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# Remote Sensing and GIS Contribution to Tsunami Risk Sites Detection in Southern Italy

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**Keywords:** remote sensing, tsunami risk site detection, GIS, SRTM based maps products, terrain analysis

**Summary:** Based on LANDSAT ETM and Digital Elevation Model (DEM) data derived by the Shuttle Radar Topography Mission (SRTM) of the coastal areas of Southern Italy 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 areas 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 morphological traces of waves as curvilinear scarps open to the sea-side are clearly visible.

**Kurzfassung:** *Fernerkundung und GIS Methoden bei der Erfassung Tsunami gefährdeter Gebiete in Süd-Italien.* LANDSAT ETM- und Digitale Höhendaten auf der Basis der Shuttle Radar Topography Mission (SRTM) von Süd-Italien wurden mit Methoden der digitalen Bildverarbeitung aufbereitet und zusammen mit seismotektonischen Daten in ein Geografisches Informationssystem (GIS) integriert. Die Auswertung der verschiedenen Bild- und Kartenprodukte auf der Basis der SRTM-DEM Daten wie simulierte Reliefdarstellungen, Hangneigungskarten, Karten der minimalen und maximalen Geländewölbungen liefern in den Küstenbereichen Süd-Italiens Hinweise auf charakteristische, morphologische Spuren, die wahrscheinlich auf die Einwirkung früherer Tsunami-Ereignisse zurückgeführt werden können. Das Bild- und Kartenmaterial ermöglicht eine Übersicht über potentiell Tsunami gefährdete Küstenbereiche in Süd-Italien.

## 1 Introduction

This study is considering tsunami risk mapping for 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 in Sumatra and where historical records of tsunamis are available and reliable. A tsunami hazard map of such an area that predicts the 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 tsunami waves, and in addition for the generation of tsunami waves produced in the near-shore zone that could have catastrophic effects on a local scale (BOSCHI et al. 2005). 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

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probable tsunamigenic sea bottom structures, there are numerous source areas which may be considered responsible for severe tsunami waves. One of the important source areas of tsunamis in the Mediterranean are the normal fault zones of Southern Italy and the subduction in the Tyrrhenian sea. During the last centuries the largest tsunamigenic earthquakes that hit the Italian peninsula occurred in Calabria and Sicily (TINTI & PIATANESI 2001). The tsunamis caused severe damage and flooded low lands in many segments of the coast. The Calabrian arc and eastern Sicily are currently affected by large earthquakes and by an intense volcanic activity. The main regional feature in this area is given by a prominent normal fault belt that runs more or less continuously for a total length of about 370 km along the inner side of the Calabrian arc, extending through the Strait of Messina along the Ionian coast of Sicily. The different fault segments are responsible for the large earthquakes that have occurred in this region as the seismic sequences of 1783 in Southern Calabria and of 1693 in the Eastern Sicily, and the 1905 (Monteleone) and 1908 (Messina) earthquakes. The most recent and well known tsunami occurred during the 1908 Messina earthquake that has been related to a rupture along the west facing Reggio fault that partially extends off-shore south of Reggio Calabria. This event was characterized by waves that reached the maximum heights of 13 meters in the Calabrian side of the Straits of Messina, inundating large portions of the eastern Sicily coast (MONACO & TORTORCI 2005). Geomorphological research reveals that the Apulian coast has been affected by the destructive action of tsunamis several times in history. Along low sloping rocky coasts of southern Apulia large boulders accumulations have been found. Boulders are arranged either isolated, in small groups or rows composed of a few imbricated elements. The collated data suggest that two tsunamis may have recently struck the Adriatic coast of southern Apulia. The first possibly took place on the Dalmatian coast as a result of the earthquake on April, 6, 1667 which destroyed Ragusa (Dubrovnik). The second tsunami event is connected to the strong earthquake which hit southern Apulia on February, 20, 1743 (MASTRONUZZI & SANSO 2005).

## 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 Southern Italy. 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 and data of historical tsunami events (Fig. 1a). LANDSAT ETM and DEM data were used for generating an image based GIS and combined with ESRI data and other thematic maps, see Fig.1b. These include an inventory of seismic records, large-scale geomorphologic analysis, digital elevation data and suitable 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 Southern Italy is proposed. There are typical geomorphologic features found in regions 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

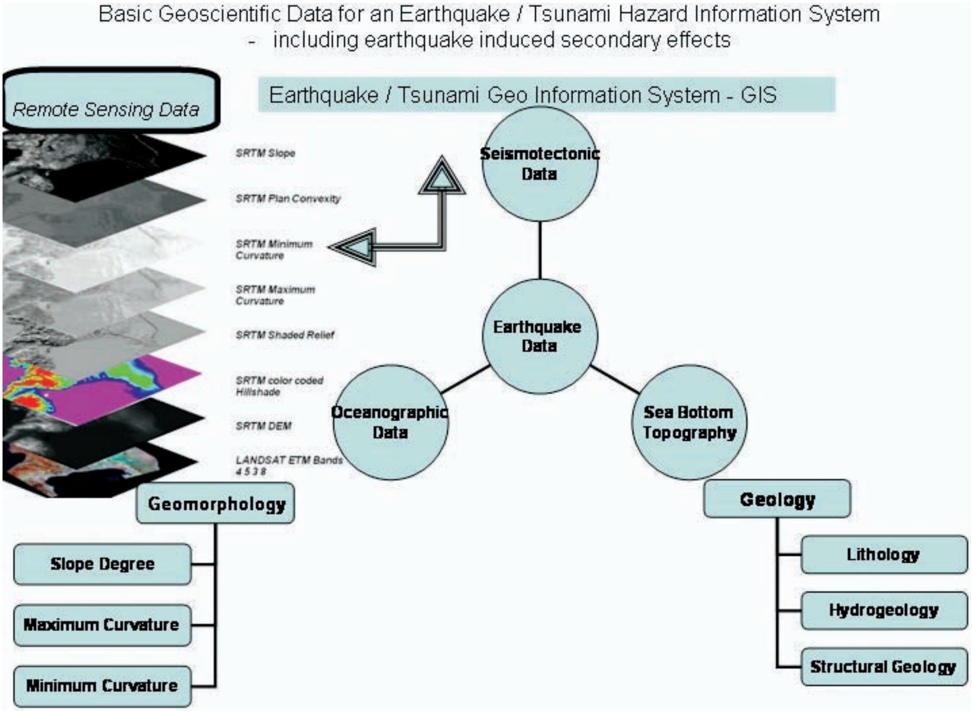

**Fig. 1a:** Main components of a Tsunami Hazard Information System.

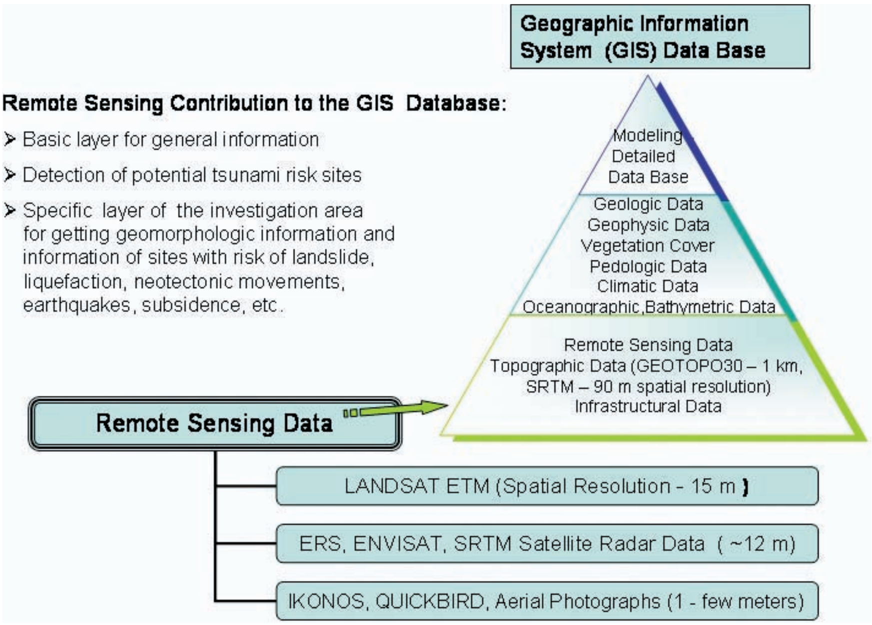

**Fig. 1b:** Remote Sensing contribution to a Tsunami Hazard Information System.

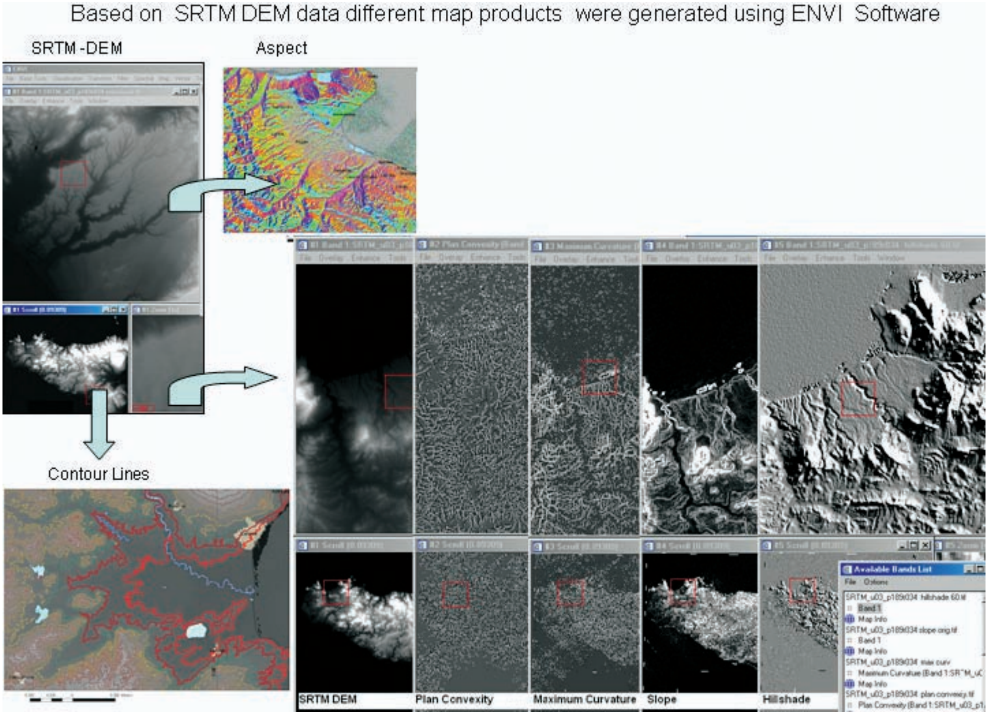

**Fig. 2:** SRTM based maps.

resolution) were used as base maps. One of the limitations of the models and processing, however, was the scale of analysis implied by the SRTM – DEM resolution of 90 m. 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, for example to find the best suited contrast stretching parameters. Other geodata as provided by ESRI Web 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).

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 and 3D-Analyst and ArcGIS 9.0 of ESRI (Fig. 3). 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/).

## 3 Evaluation of SRTM and LANDSAT ETM Data from Southern Italy

Potential risk sites for hazardous tsunami waves were identified by analyzing areas in Southern Italy showing heights below 20 m above sea level. The areas were studied then more detailed. As first example the Bay of Manfredonia is presented. Fig. 4–8 show the results of SRTM data based map products.

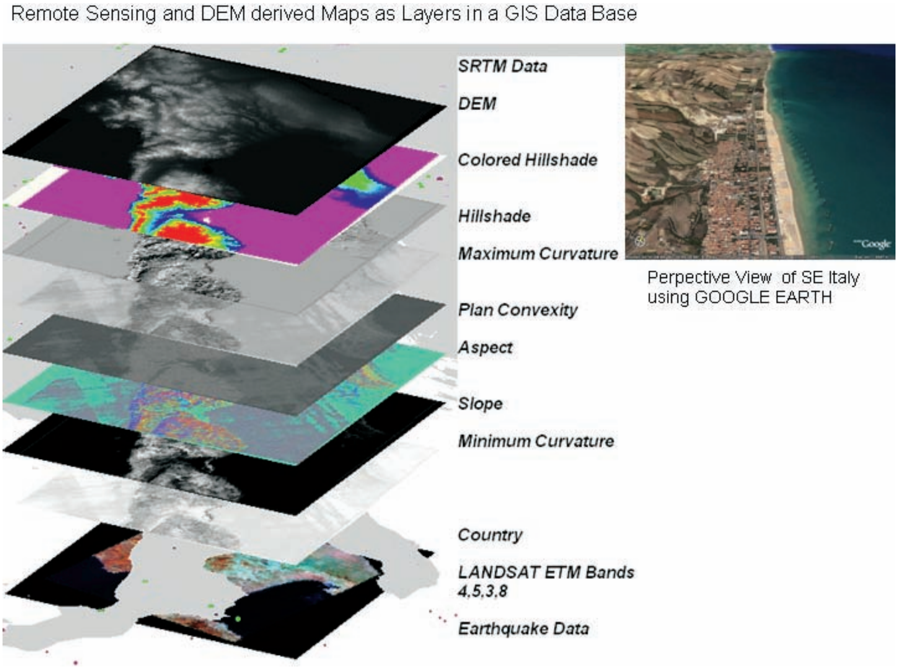

**Fig. 3:** Layers in a GIS.

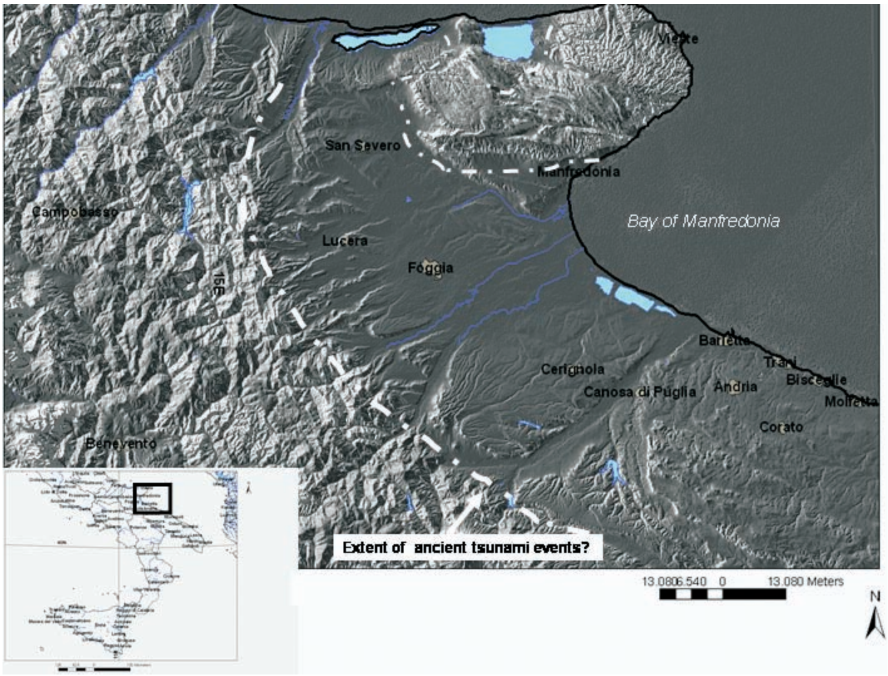

**Fig. 4:** SRTM based shaded relief and slope map of the Bay of Manfredonia area. The dashed line illustrates the area estimated as flooded by probably catastrophic tsunami events according to the geomorphologic properties of the area.

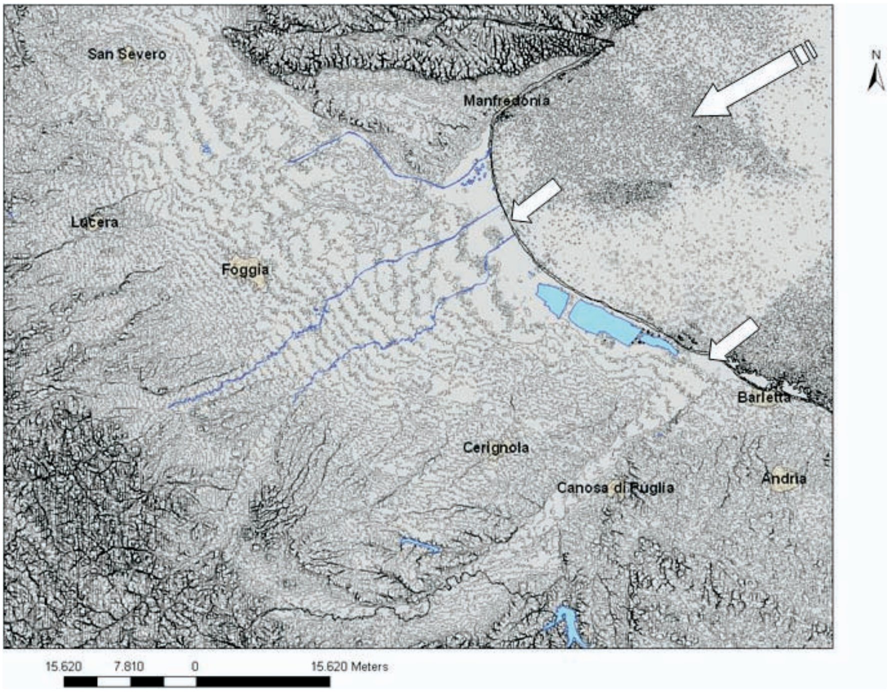

**Fig. 5:** SRTM based Minimum Curvature map of the Manfredonia Bay. The map shows traces of walls and ridges related to flood waves as their arc shaped contours are opened to the sea.

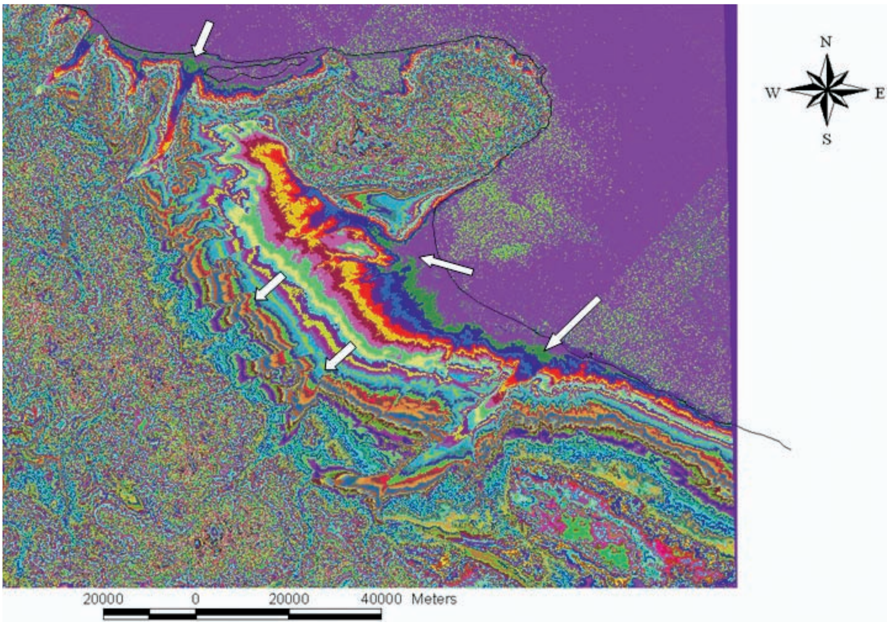

**Fig. 6:** Color coded SRTM DEM of the Bay of Manfredonia. Tsunami waves obviously ‘‘intruded’’ along existing river beds. Therefore run up and inundation distance of the floods along riverbeds was probably more extended than in the adjacent areas.

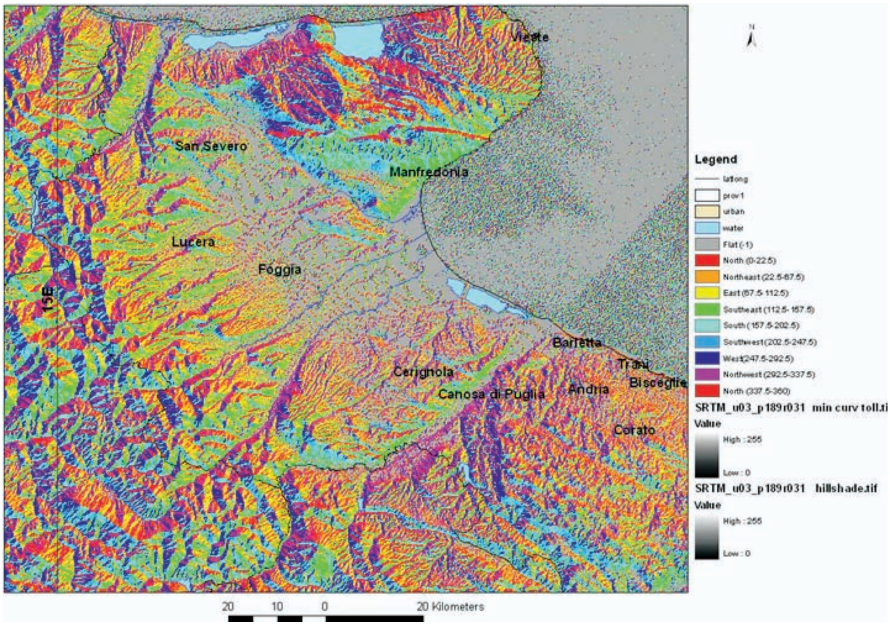

**Fig. 7:** Aspect Map merged with the hillshade map based on SRTM data from the Bay of Manfredonia illustrating the seawards orientation of the fan-shaped terrain.

**Fig. 8:** Perspective 3D view based on LANDSAT ETM imageries of the Bay of Manfredonia using Google Earth.

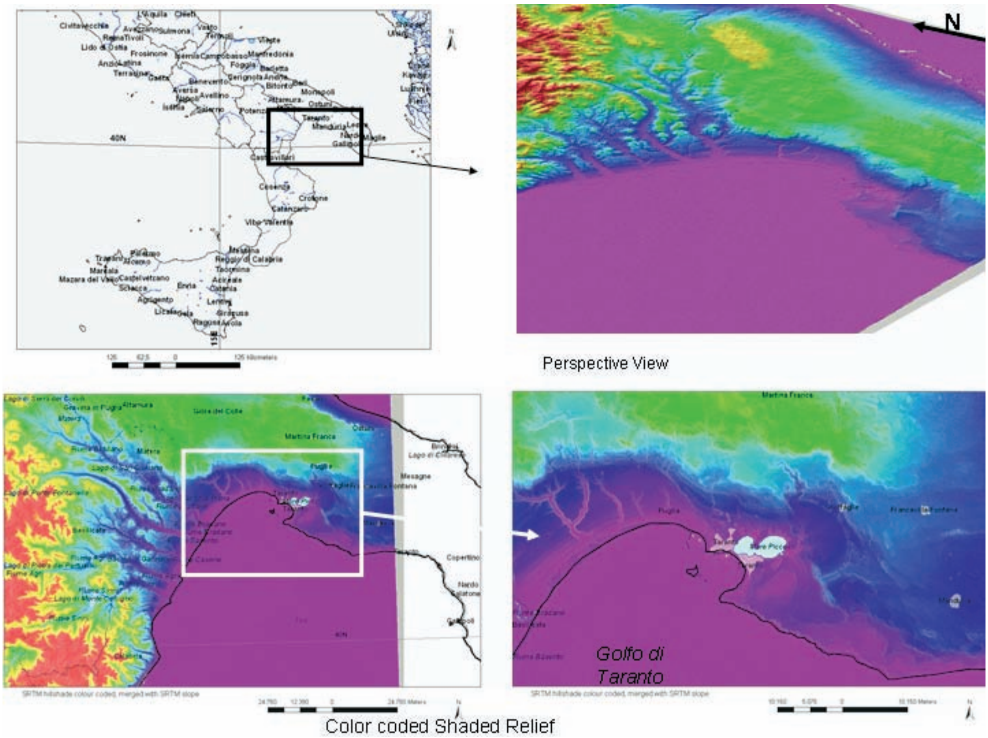

**Fig. 9:** Color coded Shaded Relief (SRTM) imageries of the Bay of Taranto showing areas prone to flooding risk in violet colors.

Provided that the morphologic properties of the Manfredonia bay are related to tsunami events it can be assumed that the fan-shaped morphology is the result of abrasion due to catastrophic tsunamis. The tsunami floods obviously propagated from east. According to the characteristic morphologic properties visible on the hillshade, the aspect, minimum curvature and slope map the run-up heights along the east-facing, flat shorelines are estimated at least of about +/– 20 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 Manfredonia.

Potential traces of flood waves as parallel, arc-shaped walls can be inferred by minimum curvature maps as presented in Fig. 5 as well as by color coding the DEM map (Fig. 6).

Potential traces of run-up can be detected considering the parallel curvatures, especially in broader river beds. Estuary plains and broader river beds were probably prone more to tsunami wave propagation than the higher environment. River mouths represented a large entrance for tsunami waves. This assumption is confirmed by the color coded DEM (Fig. 6). The map clearly shows the different levels formed by floods. The aspect map illustrates the seawards orientation of the terrain and enhances as well smaller walls, ridges and terraces with seawards opened, arc-shaped contours (Fig. 7). Fig. 8 presents a perspective view based on a LANDSAT ETM imagery combined with DEM data (Google Earth) to demonstrate that the SRTM based maps provide information of the terrain that are not visible on LANDSAT imageries.

The next example illustrates the potential of SRTM and LANDSAT data for enhancing

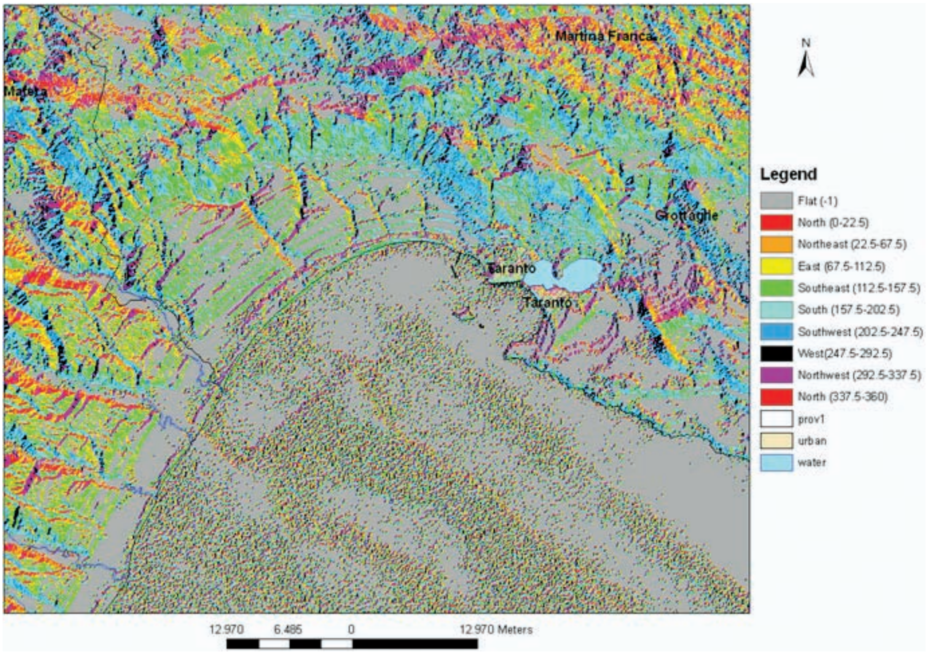

**Fig. 10:** SRTM based Aspect Map of the Eastern Bay of Taranto.

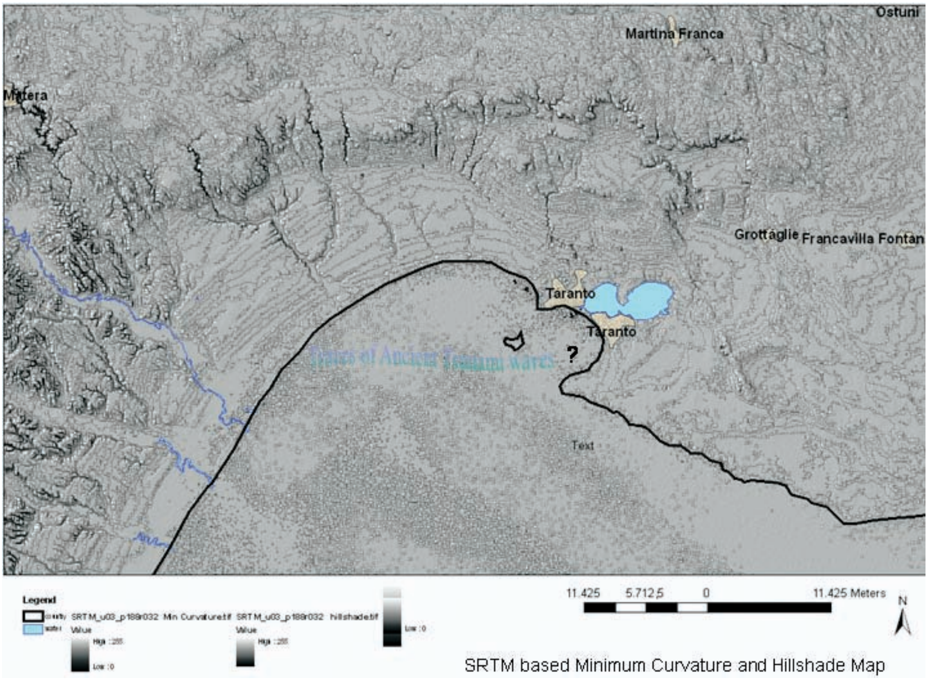

**Fig. 11:** Traces of flood waves in the Eastern Bay of Taranto on the SRTM based Minimum Curvature Map. The walls can be identified as well on oblique 3D views of LANDSAT ETM imageries of this area provided by Google Earth.

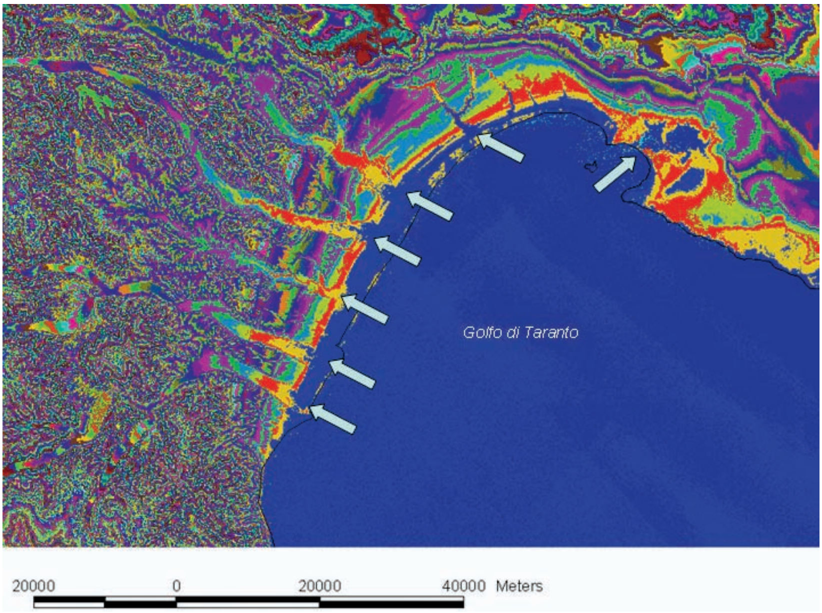

**Fig. 12a:** Color coded SRTM DEM from the Taranto Bay. The arrows indicate river beds serving as main entrance for floods. The shape of the bay must have influenced the intensity of tsunami waves focusing the energy especially in the central part of the bay.

**Fig. 12b:** River bed of Fiume Agri with potential flooding risk during a stronger tsunami event.

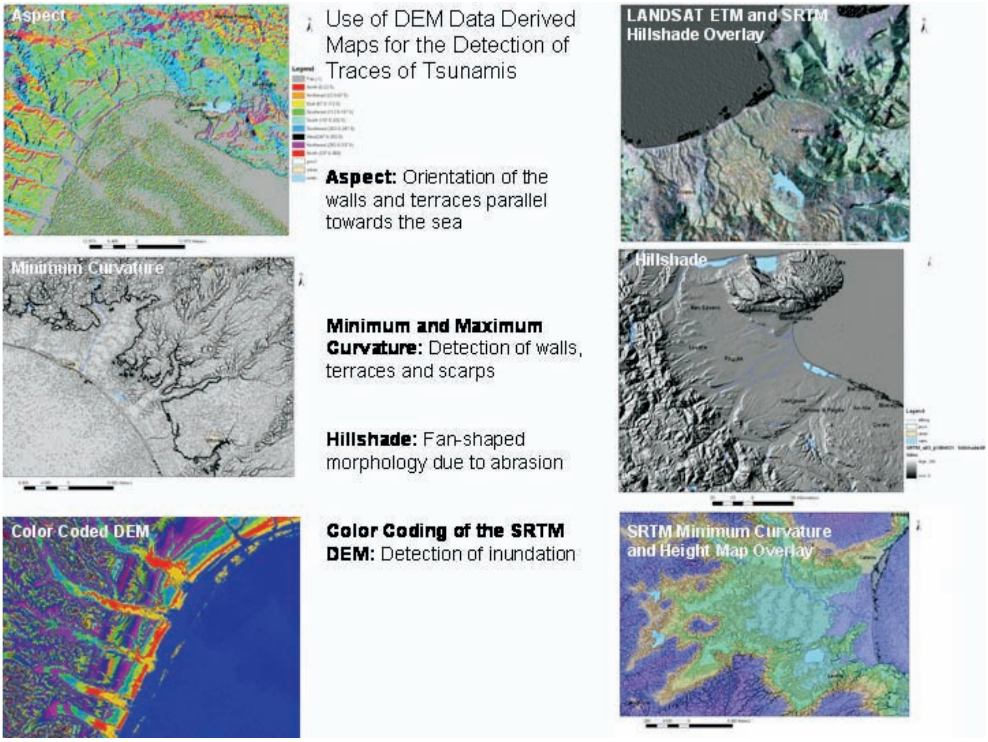

**Fig. 13:** Traces of tsunami waves on SRTM derived maps.

tsunami risk sites in the Bay of Taranto. Run-up values of approximately 20 km depending on coastal exposure can be assumed based on the digitally processed SRTM data. Fig. 9 shows color coded SRTM hillshade imageries providing an overview of the geomorphologic setting of the Bay of Taranto.

Fig. 10 presents the SRTM based aspect map of the area and Fig. 11 the minimum curvature map 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).

## 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 Southern Italy:

- 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.

Some of these properties are summarized in Fig. 13.

Considering such tsunami characteristic features and traces several the sites exposed to tsunami risk can be detected in Southern Italy. 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.

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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