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Use of high resolution geodata for inundation modelling as part of a tsunami risk assessment in Thailand

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Abstract

The mega-tsunami of Dec. 26, 2004 strongly impacted the Andaman Sea coast of Thailand and devastated settlements, tourism resorts and coastal ecosystems. In addition to the tragic loss of many lives, the destruction or damage of life-supporting infrastructure, such as buildings, roads, or water & power supply caused high economic losses in the region.

To mitigate future tsunami impacts there is a need to assess tsunami risks in vulnerable coastal areas at the Andaman Sea coast and to develop adequate risk management strategies.

In the bilateral German-Thai research project TRAIT mechanisms, impacts and long term consequences of the 2004 tsunami are investigated in order to conduct a local risk assessment and to design a comprehensive risk analysis tool. Methods are developed for detailed hazard analysis as well as for vulnerability analysis of the socio-economic and the ecological system combining field investigations, household and company surveys, remote sensing techniques and numerical modelling. This paper deals with the hazard analysis as one part of a risk assessment.

Hazard analysis on a local scale requires detailed knowledge of the topography and the inundation flow dynamics. Thus a high resolution digital elevation model was generated based on remote sensing data. Moreover, to include the damping effect of vegetation on the tsunami waves, a field campaign was conducted to derive roughness parameters for different land use classes in the region. Based on an object-oriented land-use classification these values were transferred into a site specific roughness map. Including a deep sea and near shore bathymetry, mult-scale resolution topographic data, roughness maps and information on structural patterns like buildings, a numerical tsunami inundation simulation could be performed. A comparison of the first results shows that the resolution of the geo basis data strongly influences the accuracy of inundation simulations and the applicability of inundation maps for risk assessment and management.

1 Background and objectives

The Indian Ocean Tsunami on 26.12.2004 caused one of the most devastating natural disasters in history. Triggered by a Mw ~9.1-9.3 megathrust earthquake (Lay et al. 2006, Stein & Okal 2005) in the Sumatra subduction zone the tsunami killed about 230.000 people around the Indian Ocean and destroyed buildings, infrastructure and coastal ecosystems. Besides Banda Aceh in Indonesia the Andaman Sea coast of Thailand was the next most heavily impacted area. The tsunami most severely affected the provinces of Phang Nga and Phuket 1:45-2h after the earthquake with run-ups of up to 15 m observed near Khao Lak (Tsuji et al. 2006).

However not all regions suffered the same degree of flood impacts, some localities were hit harder than others. Thus, in order to determine the spatial distribution of risk and to manage present and future tsunami risk, there is a need to assess the tsunami hazard and vulnerability in flood prone areas at the Andaman Sea coast.

To study the complex interactions of tsunami related impacts on and offshore in the Andaman Sea Region the German-Thai Research cooperation TRIAS (Tracing Tsunami Impacts onshore and offshore in the Andaman Sea Region) was initiated, funded by the German Research Foundation

(DFG) and the National Research Council of Thailand (NRCT). This research cooperation focuses on tsunami-related issues in order to gain a better understanding of the physical impacts of tsunamis on the seafloor and on land, resulting in sediment mobility and destruction, and to develop methods and tools for tsunami risk assessment and management. Six German-Thai research projects are part of the TRIAS cooperation addressing the whole transection of the tsunami from the deep sea, across the shelf to the coast and the coastal hinterland.

The work presented here is about one work package in one of the six projects, TRAIT (Tsunami Risks, Vulnerability and Resilience in the Phang Nga and Phuket provinces, Thailand). In TRAIT a detailed, local risk assessment is conducted for the Provinces Phang Nga and Phuket.

The overall objectives of TRAIT are:

1. Providing a quantitative approach for risk assessment including the analysis of hazard mechanisms as well as an assessment of social, economic and ecological vulnerability
2. Investigating the potentials of earth observation for vulnerability assessment, resilience monitoring and as an inherent part of a tsunami risk analysis tool
3. Developing a comprehensive risk analysis tool that assists risk mitigation and management

This paper highlights the factors and data requirements for inundation modelling as part of the hazard analysis. As TRAIT is an ongoing project and work is still in progress only preliminary outcomes are presented.

2 Study areas

The area of investigation reaches from approximately 8°52’10’’N to 7°45’30”N and covers the coastal lowlands of the provinces Phang Nga and Phuket at the Adaman Sea coast in southern Thailand.

Within this region four different types of study areas have been selected in order to cover the different aspects of risk (figure 1).

Ban Nam Khem is a small community in the North of the Phang Nga province dominated by fishery and agriculture. The community was severely affected by the 2004 tsunami due to the very flat and exposed location and the poor quality of buildings. More than 1000 out of 6000 inhabitants lost their lives by the tsunami and infrastructure as well as fishing facilities were destroyed (Paphavasit et al. 2009).

Further to the south *Khao Lak* represents a young booming tourism resort which was also strongly impacted in 2004 due to two reasons: a) the largest tsunami wave heights were measured in this area and b) many tourists were on the beaches or in hotels close to the beaches as the tsunami occurred during high season. Thousands lost their lives, among them many foreign tourists. Dozens of hotels and resorts were destroyed or damaged.

Thai Muang national park located on a spit around a tidal inlet hosts large areas of intact coastal ecosystems like mangroves or beach forests. Hence this site represents a study area where the impacts of the tsunami on vegetation and coastal habitats can be investigated.

Patong Beach on Phuket island represents the most populated and urbanized community in the area of investigation. Due to the high density of large buildings the tsunami mainly damaged the first road parallel to the coast and the buildings at the beach front. Nevertheless, the water was channelled in the streets, perpendicular to the coast and spread further into the hinterland. Due to the dense infrastructure of shops, hotels, and restaurants, the economic damage was estimated to be about 217 million €.

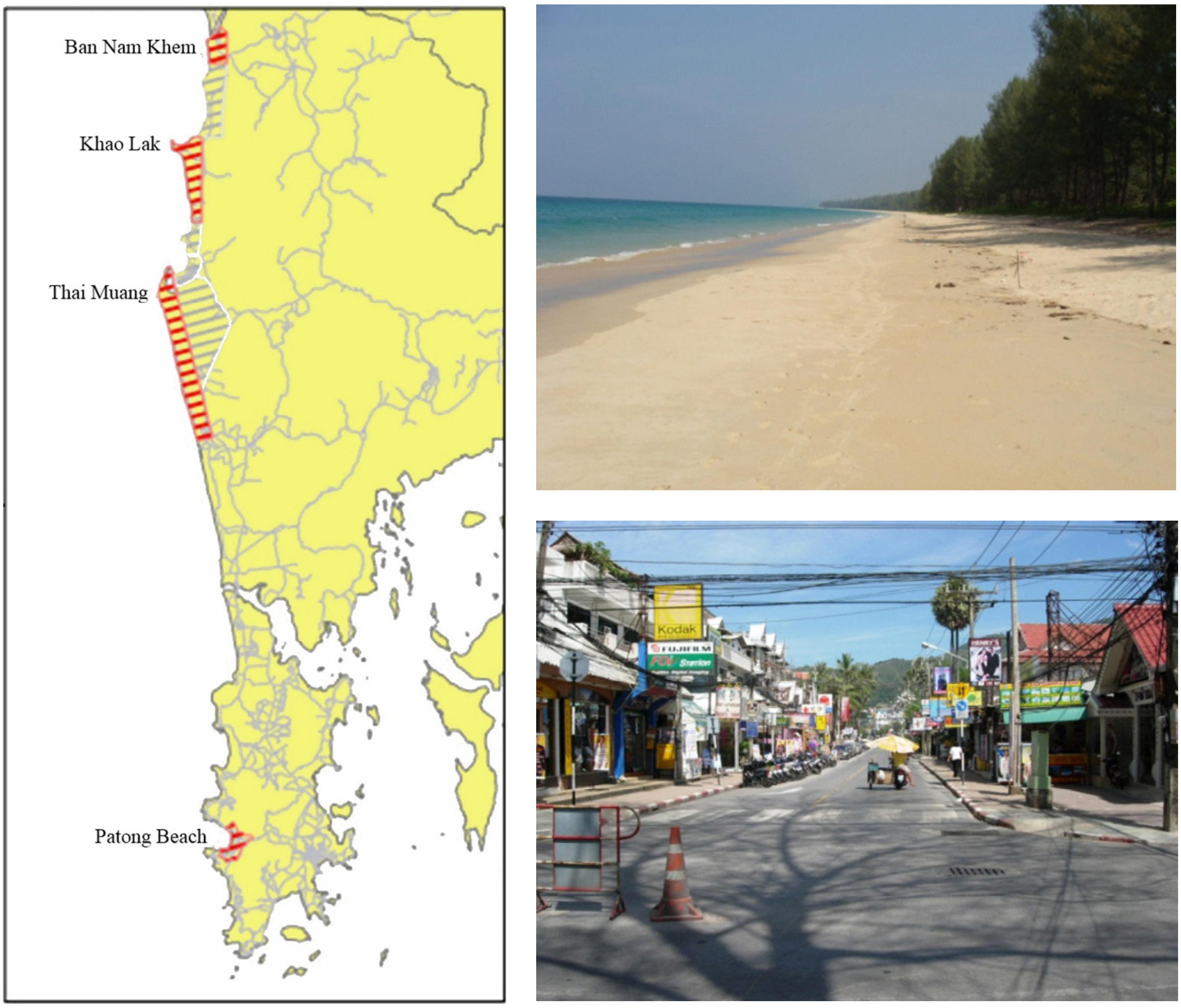

Figure 1: The study areas Ban Nam Khem, Khao Lak, Thai Muang national park (upper right) and Patong Beach (lower right) at the Andaman Sea coast of Thailand

3 Methodology

Risk assessment and the development of a risk analysis tool carried out in TRAIT are based on a common concept of risk, hazard and vulnerability widely applied in natural hazards research (amongst others Wisner et al. 2004, UNDP 2004), flood risk management (Schanze et al. 2006), and environmental science (Turner et al. 2003).

Tsunami hazard analysis in this study includes the geophysical sources of an earthquake, the modelling of the generation and propagation of waves to the coast and its landward inundation characteristics including small scale landforms like coastal forests, buildings, rivers, tidal inlets and ponds.

Vulnerability analysis is conducted by assessing the exposure of the elements at risk of the social, economic and ecological coastal system, their susceptibility to be harmed by the tsunami and their resilience, i.e. their ability to cope and recover.

This means that the tsunami impacts are a function of various risk parameters which vary with time and space.

In TRAIT an integrated approach is applied including extensive field investigations, numerical modelling, household and company surveys as well as GIS and earth observation. Special focus is given to the application of remote sensing techniques, not only for quick assessment of damages caused by the tsunami but also for monitoring processes. A time-series of multi-scale remote sensing data (i.e. SRTM, ASTER, IKONOS, MFC) is used to derive digital surface and elevation models, to assess damages to buildings, to detect beach erosion or uprooting of vegetation, and to gain information on how the recovery process has proceeded until today (e.g. recovery of coastal forests, restoration of tidal inlets).

As the Asian Tsunami of 2004 and its impacts are documented very well, a detailed analysis of mechanisms and consequences of this event is conducted. From this detailed analysis key parameters of tsunami risk will be derived to allow for comprehensive, quantitative risk assessment. The combination of the numerical modelling and a GIS database with quantitative vulnerability criteria provides a comprehensive GIS-based tsunami risk analysis tool.

Hazard analysis

The tsunami hazard analysis, as part of the overall risk assessment, comprises modelling of the tsunami generation, propagation and inundation including the interaction of the tsunami with vegetation or buildings (figure 2). The analysis is performed for the 2004 event as well as for different scenarios for the study areas Patong Beach, Khao Lak, Thai Muang national park and Ban Nam Khem. Special consideration is given to the inundation simulation as inundation depth, velocity, and expansion are crucial for risk analysis, risk management and evacuation planning.

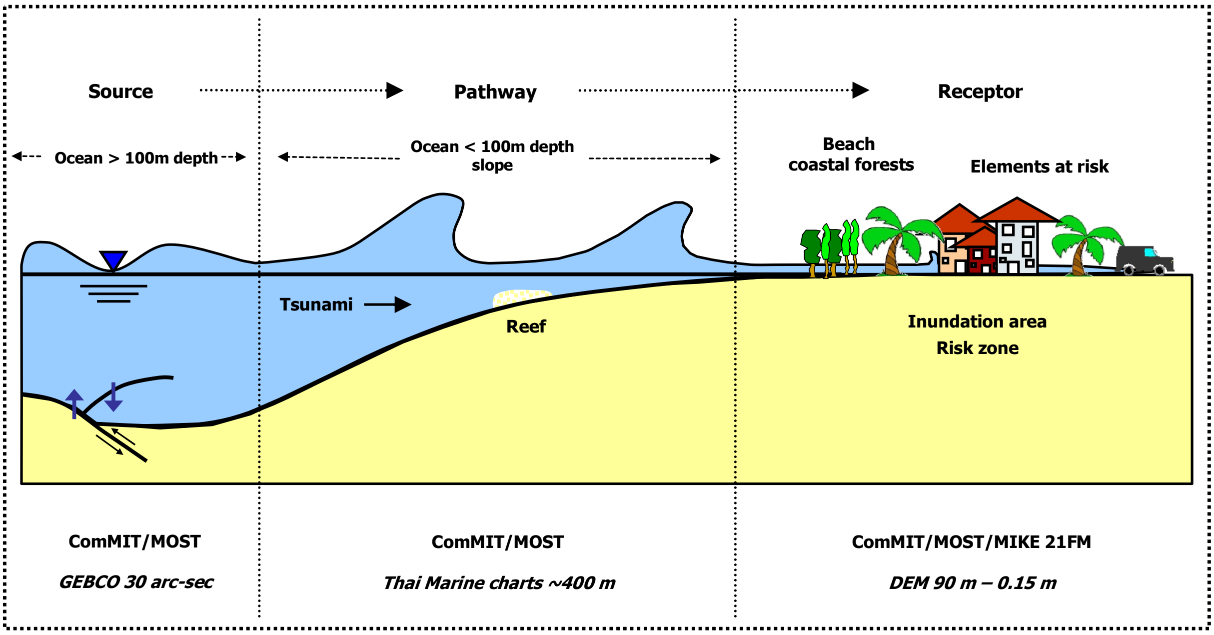

Figure 2: Tsunami risk model

As the quality of the model results strongly depends on the detail and the resolution of the input data, we check how different data sets on different scales influence the results of the tsunami modelling. The key data sets are bathymetry, topography and a roughness maps, representing bottom friction caused by land cover.

Land use classification

A detailed land use map is an important basis for hazard and vulnerability assessment as it provides information on the spatial characteristics of land cover in the area of investigation. The land use information was derived from high-resolution satellite images (IKONOS) with a horizontal resolution of 4 m in the multispectral channels. With a rule-based object-oriented classification scheme (Definiens Developer 7.0 software) land use information could be extracted very accurately from the multispectral image.

The preliminary step of the object oriented classification is to segment a raster image into image objects or segments which fulfil a user defined homogeneity criteria (Blaschke & Strobl 2001). The multi-resolution segmentation, which is a patented segmentation algorithm of Definiens AG, was realized by using two hierarchical segment levels. Subsequently the image objects could be assigned to a respective land use class by analyzing the spectral, shape-specific, textural and neighbourhood-specific characteristics of the segments. For this, a complex system of rules (rule set) was created which incorporates both crisp and fuzzy rule definitions. Finally the quality and robustness of the developed rule set was evaluated by transferring the rule set to a different IKONOS scene.

The final classification map for the coastal zone between Ban Nam Khem and Thai Muang city includes 42 different land use classes which are organized in the following nine super-classes:

- Agriculture and Aquaculture: includes plantations, orchards and aquaculture
- Barren land: sandy beaches, sand mining, mudflats etc.
- Buildings and infrastructure
- Grassland and Herbaceous vegetation: dense and sparse grassland with scattered trees
- Scrubland: predominance of scrubs
- Semi-open landscapes: mixture of woodland, scrubland and grassland, comparable to savannahs
- Water: water surfaces like ponds, rivers, bays
- Woodland: different types of natural forests, e.g. Mangroves, Casuarina forest, Primary Rain forest
- Other: clouds, shadows and no data values.

In connection with the hazard analysis, the land use map contributed to generating digital elevation models and to provide the spatial distribution of roughness values.

Hydrological roughness

Coastal forests like mangroves or beach forests are assumed to have a damping effect on the tsunami wave (Dahdouh-Guebas et al. 2005, Wolanski 2007, Danielsen et al. 2005). To prove this for the study areas, IKONOS data from 2003 and 2005 were compared with change detection techniques to identify areas with damaged vegetation and to gain rough information on the protective function of vegetation during the 2004 tsunami. To include the effect of wave attenuation in the inundation simulation a method was developed to calculate the appropriate Mannings roughness coefficients for each land use class in the study areas.

To use this aforementioned method seven vegetation classes, defined as coastal habitats, were investigated in the field, which included three types of plantations with a large extent in the study areas: coconut plantations, oil palm plantations and rubber plantations as well as natural habitats: mangrove forest, beach forest (outer beach forest fringing the sandy beach and inner beach forest adjacent to the outer area), and a temporary swamp forest (Melaleuca area). For these habitats tree parameters like the “diameter at breast height” or “vegetation density” were measured and transferred into Manning values according to Petryk & Bosmajian (1975).

For the remaining habitats in the study areas Manning values were estimated according to the “Guide for selecting Manning’s roughness coefficients for natural channels and flood plains” by Arcement and Schneider (1989) to avoid gaps in the final maps.

Additionally an estimation of the influence of the drag coefficient was performed following the approach of Tanaka et al. (2009). Eventually a roughness map with Manning values was generated and implemented in the modelling (figure 3).

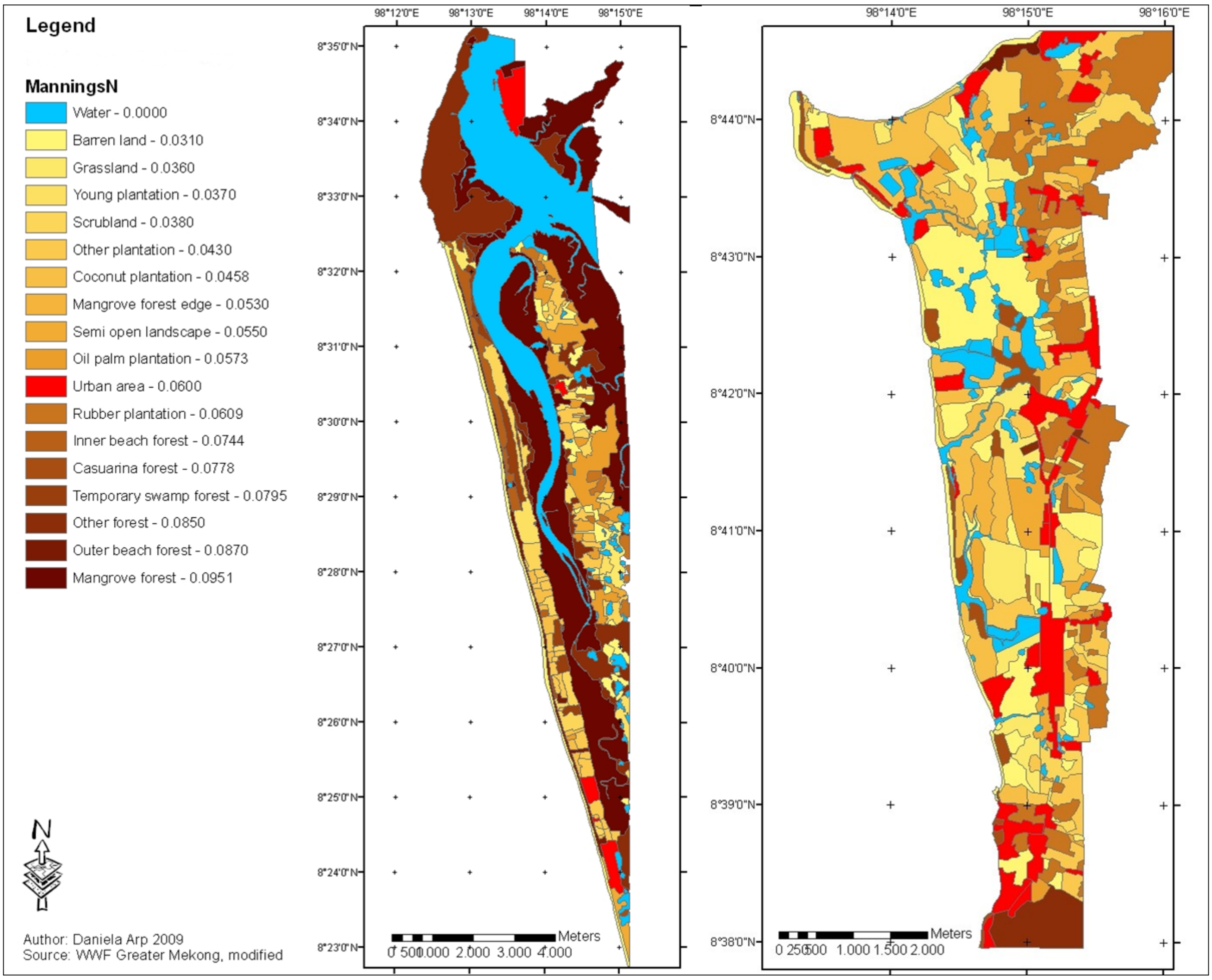

Figure 3: Land use classification with Manning values for each land use class, left: Thai Muang, right: Khao Lak

Generation of digital elevation models

Two different elevation models were generated, processed, and applied to investigate the effect of the resolution of the topography on inundation simulations: (1) Data from the Shuttle Radar Topography Mission (SRTM) with 90 m resolution and (2) a 0.15 m surface model derived from an airborne flight campaign conducted in the study areas with the multi- functional camera MFC-3, which contains an array of three RGB-Charge-Coupled-Device (CCD)-lines-modules (Börner et al. 2008).

The SRTM is a digital surface model, including vegetation and buildings in its surface description. Hence the height information in each raster cell is a function of land surface characteristics. Thus in forest-covered areas SRTM C-band interferometric SAR measures heights within the tree canopy generating height differences of up to 20 m in the study areas due to patches of tropical forest. As this caused problems in using SRTM data for inundation modelling the surface model had to be corrected to a real ground model. Information on the vegetation structure was measured in the field to gain surface heights of typical land use classes. The mean height values of every land use class and the ground coverage were then added to the land use classification which was converted into a raster, resampled and eventually subtracted from the SRTM data using GIS techniques. Finally a filter was applied to smooth the results, and rivers, ponds and tidal inlets were corrected with additional vector files. The results were validated with GPS elevation measurements gained in the field. Although this methodology generated good results in homogenous land use classes, some restrictions became obvious: The vegetation heights to be subtracted as well as the SRTM raster cell information represent mean values leading to inaccuracies. Moreover the land use classification is based on 2003 imagery, while SRTM data were collected in 2000, when land use may have been different.

To get a more detailed elevation model including buildings, river mouths and small scale changes in the topography, which influence tsunami flow patterns, a MFC surface model with 0.15 m resolution was generated from the aforementioned airborne flight campaign (figure 4). In this model vegetation was removed by filtering. However, in densely urban areas (e.g. Patong Beach) buildings were not removed from the surface model, as resistant buildings are supposed to influence flow dynamics.

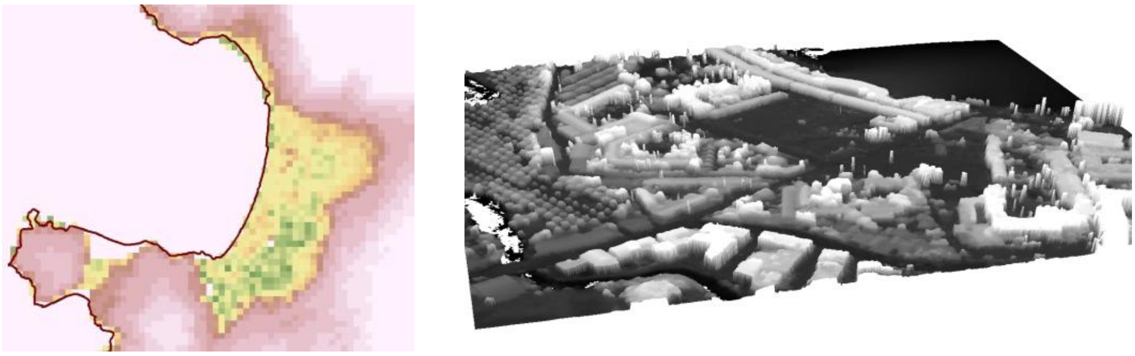

Figure 4: Digital surface models of Patong Beach with SRTM/90 m (left) and MFC DSM/0.15 m (right) resolution

Inundation maps

Based on the GEBCO 30 arc-second bathymetry combined with digitized marine charts in the near shore zone (resolution ~ 400 m), the topography and roughness maps, nested grids were generated with different resolution to model tsunami inundation in the study areas.

For the tsunami modeling two numerical models are being applied, which are boths based on the non-linear shallow water equations including bottom friction using Manning values. The MOST/ComMIT model (Method of Splitting Tsunami, (Titov & Gonzalez 1997)) uses a seismic deformation model to compute wave propagation and run-up over a set of three nested rectangular computational grids. Here, ComMIT is used for tsunami generation and propagation of the tsunami over the ocean. The model is connected to the MIKE 21 HD FM model (DHI) for inundation modelling. MIKE 21, which is based on an unstructured mesh, allows the inclusion of a detailed roughness map in the inundation simulations. To validate the model results, computed values are compared with measured tsunami heights provided by several research groups (e.g. Tsuji et al. 2006, Thailand Group 2005).

Various inundation maps have been produced based on different elevation models and for different roughness. Analysis of the first results has shown that a correction and filtering of digital surface models is inevitable for inundation modelling in densely vegetated areas. The SRTM elevation data are a useful source as they are available for most areas in the world. Nevertheless, for risk management the resolution turned out to be too coarse as small scale changes in topography, fluvial structures, or buildings can not be differentiated. For an analysis of the flow dynamics including barriers like buildings and different roughness within urban areas high resolution data are required. An analysis of the effect of buildings shows that including buildings as height information in the model generates a much more realistic indundation according to the measured inundation in the field.

Figure 5 examplifies this in a difference image for the inundation depth with and without buildings, showing that the inundation extent increases significantly without including buildings in the model. At the same time backwater effects occur when including buildings as height values.

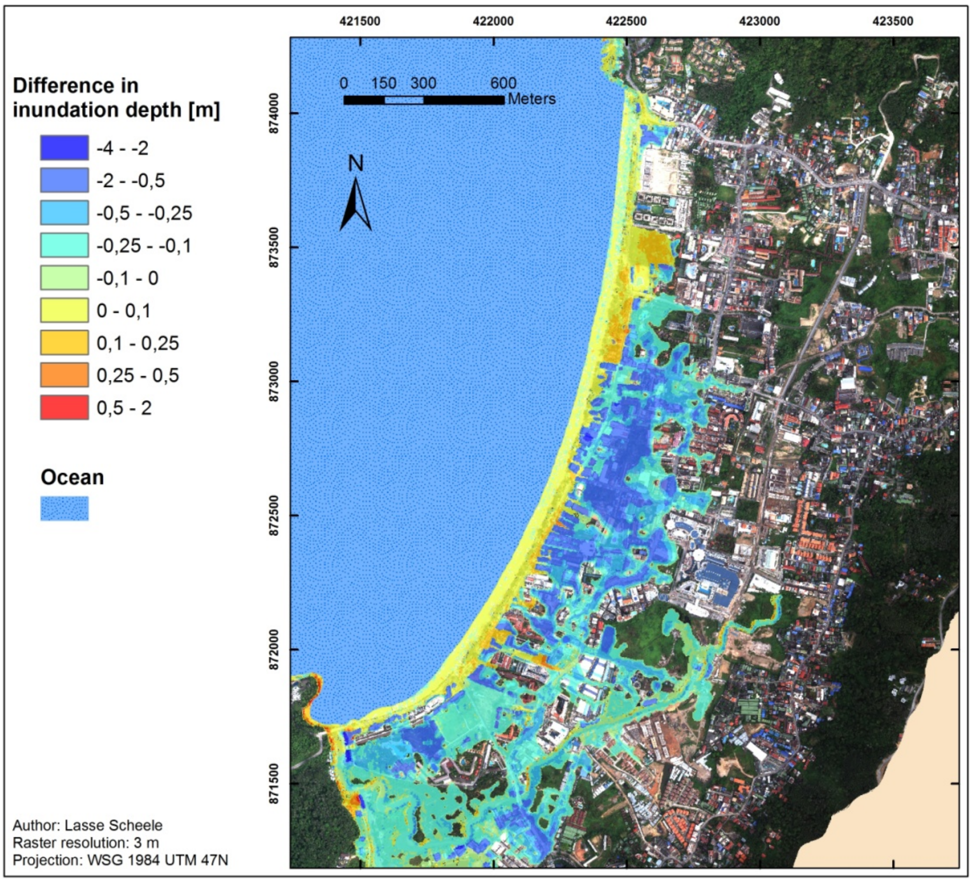

Figure 5: Inundation depth in Patong Beach showing the difference of an inundation simulation including buildings as height values and a simulation without buildings in the model grid, based on MFC data (resampled to 3 m)

4 Conclusions and outlook

In the German-Thai research project TRAIT research is performed on local tsunami risk assessment at the Andaman Sea coast of Thailand including a hazard analysis and a vulnerability analysis.

The tsunami inundation modeling provides hazard maps including the inundation depths, the maximum inundation area and flow dynamics. They build a basis for a detailed analysis of the 2004 tsunami impacts, for risk assessment and management at the Andaman Sea coast of Thailand. First outcomes of this study show that the accuracy and the resolution of the geodata used as input for the hazard analysis are crucial not only to understand the small scale mechanisms of tsunami impacts but also to provide inundation maps as a reliable basis for risk assessment, evacuation planning and risk management.

Since this paper presents work in progress further analysis will be conducted on multi-scale topography, the influence of detailed roughness information, inundation flow dynamics in urban and rural areas as well as inundation mapping.

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