Tsunami Inundation Modeling in the Aegean Sea

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SUMMARY:
The tsunami forecasting system designed in the United States is based on tsunami source functions. More than thousand tsunami source functions, i.e., $100 \, x \, 50 \, km^2$ fault planes with a slip value of $1m$ are placed along the subduction zones throughout the major ocean basins. Linearity of tsunami propagation in an open ocean allows scaling and/or combination of these sources. This database can also be used to generate different scenario events. To date, tsunami source functions have not been placed along the subduction zones in the Aegean Sea, although there are considerable number of historical tsunami events which have caused severe damage in the region. In this study, a database for historical tsunami events in the Aegean Sea has been compiled. This pre-computed scenario database will be extremely useful in developing tsunami resilient communities in the region.

Keywords: tsunami forecasting, early warning, numerical modeling, inundation, Aegean Sea

1. INTRODUCTION

Recently updated tsunami catalogues for the Mediterranean and the Aegean seas (Altınok et al., 2011; Ambraseys and Synolakis, 2010; Papadopoulos et al., 2007) indicate high potential for tsunamigenic events in the region. Indeed, the Aegean (Hellenic) Arc has regularly been the source for large shallow or intermediate-depth earthquakes. Considerable number of these earthquakes have caused damages on Greek and Turkish shorelines due to tsunamis associated with them. Shorelines are now highly populated and industrialized on both sides of the Aegean Sea and when the general lack of preparedness is added, it is indispensable that a tsunami event in the region will be disastrous for both countries. Probabilistic analyses justify this as they predict significant tsunami runup for the Aegean and the Mediterranean coasts. Most recently, Sørensen et al. (2012) performed a probabilistic tsunami hazard assessment (PTHA) and calculated probability of nearly 100% for a tsunami wave to exceed $1m$ height somewhere in the Mediterranean basin in the next 30 years. This wave height is likely to further increase by a significant amount because of wave focusing due to bathymetric features like the Mediterranean Trench (see Berry, 2007) or due to the configuration of the initial tsunami waveform itself (see Aydın, 2011). As a result, Sørensen et al. (2012) underline the urgent need for a tsunami warning system in the region. Assessment of tsunami risk for both coastlines and suggestions for development of best strategies for the reduction of this risk are planned in the framework of a joint project prepared by research groups from Greece and Turkey.

The 26 December 2004 Indian Ocean tsunami (also known as the Boxing Day tsunami), which resulted more than 230,000 casualties, proved once again the importance of tsunami forecasting and mitigation studies for tsunami-prone regions. In response, the Intergovernmental Oceanographic Commission (IOC) of UNESCO has accelerated its effort to coordinate the establishment of regional tsunami early warning systems in the Indian Ocean, the Mediterranean and the Caribbean. The Intergovernmental Coordination Group for the Tsunami Early Warning and Mitigation System in the North-eastern Atlantic, the Mediterranean and Connected Seas (ICG/NEAMTWS) was formed in June 2005. The ICG/NEAMTWS concentrated its effort in four aspects: seismic measurements, sea level data collection, hazard assessment, and public awareness. The proposed project is partly intended to supplement some aspects.

In this study, details of the pre-computed tsunami propagation database, which is currently being generated for the Mediterranean/Aegean region, is briefly explained. This database will be used for analysis of historical events and potential scenarios in the Mediterranean basin and inundation maps will be produced for two coastal towns of interest, one in Greece and one in Turkey. Simulations for several historical tsunami events has already been performed. Once finalized, this pre-computed scenario database might serve as basis for a tsunami warning system and it will be extremely useful to built tsunami resilience in the region.

Below, we first briefly explain the forecasting system used in the United States. Then, the current state of the project will be summarized.

2. THE NCTR METHODOLOGY

The Center for Tsunami Research (NCTR) of the Pacific Marine Environmental Laboratory (PMEL), National Oceanic and Atmospheric Administration (NOAA) has designed a real-time forecasting system for the Pacific Tsunami Warning Center and West Coast and Alaska Tsunami Warning Center in the United States. This system, which could be distinguished as the first operational tsunami warning system, is based on constraining tsunami source with earthquake magnitude and, more crucially, real-time deep ocean tsunami measurements. This constrained source is then used for site-specific inundation models to produce timely and accurate forecasts for tsunami-prone coastlines.

Tsunami source functions (also called *unit sources*), i.e., $100 \times 50\,km^2$ fault planes with a slip value of $1m$, are placed along the subduction zones through the ocean basins in several rows, depending on the width of the subduction zone. Ocean-base propagation from each unit source is calculated using the Method of Splitting Tsunamis (MOST) numerical model (Titov and Synolakis, 1998) and propagation database is created. Presently, the NCTR database has approximately thousand unit sources in all oceans (see Gica et al. (2008) for details). However, this database does not include any sources for the Mediterranean and the Aegean seas.

Historical or scenario events can be simulated by combining the pre-computed propagation results of unit sources due to the linearity of tsunami propagation on open ocean. The offshore scenario can be obtained by combination of unit sources constrained by the initial magnitude of the earthquake and/or deep-ocean measurements through Deep-ocean Assessment and Reporting of Tsunamis (DART^{TM}) buoys. Once the offshore scenario is obtained (constrained), the results of the propagation run are linearly combined to provide initial and boundary conditions for the high-resolution site-specific nonlinear inundation forecast models since tsunami inundation is a highly nonlinear process close to shore. Three levels of telescoping grids (called A-, B-, and C-grids) with increasing resolution are employed to model tsunami dynamics on ocean and inundation onto dry

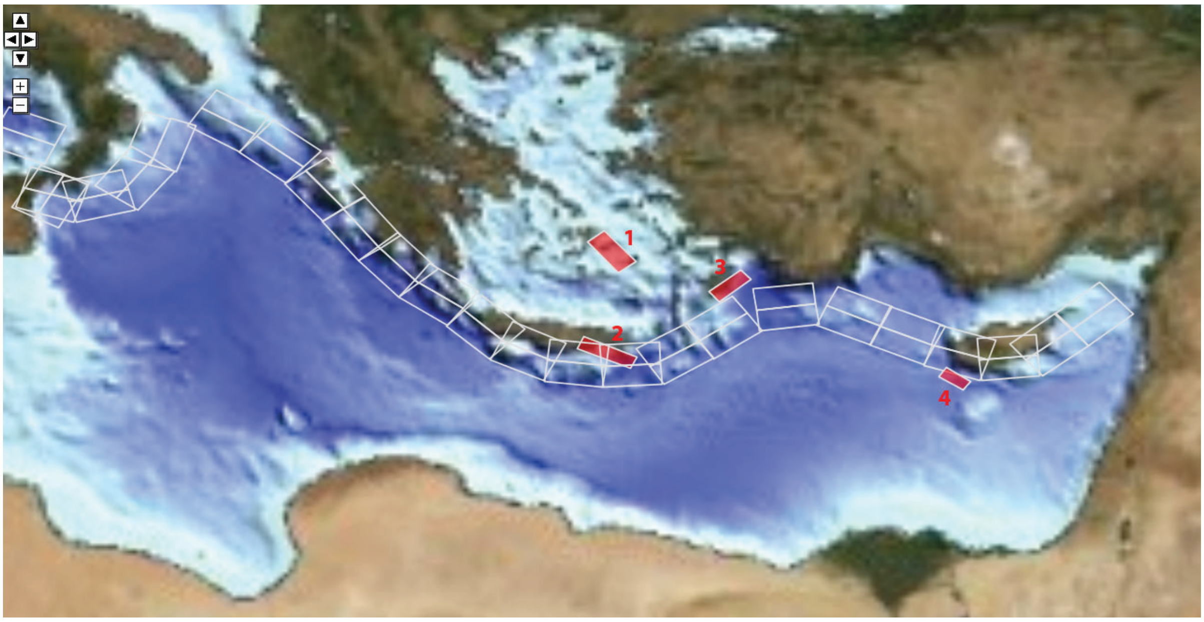

Figure 2.1. Unit sources (white rectangles) placed along the Mediterranean subduction zone in two rows. Red filled rectangles show approximate locations of the seismic sources of (1) the 1956 Amorgos, (2) the 1303 Crete, (3) the 1481 Rhodes, and (4) the 1222 Cyprus earthquakes.

land. Since its first testing during the 17 November 2003 Rat Island, Alaska tsunami, the NCTR's forecast system has produced real-time forecasts for far-field impact of almost every tsunami, including the recent 11 March 2011 Tohoku, Japan tsunami, and proven its accuracy, efficiency, and reliability in each event (Titov, 2009). The NCTR methodology is explained in detail in Wei et al. (2008) for the 15 August 2008 Peru tsunami.

3. ADAPTATION TO THE AEGEAN SEA

In this study, the NCTR system is adapted to the Mediterranean/Aegean region and unit sources are started to be placed along the subduction zones (Fig. 2.1). After generating propagation database with unit sources, project partners will use the same propagation database in order to generate initial and boundary conditions for the high resolution nested grids near the shoreline. Greece and Turkey will run their model in house and share the model results.

The project is divided into two main stages:

- *Development of the propagation database:* This phase includes the steps
  - Review of existing tsunami catalogues (Altınok et al., 2011; Ambraseys and Synolakis, 2010; Ambraseys, 1962) for identification of historical sources.
  - Review of recent literature (Lorito et al., 2008; Yolsal et al., 2007; Papazachos, 1996) for identification of potential tsunamigenic sources.
  - Review of existing deep sea data and collection of better-quality bathymetric/topographic data where available.
  - Generation of propagation database using the MOST numerical model as outlined in Gica et al. (2008).

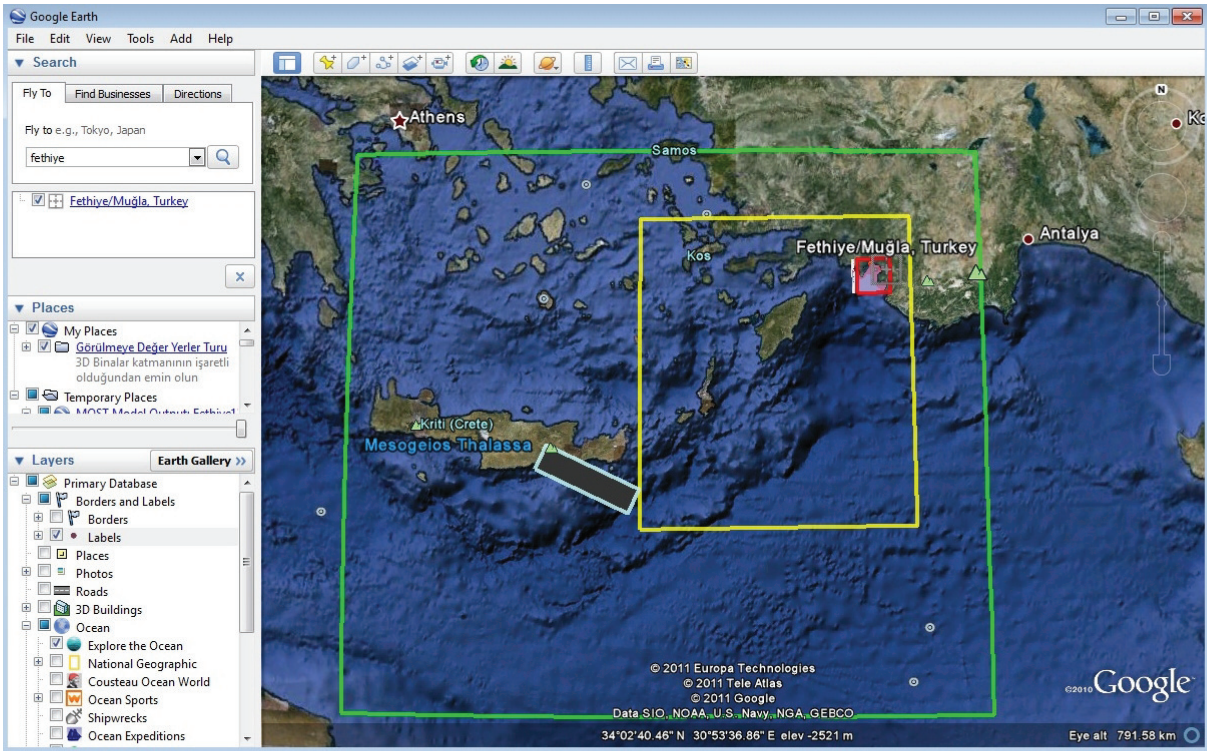

Figure 4.1. Telescoping grids, i.e., A- (green), B- (yellow), and C-grids (red) in increasing resolution. We note that the grid extends are chosen larger than necessary for demonstration purposes.

- *Inundation modeling:* This phase includes
  - Selection of two sites (one town from each country) depending on available high resolution bathymetric/topographic data.
  - Generation of inundation maps using the interface ComMIT to the MOST numerical model as outlined in Titov et al. (2011).
  - Dissemination of results to local authorities.

4. CURRENT ISSUES AND FUTURE WORK

Currently, the first phase of the project is about to be completed. Also, preliminary version of inundation maps are produced. However, the major problem is the quality of the bathymetry/topography data in the region. This is an important issue for correct propagation results and is also crucial for the confidence in inundation maps. After collection of bathymetric/topographic data with sufficient quality, the propagation database will be revised with new bathymetry. In addition, during the next phase, near-shore inundation modeling will be performed and inundation maps will be prepared for two towns, one from each country, where high resolution bathymetric/topographic data is available. Also, use of smaller size (e.g., $50 \times 50\, km^2$) unit sources will be examined and results will be discussed.

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