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Impact of DEM source and resolution on topographic seismic amplification

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ABSTRACT

The impact of topographic attributes on the uneven distribution of seismic response and associated devastation has frequently been observed and documented during seismic events, but has rarely been investigated at a regional scale. Existing numerical and experimental techniques applied to explore the impact of topographic attributes in the aggravation of seismic response, have been limited to isolated and/or synthetic hills and ridges. Predicting the realistic regional impact of topographic seismic response is strongly dependent on the resolution and accuracy of regional topographic information. This study evaluates the topographic attributes and seismic parameters computed from multi-resolution and source DEMs, to investigate the impact of data source and resolution on the derived topographic seismic response. Methodologies are developed to readily derive the spatial distribution of relevant topographic attributes and seismic parameters, utilizing the multi-resolution and source DEMs. The impact of DEM source and resolution on slope gradient, relative height of terrain and shear wave velocity (V_S^{30}) are addressed. It is observed that, even though, relatively coarse resolution DEMs underestimate the critical sites of steep slope gradient and the lower V_S^{30} zones, this has limited impact on the derived normalized topographic aggravation factor. The free and easily accessible DEMs provide an opportunity for reasonable prediction of topographic seismic response, especially in near-real time. The slope gradient is observed to be the most sensitive topographic attribute to amplified seismic response, followed by the relative height.

1. Introduction

Seismologists have long been aware of the role of topography, soil physical characteristics and lithology in influencing the intensity of seismic response. Moreover, soil physical characteristics and lithology can be related to topographic attributes of the area (Tromp-van Meerveld and McDonnell, 2006; Wald and Allen, 2007). During several past seismic events, such as the Lambesc earthquake in France (1909), the San Fernando earthquake in USA (1971), the Friuli earthquake in Italy (1971), and the Kashmir earthquake in Pakistan (2005), intensified building damage was recorded on steep slopes and hill ridges (Stamatopoulos et al., 2007). Extensive numerical, analytical and experimental research since the 1960s has explored this amplification of seismic response at ridge crests and de-amplification at ridge toes (Donati et al., 2001; Assimaki et al., 2005; Nguyen and Gatmiri, 2007). However, due to the scarcity of the detailed subsurface information and seismic motion records, the topographic amplification effect is not clearly understood, except for qualitative trends (Chávez-García et al., 2000; Assimaki and Gazetas, 2004).

Recently seismologists have been working towards the development of techniques for near-real time ground shaking prediction. These techniques predict the spatial variation of ground shaking at a regional scale, i.e. large areas without exact boundaries and comprising of many topographic features. The most common and frequently applied tool, ShakeMap, was developed by the USGS (Wald et al., 2006). Other tools include Prompt Assessment of Global Earthquakes for Response (PAGER) for damage assessment and site specific attenuation models (Ozbey et al., 2004; Iyengar and Raghukanth, 2004; Earle et al., 2008).

In the aforementioned models, however, topography has not been considered as an independent parameter in the estimation of ground shaking, even though, it has been observed that topography can change the Peak Ground Acceleration (PGA) values by ±50% in rugged terrain (Lee et al., 2009a). Furthermore, the spatial distribution of seismic parameters, such as shear wave velocity (V_S), has been observed to be strongly correlated with the topographic slope gradient (Wald and Allen, 2007; Allen and Wald, 2009). The predicted shaking maps, therefore, result in uncertainty in the predicted shaking at local scale, i.e. the area comprising an individual topographic feature (Wald et al., 2006). Since

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most seismically active areas are associated with rugged terrain, investigating and incorporating the topographic impact on seismic response is important for the seismic hazard assessment, mitigation and near-real time seismic shaking prediction.

With the widespread availability of digital terrain representations, generically referred to as Digital Elevation Models (DEM), many terrain analysis studies have explored the utility of DEMs and their derived topographic attributes for environmental modeling (Wise, 2007). DEMs are commonly generated from point or transect measurements in the field, existing contour lines or, increasingly, remote sensing data (Raaflaub and Collins, 2006). Traditionally, photogrammetric methods applied to optical stereo data have been most prominent, while more recently Light Detection and Ranging (LiDAR) and RADAR data derived gridded DEMs have gained prominence. The grid or the pixel size of these DEMs determines the area covered by an individual pixel, also denoted by the spatial resolution, hereafter called the resolution. The inherent resolution of a DEM is a direct function of the point sampling strategy employed, e.g. the density of field measurement or the resolution of the image. Consequently, terrain features smaller than the DEM resolution cannot be represented distinctly and with their true value, but instead are averaged to a single pixel value. The technique and system employed to generate a DEM strongly determine both precision and accuracy of the elevation data. The resolution and the accuracy of a DEM in turn have a significant impact on the quality of DEM derivatives, such as slope, relative height, aspect and curvature of the terrain (Smith et al., 2006; Sørensen and Seibert, 2007; Wu et al., 2008). They thus attain critical importance when DEM derivatives are used for predictive modeling, such as for topographic seismic response prediction. While high resolution LiDAR DEM data are expensive and still rarely available, the 90 m Shuttle Radar Topography Mission (SRTM) DEM and the 30 m Space borne Thermal Emission and Reflection Radiometer (ASTER) derived DEM are available free of charge for nearly all land areas (CGIAR-CSI, 2004; ERSDAC, 2009). These readily available data may also be useful for predicting topographic seismic response at regional and local scale, particularly in near-real time.

In the recent past, several studies used DEMs of various resolutions and sources for estimating spatial distribution of shear wave velocity of the top 30 m crust (V_S^{30}) (Wald and Allen, 2007; Allen and Wald, 2009), and topographic seismic response evaluation (Lee et al., 2009a,b). However, the impact of DEM resolution and source on derived V_S^{30} or the topographic seismic response has not being explicitly addressed. Therefore, an important question is how the topographic and seismic parameters computed from DEMs are affected by the DEM resolution and data source, and how they can be compared. This study used DEMs from various sources and resolutions to investigate the impact of these parameters on terrain representation, terrain slope, relative height, V_S^{30} and the derived topographic aggravation of seismic response.

2. Methods

2.1. Study area and data used

The study area is located in the seismically active region in Carboneras, southern Spain, covering an area of about 18 km^2 (Fig. 1). Topography of the study area ranges from 60 m to 457 m ASL, and terrain slope values approach a steep of 70°. DEMs of varying resolutions and sources derived from air and spaceborne data generated through different systems and techniques were used. A high resolution DEM with pixel size of 1 m and a documented vertical RMSE of ±0.2 m (Tsutsui et al., 2007), derived from LiDAR data, was used as the most detailed and accurate elevation model. To obtain and test the majority of DEM resolutions used in recent seismic studies, the 1 m LiDAR DEM was resampled to 5 m, 10 m, 20 m, 30 m, 60 m and 90 m DEMs (Fig. 2). The results derived from these DEMs were than compared with the results from the satellite derived ASTER and SRTM DEMs. ASTER data contain stereo pairs that allow DEMs generation (Abrams, 2000), though with a RMSE of ±15 m (Abrams and Hook, 1995), which for this study was acquired from the USGS with 30 m pixel size. Moving towards coarser DEMs, SRTM recorded elevation data with a RMSE of ±16 m on a near-global scale, pro-

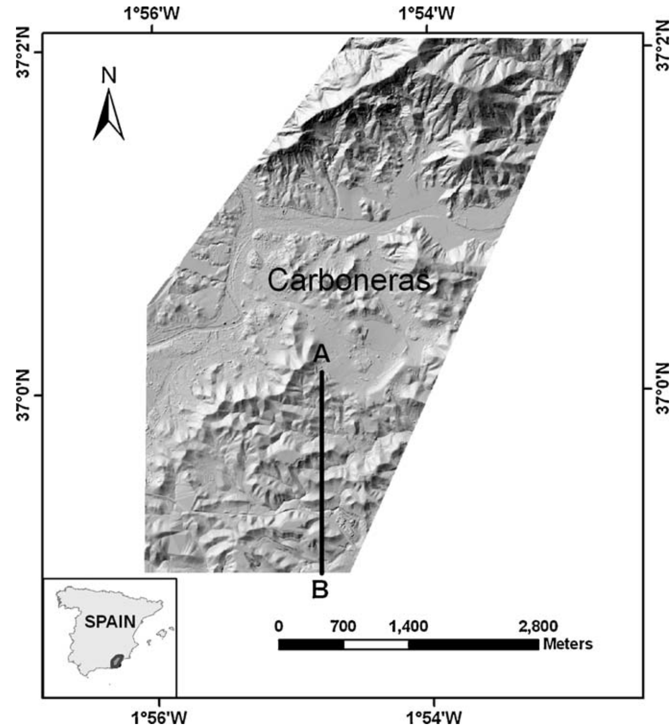

Fig. 1. Location map of study area located in Carboneras, southern Spain.

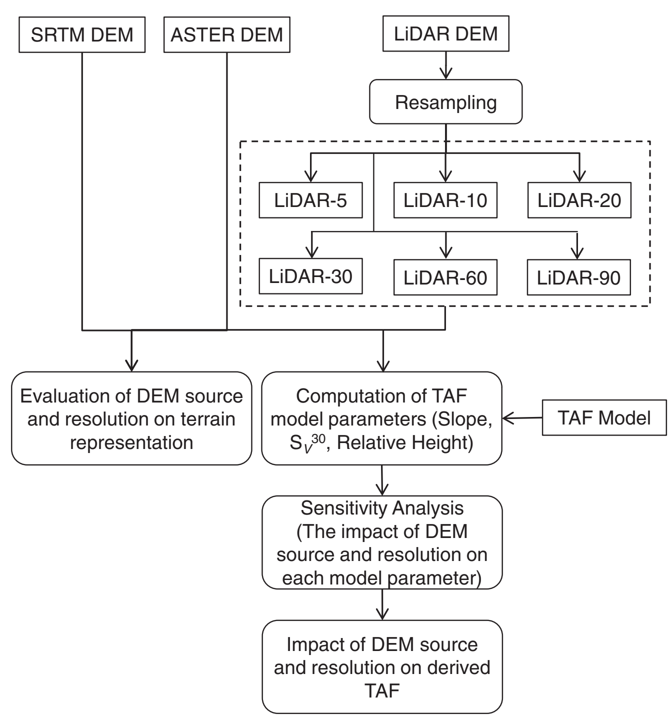

Fig. 2. Flowchart showing the data and procedures followed for the study.