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An assessment of flood hazard and flood risk due to storm-surge along the Black Sea coast of Bulgaria

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INTRODUCTION

Flood hazard mapping and damage assessment along the Black Sea coast of Bulgaria have been done within the project IncREO. The storm surge level values for two historic situations with stormy conditions along the Bulgarian coastline, in 1979 and 2012, were obtained using the numerical storm-surge model developed by Meteo-France and implemented for the Black Sea area. The storm surge model was forced by the downscaled ERA-Interim historical reanalyses of 10 m wind and mean sea level pressure. The wave forcing also contributes to the total rise in water level. The statistical approach has been used to simulate the potential water levels due to storm surges and waves. The maximum of the simulated storm-surge levels is used to develop a simplified method to approximate significant wave heights and wave transformation along the coastline and in shallow water. Finally the obtained water levels have been used for calculating damages. The spatial extent and depth of flooding is modelled using the software FloodArea HPC based on a digital elevation model with a spatial resolution of 8 m. It is provided by the IncREO project end-user, the Directorate of Water management in the Black sea region (BDBS), Ministry of Environment and Waters of Bulgaria. Examples of flood hazard and risk maps are presented for most severe storm occurred in 1979 over the Bulgarian coasline for the last 40 years and can be used by BDBS for the implementation of the EU Flood Directive.

METHODOLOGY

Storm surge modeling

The simulations along the coastline of Bulgaria are based on estimated maximum storm surge levels for two historical events in 1979 and 2012. The data was supplied by the National Institute of Meteorology and Hydrology of Bulgaria (NIMH). The storm surge model used by the NIMH is the storm-surge model of METEO FRANCE (Daniel et al 2001, Mungov and Daniel 2000). The model is depth-integrated (two dimensional storm-surge model, tides are not considered due to the fact, that they are minor in Black Sea region having an amplitude less than 9 cm).
The model grid for the Black Sea is regular with a spatial resolution of 2'. The model domain is covering the entire Black Sea. The bottom friction coefficient over the shelf is 0.0015 and over the liquid bottom is 0.000015. The wind drag coefficient is according to the Smith and Banke formulation (Mungov et al 2001). The calculations by the model start several days before the storm with zero initial conditions (zero sea level elevation and currents).

Storm surge model input

- Bathymetry of the Black Sea (2' grid resolution, provided by the Military Hydrographic Service of Bulgaria)
- Downscaled fields of mean sea level pressure
- Downscaled wind fields

Storm surge model output quantities

- The coastal profile of the maximum storm surge elevations along the Bulgarian Black Sea coast, time series of sea level elevations

NIMH runs the storm surge model two times, first with ERA-Interim wind and atmospheric pressure forcing (coarse spatial grid resolution of about 79 km) and the second time with the downscaled (high resolution) atmospheric forcing with high resolution of 9 km latitude/longitude grid (Kortcheva et al, 2014, Bresson et al 2014).
Figure 1 presents the time series of sea level elevations due to storm-surge at tide gauge location Irakli obtained from simulations with storm surge model forced by ERA-Interim reanalysis and downscaled reanalysis data and the measurements at the tide gauge. The storm-surges hindcast was improved when the high-resolution (downscaled) atmospheric forcing was used for the storm surge model simulations of historical storm events.

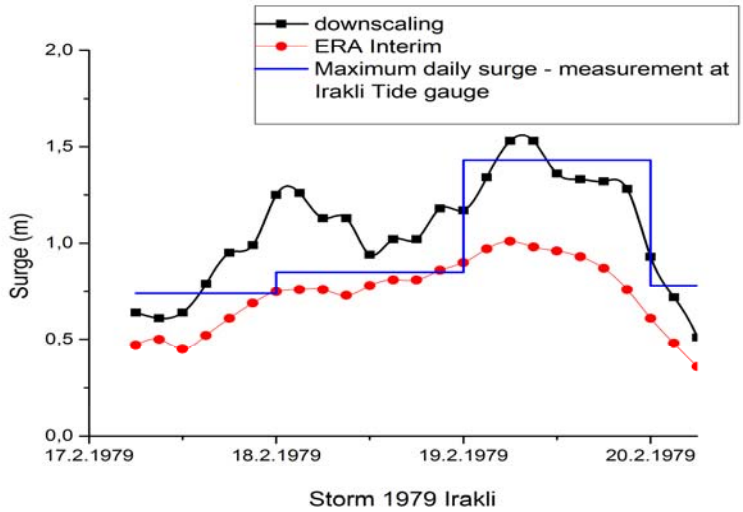

Figure 1: Time series of sea level elevations due to storm-surge in February 1979 at tide gauge location Irakli obtained from simulations with storm-surge model forced by ERA-Interim reanalysis (in red) and downscaled reanalysis data (in black). Source: NIMH

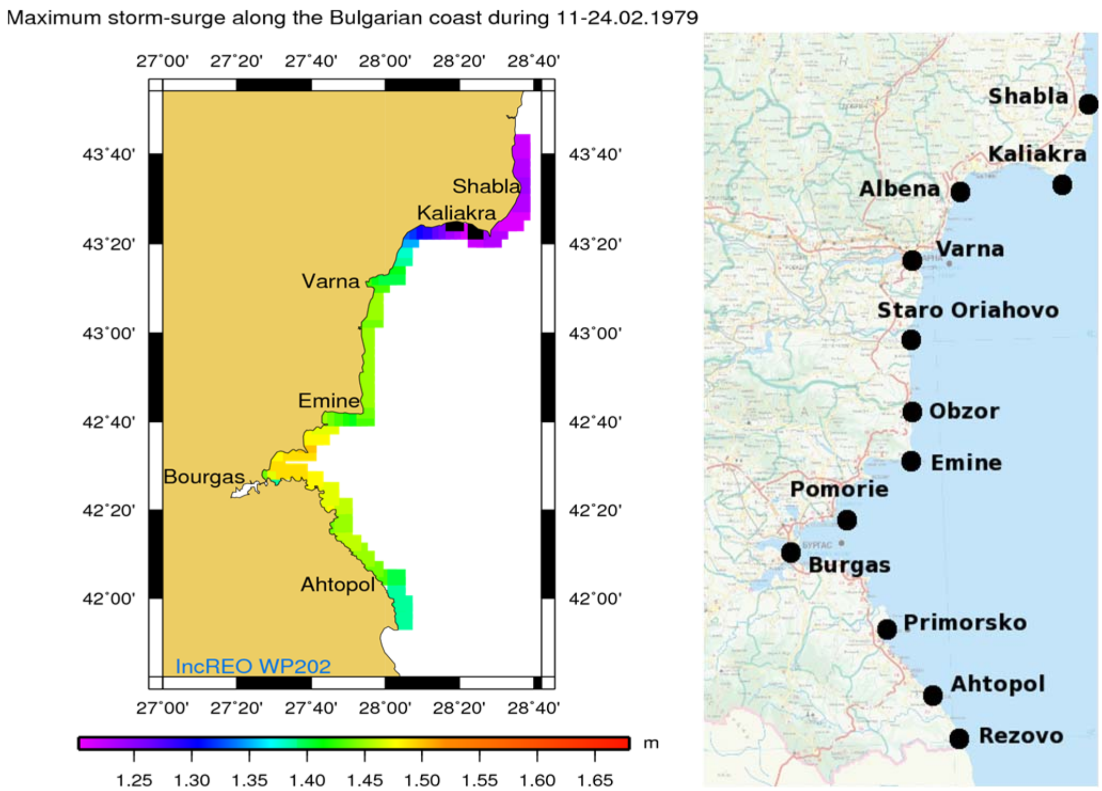

Figure 2: Maximum storm-surges along the Bulgarian coast of the Black Sea for the storm event in 1979. Source: NIMH.

Figure 2 shows the maximum estimated storm-surge water level by the storm-surge model forced by the downscaled ERA-Interim historical reanalyses of 10 m wind and mean sea level pressure.

Wave transformation in shallow water

The wave activity contributes to the total water level height. To predict more accurately the potential sea level it is necessary to take into consideration also the wave contribution to the total sea level. A statistical approach has been used to simulate the potential water levels due to storm surges and waves. With a first assumption significant wave heights offshore are derivated from the estimated maximum storm surge levels for two historical events in 1979 and 2012. The significant wave height describes a statistical parameter for the distribution of ocean waves. Therefore the given data are considered as the arithmetic mean for the significant wave height in meters. For the modeling a wave height of 1 from 100 waves (Raylight Distribution) was specified to conclude the wave heights for different storm surge levels. Figure 3 shows significant wave heights for different occurrence intervals of single waves and four different storm surge levels (increasing from blue to orange).
Additionally the transformation of waves (wave set up and wave run up), caused by decreasing water depth, is calculated for the coastal areas with a simplified approach. The heights of the breaking waves along the coastline are approximated to the assumption that the importance of wave length and velocity is less important for the wave height than the water depth in shallow areas. The characteristic of wave transformation is based on this assumption. The transformation of different wave heights with decreasing water depth is illustrated in Figure 4.

The information about the sea floor elevations for the coastline of Bulgaria is taken from the World digital elevation model (ETOPO5), supplied by the European Environmental Agency. The ETOPO5 is generated from a digital data base of land and sea- floor elevations on a 5-minute latitude/longitude grid (http://www.eea.europa.eu/data-and-maps/data/world-digital-elevation-model-etopo5, 08.07.2014).

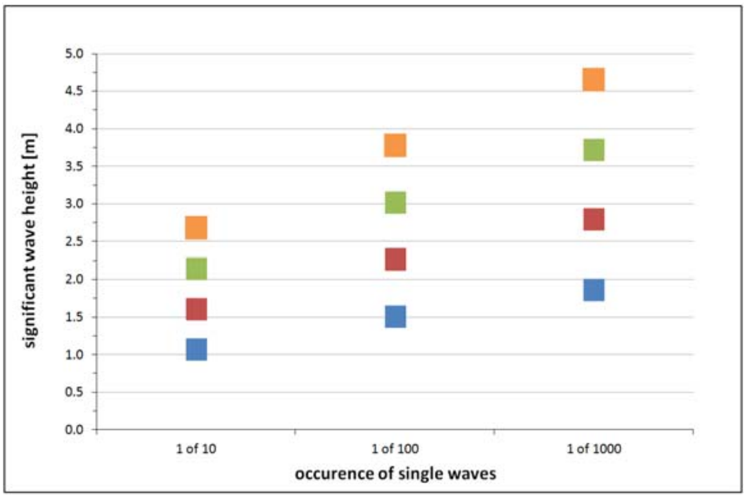

Figure 3: Significant wave heights for four different storm surge levels of 1 m (blue), 1.5 m (red), 2 m (green) and 2.5 m (orange). Source: geomer GmbH.

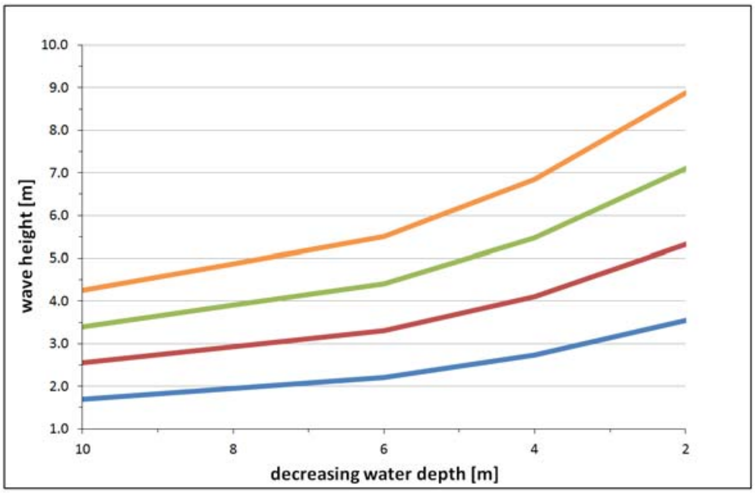

Figure 4: Exemplary wave transformation in shallow water for four different wave heights of a storm surge level of 1 m (blue), 1.5 m (red), 2 m (green) and 2.5 m (orange). Source: geomer GmbH.

RESULTS

Modeling of flooded areas and inundation depths

The extent and inundation depth of the water levels along the coastline is simulated with the software FloodArea HPC. The wave heights from the described simplified method and a Digital Elevation Model from the Ministry of Environment with 8x8 m resolution are used as input data for the modeling.
Figure 5 shows the example of flood hazard and damage map for the coastal area near the town of Pomorie and the schematic map adressing the end-user. The red lines at the end-user maps indicate coastal areas being flooded at least once in the last hundred years. This was elaborated using historical data.

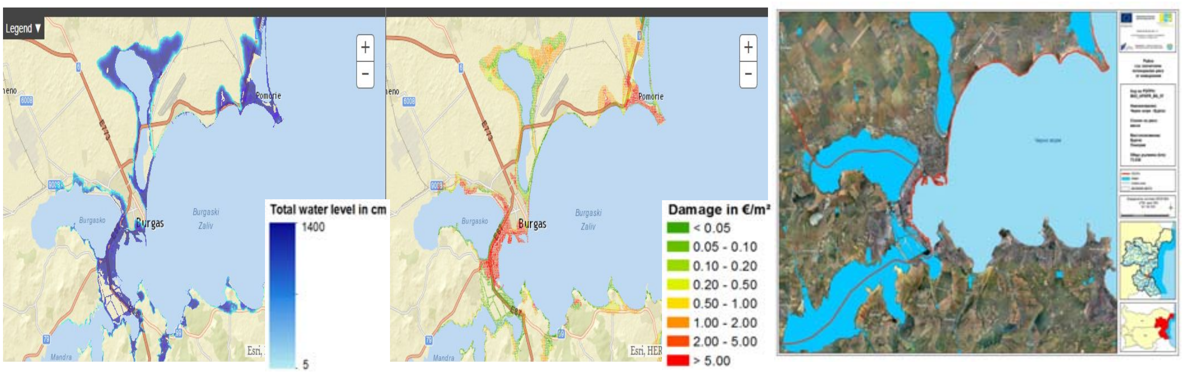

Figure 5 : Flood hazard map (left) and risk map (middle) for the Bulgarian coast of the Black sea (area near the town of Pomorie) and schematic map of end-user (right). Source: geomer GmbH & BDBS.

There are lots of matching between the historical flood map and the simulated water heights. The IncREO maps provide not only the flood hazard including also depth information but also information about the potential damages in case of flooding due to wind waves and storm-surges.

Damage calculation

Following both simulations the potential damages were calculated. For a damage calculation the hazard information is needed as intensity, assets data and specific damage functions. The intensity information is available as water level in cm from the preceding simulation. The assets data is based on the Basic European Assets Map (BEAM). BEAM has been developed to estimate, evaluate and compare real and potential damages caused by natural disasters all across Europe, focussing both on European and national studies, which results in a significant advantage in cross border areas. BEAM displays assets in monetary values per area unit (€/m²). The complete asset information is composed of different layers, as within a damage assessment calculation each type of asset needs to be calculated applying a different damage function. BEAM has been designed to be used all over Europe. As it is based mainly on CORINE (land cover) and EUROSTAT (statistics) data it can be applied wherever these or similar data sets are accessible.

Figure 6: Example of BEAM layer for the coastline of Bulgaria. BEAM contains asset values for buildings, household, vehicles, livestock, both net asset values and stock in trade values of agriculture, industry and service and trade, and more. Source: geomer GmbH.

Finally specific flood damage functions are used to calculate the damages at different water levels for the BEAM asset types: residential buildings, household, vehicles, livestock, grasslands, forest, roads, both net asset values and stock in trade values of agriculture, industry and service and trade. Damage functions describe the relation between the intensity and the maximal damage from zero to one hundred percent. As illustrated in Figure 7 the damage grade of an asset depends on the intensity of the specific hazard and on the type of asset. For example a building of clay material will suffer more damage than a reinforced concrete building at the same water level. Figure 8 compares the flood simulation (left), the damage calculation values (middle) and the BEAM data (right) the calculation is based on.

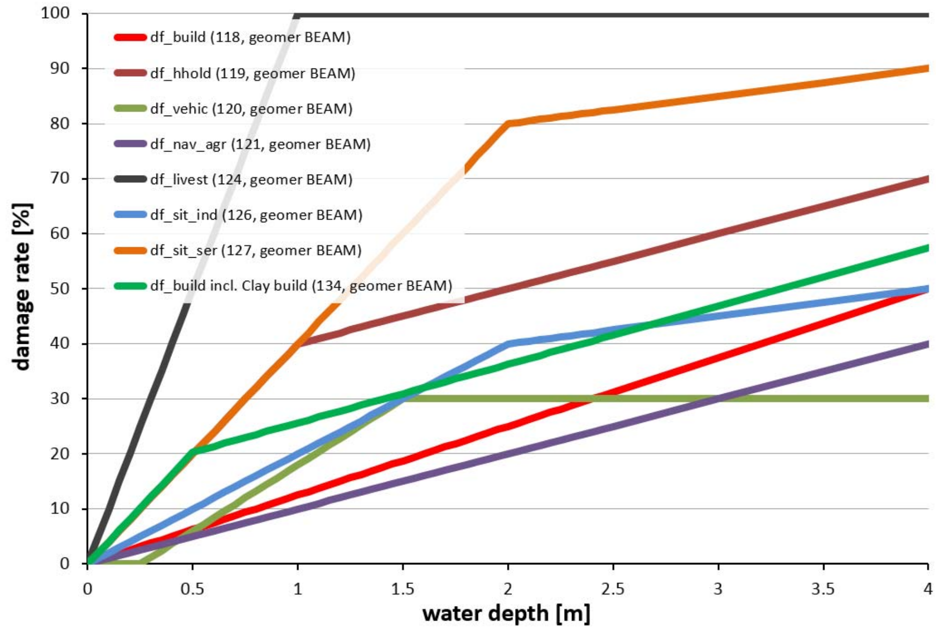

Figure 7: Flood damage functions for BEAM assets. Source: geomer GmbH.

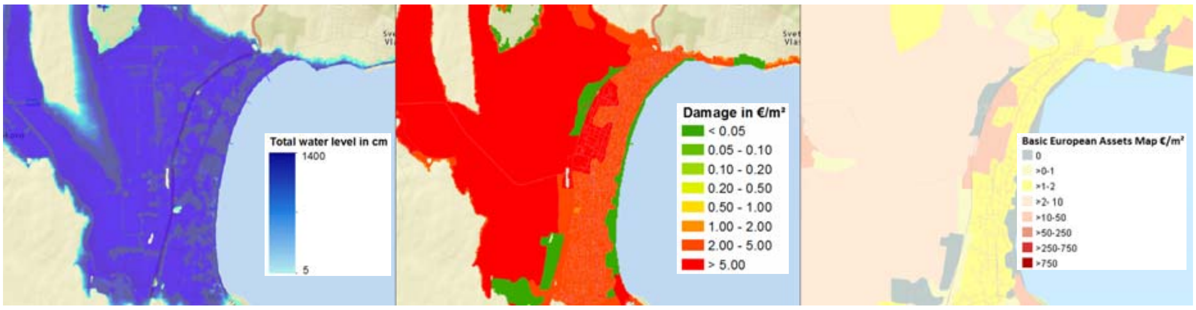

Figure 8: Comparison of flood simulation, damage values and BEAM assets. Source: geomer GmbH.

CONCLUSIONS

The IncREO maps provide detailed visualization of the expected water level and potential damages in case of flooding due to wind waves and storm-surges along the Bulgarian coast of the Black Sea. These maps facilitate the collection of data and information on coastal flood hazards and risks, little studied and mapped until now in Bulgaria. The flood damage assessment methodology is useful for BDBS and could be used in the performance of activities related to drafting the Flood Risk Management Plan for the Black Sea basin region in accordance with the implementation of the EU Flood Directive 2007/60/EC.

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