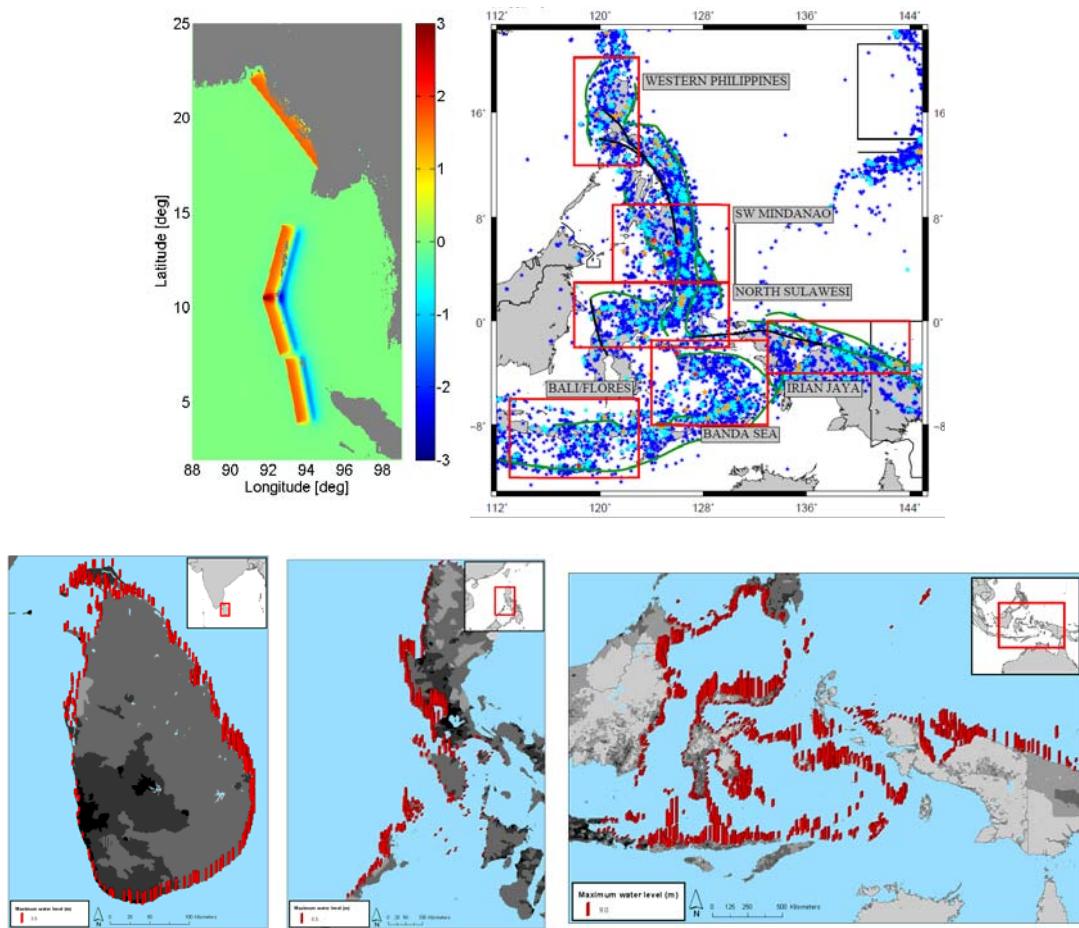


Evaluation tsunami hazard in Vietnam and Gulf og Thailand

Tsunami Risk Reduction Measures Phase 2



November 2009

Cover pictures;

Initial water displacements (m) for the three northernmost Sunda Arc scenarios of magnitude M 8.55, 8.53 and 8.60 respectively, as well as the M 8.86 Burma fault scenario.	Seismicity of the study region for 1963-2006, with symbols differentiating the magnitudes.	
Merged tsunami hazard map for Sri Lanka.	Merged tsunami hazard map for the Philippines	Merged tsunami hazard map for Eastern Indonesia

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Note: The conclusions and recommendations of this publication have not been specifically endorsed by, or reflect the views of the organizations which have supported the production of this project, both financially and with content.



Project

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Summary

This report presents tsunami simulations to exemplify the tsunami hazard towards Vietnam and the Gulf of Thailand. We conclude that the tsunami hazard due to seismic origin against Vietnam is moderate to low. The simulations reveal further that tsunami threat due to seismic origin to the Gulf of Thailand is almost non-existent. The results show that a magnitude 8.2 earthquake located at the Manila Trench is needed to generate a significant tsunami towards Vietnam, whereas tsunamis due to smaller earthquakes (magnitude 8.0 and less) are insignificant. It is stressed that a magnitude 8.2 scenario represents the upper range of expected earthquakes, and has a magnitude markedly above the largest magnitudes in available catalogues. The return period for a magnitude 8.2 earthquake along the Manila Trench is uncertain. Regional seismicity indicates a lower bound return period of about 120 years, however, the expected return period for the credible

Summary (cont.)

worst case magnitude 8.2 scenario with respect to Vietnam is most likely a few times longer than this lower bound. As a consequence, such events may not be completely ruled out, also due to the high convergence rate of the Manila Trench. Related to the possible consequences for Vietnam due to a tsunami generated by a magnitude 8.2 earthquake dedicated inundation models taking into account effects of local topography and bathymetry are needed to quantify the maximum water level in more detail. Finally, it is noted that the evidence of past mega landslides off the north coast of Brunei and Sarawak, Malaysia, indicates a possible tsunami threat from landslides from this region. However, the landslide generated tsunami hazard is not assessed further in this report.

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1 Introduction

The project “Tsunami Risk Assessment and mitigation in S&SE Asia – Phase 2” has been financed by The Norwegian Ministry of Foreign Affairs (MFA). The Coordinating Committee for Geoscience Programmes in East and Southeast Asia (CCOP), through their Technical Secretariat in Bangkok, acted as the project responsible institution towards MFA. The Norwegian Geotechnical Institute (NGI) had the role as Technical Executing Organisation (TEO). NGI subcontracted NORSLAR for performing the seismological analyses required. The project was contracted in 2008 with four Asian countries: Indonesia, the Philippines, Vietnam, and Sri Lanka. The main goals of the project have been to reduce the tsunami risk in South and Southeast Asia by:

- Enhanced assessment of tsunami hazard and recommendations of risk mitigation measures in specified regions
- Enhanced capacities of hazard assessment and risk reduction for regional, national, and local institutions

The detailed scope of work (SoW) for the invited countries the Philippines, Indonesia, Vietnam, and Sri Lanka varied according to the needs defined from previous tsunami hazard assessments and the capabilities of the individual countries. The SoW's were agreed in project meetings with the countries in the early phase of the project.

This report presents tsunami hazard analyses dedicated to the coastline of Vietnam, and a rough evaluation of the tsunami hazard towards the Gulf of Thailand. In the complete project report (NGI, 2009) findings for all the four countries and more elaborate details of the analysis relevant for Vietnam and the Gulf of Thailand are given. For this purpose, NGI (2009) is extensively cited herein. It is emphasised that this report considers only potential tsunamis of seismic origin, hence tsunamis generated by landslides and volcanoes are omitted.

2 Definitions

Below, some definitions of technical key terms used in this text are given to help the reader. As far as possible, compatibility with the UNESCO-IOC tsunami glossary (UNESCO-IOC, 2006) is endeavoured. In addition, a brief definition sketch defining the parameters related to the tsunami inundation process is given in Figure 1.

- **Fault** - A fracture or a zone of fractures along which displacement has occurred parallel to the fracture. Earthquakes are caused by a sudden rupture along a fault or fault system; the ruptured area may be up to several thousand square kilometers. Relative movements across a fault may typically be tens of centimeters for magnitude 6.0-6.5 earthquakes, several meters for magnitude 7-9 earthquakes.
- **Flow depth** – Water elevation above land during inundation.

- **Hazard** - Probability that a particular danger (threat) occurs within a given period of time. Here, the tsunami hazard is the maximum water level associated with a scenario return period.
- **Inundation distance** – Maximum horizontal penetration of the tsunami from the shoreline (see Figure 1).
- **Magnitude** - A measure of earthquake size at its source. Magnitude was defined by C. Richter in 1935 as: “The logarithm to the trace amplitude in 0.001 mm on a standard Wood-Anderson seismometer located 100 km from the epicenter” The Wood-Anderson instrument measures the responses in the period range near 1 sec. Other magnitude scales have later been devised based on the responses measured in other period ranges, and on maximum amplitudes of specific wave forms. In this report, we mostly refer to the moment magnitude (with abbreviation Mw). The moment magnitude is based on the seismic moment computed directly from source parameters or from long period components in the earthquake record. Symbol M is also used for this magnitude.
- **Maximum water level** – Here, defined as the largest water elevation above the still water level (see Figure 1).
- **Probability** - A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty). It is an estimate of the likelihood of the magnitude of the uncertain quantity, or the likelihood of the occurrence of the uncertain future event.
- **Return period** - Average time period between events of a given size in a particular region, cycle time.
- **Risk** - Measure of the probability and severity of an adverse effect to life, health, property, or the environment. Quantitatively, Risk = Hazard × Potential Worth of Loss. This can be also expressed as “Probability of an adverse event times the consequences if the event occurs”.
- **Run-up height** – Water level above the still water level at the inundation limit (see Figure 1).
- **Surface elevation** – Here, defined as the water elevation relative to the mean sea (can be negative or positive). See Figure 1 for a definition sketch.
- **Threat** - The natural phenomenon that could lead to damage, described in terms of its geometry, mechanical and other characteristics. The danger can be an existing one (such as a creeping slope) or a potential one (such as a tsunami). The characterization of a danger or threat does not include any forecasting. Here, the tsunami threat is mostly reported as the maximum water level.
- **Trench** - Topographic depressions of the sea floor.
- **Vulnerability** - (1) The degree of loss to a given element at risk, or set of such elements, resulting from an event of a given magnitude or intensity, usually expressed on a scale from 0 (no loss) to 1 (total loss). (2) Degree of damage caused by various levels of loading.

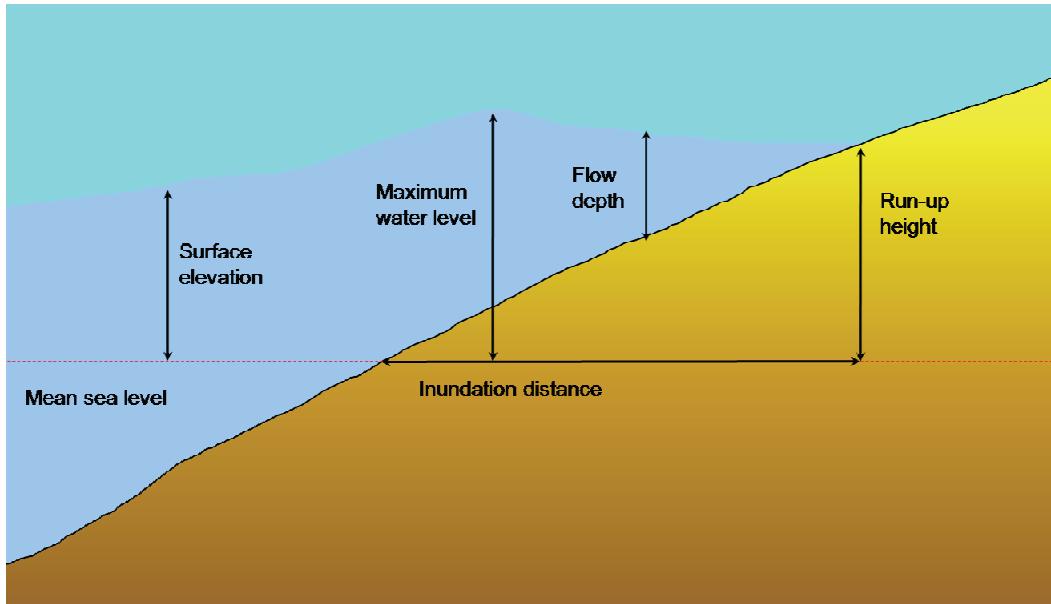


Figure 1: Definition sketch for tsunami parameters.

3 Seismotectonic background, tsunamigenic earthquake potential, and scenarios

Tsunamis generated by earthquakes in the Manila Trench off the western coast of Luzon Island, the Philippines, are considered the most serious threat towards the Vietnam coastlines. Figure 2 shows historical tsunami events in the northern Philippines, as well as main tectonic features and historical seismicity. Relatively few historical events are identified, and the largest earthquake magnitude along the Manila Trench in recorded history is 7.5. Still, due to the high convergence rate related to the Manila Trench subduction zone, larger tsunamigenic earthquakes cannot be excluded.

As noted above, tsunamis due to landslides are excluded. There exist evidence for a past mega landslide of volume 1200 km^3 off the north coast of Brunei and Sarawak, Malaysia (Gee et al. 2007). A landslide of similar landslide and location could pose a major threat towards Vietnam. The enormous landslide is reported by Gee et al. (2007) to be the largest landslide volume associated with an active delta, and evidence for other older events at larger depth indicates repeatability. However, the authors do not date this or any of the other landslide events, and hence no measures of the return period is available. However, it is anticipated that the return periods for such mega landslides are long. The identification of possible landslide prone sediment is extremely demanding and beyond the scope of this report. Nevertheless, modelling of landslide generated tsunamis is exemplified in NGI (2009).

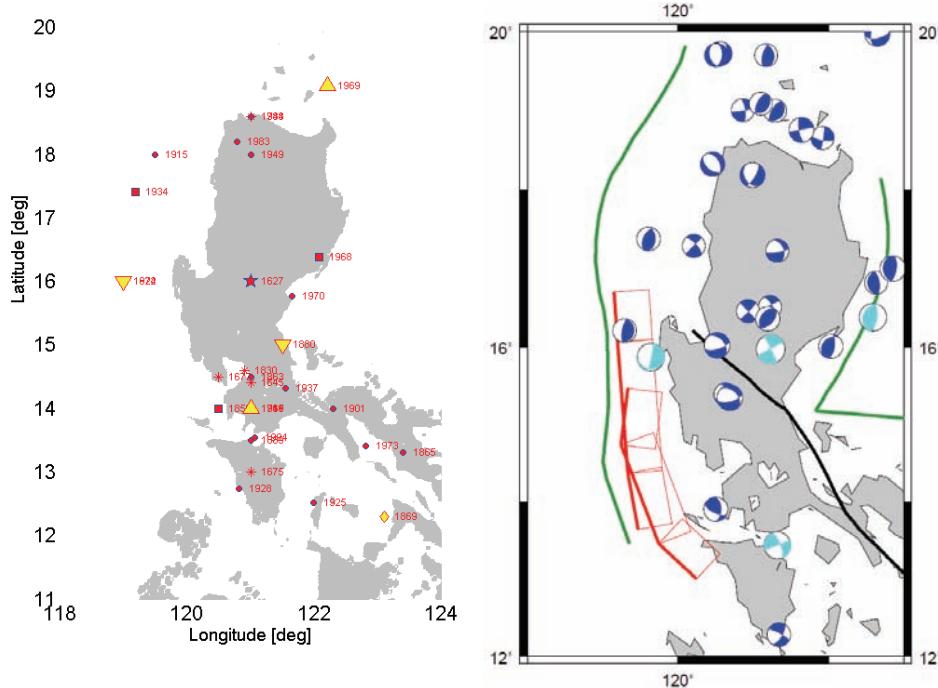


Figure 2: Left panel, source location and year of occurrence for recorded earthquake generated historical tsunamis in the northern Philippines with source information. Yellow markers indicate non seismic or unknown sources, red markers indicate seismic sources. Large stars magnitudes $M \geq 8.5$; small stars $8.5 > M \geq 8.0$; squares $8.0 > M \geq 7.5$; circles $M < 7.5$; asterisk, no magnitude reported. Upward-pointing triangles indicate volcanoes or combinations of volcanoes and other sources. Downward-pointing triangles indicate landslides or landslides and earthquakes. Diamonds indicate unknown sources. Right panel, major fault zones (green and black lines) and earthquake focal mechanisms in the northern Philippines. Blue markers indicate magnitude 6-7 earthquakes, light blue magnitude 7-8. The red rectangles indicate the location of two composite magnitude 8.2 earthquake scenarios.

Based on the detailed assessment in NGI (2009) three possible earthquake scenarios are analyzed (see Figure 3) with respect to tsunami generation: As a ‘conservative worst case’ event with respect to tsunami impact on Vietnam, a magnitude 8.2 earthquake in the northern part of the Manila Trench is selected. The lower bound return period for a magnitude 8.2 earthquake along the Manila Trench is about 120 years, obtained from a Gutenberg-Richter relation on the full domain in the right panel in Figure 2. However, the return period for the individual scenario is expected to be a few times longer, as elaborated by NGI (2009). As second and third scenarios, magnitude 8.0 and 7.6 earthquakes are placed in the same location. Lower bound return periods for earthquakes of these magnitudes are about 75 and 30 years, respectively, and again the scenario return periods should be clearly longer than the lower bound. It is noted that another magnitude 8.2 earthquake located further south was analyzed for the Philippines, but wave simulations for this scenario is not conducted towards Vietnam. The

latter scenario is assumed to generate slightly smaller maximum water level in Vietnam than the northern scenario with the same magnitude due to its orientation, and hence contribute less to the tsunami hazard and risk.

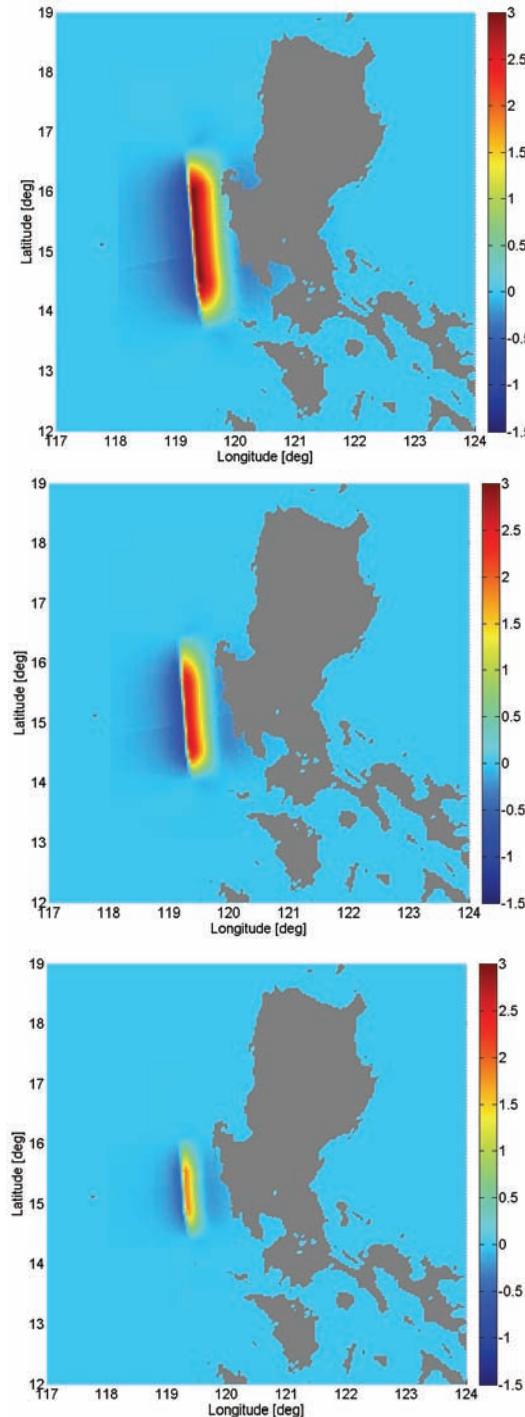


Figure 3: Initial water displacements (m) for the three earthquake scenarios used as input to tsunami simulations towards Vietnam. Upper panel $M_w 8.2$ scenario, mid panel $M_w 8.0$ scenario, lower panel $M_w 7.6$ scenario.

4 Tsunami simulations and hazard evaluations for Vietnam

Simulations of the tsunami propagation for the three scenarios shown in Figure 3 are conducted for the South China Sea. Time series results for the Vietnam coastline are evaluated at 5 locations as shown in Figure 4. In addition, the maximum water level is computed using the method of amplification factors (NGI, 2009) for one of the scenarios investigated. As emphasised by NGI (2009), this methodology does not give a precise and detailed picture of the maximum water level, but rather some overall value based on the characteristics of the incident wave and the seabed slope obtained from public domain information of the seabed.

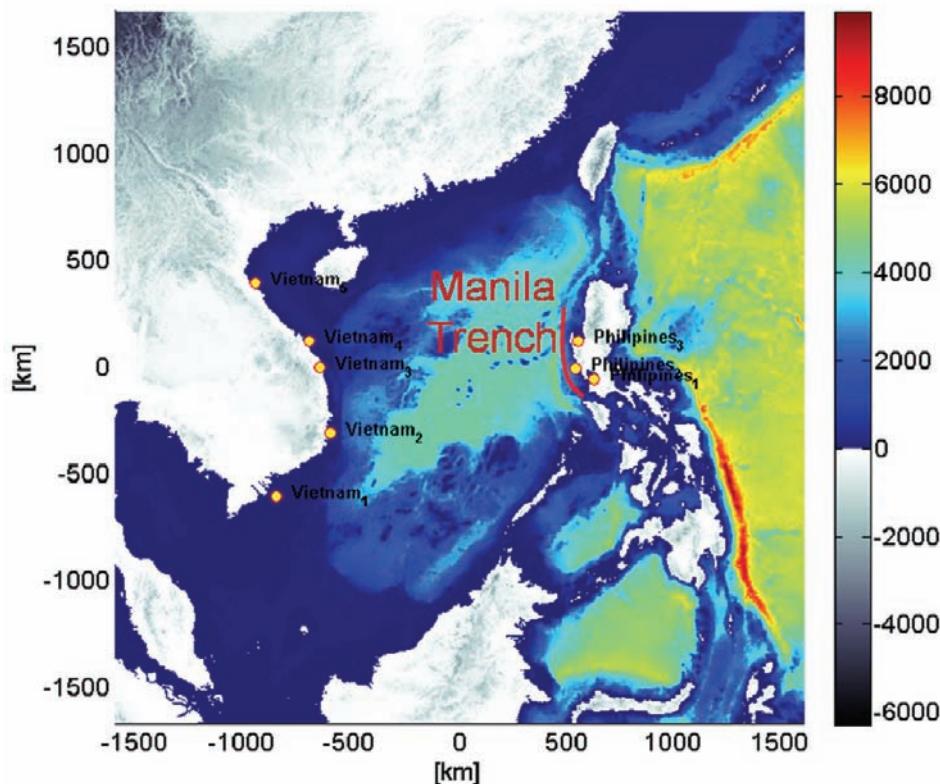


Figure 4: Bathymetric and topographic map of the South China Sea and surroundings. It should be noted that a positive water depth and negative topography is shown (elevation in meters indicated by colour bar). The red line indicates the Manila Trench where the earthquake scenarios are located. Locations of 5 control points used for evaluating simulation results along the Vietnamese coastline are shown.

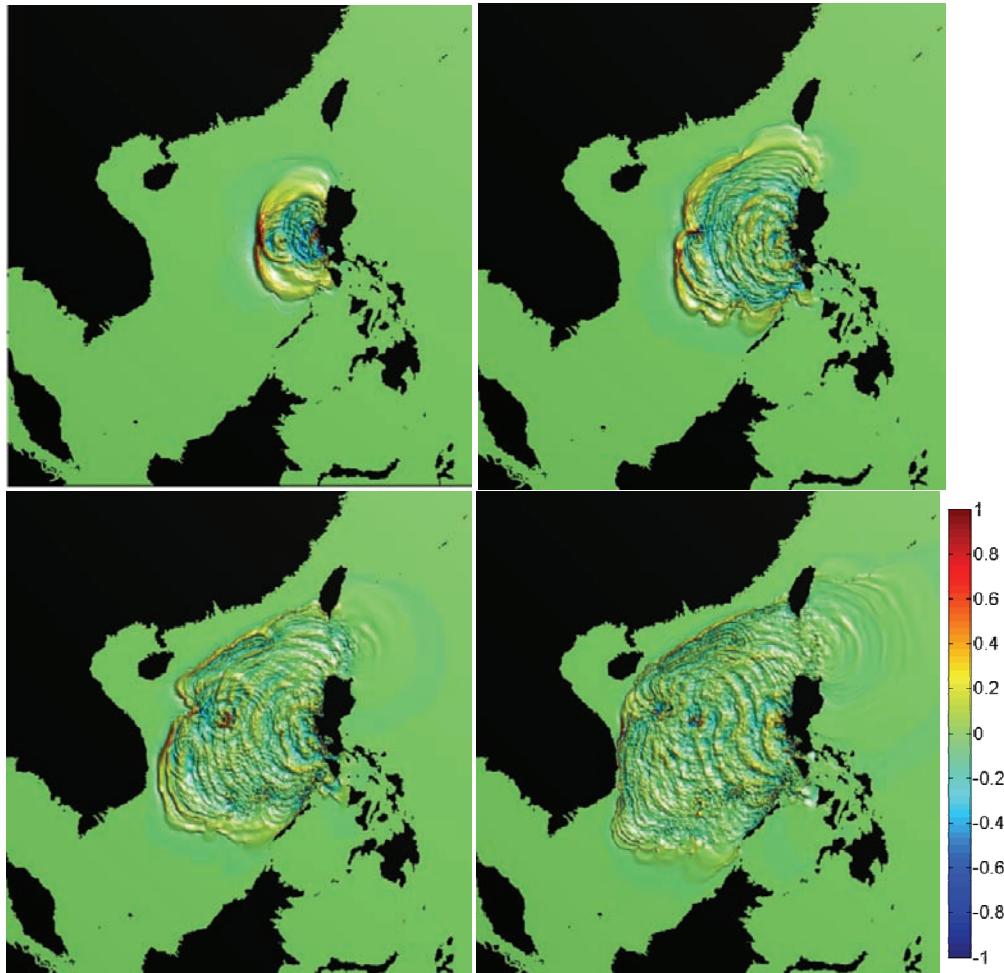


Figure 5: Snapshots of the simulated tsunami generated by the $M_w8.2$ Manila Trench scenario earthquake. Upper left, 30 minutes; upper right, 1 hour; lower left, 1 hour 30 minutes; lower right 2 hours. The colour bar gives the surface elevation in meters.

The simulated wave generated by the northern magnitude 8.2 scenario, is shown in Figure 5. The Figure shows that strongest directivity is in the east-west direction, and hence unfortunate with respect to the possible impact of Vietnam. The corresponding maximum surface elevation for the whole simulation is shown in Figure 6. As shown, the maximum surface elevation offshore does not exceed 2 m. However, Figure 6 also shows that the method of amplification factors indicate that this may lead to more than 4 m maximum water level. Inundation modelling using local bathymetry and topography is required for more detailed quantification of the maximum water level. Maximum surface elevations for the smaller scenarios shown in Figure 7 reveals that the potential tsunamis related to earthquakes of smaller magnitudes than 8.2 are almost negligible.

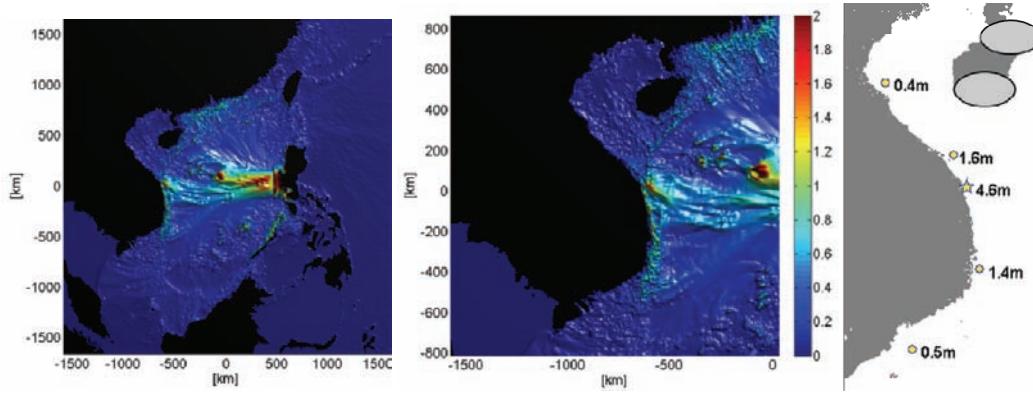


Figure 6: Simulated maximum surface elevation (m) for the $M_w 8.2$ Manila Trench scenario. Left panel, for the whole computational domain. Mid panel, close up for the Vietnamese coastline. The right panel shows the maximum water level at the shoreline, calculated from the maximum surface elevations at the depicted control points

The numerical simulations are extended to the Gulf of Thailand, but are not analysed in detail beyond the south eastern part of Vietnam. However, based on the results from the simulations shown in Figure 6, we may conclude that the coastlines along the Gulf of Thailand are not threatened by tsunamis of origin from the Manila Trench. Tsunamis due to other subduction zones are believed to constitute even less threat to Gulf of Thailand.

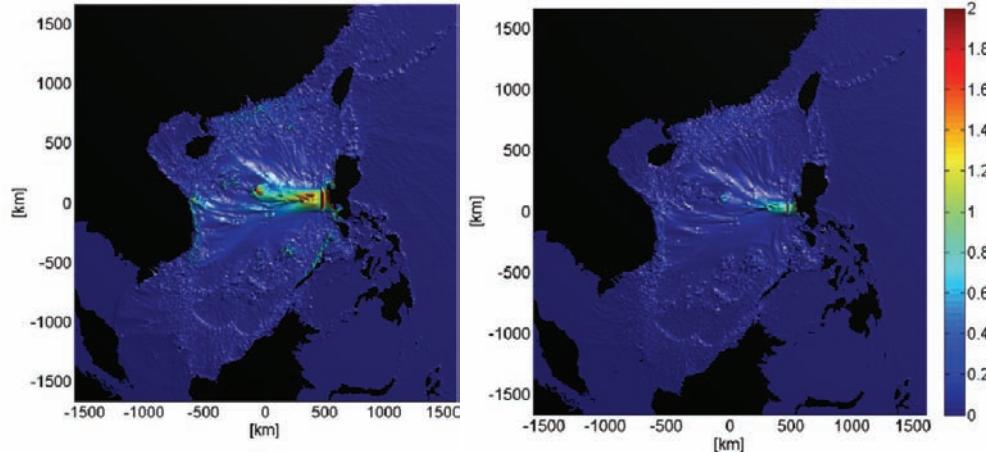


Figure 7: Simulated maximum surface elevation (m) for the $M_w 8.0$ Manila Trench scenario (left panel) and the $M_w 7.6$ Manila Trench scenario (right panel).

5 Concluding remarks

Numerical simulations of earthquake generated tsunamis and the associated threat towards Vietnam and the Gulf of Thailand are assessed in this report. The results show that a magnitude 8.2 earthquake may generate tsunamis of more than 4 m maximum water level towards the central part of Vietnam. Related to this result, two issues are stressed: (i) The magnitude 8.2 scenario represents the upper range of expected earthquakes, and has a magnitude markedly above the largest magnitudes in available catalogues. The return periods of this scenario is expected to be a few times longer than 120 years, which is the lower bound return period obtained from the regional seismicity (ii) The estimated maximum water level above 4 m is found in one control point only, and is computed using a rough method without including any kind of local effects. Moreover, to these authors experience, the method of amplification factors is conservative and gives maximum water level upper bounds. Therefore, we conclude that the tsunami hazard due to seismic origin against Vietnam is moderate to low. The simulations reveal further that the tsunami threat due to seismic origin to the Gulf of Thailand is almost non-existent. Finally, it is noted that the evidence of past mega landslides off the north coast of Brunei and Sarawak, Malaysia (Gee et al. 2007), indicates a possible tsunami threat from landslides from this region. However, landslide generated tsunami hazard is not assessed further in this report.

There has not been performed a specific risk assessment study for Vietnam and the Gulf of Thailand. For a detailed description of methodology and applications for tsunami vulnerability and risk mapping, please consult the main project report (NGI, 2009).

6 Acknowledgements

The NGI and NORSAR staffs in charge of producing this report greatly acknowledge the contributions made from the coordinating committee CCOP under the guidance of Mr. Niran Chaimanee, and from our partner in Vietnam, the Institute of Meteorology and Hydrology, IMH.

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