG, Dr. Ken Gledhill, Dr. Philip Liu]</td>
</tr>
<tr>
<td>12:00-12:30</td>
<td>4.1. Earthquake based scenarios – key parameters and geometry of the faults</td>
</tr>
<tr>
<td></td>
<td>4.2. Land-slide tsunami potential – coastal areas to be prioritised for local preparedness</td>
</tr>
<tr>
<td></td>
<td>4.3. Tsunami modelling – datasets inventory for topography and bathymetry, priority gaps</td>
</tr>
<tr>
<td>12:30-13:30</td>
<td>LUNCH</td>
</tr>
<tr>
<td>13:30-15:00</td>
<td>Continued Break-out Groups – each group discuss the three subjects</td>
</tr>
<tr>
<td>15:00-16:00</td>
<td>COFFEE BREAK</td>
</tr>
<tr>
<td>16:00-17:00</td>
<td>Summary session – breakout groups reports &amp; recommendations</td>
</tr>
<tr>
<td>DAY 3</td>
<td>18 NOVEMBER 2015</td>
</tr>
<tr>
<td>09:00-10:00</td>
<td>Summary session – breakout groups reports and recommendations</td>
</tr>
<tr>
<td>10:00-11:00</td>
<td>COFFEE BREAK</td>
</tr>
<tr>
<td>11:00-12:30</td>
<td>FINAL RECOMMENDATIONS AND CLOSING</td>
</tr>
</tbody>
</table>
ANNEX II

BIBLIOGRAPHY AND REFERENCES


http://www.globalquakemodel.org/what/seismic-hazard/historical-catalogue/


http://services.bepress.com/eci/geohazards/28

http://earthquake.usgs.gov/earthquakes/

http://www.ngdc.noaa.gov/hazard/earthqk.shtml


[22] TLN. Tsunami Laboratory Novosibirsk.
http://tsun.ssc.ru/On_line_Cat.htm


ANNEX III

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ANNEX IV

LIST OF ACRONYMS

Mw  Moment magnitude