Impact of DEM source and resolution on topographic seismic amplification

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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 Lombok 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., 2006; 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...
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 (Raaff 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 been 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 km² (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.](image)

![Flowchart showing the data and procedures followed for the study.](image)
viding the most complete digital topographic database of the Earth surface (Berry et al., 2007). A SRTM DEM with 90 m pixel size was acquired from CGIAR-CSI, which re-processed the raw data to fill voids with high resolution elevation data (Jarvis et al., 2004; Walker et al., 2007).

The impact of DEM resolution on the terrain representation and derived slope was evaluated by comparing the terrain profile of synthetic terrain features with varying base width, related to the pixel size of the used DEMs, but constant height. The findings from this synthetic experiment were further validated by comparing the impact of varying DEM resolution on a realistic terrain profile extracted from the study area. The original (LiDAR, ASTER and SRTM DEMs) and the LiDAR resampled DEMs were used to explore the impact of DEM resolution on terrain representation, and computed topographic and seismic attributes (Fig. 2).

2.2. Resampling

The common resampling techniques, i.e. nearest neighbor (NN), bilinear interpolation (BI), and cubic convolution (CC), vary in the number of pixels involved in assigning a new value to the resampled pixel. Resampling a DEM to > 4 times of its existing resolution, pixels that are lying beyond the nearest 16 pixels are ignored in the resampling, resulting in significant loss of information (Fig. 3a) and leading to an unexpected increase of mean elevation with coarsening DEM resolution (Fig. 3c). To tackle this limitation, we followed the block statistic technique (ESRI, 2009) to calculate the average elevation in a square, and subsequently assign it to the whole block (Fig. 3b). This technique was applied to resampling the 1 m LiDAR DEM. The mean elevation of the resampled DEM derived through the block statistic technique as expected continuously declined with coarsening resolution, due to the smoothening effect (Fig. 3d). The range of decline in mean elevation values depends on the spatial extent and terrain of the area. Topographic attributes, such as slope, aspect and curvature were derived from the DEMs, employing a number of algorithms to a moving 3 × 3 pixels window. Consequently, the spatial extent over which these values were computed also varies with the DEM resolution, causing all topographic attributes calculated to vary accordingly. Topographic features larger than the DEM resolution, but still smaller than the topographic attributes calculated to vary correspondingly. Topographic attributes, estimated from the nearest 16 pixels, but constant height; will be suppressed and smoothened during the topographic attribute computation (Smith et al., 2006).

2.3. Model

Slope, aspect, curvature and relative height are the crucial topographic attributes that, together with seismic waves characteristics such as wavelength, shear wave velocity and attenuation, influence the seismic response. Phenomena such as scattering, reflection, diffraction, focusing, trapping, and angle of incidence of seismic waves due to rough terrain, are known for amplification or de-amplification of topographic seismic response. The majority of published studies dealt with either a specific terrain feature (Gazetas et al., 2002; Assimaki and Gazetas, 2004; Ktenidou et al., 2007; Gaudio and Wasowski, 2007; Lee et al., 2009a) or a specific phenomenon of topographic seismic amplification (Boore et al., 1981; Paolucci, 2002; Sepulveda et al., 2005; Assimaki et al., 2005; Wald and Allen, 2007; Nguyen and Gatmiri, 2007). Parametric studies (Ashford and Sitar, 1997; Ashford et al., 1997; Bouckovalas and Papadimitriou, 2005) evaluating the exclusive impact of slope gradient, relative height, seismic wave type (P, SH, SV), shear wave velocity, wavelength and material damping, have resulted in numerical models that predict the topographic aggravation factor (TAF). TAF is the ratio of seismic response at the ridge crest and the seismic response at the free field. The free field are sites of flat topography in this case, hence no impact of topography on seismic response. This study focused on selecting a model that incorporates most of the topographic and seismic parameters that have been shown to be critical in the literature, and has been verified in real case scenarios. The numerical model developed and tested by Bouckovalas and Papadimitriou (2005), to predict TAF in the horizontal direction (Eq. (1)) was considered most suitable in this regard. The model parameters comprise of slope gradient, relative height of terrain features, seismic wave’s wavelength, shear wave velocity and the material damping, overlaying a homogeneous half-space.

\[
A_{h,\text{max}} = 1 + \frac{0.225(H/\lambda)^{0.4}[(I^2 + 2\varepsilon)^{0.5}/(I + 0.02)]}{1 + 0.9\varepsilon}
\]

where \(A_{h,\text{max}}\) is the horizontal TAF; \(I\) is the slope; \(H\) is the relative height; \(\lambda\) is the wavelength; \(\varepsilon\) is the material damping.

The model assumes vertically incident SV seismic waves to a terrain profile, which are transformed to P, SV and the Rayleigh surface waves when intersecting with the inclined terrain (for details about the seismic waves see Kramer (1996)). These newly generated reflected seismic waves amplify the seismic response when arriving at the ridge crest. Unlike in the original study by Bouckovalas and Papadimitriou (2005), we computed the model parameters from the DEMs of different sources and resolutions, and subsequently evaluated the effect on the computed model parameters and derived TAF. One of the limitations of the model is that it was developed for analysis of a synthetic profile assumed to be a single unit. In our case the model was applied to each pixel of the DEM, consequently not taking into account the whole topographic feature, but rather the model parameters values of each pixel.

2.4. Model parameters

The slope of the terrain features was computed from the original and the resampled DEMs. In contrast to absolute elevation as given in DEMs, modeling the topographic seismic response requires the relative height of terrain features, estimated from the nearest toe of a profile or the hill (Pedersen et al., 1994; Ashford et al., 1997; Assimaki and Gazetas, 2004; Bouckovalas and Papadimitriou, 2005). To derive relative height from a DEM, local minima were extracted along automatically detected drainage networks, from which a base level was derived. This base level was subtracted from the actual elevation, resulting in relative height of the terrain features for each pixel. Seismic wavelength in this study was derived from a numerical model developed by Nave (2000), considering the shear wave velocity and the predominant acceleration time, a procedure also adopted by Bouckovalas and Papadimitriou (2005). Shear wave velocity was computed through the relation of Allen and Wald (2009) for active tectonics, and a predominant acceleration period of 1 s was assumed for this study. For an actual event the predominant period of acceleration can be retrieved from the accelerograms of the specific event.

3. Results
3.1. Impact of DEM resolution on terrain representation

The correlation between various DEMs and their computed topographic attributes was explored by comparing the resampled LiDAR, ASTER, and SRTM DEMs with the original LiDAR DEM (Table 1). It was observed that correlation between the original and the resampled LiDAR DEMs continuously decreases with increasing the pixel size. Relatively higher correlation was observed between LiDAR and SRTM DEMs compared to LiDAR and ASTER DEMs. Spatial comparison of the original and resampled DEMs suggests that resampling results in higher variability on steep surfaces than on
Table 1

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flat terrain. Consequently, since the topographic seismic response intensifies on steep terrain, the resampling of DEM likely has a considerable impact on the predicted TAF.

The effect of DEM resolution on the terrain representation and computed slope gradient was evaluated graphically through two terrain profiles, each derived from a 1 m resolution DEM generated synthetically (Fig. 4) and extracted from the real environment (Fig. 5 (line A–B in Fig. 1)) respectively. Both of the initial 1 m resolution terrain profiles in Figs. 4a and 5a were resampled to 30, 60, and 90 m resolution profiles (Figs. 4a and 5a), and subsequently the corresponding slope was computed (Figs. 4b and 5b). The impact of DEM resolution on smoothing, shape and height is profound on terrain features with a base width smaller than the respective DEM resolution. Terrain features having a base width of 5 m and 10 m can hardly be identified in the 30 m resolution profile (Fig. 4a), and disappear entirely in the 90 m resolution terrain profile. Terrain features with a base width of 30–90 m could be identified in the 90 m resolution profile, but only with significant loss in height. The flat areas adjacent to the ridges were raised due to the averaging of elevation values with coarsening the DEM resolution (Figs. 4a and 5a). The flat area located between the ridges (Fig. 4a) was raised by 12% in the 90 m resolution profile. Simultaneously, the ridges (Fig. 4a) were reduced by 20% in the 90 m resolution profile. Terrain features significantly larger than the DEM resolution were not significantly smoothed, leading to a continuous decline in mean TAF in the study area.

3.2. Topographic aggravation of seismic response

The impact of DEM resolution and source on the computed topographic aggravation of seismic response (TAF) was explored by using the model developed by Bouckovalas and Papadimitriou (2005). The model parameters, i.e. slope, shear wave velocity, relative height, and wavelength, were computed from the multi-source and resolution DEMs.

Smoothing of terrain features with coarsening the DEM resolution led to a regular decline in mean TAF in the study area. To explore further the discrepancies in the TAF derived from the employed DEMs, the maximum TAF values from each DEM were normalized, and subsequently converted to percentages, hereafter referred to as normalized TAF factor (Fig. 6). The sharp decline in normalized TAF from the 1 m to 5 m DEMs is due to the smoothing of minor and sharp irregularities recorded by the 1 m DEM during the resampling to 5 m. The features still distinctly identifiable in the 5 m DEM were further smoothed in the lower resolution DEMs. In the 20 m DEM the terrain features were already smoothed to an extent that further coarsening of the DEM up to a resolution of 90 m does not significantly alter the normalized TAF factor. The normalized TAF factor derived from the 1 m LiDAR is 56% higher than the normalized TAF factor derived for the 5 m LiDAR DEM, and 72% higher than the normalized TAF derived for the 90 m LiDAR DEM (Fig. 6).

The behavior of varying TAF with changing DEM resolution was also found to be influenced by the spatial extent and topography of the study area. In small areas with rugged terrain, the terrain features smaller or equal to the DEM resolution were significantly smoothed, leading to a continuous decline in mean TAF in the study area. However, for terrain features significantly larger than the respective DEM resolutions, such as mountain ranges in the Himalaya, Alps or Andes, the DEM resolution will have less impact on representation of topography (Fig. 4a (i)). Therefore the derived TAF values at such terrain features were almost unaffected by varying the DEM resolution (Fig. 6).
Fig. 4. Schematic presentation of impact of DEM resolution on terrain representation in a synthetic environment, (a) Impact of resolution on elevation (the numbers on the top of the ridges represent the width of the ridge base) and (b) Impact of resolution on the computed slope.

Fig. 5. Schematic presentation of impact of DEM resolution on terrain representation in a real environment, (a) Impact of resolution on elevation and (b) Impact of resolution on the computed slope.
The variation in the model parameters computed from multi-source and resolution DEMs was counterbalanced in the model used, leading to limited impact of the DEM source on the computed normalized TAF. Therefore, the sensitivity of each computed model parameter to DEM resolution and source was also evaluated.

3.3. Sensitivity analysis

The sensitivity of the different model parameters to DEM resolution and source is addressed in the following sections.

3.3.1. Slope

The slope gradient has previously been observed to be a critical parameter in influencing the topographic seismic response (Bouckovalas and Papadimitriou, 2005; Gaudio and Wasowski, 2007; Nguyen and Gatmiri, 2007; Statamopoulos et al., 2007; Wald and Allen, 2007). Coarsening of DEM resolution has a larger impact on slope values than on the actual elevation, due to the neighborhood size. Therefore, the correlation ($R$) between slope values computed from various resolution and source DEMs was significantly lower for slope than for elevation (Table 1). Due to smoothing and averaging of ridges with adjacent flat areas with coarsening resolution from 1 m to 90 m (Fig. 4b), the computed slope increased by 166% in flat areas, while decreased by up to 450% on steep slopes. In the real case scenario (Fig. 5b), the mean slope was reduced by 151% in the coarser resolution DEM, which is in agreement with previous studies (Chang and Tsai, 1991; Wolock and Price, 1994; Zhang and Montgomery, 1994; Thieken et al., 1999). The mean slope decreased consistently with the DEM growing coarser (Fig. 7a), consistent with Fig. 3d, and also shown in previous studies by Chang and Tsai (1991); Wilson and Gallant (2000); Smith et al. (2006); Sørensen and Seibert (2007) and Wu et al. (2008).

The slope derived from the 1 m DEM resulted in unusually high variability of terrain (Figs. 4b and 5b), which is less sensitive to seismic waves with longer wavelength. Consequently, use of slope values computed from a 1 m DEM leads to unrealistic results in seismic response modeling, and also significantly extends the computation duration, especially in near-real-time.

3.3.2. Shear wave velocity ($V_{S}^{30}$)

The $V_{S}^{30}$ values computed from multi-source and resolution DEMs showed that relatively fine resolution DEMs lead to more pixels at the extreme $V_{S}^{30}$ values, while relatively fewer pixels fall in medium $V_{S}^{30}$ ranges (Fig. 7b). At the lower end of the $V_{S}^{30}$ values, all the used DEM consistently predicted zero pixels, while at the higher end, the $V_{S}^{30}$ computed from 1 m LiDAR DEM showed 44.81% more pixels than the SRTM DEM. This trend of decline in the percentage of pixels of the $V_{S}^{30}$ range of 360–620 m/s continued with coarsening DEM resolution (Fig. 7b). Serious underestimation of low and high $V_{S}^{30}$ zones, and overestimation of moderate $V_{S}^{30}$ zones was observed in $V_{S}^{30}$ values computed from the 1 km resolution DEM. This was due to the fact that high $V_{S}^{30}$ values assigned to steep slopes were smoothed, and low $V_{S}^{30}$ values assigned to flat areas increased with coarsening the DEM resolution (Section 3.1). Consequently, $V_{S}^{30}$ computed from coarse resolution DEMs underestimated the regions of critically low $V_{S}^{30}$ regions that tend to amplify seismic shaking (Allen and Wald, 2009), and high $V_{S}^{30}$ regions, while overestimating the regions of moderate $V_{S}^{30}$. This observation casts doubts on the accuracy of an implementation of topographic parameters and the spatial distribution of $V_{S}^{30}$ values.
computed from coarse resolution elevation models at local scale, such as 1 km in this case, and ultimately the predicted site condition maps. Relatively fine resolution DEMs might increase the cost and extend the computation requirements, especially in near-real time prediction, but they also present a more realistic prediction of seismic response.

3.3.3. Relative height

Bouchon (1973) theorized that seismic amplification at the ridge top depends on the base-to-height ratio of the terrain undergoing seismic excitation. The methodology explained in Section (2.4), to compute relative height was applied to all DEMs. The mean of the derived relative height of the terrain features (Fig. 7c) was found to be declining continuously with coarsening DEM resolution. The mean relative height computed from the 1 m LiDAR DEM was taken as 100%, and the continuous decline in mean relative height with coarsening the DEM resolution indicated in percentage values. A sharp continuous decline of 10% was observed in the mean relative height from the 1 m LiDAR to the 30 m LiDAR DEM (Fig. 7c). The ASTER DEM only displayed a 0.5% higher mean relative height, compared to the 30 m LiDAR surface. The mean relative height of the 1 m LiDAR DEM was 13% higher than that of the 90 m LiDAR DEM, and 14% higher than of the SRTM DEM. Better consistency of computed relative height was observed between LiDAR 90 m and SRTM, and among LiDAR 30 m and ASTER (Fig. 7c).

4. Discussion

A wide range of DEMs is available with varying resolutions and derived from different sources, which can be used for exploring the impact of topography on seismic response. For instance Lee et al. (2009a) used a 1 m LiDAR DEM, Yong et al. (2008a,b) a 30 m ASTER DEM, while Allen and Wald (2009) employed a 90 m SRTM DEM. In addition, SPOT derived elevation data are available at up to 10 m resolution. Often the DEMs of varying resolutions are computed through interpolation of contour lines, usually resulting in resolutions in the range of 5–20 m. To explore the trend of the resolution impact and avoid sudden jumps between 30 m and 90 m DEMs, a DEM of 60 m was also included in the analysis. Hence we attempted to explore the role of all these possible DEMs resolutions and their impact on computation of topographic attributes and ultimately derived topographic aggravation of seismic response.

Both LiDAR and SRTM DEMs resulted from active remote sensing methods, while the ASTER DEM was generated photogrammetrically from optical stereo data. The LiDAR and SRTM DEMs were found to be more consistent in elevation and computed attributes, compared to the ASTER elevation data (Table 1). The variation in the computed model parameters among the utilized DEMs was almost balanced in the normalized TAF factor computation (Fig. 6), as the impact of relatively less mean slopes from the ASTER DEM (Fig. 7a) on derived TAF was subdued by its relatively high mean height (Fig. 7c). It was observed that for terrain features considerably larger than the respective DEM resolution the impact on the normalized TAF factor was negligible. To demarcate the terrain features of interest, the feature size should match the resolution of the DEM used.

Acquisition of fine resolution DEMs, such as from LiDAR in this case, especially in near-real time after a seismic event likely poses an obstacle. Moreover, the high price and limited spatial coverage of such data is also a barrier for its use in pre and post earthquake response investigation and at regional scale. The scale of variation recorded by the LiDAR DEM also appeared insignificant, considering the wavelength of the seismic waves propagation during a seismic event. Hence, the SRTM DEM with 90 m resolution, and recently published and freely available ASTER Global DEM (GDEM) at 30 m resolution, both with near-global coverage, constitute attractive alternatives for stable and near-real time prediction of seismic response.

The parameters of the numerical model used were derived from the true topography LiDAR DEM, from which TAF was subsequently derived. Furthermore, the model parameters were also computed from the ASTER and the SRTM DEMs to compute TAF. The discrepancies in the TAF computed from LiDAR DEM and the ASTER and SRTM DEMs can be attributed to the differences in the DEMs sources, resolution and the inaccuracies.

The numerical model used (Eq. (1)) revealed a linear correlation between slope and TAF with $R^2$ of 0.80, and with relative height a non-linear but still positive correlation with $R^2$ of 0.72. However, where steep slopes are observed at lower heights, or larger heights with gentle slopes, the ultimate aggravation of seismic response will be reduced. Sensitivity of slope to seismic response is due to the fact that with steeper slope gradient the incident seismic waves are reflected towards the ridge crest and ultimately get trapped, resulting in amplification of seismic response and extend the duration of seismic shaking (Geli et al., 1988; Ashford and Sitar, 1997; Ashford et al., 1997; Sepulveda et al., 2005; Bouckovalas and Papadimitriou, 2005; Lee et al., 2009b).

The observed variation in the model parameters with coarsening the DEM resolution (Fig. 7) was consistently reflected in the observed corresponding regular decrease in the mean TAF.

5. Conclusions

This study evaluated the applicability of DEM derived topographic and seismic attributes to estimate the topographic aggravation of seismic response, and explored the impact of DEM source and resolution on the topographic and seismic parameters. Coarsening the DEM resolution, in general, leads to a smoothening of terrain features and in particular, leveling of steep ridges and inclining at adjacent flat regions. These inclined flat areas lead to considerable underestimation of extreme near surface velocities ($V_{20}$). In our experiments the mean of the computed slope and relative height were declined regularly with coarsening DEM resolution. Terrain features equal to, or smaller than, the respective DEM resolution could not be identified distinctly, and the predicted seismic response at these features was unrealistic.

The TAF values derived from DEMs with gradually coarsening resolution through the numerical model used showed a regular decline with strong variation observed between 1 m and 5 m DEMs, but little variation between the 20 m and the 90 m resolution DEMs. The variation in the derived topographic and seismic parameters was balanced by the numerical model leading to a negligible impact of DEM source on TAF for coarser resolution DEMs. The derived TAF was found to be most sensitive to the terrain slope gradient, followed by relative height.

The decision of selecting a DEM for TAF estimation or near-real time shaking prediction depends on the spatial extent of the affected area and availability of the data. Acquiring fine resolution DEMs, such as from LiDAR, for remotely located seismic events with large spatial impact and especially in near-real time after a seismic event remains unrealistic at present. Furthermore, seismic waves with longer wavelength are less sensitive to minor variations in terrain features, as recorded by the LiDAR elevation data. The ASTER and SRTM DEMs can thus be seen as more suitable for regional prediction of TAF due to their free accessibility and global coverage. The choice of ASTER or SRTM DEMs for TAF estimation or near-real time shaking prediction depends on the spatial extent of the affected area, the level of required detail and the available computation time.
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