Tsunami Hazards in The Eastern Mediterranean

E. Flouri[1,3], N. Chrysoulakis[1], V. Dougalis[1], C. E. Synolakis[1,2,3] & S. Foteinis[1,2,3]

[1] Institute of Applied and Computational Mathematics, Foundation for Research and Technology – Hellas, Greece
[2] Viterbi School of Engineering, University of Southern California, Los Angeles, CA, USA.
[3] Laboratory of Natural Hazards, Technical University of Crete, Chanea, CA 73100, Greece

We present preliminary results on tsunami hazard assessment for the City of Rhodes, Greece, in the Eastern Aegean Sea. We use remote sensing data and methods to develop the maps, with topographic data derived using both satellite and aerial images. ASTER (Advanced Spaceborn Thermal Emission and Reflection Radiometer) stereo images were used to provide a Digital Elevation Model (DEM) for the whole island, whereas aerial imagery was used to derive a high resolution DEM for the Northern part where the City of Rhodes is located. We use a range of earthquake source scenarios that may affect Rhodes and we provide an overview of tsunami hazards in the Eastern Mediterranean.

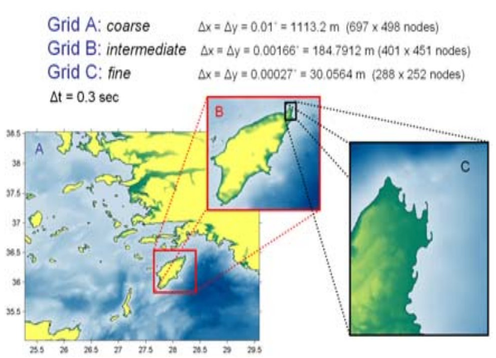
Acknowledgements

Research supported by the EU funded FP6 Project TRANSFER (Contract no. 037058).

THE STUDY AREA

The geographic area of the present study is the SE Mediterranean and more specifically the SE Aegean Sea. Under the scope of the TRANSFER project and due to its high seismicity the area has been chosen as the "Master Test Case" of the project and includes the Greek island of Rhodes and the Turkish coastal area of Fethiye . Both sites are resort areas with an economy that is based mainly on tourism. In the project, inundation maps for Rhodes are computed by the authors (FORTH), while companion maps are being developed for Fethiye by A.Yalciner and U. Kanoglu of METU.

The study area in SE Aegean Sea



NUMERICAL MODELLING OF TSUNAMI PROPAGATION AND INUNDATION

For the tsunami simulation the MOST (Method of Splitting Tsunami) numerical model (Titov & Synolakis, 1998) has been used. MOST has been extensively validated and is the code used by NOAA (National Oceanic and Atmospheric Administration) for tsunami mapping and tsunami forecasting in the Pacific and Indian Oceans, see www.pmel.noaa.gov.

The model requires three nested bathymetry/topography grids of different resolutions (Bernard et al. 2006). The finer grid used in the present study is of a 30 m resolution and covers the northern part of Rhodes island where the historic city of Rhodes, as well as the main facilities of the tourist industry are located.

Main Data Sources

Bathymetry Data

- GEBCO (General Bathymetric Chart of the Oceans) British Oceanographic Data Centre
- Hellenic Navy Hydrographical Service, ENC files (Electronic Nautical Charts)

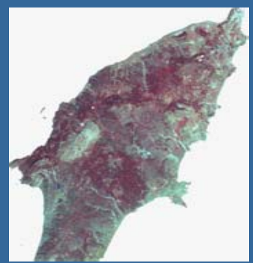
Topography Data

- Aerial stereo imageries acquired during low flight campaign
- ASTER multispectral data (14 bands)
- Ikonos multispectral data (4 bands)
- Field observations with the use of GPS

Data pre-processing

- Orthorectification of satellite imagies
- Development of VHR DEM and slope maps.
- Translation of datasets to the same parameters (reference system, units, horizontal & vertical datum). Cross-validattion.
- Elimination of discrepancies between datasets. Data correction.
- Extraction of new accurate shoreline using VHR satellite imagery.
- Merge accurate topography, bathymetry and shoreline data into a final grid.
- Construction of nested bathymetry/topography grids for input to MOST model.

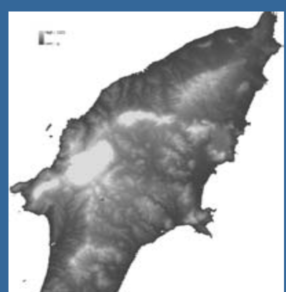
Satellite Imagery



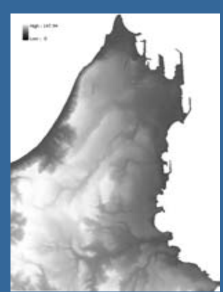
ASTER multispectral stereo (14 bands, 15 to 30 m spatial resolution).

Ikonos multispectral (4 bands, 1 m spatial resolution)

The derived DEMs



The ASTER derived DEM.



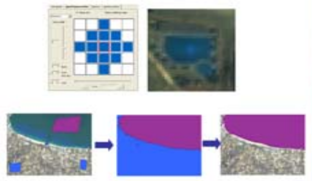
The aerial imagery derived DEM.

THE SEISMIC DATA

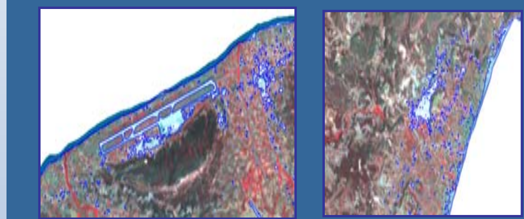
Several seismic sources have been considered for providing scenario initial conditions for the computations of the inundation maps for the City of Rhodes. Here, we present results from four extreme seismic scenarios. These were our preliminary runs and they are still being evaluated by geologists in terms of geophysical realism and relevance.

VHR shoreline extraction

- Orthorectified of Ikonos imagery
- Feature extraction techniques
- Dedicated software



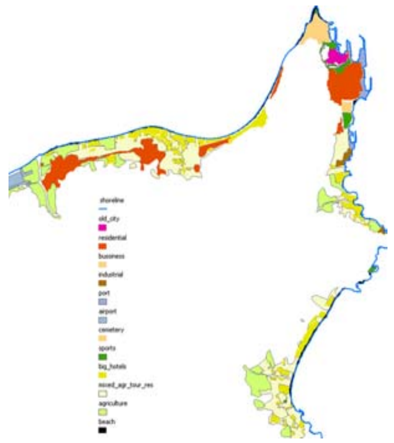
- Accurate shoreline extraction



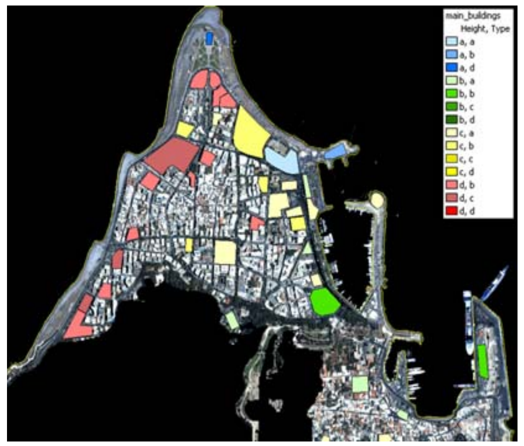
The ASTER land cover classification results (urban - non urban for the whole island) were used to derive vector information: polygons covering the urban areas of the island.

The polygon containing the airport of Rhodes (left) and the polygon containing the town of Afadou (right).

Land Use Classification



Main Buildings Classification



VULNERABLE AREAS DETECTION

Coastal Areas definition

The high resolution DEM was used to mask the Ikonos orthoimage, so the areas with elevation greater than 20 m were eliminated, because these areas were not needed in inundation mapping even in cases of extreme scenarios, - note that per Okal & Synolakis (2004), the runup seldom if ever exceeds twice the seismic slip. Therefore, the areas with elevations lower than 20 m are the suspect vulnerable coastal areas.

Land use mapping

Both ASTER and Ikonos images were used to derive the land cover/use information as needed.
The ASTER orthorectified multispectral image was classified to 11 classes by employing a per-pixel supervised classification procedure based on the maximum likelihood classification algorithm (Foody 2000, Gallego, 2004). Post-classification sorting merged the above classes into 2 main categories, urban and non-urban. A semi-automatic classification method was used to classify the Ikonos image. This method was based on both manual digitization and machine learning classification techniques (VLS 2007).

Building Classification

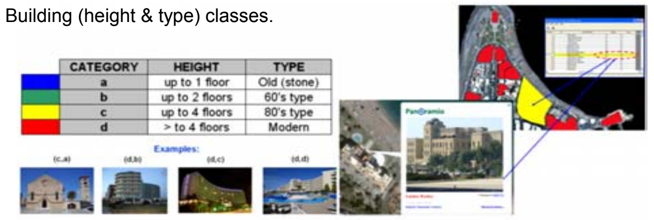
The orthorectified Ikonos imagery was used to detect 150 major buildings located in the northern part of the island. Information on building height and type was also extracted and stored in our database. Initially, a classification scheme of four building height classes (one- floor increments) and four building types (old - masonry made, 60's type, 80's type, and modern) was developed. Then the height and type information was extracted by combining Ikonos data with GoogleEarth/Panoramio

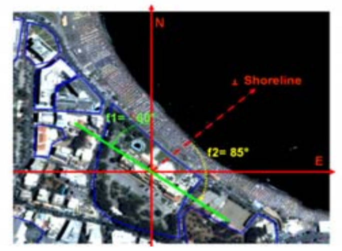
Building identification, orientation and classification

Building polygon, major axis (green line), orientation normal to the North (green) and normal to the shoreline (yellow).

Building (height & type) classes.

CATEGORY	HEIGHT	TYPE
a	up to 1 floor	Old (stone)
b	up to 2 floors	60's type
c	up to 4 floors	80's type
d	> to 4 floors	Modern



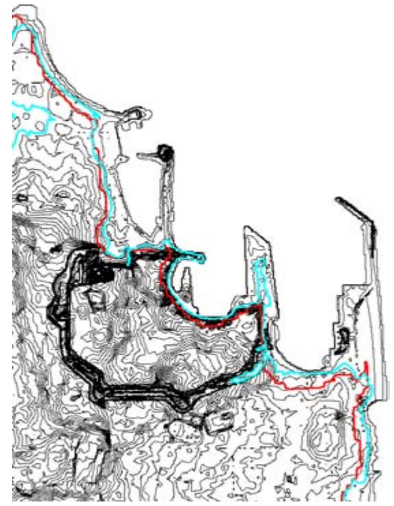


CONCLUSIONS

- Detailed input data was constructed for use in the tsunami simulation code MOST for application in the northern part of the island of Rhodes, Greece.
- A detailed study of vulnerable area detection was made. The resulting data base will be used for tsunami mitigation strategies.
- Tsunami inundation maps for the northern part of Rhodes were produced for a limited number of worst case scenarios.
- The data infrastructure developed is currently being used in a systematic probabilistic study of possible effects of tsunami hazards in the areas of Rhodes and Fethiye.

Tsunami inundation lines for the city of Rhodes

The resulted inundation lines for the four hypothetical extreme scenarios as superimposed over the Ikonos multispectral orthore-ctified image.



Contour lines as derived from the high resolution DEM. The contour of 3 m is shown in blue and the inundation line in red.

FIELD CAMPAIGN - VALIDATION OF RESULTS

In July 2008, a field campaign in the island of Rhodes was undertaken by the authors in order to validate results. During the campaign in-situ measurements were made using high resolution GPS technology.

The VHR extracted shoreline, the land use/land cover, as well as the building classifications were validated via the GPS observations with very satisfactory results. Since both the land use map and the building classification have been produced using the Ikonos orthoimage (therefore, they are georeferenced) the TRANSFER GIS structure has the potential to make use of these maps to support mitigation planning, as well as to assess the damage in a tsunami scenario.

The positioning of the inundation lines computed by MOST for the preliminary extreme scenarios was verified by GPS observations during the in-situ campaign, and it has also been compared with a contour map produced using aerial imagery- derived DEM.A strong correlation of the inundation line for the first seismic scenario with the 3 m elevation contour line has been observed. This was expected since the maximum runup was calculated as 3.7 m. This agreement is even closer for steep slopes and can be explained considering the 0.5 – 1 m vertical accuracy of the high resolution DEM, as checked using survey monuments. The positioning of the inundation line and its consistency with the 3 m contour was verified by GPS observations during the in-situ campaign in July 2008.

REFERENCES

1. Bernard, E. N., Mofjeld, H. O., Titov,, V., Synolakis, C. E. & Gonzalez, F. I. 2006. Tsunami: scientific frontiers, mitigation, forecasting, and policy implications. *Philosophical Transactions of the Royal Society A* 364.
2. Chrysoulakis, N., Abrams, M., Feidas, H. & Velianitis, D. 2004. Analysis of ASTER Multispectral Stereo Imagery to Produce DEM and Land Cover Databases for Greek Islands: The REAL-DEMS Project. In *Proceedings of e-Environment: Progress and Challege*: 411 – 424.
3. N. Chrysoulakis, E. Flouri, E. Diamandakis, V. Dougalis, C. Synolakis & S. Foteinis, "Remote sensing in support of tsunami mitigation planning in the Mediterranean", First International *Conference in Disaster Management and Emergency Response in the Mediterranean Region*, Zadar, Croatia, Sept. 22-24, 2008
4. Okal, E. A. & Synolakis, C. E. 2004. Source discriminants for nearfield tsunamis. *Geophysical Journal International* 158, 899 - 912.
5. Synolakis, C. E. 2003. Tsunami and Seiche in Earthquake Engineering Handbook, CRC Press.
6. Titov, V. V. & Synolakis, C. E. 1998. Numerical modeling of tidal wave runup. *Journal of Water-ways, Port, Coastal and Ocean Engineering ASCE* 124 (4), 157 - 171.
7. Titov, V.V. & Synolakis, C. E. 1995. Modeling of breaking and nonbreaking long wave evolution and runup using VTCS-2. *Journal of Waterways, Ports, Coastal and Ocean Engineering* 121, 308 - 316.