

# **TSUNAMI RISK SITE DETECTION IN GREECE BASED ON REMOTE SENSING AND GIS METHODS**

B. Theilen-Willige

Technical University of Berlin, Institute of Applied Geosciences  
Department of Hydrology and Bureau of Applied Geoscientific Remote Sensing (BAGF)  
Birkenweg 2, D-78333, Stockach, Germany

## **ABSTRACT**

Based on LANDSAT ETM and Digital Elevation Model (DEM) data derived by the Shuttle Radar Topography Mission (SRTM) of the coastal areas of Greece were investigated in order to detect traces of earlier tsunami events. Digital image processing methods used to produce hillshade, slope, minimum and maximum curvature maps based on the SRTM DEM data contribute to the detection of morphologic traces that might be related to catastrophic tsunami events. These maps combined with LANDSAT ETM and seismotectonic data in a GIS environment allow the delineation of coastal regions with potential tsunami risk. The evaluations of LANDSAT ETM imageries merged with digitally processed and enhanced SRTM data clearly show areas that must have been flooded in earlier times. In some cases morphologic traces of waves as curvilinear scarps open to the sea-side are clearly visible.

## 1. INTRODUCTION

This study is considering tsunami risk mapping for coastal areas where no severe tsunami has occurred recently, but the geomorphologic and topographic features and characteristics are similar to areas hit by recent catastrophic tsunamis as Sumatra. A tsunami hazard map of such an area that predicts the potential location of future tsunami occurrences is required. In the case of a catastrophic event it can provide rescue teams with the map of the areas where the tsunami energy is expected to be destructively large and damage is most severe. Around the Mediterranean Sea there is a high potential for generation of large tsunamis, and in addition, for the generation of tsunamis produced in the near-shore zone that could have catastrophic effects on a local scale (BOSCHI et al., 2005, YALÇINER et al., 2001, 2004). Parts of the Mediterranean coastline have suffered from disastrous marine waves many times in history. Historical earthquakes and associated tsunamis for the whole Mediterranean basin are identified from verified catalogues. In addition to historical and geologic information, or distribution of fault zones, volcanoes, and other probable tsunamigenic sea bottom structures, there are numerous source areas which may be considered responsible for severe tsunamis. One of the important source areas of tsunamis in the Mediterranean are the normal fault zones of Greece and the subduction in the Tyrrhenian sea. The tsunami waves caused severe damage and flooded low lands in many segments of the coast.

## 2. APPROACH

This contribution considers the support provided by remote sensing data and a GIS based spatial databases for the delineation of potential risk sites in Greece. On a regional scale the areas of potential tsunami risk will be determined by an integration of remote sensing data, geologic, seismotectonic and topographic data. LANDSAT ETM and DEM data were used for generating an image based GIS and combined with ESRI data and other thematic maps, see Fig.1 b. These include an inventory of seismic

records, large-scale geomorphologic analysis, digital elevation data and high-resolution remote sensing data. As one of the procedures to generate a tsunami hazard map a comparison between the geomorphologic/ topographic settings of the areas previously hit by tragic tsunamis in recent times (as in Sumatra) and the potential risk sites in Greece is proposed. There are typical geomorphologic features found in areas prone to catastrophic tsunami events as fan shaped flat areas, fan-shape like arranged drainage patterns, arc-shaped (seawards opened) walls and scarps, often running parallel to the coast, Remnants of tsunami floods are irregular swamps, ponds and lagoons near the coast. The evaluation of digital topographic data is of great importance as it contributes to the detection of the specific geomorphologic/ topographic settings of tsunami prone areas. For the objectives of this study the following digital elevation data have been evaluated: Shuttle Radar Topography Mission - SRTM, 90 m resolution) data provided by the University of Maryland, Global Land Cover Facility (<http://glcfapp.umiacs.umd.edu:8080/esdi/>) and GTOPO30 data provided by USGS (<http://www.diva-gis.org/Data.htm>, 1 km resolution) were used as base maps. Height values for the SRTM dataset are referenced to GTOPO 30 global digital elevation model. SRTMT data offer a useful and numerous advantages for tsunami research.

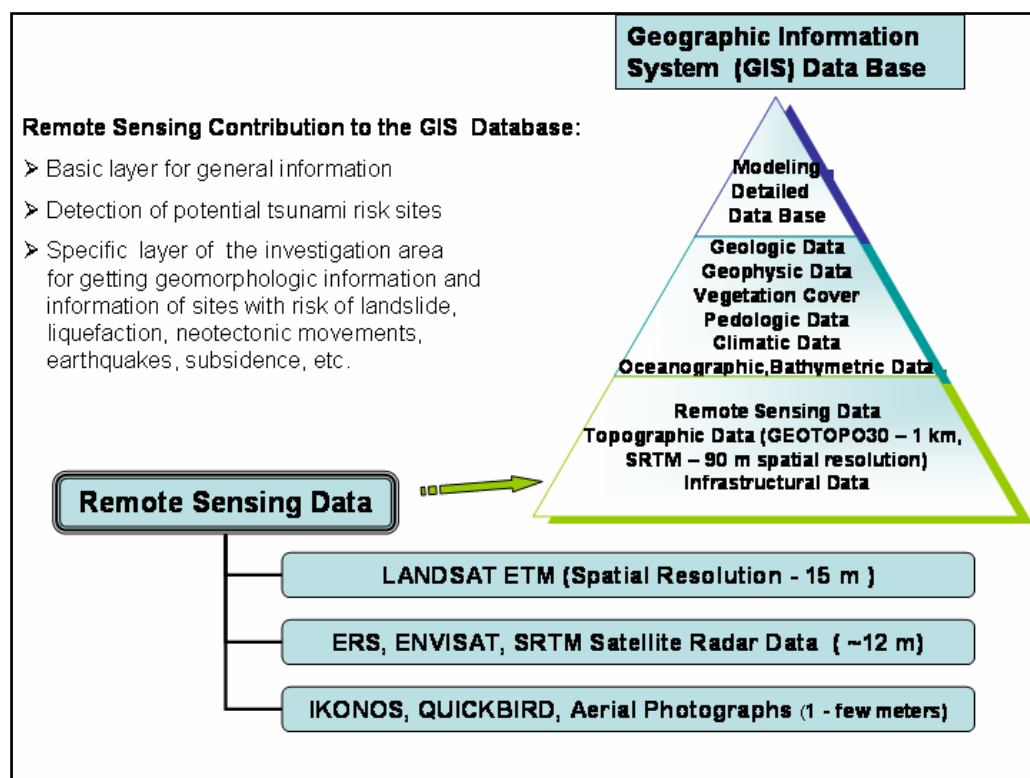


Figure 1 : Remote Sensing Contribution to a Tsunami Hazard Information System

The digital topographic data were merged and overlain with LANDSAT ETM data (Band 8: 15 m resolution). For enhancing the LANDSAT ETM data digital image processing procedures have been carried out. Various image tools delivered by ENVI Software/ CREASO were tested. Effective cartographic displays are achieved when DEMs are combined with landcover information derived from satellite imagery. Other geodata as provided by ESRI ArcIMS GIS were included, so earthquake data or bathymetric maps. With digital image processing techniques maps can be generated to meet specific requirements considering risk mapping: For getting a geomorphologic overview SRTM data terrain parameters were extracted from a DEM as shaded relief, aspect and slope degree, minimum and maximum curvature or plan convexity maps using ENVI and ArcMap software (Fig.2).

Geomorphometric parameters as slope degree, minimum or maximum curvature provide information of the terrain morphology indicating geomorphologic features that might be related to tsunami events. These SRTM derived, morphometric parameters correspond to groups of 0, 1st and 2nd order differentials, where the 1st and 2nd order functions have components in the XY and orthogonal planes.

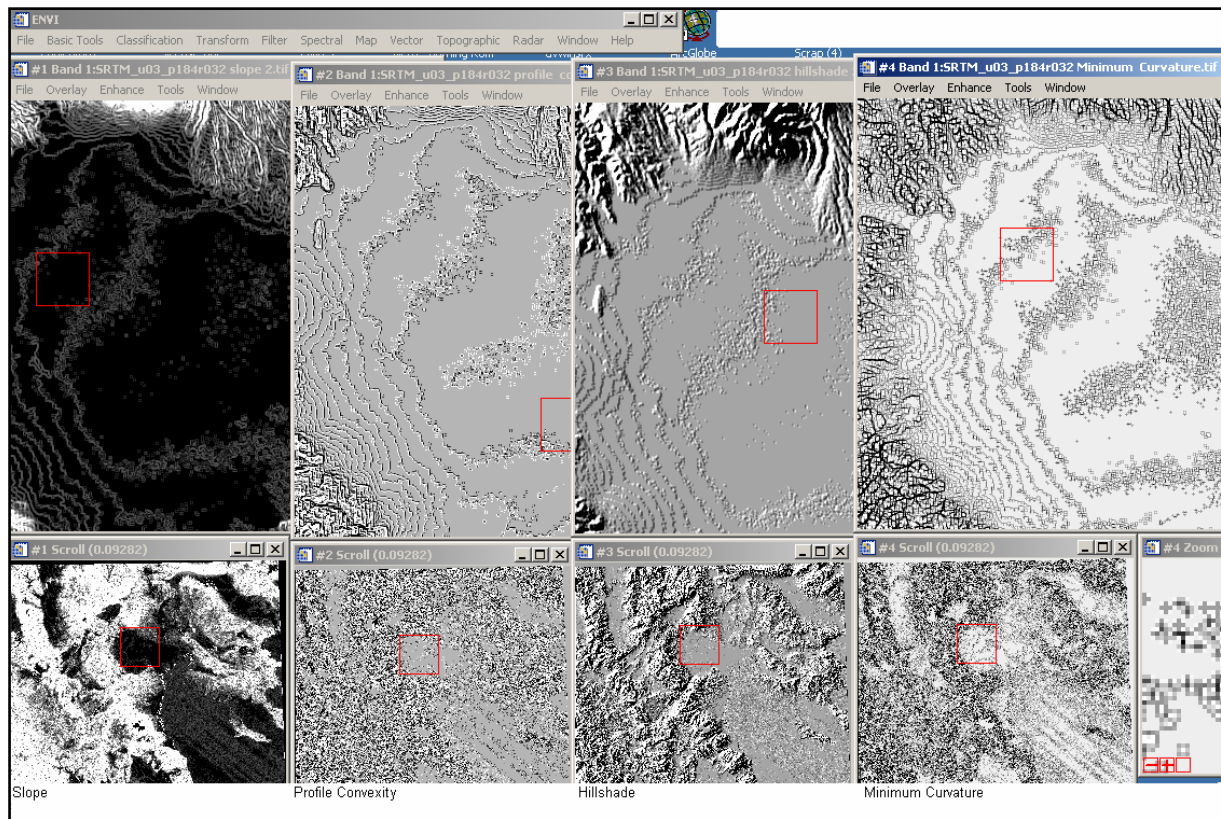


Figure 2 : SRTM based maps from the area of Thessaloniki

The various data sets as LANDSAT ETM data, topographic, geological and geophysical data from the studied areas were integrated as layers into GIS using the software ArcView GIS 3.3 with the extensions Spatial Analyst und 3D-Analyst and ArcGIS 9.0 of ESRI. As a complementary tool Google Earth Software was used in order to benefit from the 3D imageries of the various investigation areas (<http://earth.google.com/>).

A systematic GIS approach is recommended as described in Figs.3 and 4 extracting geomorphometric parameters based on the SRTM DEM data as part of a Tsunami Information System.

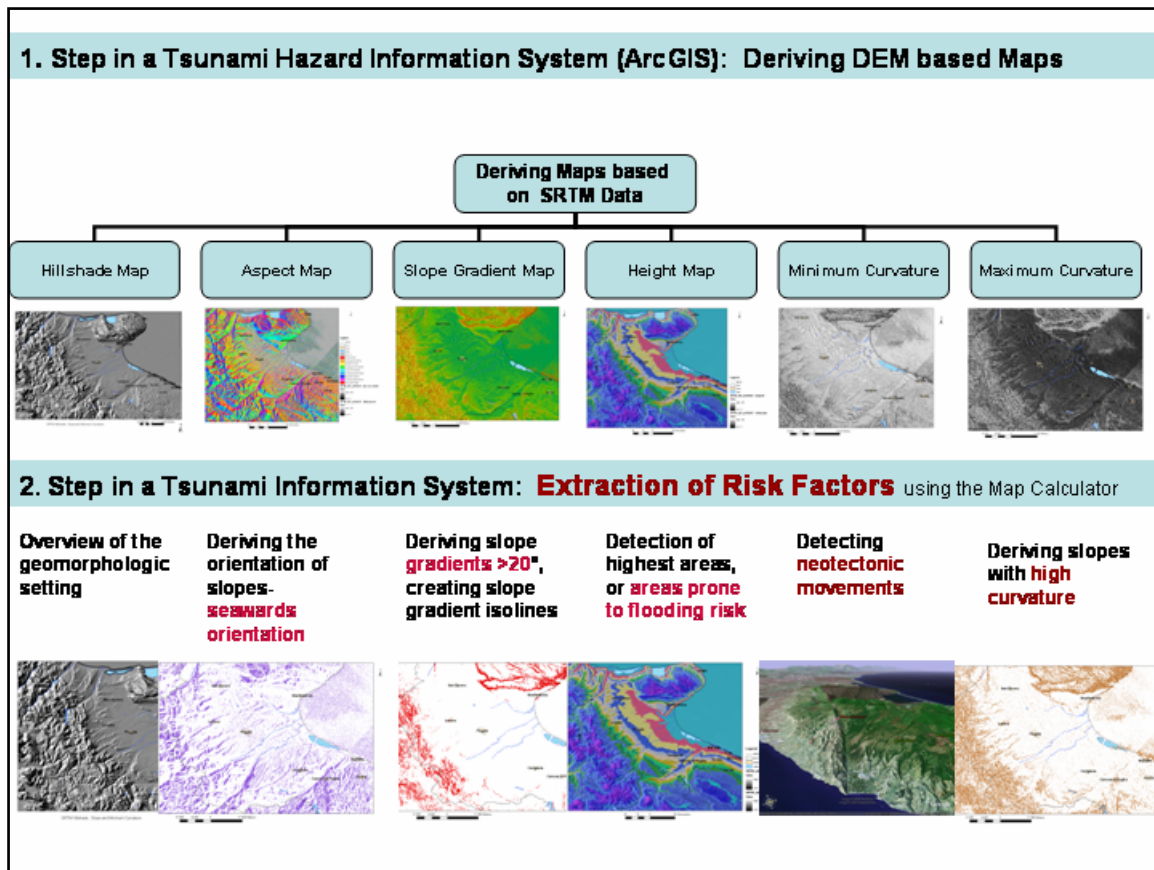


Figure 3: Workflow in a Tsunami Hazard Information System

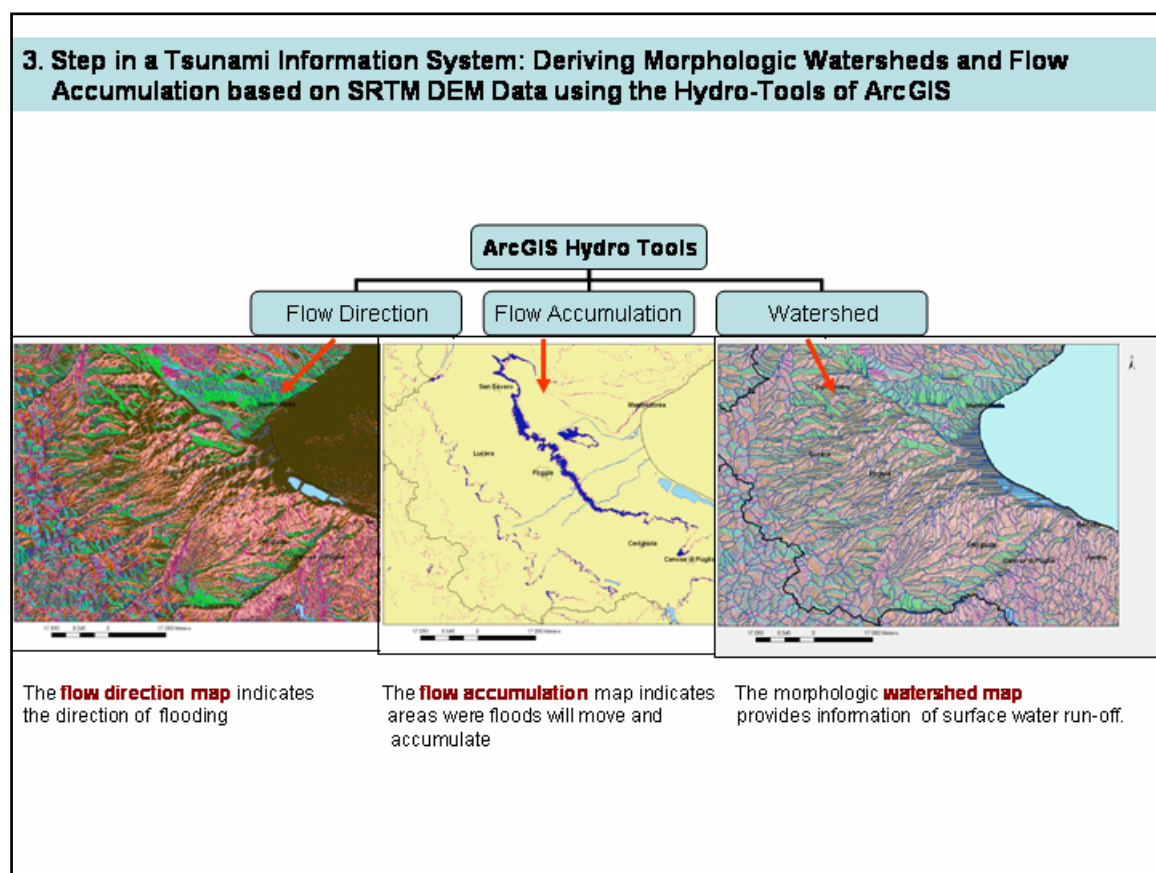


Figure 4: Deriving hydro-morphometric parameters

### 3. EVALUATION OF SRTM AND LANDSAT ETM DATA FROM COASTAL AREAS OF GREECE

Potential risk sites for hazardous tsunami waves were identified by analyzing areas in Greece showing heights below 20 m above sea level (Fig.5). These areas below 20 m height were studied then more detailed.

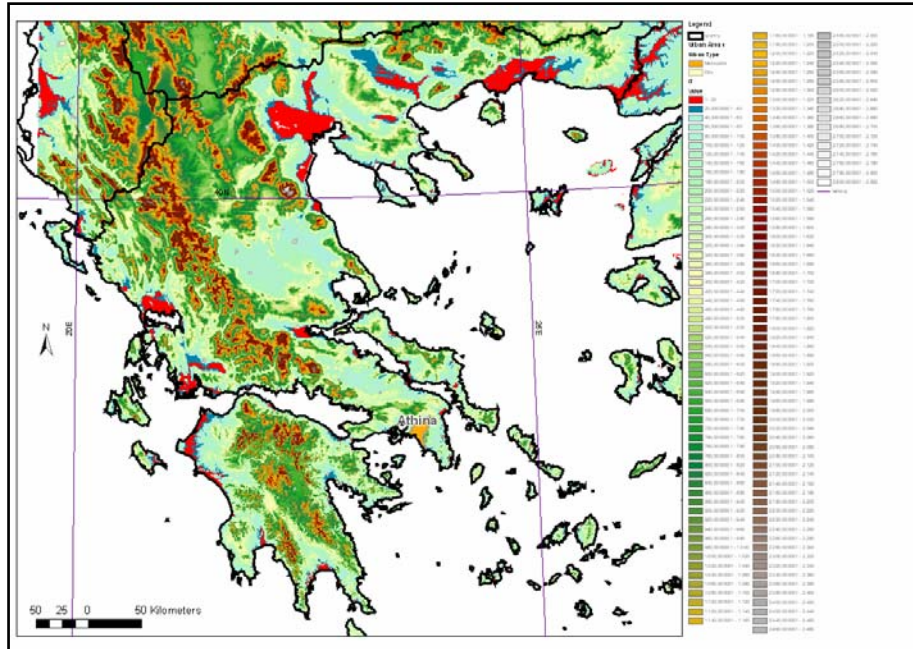


Figure 5: Height map of Greece indicating areas below 20m height above sea level.

As first example the Bay of Thessaloniki is presented. Figs.6 - 9 show the results of SRTM data based map products. Potential traces of flood waves as parallel, arc-shaped walls can be inferred by minimum curvature maps as presented in Fig.6 as well as by color coding the DEM map (Fig.7). Potential traces of run-up can be detected considering the parallel, sea-wards opened curvatures. By far the most common method of displaying raster data in a GIS is to use a 2-dimensional colour coding where each elevation value is assigned a colour value. By colour coding the DEM map of the study area flat regions and different height levels become visible. Estuary plains and broader river beds were probably prone more to tsunami wave propagation risk than the higher environment. River mouths represented a large entrance for tsunami waves. Especially the Axios, Aliakmonas, Galikos and Loudias rivers would be prone to flooding.

Provided that the morphologic properties of the Thessaloniki Bay area are related to tsunami events it can be assumed that the morphology is the result of abrasion due to catastrophic tsunami floods. This assumption is confirmed by the hillshade map (Fig.8). The flooding tsunami waves obviously came by South.

According to the characteristic morphologic properties visible on the hillshade, the aspect, minimum curvature and slope map the run-up heights along the south-facing, flat shorelines are estimated at least of about +/- 30 km.

Submarine mass movements as slumps, turbidity currents and landslides presumably triggered by earthquakes might be an explanation for the intensity of waves and floods forming the coast-near landscape in the Bay of Thessaloniki.

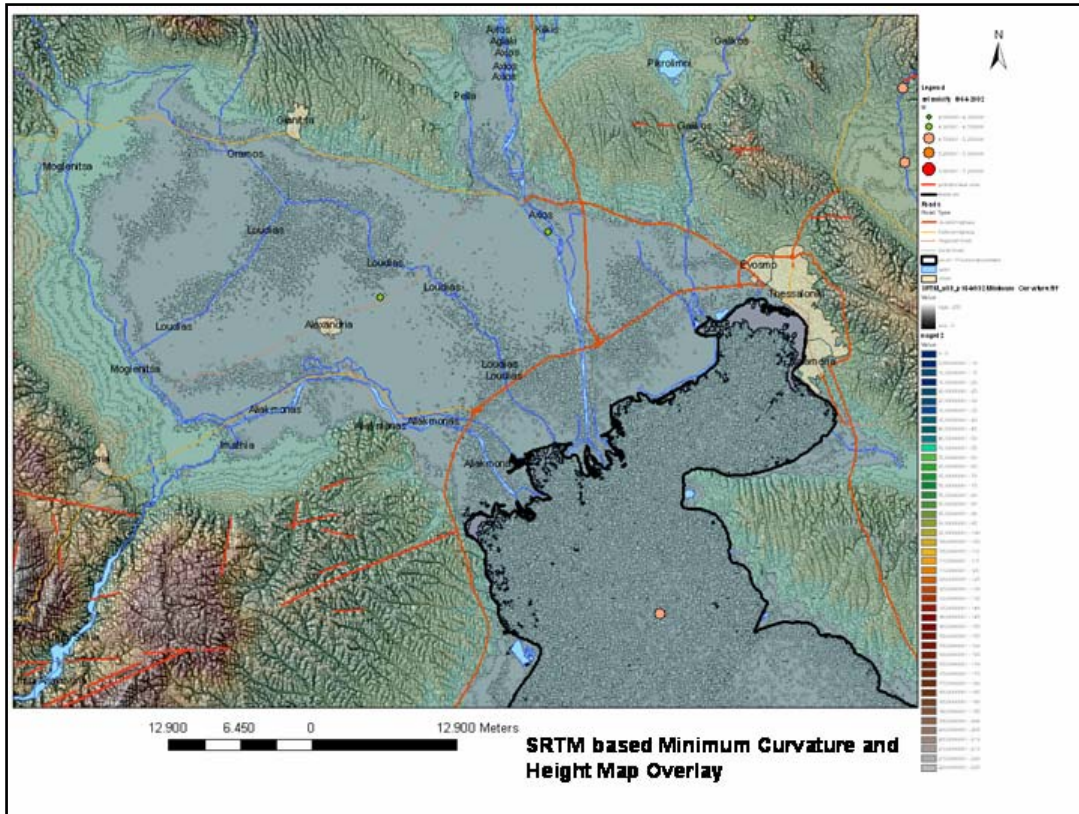


Figure 6: SRTM based shaded relief and minimum curvature map of the Bay of Thessaloniki

The minimum curvature map illustrates the seawards orientation of the terrain and enhances as well smaller walls, ridges and terraces with seawards opened, arc-shaped contours.

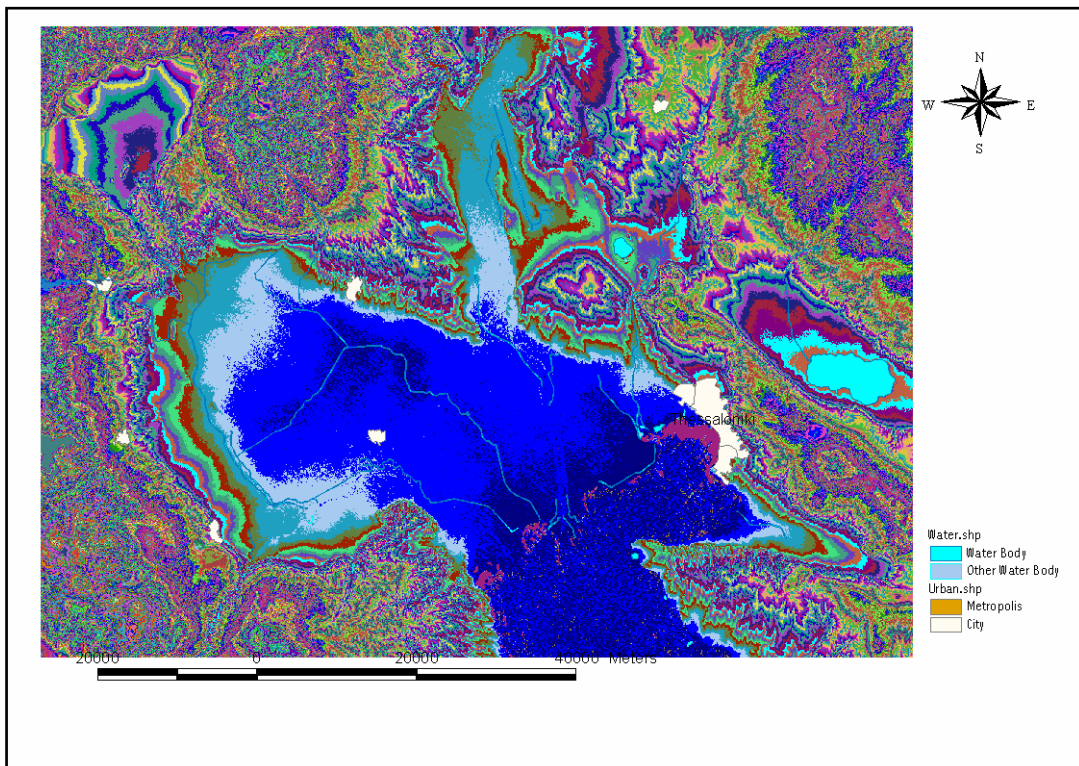


Figure 7: Height map based on SRTM DEM data using ArcView GIS

The map clearly shows the different levels in the basin probably formed by floods. It seems that tsunami waves “intruded” along existing river beds. Therefore run up and inundation distance of the floods along riverbeds was probably more extended than in the adjacent areas.

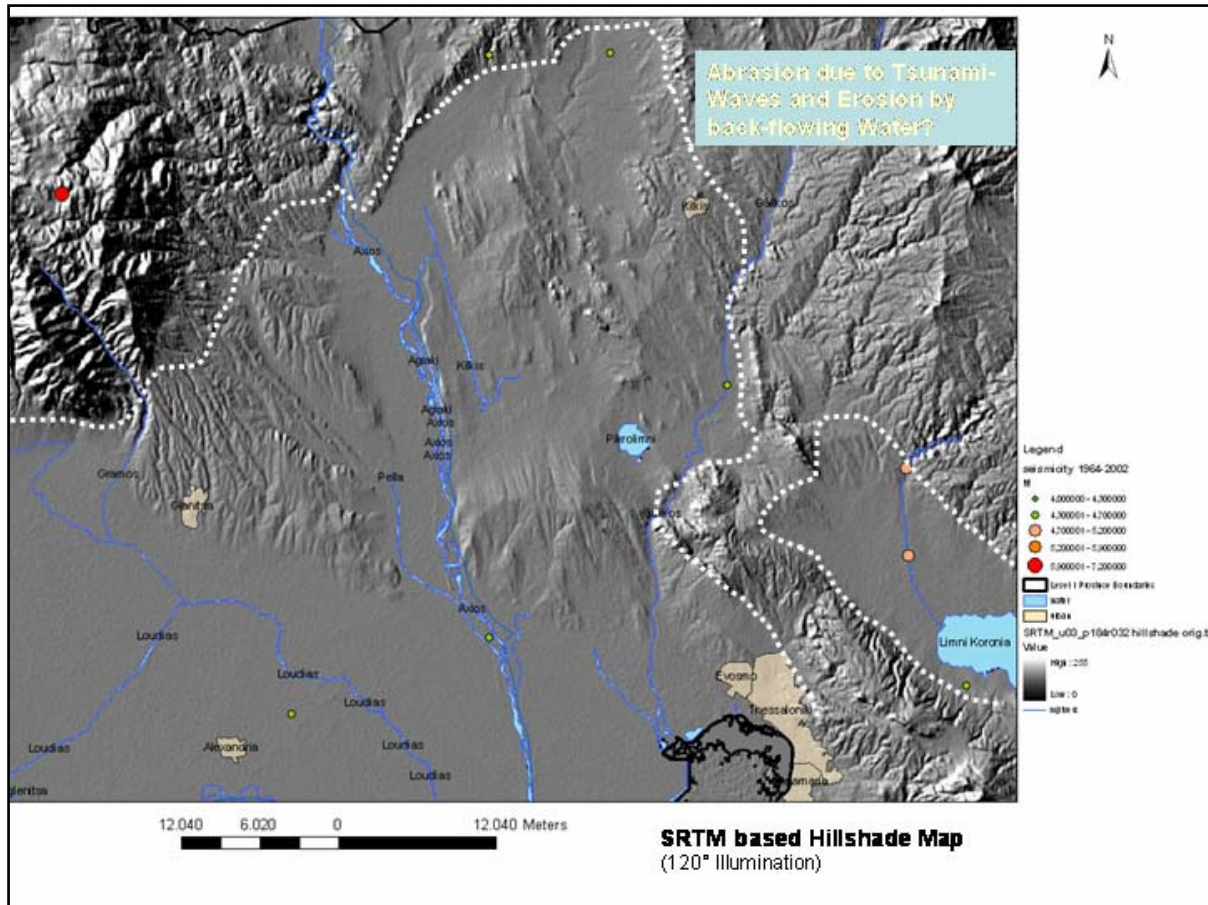


Figure 8 : SRTM based Hillshade map of the northern Thessaloniki area

The dashed line illustrates the area assumed as flooded by probably catastrophic tsunami events according to the geomorphologic properties of the area. The surfaces seem to be “smoothened” by abrasion and erosion. There is a distinct morphologic difference to the surrounding area.

Fig.9 presents the minimum curvature map of the airport area south of Thessaloniki enhancing walls and terraces opened to the sea, obviously related to floods and varying sea levels, including sea level changes caused by earthquakes and aseismic movements (uplift and subsidence).

Digital image processing of LANDSAT ETM data provides information of water streaming and current mechanisms in the Bay of Thessaloniki as indicated in Fig.10. Due to the coastal morphology and shape of the shore line the main stream can be observed at the southern part of the bay near the airport. The shape of the bay influences the intensity of currents focusing the energy especially in the eastern part of the bay.

Thus, LANDSAT ETM imageries contribute to a better understanding of streaming mechanisms that might be of importance for potential tsunami waves and their interactions with the contour of the shore line..

Several case studies of tsunami risk levels are presented in Fig.11.



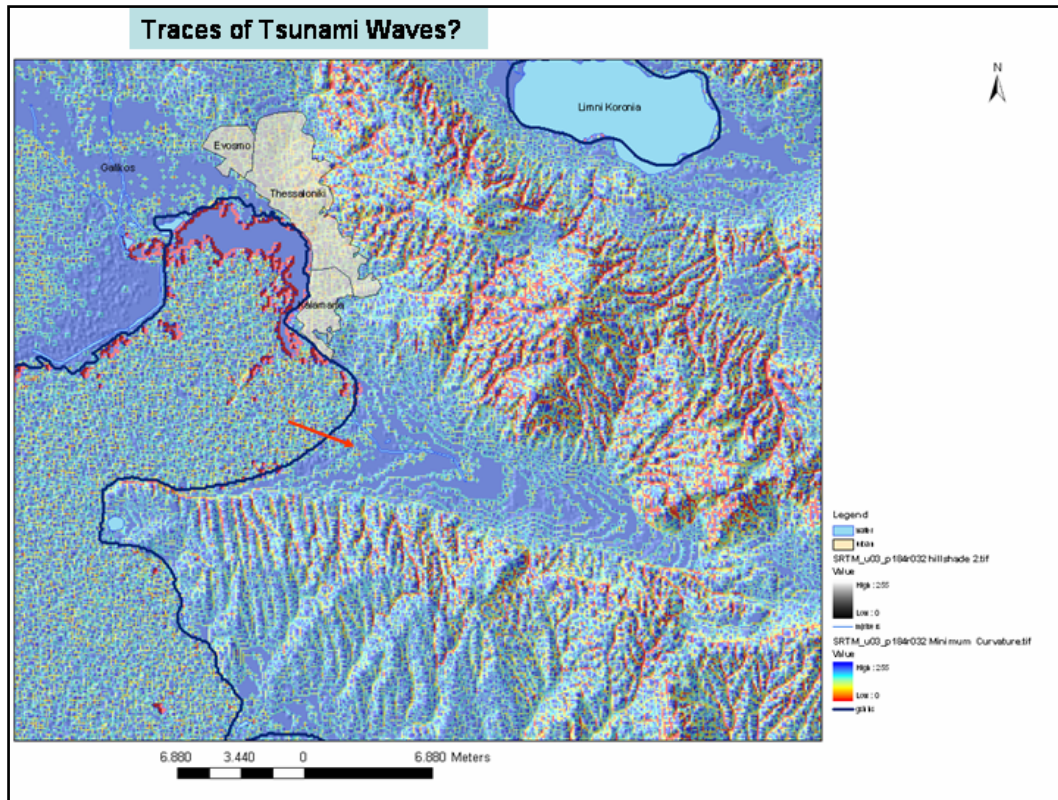


Figure 9: Color coded Minimum Curvature Map based on SRTM DEM of the Bay of Thessaloniki

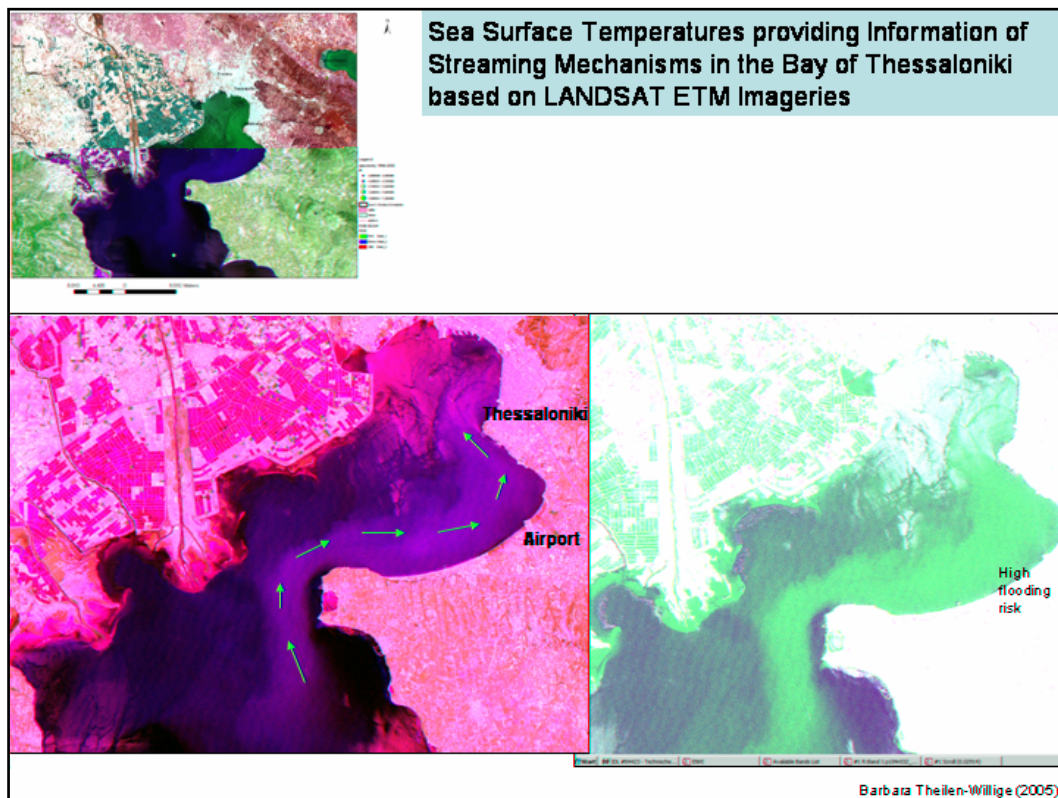
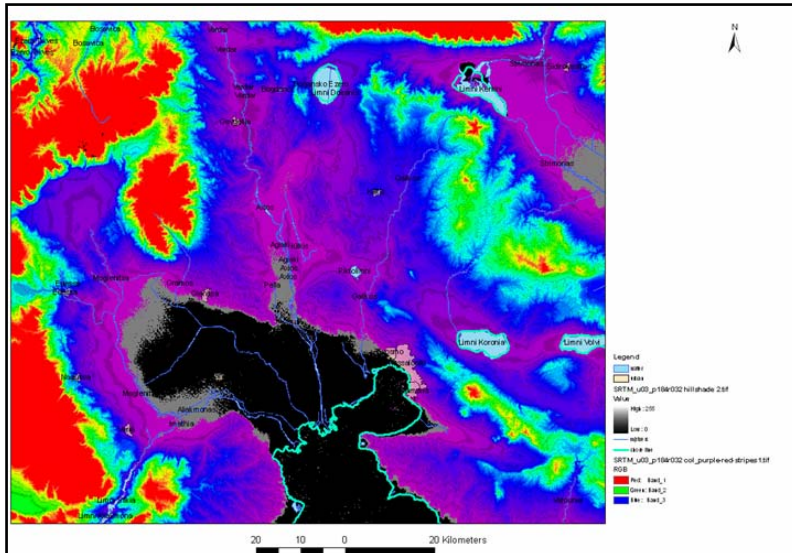
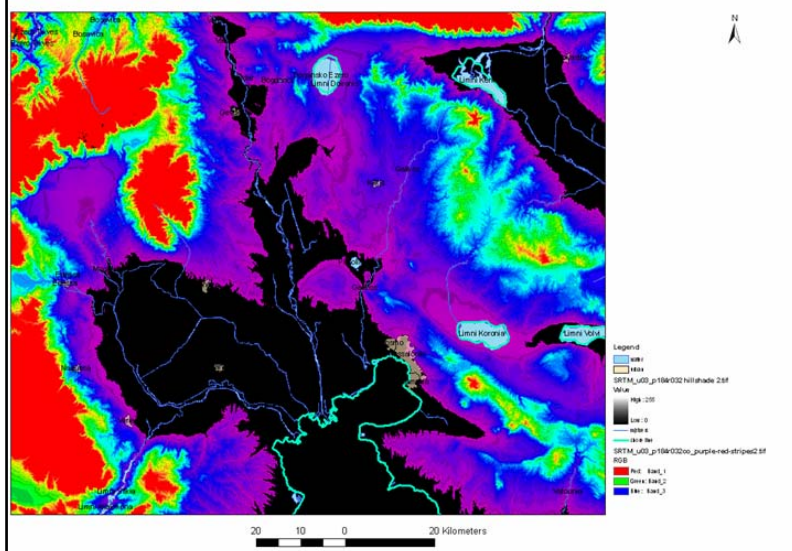


Figure 10: Digital image processing of LANDSAT ETM data for enhancing water currents  
 The Red, Green, Blue - RGB-Principle is reviewed briefly: Three images from the different LANDSAT bands to be used as end-members in a triplet are projected, one image through one primary colour each, i.e. one image is coded in blue, the second in green and the third in red. In this way, each image is given a particular false colour (GUPTA,1991 and 2003).



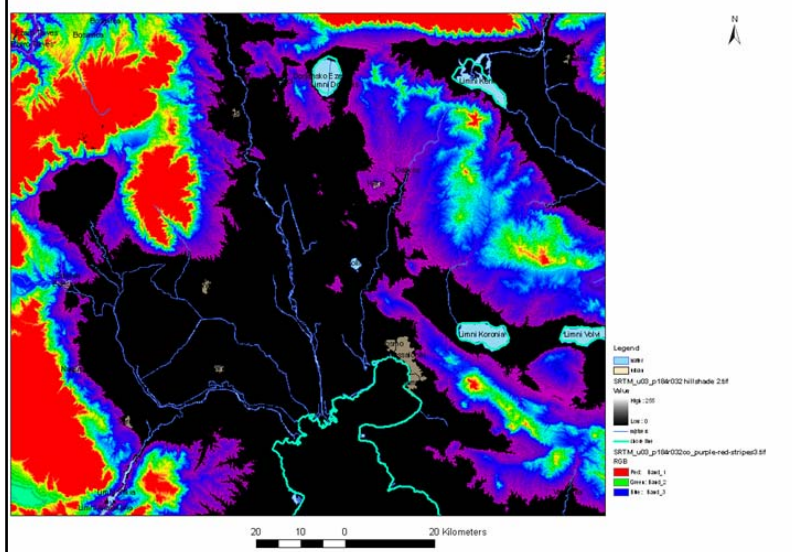
**Catastrophic Tsunami: Case 1**

Barbara Thellen-Willige (2005)



**Catastrophic Tsunami: Case 2**

Barbara Thellen-Willige (2005)



**Catastrophic Tsunami: Case 3**

Barbara Thellen-Willige (2005)

Figure 11: Tsunami risk sites (black colour) in case of different levels of catastrophic tsunami events

Another example of a potential tsunami risk site is shown in the Figures 12 a-c from Northeast Greece. The Bay of Lagos is investigated considering its potential tsunami risk based on SRTM DEM derived morphometric maps.

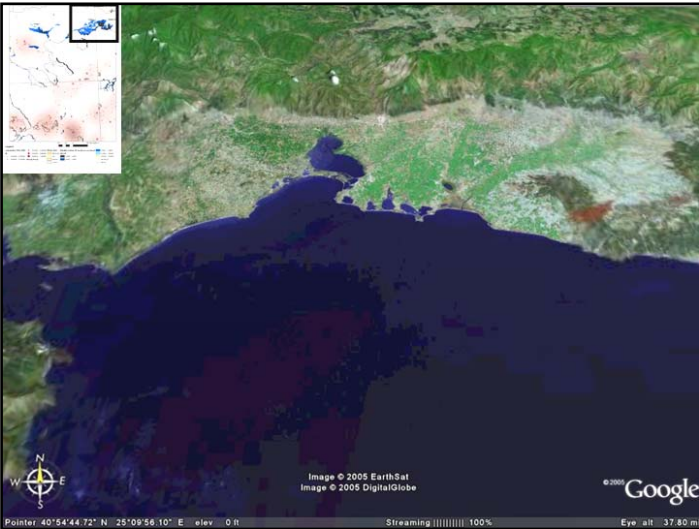


Figure12 a: Test site in NE Greece

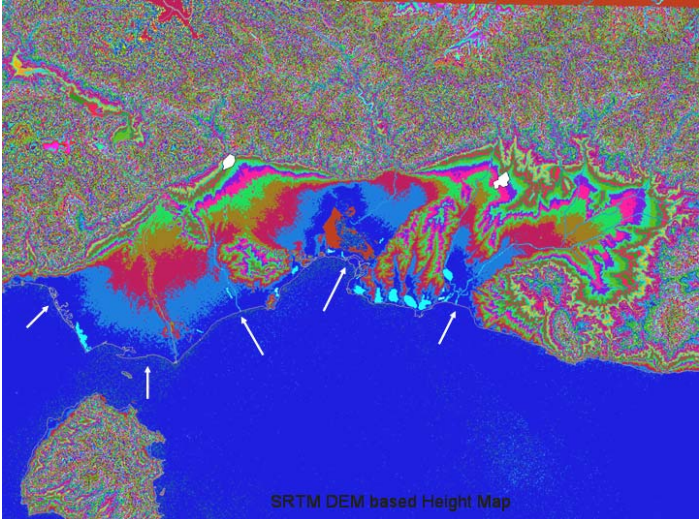


Figure 12 b: Colour coded DEM indicating the potential tsunami risk sites (blue)

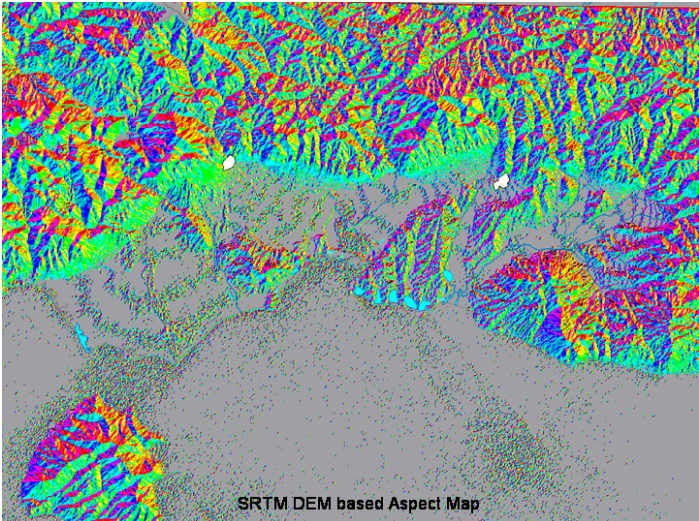


Figure12 c: Aspect map showing the seawards orientation of the slopes near the coast

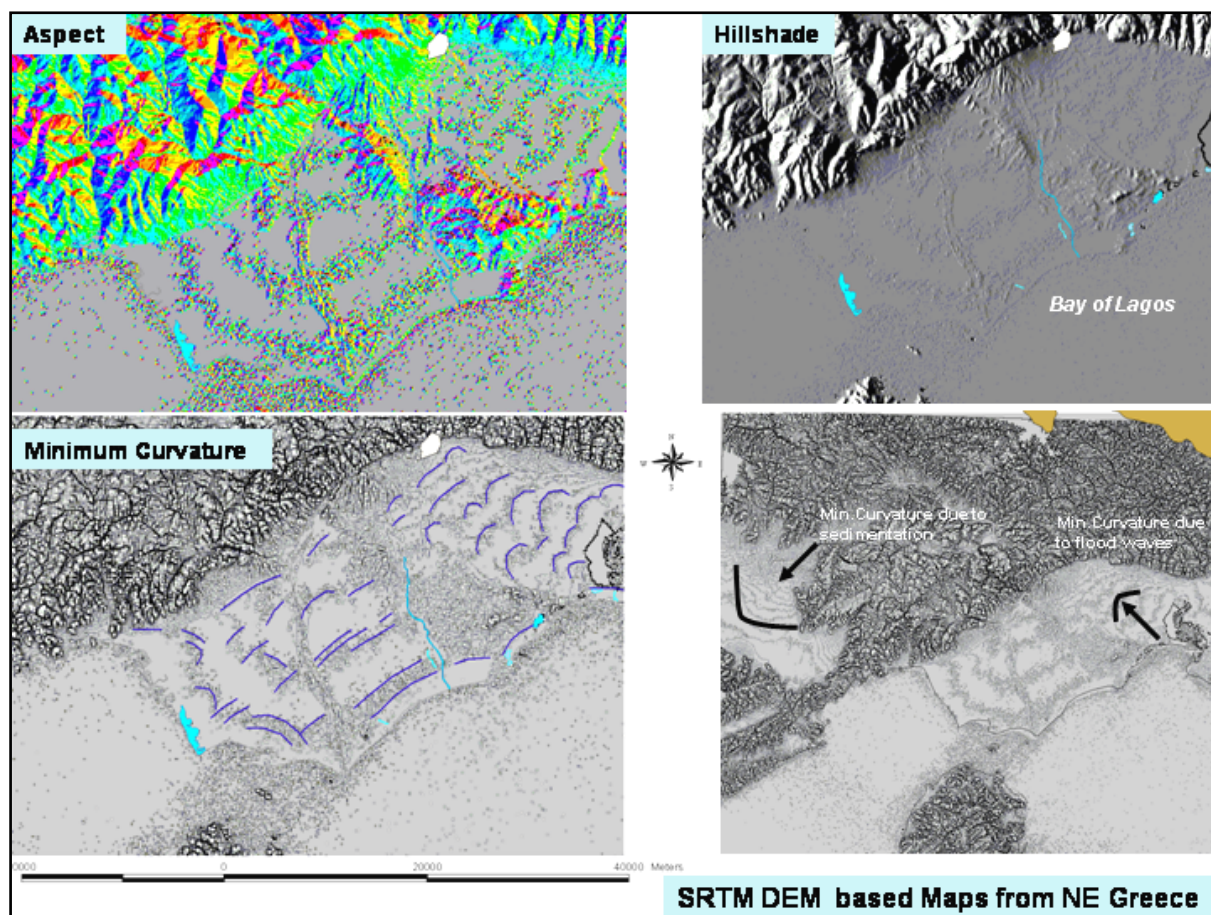


Figure12 d: Evaluation of the morphometric maps  
 By analyzing the morphometric maps it seem to obvious that the subtle geomorphologic features near the coast were formed by flood waves from the sea.

#### 4. CONCLUSIONS

The evaluation of digital processed and enhanced LANDSAT ETM data merged with SRTM derived map products as hillshade, slope gradient, minimum and maximum curvature in a GIS environment can contribute to the detection of traces of past tsunami events and future potential tsunami sites. In sum, several geomorphologic evidences of tsunami events can be found in Greece:

- fan shaped, flat areas near the coast
- irregular lagoons, ponds and lakes
- arc-shaped (seawards opened) small walls, ridges and scarps parallel to the coast
- seawards orientation of the slopes
- fan-shape like arranged drainage pattern.

Considering such tsunami characteristic features and traces several the sites exposed to tsunami risk can be detected in the coastal areas of Greece.

Using Earth observation data it is possible to detect traces of past tsunami events, to compare different tsunami prone areas and to analyse recently affected areas. The interpretation of remote sensing data from ancient tsunami prone areas will help to a better recognition of hazardous sites and, thus, being one basic layer for a tsunami alert system. Remote sensing technology embedded in a GIS information database can be used as a complementary tool for existing tsunami hazard studies offering an independent and complementary approach providing a base for further field research..

By providing up-to-date information and integrating the results with traditional tsunami hazard assessment studies, coherent and reliable information is provided. By these means the information can be used for early-warning, for decision support in disaster management. However, a lot of work still needs to be done in order to take the appropriate actions for the mitigation of the tsunami catastrophic effects on Circum Mediterranean countries.

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