Dear Editors & Reviewers:

We appreciate the constructive feedback on our manuscript. We have significantly edited our manuscript in response to reviewer comments. Particular focus has been placed on improving our discussion of relevant uncertainties and framing the results in the context of methodological limitations.

Overview of Major Changes

1. The title of the manuscript has been changed slightly to reflect the manuscript-level terminology change from ‘casualty’ to ‘fatality’.

2. We have substantially edited the entire manuscript for clarity, consistency, and style. Special attention has been made to terminology concerns raised by reviewers, sources of uncertainty, and limitations.

3. We have introduced a major change in how building occupancy for refugees is calculated. The model now simulates a range of potential occupancy patterns for refugee populations to assess the magnitude of corresponding fatality variations. The related methodology, results, and discussion sections have been reworked accordingly.

4. The format of the discussion has been smoothed out. Fatalities are now discussed for non-refugee and refugee populations separately, then compared. Additionally, the comparison between refugee and non-refugee fatalities is now in the form of a new Figure instead of a table. We feel these changes better contextualizes the nature of the study.

5. Two subsections have been added to the discussion. One introduces the interpretation of fatality estimates and the other discusses total model uncertainty. We feel that that the addition of these two sections properly frames the limitations of our results.

Response to Reviewers

Referee 1:

Migration data accuracy concerns:

Concerns were raised over the migration data accuracy. We have included a more substantial explanation of where these statistics come from and what they cover. We have added a statement distinguishing between refugee populations and displaced persons, indicating that the data we used only covers registered refugee populations and may underestimate the total number of Syrians present in our study area. We have also improved the clarity regarding our disaggregation methodology and its relative strengths and drawbacks. (p. 6-7, section 4.1.1)

Additionally, it was not clear in our original draft that the statistics we were using are official registered refugee counts put out by the Turkish Department of the Interior---the same data used by the U.N. and U.S. Dept. of State in their publications. We have adjusted our manuscript to state this explicitly. (p. 6, l. 10-15)

Differentiation between homes:
We have completely redesigned how we account for the building occupancy of refugee populations in response to reviewer feedback. Refugee fatality estimations are now calculated 500 times, each with semi-randomly generated building occupancy percentages. The new methodology used to generate refugee occupancy tables is discussed at length in the new manuscript version, along with justification for the modified approach. (See p. 10)

We have updated the results to include the median fatality estimates along with median absolute deviations. We have also rewritten our discussion section for refugee related fatalities with more focus on the interpretation of the results. (See p. 13-14, Sec. 5.3)

Casualties vs. Deaths
Upon review of relevant literature, we determined that fatalities would be a more appropriate term than casualties. This has been changed throughout the entire manuscript.

General Comments:
Both grammatical errors pointed out have been fixed. (p. 2, l. 3-4, 8-9). The statement on loss estimations has been reworked to appropriately reflect the use of fatality estimation/rapid response systems. Three citations have been added to support our conclusions. (p. 2, l. 29-32.)

Referee 2:
General Comments:
Both errors pointed out by the reviewer (aeral instead of areal and improper citation format) have been fixed. (p. 5, Fig 3. & p.6 Section 4 – Data and Methods) Table 2 is now linked to the appendix when describing its construction (p. 10, l.1)

Fault Parameter Table:
We have added a more complete description of how the parameters in Table 1 are utilized in OpenQuake. As mentioned in our original response, OpenQuake uses magnitude and rake to create rupture areas within the calculations itself. Accordingly, changed the Table 1 title to ‘earthquake rupture input parameters’ to indicate that this information is being passed into OpenQuake. (p. 8, l. 7-17)

Working hour population percentages:
As recommended, we have referenced this in the discussion. We have also listed it as a limitation because our models do not account for outdoors populations. (p 12. l. 26)

Assessing the impact of Syrian refugees on earthquake ~~casualty~~ fatality estimations in southeast Turkey

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Abstract. The influx of millions of Syrian refugees into Turkey has rapidly changed the population distribution along the Dead Sea Rift and East Anatolian fault zones. In contrast to other countries in the Middle East where refugees are accommodated in camp environments, the majority of displaced individuals in Turkey are integrated into local cities, towns, and villages—placing stress on urban settings and increasing potential exposure to strong earthquake shaking. Yet, displaced populations are often unaccounted for in the census based population models used in earthquake ~~casualty estimations. Accordingly, this study constructs a refugee inclusive~~ fatality estimations. This study creates a minimally modeled refugee gridded population model and analyzes its impact on semi-empirical ~~casualty~~ fatality estimations across southeast Turkey. Daytime and nighttime fatality estimates were ~~calculated for five geographically distributed fault zones~~ produced for five fault segments at earthquake magnitudes 5.8, 6.4, and 7.0. ~~Total casualty estimates ranged from 28-7723 individuals, with the contribution of refugees varying from 1~~Baseline fatality estimates calculated from census-based population estimates for the study area varied in scale from tens to thousands of fatalities, with higher death totals in nighttime scenarios. Refugee fatality estimations were analyzed across 500 semi-random building occupancy distributions. Median fatality estimates for refugee populations added non-negligible contributions to earthquake fatalities at four of five fault locations, increasing total fatality estimates by 7-27%~~-26% of total estimated casualties. On average, these percentages correspond to casualty underestimations of tens to hundreds of individuals~~. These findings communicate the necessity of incorporating refugee statistics into earthquake ~~risk analyses~~ fatality estimations in southeast Turkey and the ongoing importance of placing environmental hazards in their appropriate regional and temporal context.

1 Introduction

Since Syria's devolution into Civil War in early 2011, millions of Syrians have fled into Turkey seeking reprieve from areas of territorial conflict. As of December, 2016, the refugee population in Turkey is nearing 2.8 million, with majority populations located in southeastern provinces (Republic of Turkey, 2015). This influx of population has rapidly changed the population distribution of earthquake prone areas near the East Anatolian and Dead Sea Rift fault systems, increasing the number of individuals potentially exposed to strong earthquake shaking.

The refugee crisis in Turkey is unique in several ways that ~~amplify earthquake risk concerns~~are relevant to earthquake risks. In contrast to other countries in the Middle East, the majority of Syrian refugees in Turkey are settled amongst local populations rather than formalized refugee camps. ~~Therefore, migrated populations represent significant increases in population density—a~~ This implies a form of temporary ~~urbanization. Rapidly increasing urban populations is stressing~~ urbanization—3RP (2015) notes that increased volume of refugees is stressing to local cities seeking to adequately ~~house refugee populations(3RP, 2015).~~ accommodate increased populations. This distinction also complicates the process of accounting for refugees in population models. Refugees in Turkey have to be modeled across large geographic areas rather than simply including refugee camp populations.

~~In the past, high rates of urbanization have been attributed to the Turkish government's failure to enforce seismic building codes (Erdik, 2001). The~~ Increased building occupancy raises the potential for earthquake disasters in southeast Turkey, especially given the country's poor historical precedent for earthquake mitigation. There are clear relationships between urbanization, building code enforcement, and earthquake fatalities in Turkey. The lack of seismic building code enforcement is an ongoing problem, and has been linked to high rates of urbanization the past (Erdik, 2001). This is particularly problematic in light of clear relationships between earthquake fatalities and building collapse (Oskai and Minowa, 2001; Nadim et al., 2004; Coburn and S and major concerns over the structural integrity of existing building stock ~~is a widespread issue throughout Turkey (Ilki and Celep, 2012), with poor code enforcement contributing~~ (Ilki and Celep, 2012). Poor code enforcement has been mentioned as a contributing factor to high death tolls in recent Turkish earthquakes (Erdik, 2001; Güney, 2012). ~~Fatality occurrence in earthquakes is strongly linked to building collapse (Oskai and Minowa, 2001; Nadim et al., 2004; Coburn and Spence, 2002). This linkage contributes to the disparaging~~ This particular issue however, extends beyond Turkey. The lack of building code enforcement is a major contributing factor to elevated earthquake mortality rates ~~in the developing versus the developed~~ across the developing world. Earthquake resistant structures are both expensive to construct and time consuming to license and verify~~, creating~~. This creates opportunities for corrupt payments, bribes, and a lack of political incentives to ~~drive the under~~ diminish enforcement of building codes (Keefer et al., 2011; Anbarci et al., 2005). ~~The combination of poor historical precedent for earthquake mitigation and rapidly increasing occupancy in urban structures raises concerns about the scale of future earthquake disasters in southeast Turkey.~~

Structural vulnerability is ~~critically intertwined with assessments of~~ intertwined with population exposure in earthquake risk analyses. Accurately mapping population exposure is an essential part of the risk analysis process for environmental hazards (Chen et al., 2004; Freire and Aubrecht, 2012; Aubrecht et al., 2012). The presence of Syrian refugees in southeast Turkey ~~has complicated~~ complicates this process, especially as it pertains to datasets commonly used in earthquake ~~loss~~ fatality estimations. Displaced Syrian populations are tracked at varying levels by the Turkish government and international agencies, but are difficult to model at high-resolution. Refugees are registered at the province level, but are ~~allowed to freely move~~ afforded freedom of movement within their registered province under the Temporary Protection Regulations~~stipulations~~, the legal framework for refugees in Turkey (Çorabatır, 2016). Thus, the position of refugees within any designation smaller than provinces—district, city, village—is uncertain. These uncertainties present challenges for earthquake loss estimations that rely on accurate population estimates.

Improved human exposure data impacts several components of the risk analysis process, including loss estimation and disaster relief (Chen et al., 2004; Aubrecht et al., 2012; Guha-Sapir and Vos, 2011). Studies by Aubrecht et al. (2012) and Ara

(2014) have shown the paramount importance incorporating temporal factors into population datasets. Despite these findings, most earthquake related hazard studies do not account for temporal population changes and instead rely on census-based population estimates (Freire and Aubrecht, 2012). In the absence of building level data on structural ~~class~~ type and time-varying occupancy (which are often nonexistent, especially in developing nations), ~~casualty estimations rely on using~~ fatality estimations utilize census data or modified versions of census data—either disaggregated by uniformly distributing population over ~~an aeral unit~~ areal units or converted into a finer-resolution dasymetric model using a variety of geographical constraints.

~~Casualty~~ Fatality estimation tools play an important role in both mitigation and relief and recovery processes. ~~Because loss estimation systems can be used to direct rapid post-event humanitarian decisions (Jaiswal et al., 2011b), their accuracy is crucial~~Earthquake rapid response systems have shown promise in accurately characterizing earthquake impacts for emergency management purposes (Wyss, 2004; Erdik et al., 2011; van Stiphout et al., 2010). However, the accuracy of input data in developing nations remains a major concern (Wyss, 2004). In Turkey, refugee populations are not accounted for in the census data due to recency—the last census was completed in the 2011, the same year of the Syrian crisis' onset. Therefore, any product produced using census based population sources is likely to underestimate population exposure unless explicitly adjusted for Syrian populations. ~~In southeastern provinces where the percentage of Syrian refugees often reaches over ten percent of the native population, accounting for these populations is a salient component of the casualty estimation process.~~

~~Accordingly, this~~ This study addresses this challenge by (1) minimally modeling refugee populations statistics with Turkish population estimates into a ~~gridded population dataset~~ series of gridded population datasets and (2) assessing the corresponding impact on earthquake ~~casualty estimations across four~~ fatality estimations at five geographically distributed fault segments across southeast Turkey. Using the semi-empirical loss estimation technique of Jaiswal and Wald (2010), ~~human casualty~~ fatality estimates are simulated for a range of earthquake magnitudes. By ~~comparing the casualty estimates from the refugee inclusive population model to traditional census based approaches~~evaluating the relative contribution of refugee populations within total fatality estimates, it is shown ~~what magnitude of underestimations should be expected in the absence of dedicated population exposure adjustments~~the degree to which census based approaches underestimate fatalities. These results communicate ~~why incorporating migration statistics is a necessary step for properly assessing earthquake exposure in this region—communicating the ongoing importance of analyzing natural hazards within an appropriate regional setting~~the importance of incorporating refugee populations into natural hazards risk assessments.

2 Study area

As of December, 2016, there ~~are~~ were 2,790,767 registered Syrian refugees in Turkey, over half of the Syrian conflict's total refugees and more than any other country in the Middle East. Turkey currently has twenty three refugee camps operating at full capacity across ten provinces, accommodating approximately 10% of the total registered population. The remaining 90% of refugees are settled amongst local communities in their provinces of registration. This comes in stark contrast to other countries in the Middle East where a majority of refugees are housed in camped environments. The Turkish Ministry of

Figure 1. Study area within southeastern Turkey.

the Interior Directorate General of Migration Management consistently updates these statistics as more Syrians are formally registered as refugees within the country.

A majority (60%) of Syrian refugees have settled in southeastern provinces near the Turkey-Syria border, with the highest concentrations located in provinces bordering Syria directly (Fig. 2). The area of focus for this study encompasses twelve primary southeastern provinces and portions of three additional provinces. This region extends from the northwest corner of Kayseri to the southeast corner of Şanlıurfa (Fig. 1). Tectonically, this region is dominated by two primary left lateral strike-slip fault systems, the East Anatolian fault zone and the Dead Sea Rift fault zone, which bound the intersection between the relatively stable Arabian platform and the Anatolide-Tauride block. The precise structural relationship between these two fault systems is complex and poorly understood. Their intersection is generally placed at a triple junction near the city of Kahramanmaraş (Chorowicz et al., 1994), or slightly further south near Antakya (Over et al., 2004). Various explanations for the mechanics of the two systems have been explored in Doğan Perinçek and İbrahim Çemen (1990); Duman and Emre (2013). Under either explanation, refugee settlement in southeastern Turkey represents a migration away from a stable tectonic setting into an area characterized by frequent earthquake activity.

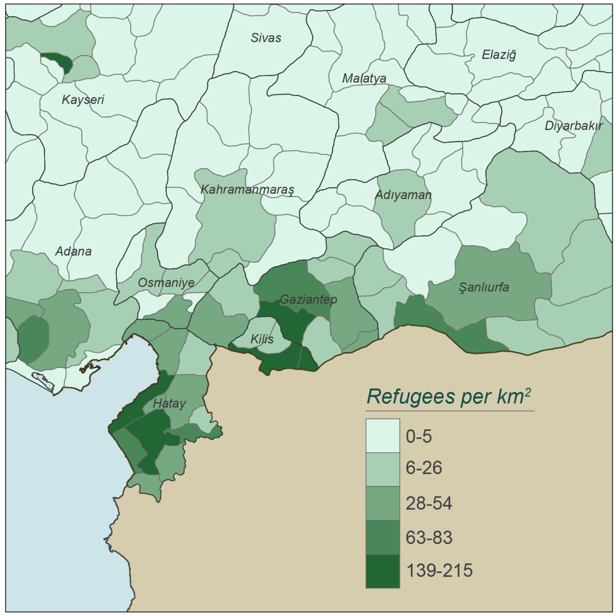

Figure 2. Migrated population density, December 2016.

3 Historical seismicity

There is a ~~wealth of information detailing the long history of earthquake activity~~ robust record of earthquake activity earthquake activity on the East Anatolian and Dead Sea Rift fault systems (Ambraseys, 2009; Sbeinati et al., 2005; Barka and Kadinsky-Cade, 1988; Garfunkel et al., 1981). Ambraseys (2009) provides a detailed overview of historical seismicity in the region, with Sbeinati et al. (2005) providing additional information on Syrian earthquakes. Both the East Anatolian and Dead Sea Rift fault systems have seen a recent quiescence in seismic activity, but paleoseismic evidence indicates a consistent long term pattern of infrequent large earthquakes (Ambraseys, 1989; Meghraoui et al., 2003). ~~Large earthquakes in southern Turkey first appear in the historical records in 148 B.C.E. in the writings of John Malalas, who chronicles the destruction of the city of Antioch due to the 'Wrath of God', a phrase often used to describe earthquake events (Ambraseys, 2009). The city of Antioch alone, located in the modern day Hatay province, is shaken over forty times before 1900 C.E..~~ Figure 3 plots seismic activity greater than magnitude 5.0 across the study area over the last millennia, showing an fairly even distribution across the length of the fault zones.

Historical records also provide insight into the human impact of several notable earthquakes. The earthquakes that destroy ~~Antioch in~~ the city of Antioch (located in the Hatay province of modern day Turkey) in 115 C.E. and 526 C.E. are estimated to have killed 250,000 or more individuals each. If these numbers are correct, both earthquakes fall into the top ten most deadly earthquakes of all time (Musson, 2001) (the death estimates may be exaggerated, but are generally considered to be plausible (Ambraseys, 2009)). The 526 C.E. earthquake is particularly notable, striking on the 29th of May, Ascension Day. Ambraseys

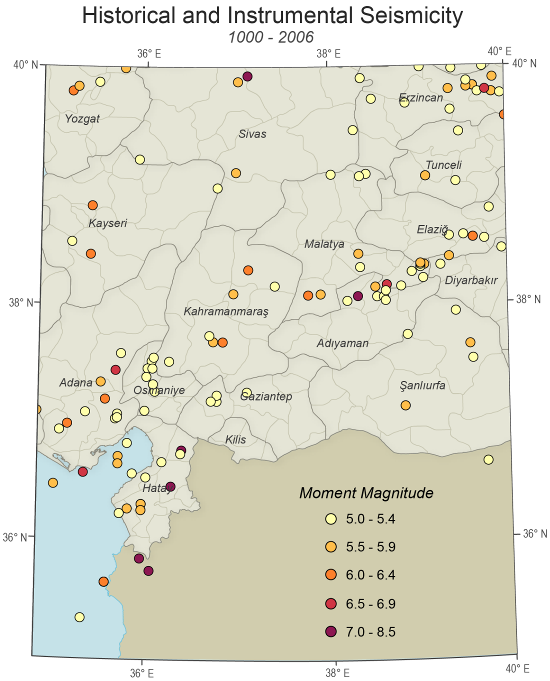

Figure 3. The distribution of earthquake shaking as gathered from historical documents and modern seismic networks, compiled in ~~(Sesetyan et al., 2013)~~Sesetyan et al. (2013).

(2009) ~~notes that the high death totals for this earthquake (250,000-300,000) were likely amplified by the~~ mentions that the influx of visitors into the city likely amplified fatalities.

4 Data and methods

4.1 Refugee-inclusive population model

The last Turkish census was completed in 2011 before the onset of Syrian mass migration. Therefore, most population models built from census-based sources do not account for the presences of Syrian refugees. This is not an intentional error (The Gridded Population of the World, version 4 dataset (GPWv4) (Doxsey-Whitfield et al., 2015) explicitly states this particular shortcoming), but rather a systematic problem associated with infrequent data collection. Any forward modeled population dataset for Turkey based on pre-2011 data will mischaracterize true populations ~~in high migration areas~~ unless refugees are explicitly included. ~~Furthermore, the uncertainty associated with the sub-province level position of refugees complicates their inclusion in disaggregated grid-based datasets.~~ Population models that ~~include Syrian migration~~ incorporate migration at some level do exist, most notably Oak Ridge National Laboratory's LandScan™ database (ORNL, 2016)~~—a proprietary product used by the U. S. Department of Defense and U.S. Geological Survey among others.~~ , but they remain proprietary products.

As a framework for modifying regional census data for inter-period migration events, a geographic information systems (GIS) workflow was utilized to construct a regional refugee inclusive gridded population model using freely available data from Turkey's Address Based Population Registration System (ABPRS) and the Turkish Directorate General of Migration Management ~~. This model, like the GPWv4,~~ (DGMM). The DGMM, part of the Turkish Department of the Interior, is responsible for regularly disseminating registered refugee populations statistics. These statistics are widely used in refugee-related reporting by the European Commission, United Nations High Commissioner for Refugees, and the U.S. Humanitarian Information Unit, among others.

The framework for this study employs a minimally modeled ~~aeral~~ areal distribution process that disaggregates administrative population counts into cells of equal population. Turkish district level boundaries from the GADM database of Global Administrative Areas (GAA, 2015), clipped to the area of interest, were first converted into three kilometer grid cells and equally distributed 2015 ABPRS populations according to the proportional number of cells in each district.

Refugee migration data is monitored at the province level, one administrative boundary larger than the ABPRS estimates. As mentioned above, the exact position of non-camped Syrian refugees within their respective provinces is unknown. Accordingly, the existing district level population distribution was used as a proxy for refugee settlement patterns. The non-camped refugee population was distributed according to ~~each district's relative percentage of its corresponding province province percentage. Known camped~~ the relative percentages between district and province level populations. Camped refugee populations were assigned to ~~their residing district~~ the district corresponding to the camp location and removed from the populations otherwise distributed. The model was finalized by repeating the process used above for distributing ABPRS populations to allocate refugees into equally populated grid cells. The resulting gridded population model (Fig. 4) is spatially consistent and has discrete values for base population and ~~migrated~~ registered refugee population.

4.1.1 Advantages and drawbacks

~~This population model has a number of advantages and drawbacks over other freely available population models. The primary advantage being that, in~~ In contrast to other ~~aeral grid~~ areal gridded population models, this ~~model~~ study explicitly accounts for ~~the spatial distribution refugee migration, as characterized by the Turkish Directorate General of Migration Management. Furthermore, it takes into account the most recently available statistical information from the Turkish government regarding local population counts. The 2015 ABPRS data does provide slightly improved estimates compared to 2011 census data forward modeled with growth equations. Large study areasor regions with smaller migrated populations might~~ registered refugee populations. The methods used to incorporate temporary populations are straightforward to replicate and update as the DGMM releases new registration statistics. It should be noted however, that refugees and displaced persons are not equivalent designations. The DGMM statistics used in this study only include registered refugee populations, and many not capture the full number of displaced Syrians living in Turkey. Other fatality estimation studies, particularly those with larger study areas, may prefer a globally gridded model (like the GPWv4 ~~database), but such datasets suffer in this particular region due to the scale of~~

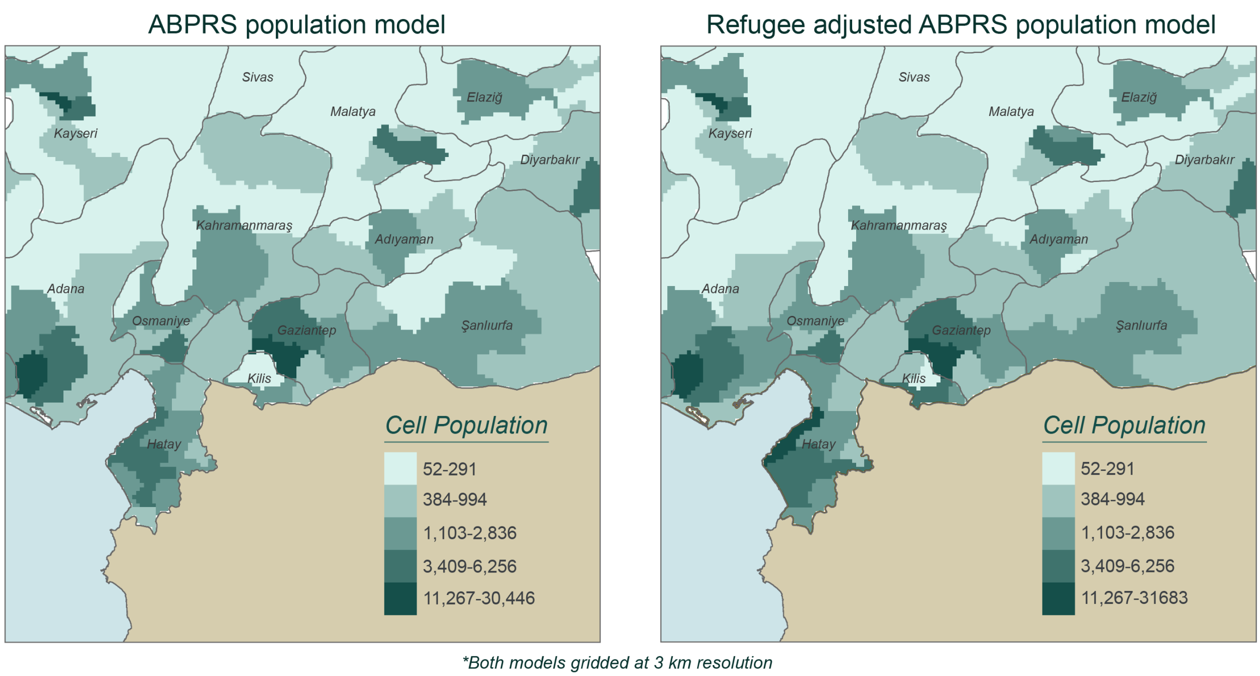

Figure 4. Gridded cellular population models produced from Turkish ABPRS data before (left) and after (right) including refugee statistics.

~~short period population changes. Proprietary~~ dataset). Alternatively, proprietary gridded population models ~~like LandScan™ are~~ are also an option. LandScan™ is updated yearly and may provide improved characterization of refugee settlement, but ~~their dasymetric mapping approaches~~ its dasymetric mapping techniques are not open source.

~~Two primary assumptions were necessary for the construction of this model. First, refugees were distributed from the province level to the district level in an equivalent distribution to the existing population~~The primary drawback to the methodology used in this study is the assumption that refugees and local populations are distributed equally at the sub-province level throughout the study area. It is probable that actual refugee populations exhibit different spatial clustering~~patterns, but this information is difficult to model without~~ . However, refugees are allowed freedom of movement within their province of registration (Çorabatır, 2016), making it difficult to specify an alternative distribution without any additional constraining information. ~~The Turkish government has started tracking province level registration and implemented freedom of movement restrictions as of August, 2015, but these regulations still allow for movement for refugees within their registered provinces (Çorabatır, 2016). Assuming an equivalent population distribution to that of existing populations~~ Using equal district level distributions, with camp locations taken into account, at minimum maintains the regional urban-rural ~~breakdown—an important element in building-type assignment for loss estimation. Outside of specific refugee camp locations (which have been accounted for), there is not clear evidence for assigning an alternative distribution pattern. Secondly, refugee populations were aerally distributed equally into district level grid cells—the same assumption made for Turkish populations. This assumption retains~~

consistency between population types in the absence of sufficient reason to minimally model refugees differently than that of existing population. distribution—an important classification for fatality estimations.

4.2 Earthquake scenarios

Earthquake scenarios are an important tool for emergency management planning. Tools like the USGS' Prompt Assessment of Global Earthquake Risk (PAGER) system and FEMA's HAZUS software have been used in the U.S. for emergency planning and both the national and state level (FEMA, 2008; Chen et al., 2016; EERI, 2015). As part of the earthquake loss fatality estimation process, synthetic ground motion fields were produced for a series of earthquake ruptures spanning five faults across southeastern Turkey. For each fault, moment magnitude 5.8, 6.4 and 7.0 earthquakes were simulated. This spread of earthquake magnitudes reflects moderate to major earthquakes within the magnitude range of historical earthquakes in the area as seen in earthquake catalogs covering Turkey (Zare et al., 2014; Woessner et al., 2015). Five earthquake epicentral locations were selected along fault traces provided in the fault-source background model in the Seismic Hazard Harmonization of Europe (SHARE) project. It should be noted that the choice of exact epicentral location is somewhat arbitrary, but can have an impact on casualty estimationsfatality levels. Epicenters for this study were selected to represent geographically distributed fault segments and were chosen independently of refugee migration patterns.

The Global Earthquake Model's OpenQuake software platform was utilized to produce ground motion fields for each earthquake scenario. OpenQuake's scenario-based hazard assessment implements ground motion prediction equations to estimate the geographic distribution of shaking intensity for a user-specified fault rupture (GEM, 2016). An overview of rupture information input parameters for each fault segment used in this study is available in Table 1. For each scenario, OpenQuake generates the rupture area internally from magnitude and rake using the area-magnitude scaling relationship defined in Wells and Coppersmith (1994). The rupture area is allowed to float along its corresponding fault trace (Figure 5). All of the scenarios in this study utilized the ground motion prediction equation detailed in Akkar and Bommer (2010), relevant to earthquakes in Europe and the Middle East. Site amplification was accounted for by using Vs30 estimates from the USGS Global Vs30 Map server, which estimates Vs30 from topographic slope (Wald and Allen, 2007). OpenQuake implements site parameters by assigning each observation grid cell the site parameters of the nearest measurement in the Vs30 grid (GEM, 2016). For each earthquake scenario, ten ground-motion fields were produced—each resampling the aleatory uncertainty in the ground motion prediction equation.

The Global Earthquake Model's OpenQuake software platform was utilized to produce ground motion fields for each earthquake scenario. OpenQuake's scenario-based hazard assessment implements ground motion prediction equations to estimate the geographic distribution of shaking intensity for a user-specified fault rupture (GEM, 2016). All of our scenarios utilized the ground motion prediction equation detailed in Akkar and Bommer (2010), relevant to earthquakes in Europe and the Middle East. We accounted for seismic site amplification using Vs30 estimates from the USGS Global Vs30 Map server, which estimates Vs30 from topographic slope (Wald and Allen, 2007). OpenQuake implements site parameters by assigning each observation grid cell the site parameters of the nearest measurement in the Vs30 grid (GEM, 2016). For each earthquake scenario, we produced ten ground-motion fields—each resampling the aleatory uncertainty in the calculation.

Table 1. Earthquake rupture input parameters

Fault name	Hypocenter (Lon,Lat)	Depth	Dip	Rake
Pütürge	(38.20, 37.77)	13.2	70.0	0.0
Kırıkhan	(36.08, 36.27)	13.2	80.0	0.0
Türkoğlu	(37.48, 37.04)	13.2	80.0	0.0
Göksun	(37.03, 35.77)	13.2	80.0	0.0
Bozova	(37.32, 38.59)	13.2	80.0	180.0

Upper and lower boundaries of the seismogenic layer were set to 0 and 20 km, respectively.

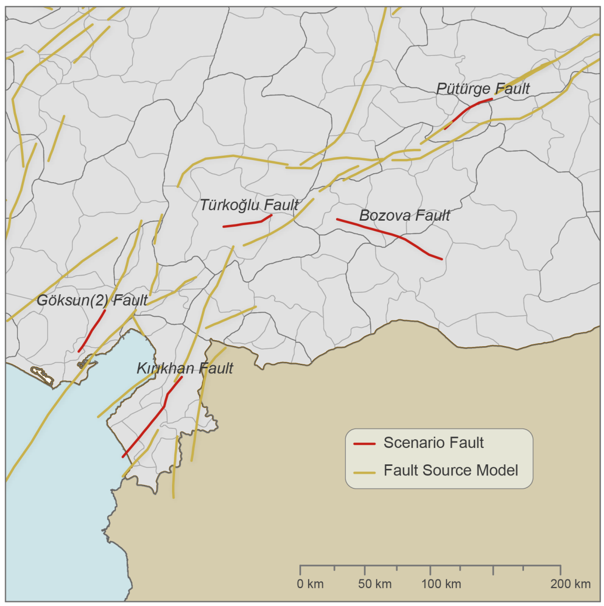

Figure 5. Fault locations selected for earthquake scenarios.

4.3 ~~Casualty estimations~~

~~A variety of techniques exist for performing earthquake casualty estimation. Jaiswal et al. (2011b) defines~~

4.3 Fatality estimations

There are a variety of methods for estimating earthquake fatalities. Jaiswal et al. (2011b) specifies three primary categories: empirical, analytical, and hybrid approaches. ~~Empirical and analytical methodologies exist at opposite ends of the spectrum, with empirical approaches estimating casualties as a function of past losses in similar geographical areas while analytical~~

~~methodologies estimate casualties using structural engineering approaches. Hybrid, or~~ The three categories differ in their input data. Empirical methods derive fatality rates from historical records, analytical methods use detailed structural engineering and building occupancy information, and hybrid (semi-empirical~~approaches can be thought of as simplified analytical approaches, estimating casualties using~~) approaches use empirical estimates of ~~structural parameters~~building collapse rates and occupancy. The choice of methodology ~~depends primarily on~~ is usually dictated by data availability and the scale of analysis (Jaiswal et al., 2011b).

~~This analysis seeks to assess the impact of refugee migration on the magnitude of earthquake casualty estimates. Fully empirical approaches that rely on fatalities in past earthquake events are~~ In this study, a semi-empirical methodology was used to estimate fatalities in earthquake scenarios. Empirical approaches were deemed poorly suited to ~~analyzing short term variability in loss estimations, a fundamental portion of this analysis. A fully analytical approach would be preferable, but the structural engineering~~ this particular problem because fatality rates are derived from numerous historical earthquake events. This study is based on the concept that earthquakes in the short term will have higher fatalities due to contextual population increases. Analytical approaches, while the most robust of the three methods, also have the highest data requirements. The structural performance and building occupancy data ~~does not exist to support such calculations. Even if structural information was available at the individual buildings level, improved refugee settlement data would be necessary for disaggregating province level refugee populationsinto specific building occupancy. Therefore~~necessary to support an analytic approach is not available for Turkey, even before considering the challenges of including refugee populations. Accordingly, this study ~~instead employs the hybrid,~~ employs the semi-empirical ~~loss estimation~~ approach detailed in (Jaiswal and Wald, 2010), given by Eq. (1).

$$E[L] \approx \sum_{i=1}^{n}\sum_{j=1}^{m} P_i \times f_{ij} \times CR_j(S_i) \times FR_j \qquad (1)$$

This approach estimates fatalities given a series of n grid cells and m structural types. Each grid cell's population P_i is first broken out into a fractional percentage for a given structural type f_{ij}. Fatalities are then calculated based on of the collapse rate of structural type j ($CR_j(S_i)$) at macroseismic intensity (S_i), and the fatality rate FR_j of structure type j under collapse (Jaiswal and Wald, 2010).

Empirical data from the World Housing Encyclopedia (WHE)-PAGER project, phase I, was used to constrain collapse rates. Jaiswal and Wald (2009b) provides estimates of the building stock distribution under the PAGER taxonomy along with estimated collapse percentages. It is noted that several of the collapse probabilities ~~for Turkey are listed higher than those generalized for European macroseismic scale intensities~~ in Jaiswal and Wald (2009b) are higher than estimates that have been generalized across the entire WHE-PAGER phase I dataset (Jaiswal et al., 2011a). Accordingly, when available, collapse rates ~~are~~ were calculated using generalized fragility coefficients (listed in Appendix A) using Eq. (2). For building types without published coefficients, values ~~have been~~ were estimated using the methodology in Jaiswal and Wald (2010), minimizing the residual error of the power function in Eq. (2) fit to a single set of collapse rates at given intensities. Fatality rates ~~are implemented using values~~ were drawn from Jaiswal and Wald (2010) for building types with HAZUS-MH fatality rates, and generalized Turkish values from Porter et al. (2008) in their absence.

$$CR_j(S) = A_j \times 10^{\frac{B_j}{S - C_j}} \tag{2}$$

~~The casualty estimation process was implemented by loading the average peak~~

4.3.1 Implementation

All fatality estimations were calculated using R statistical software. Peak ground acceleration (PGA) values for each ~~scenario into GIS software and spatially joining them to the gridded population model. The grid raster for each scenariowas exported to a CSV file containing each cell's district identifier code, PGA value, pre-migration population estimate, and migrated population estimate. These CSV files were combined with the fragility information provided in Table 2 and population distribution information from Table~~ earthquake scenario were converted to Modified Mercalli Intensity values using the relationship specified in Wald et al. (1999) and spatially joined to both refugee and non-refugee populations. For each scenario, fatality estimations were first calculated for non-refugee populations. At each grid cell, populations were fractionally divided into building types using the occupancy distributions shown in Table 3 ~~to implement Eq. (1) in R. For each grid cell, the PGA value was converted to Modified Mercalli Intensity values using the relationship of Wald et al. (1999) and the gridded cell populationswere fractionally divided into building types according to the percentages in Table~~ and an urban rural classification of 150 persons per kilometer (based on the definition in OECD (1994)). Collapse and fatality percentages for each building typology ($CR_j(S_i)$ and FR_j) were drawn from Table 2. ~~While~~ The same framework was applied to refugee populations, but several adjustments were made to account for increased uncertainty in the housing situation of refugees. Instead of using the occupancy percentages in Table 3 (which represent expert estimates for local populations), refugee populations were distributed into 500 semi-random occupancy tables. All other parameters (collapse rates, fatality rates, urban-rural classifications) remained the same. Total scenario level fatality estimates were then finalized by summing median refugee fatality estimates with non-refugee fatalities.

Refugee occupancy tables were generated by sampling normal random number generators. Unique generators were created for every building type in all population distribution scenarios (urban day, urban night, rural day, rural night). The normal distributions for each generator were based on the information in Table 3: means were set to the existing occupancy percentages and standard deviations were set to the calculated standard distribution for each population distribution scenario. This approach was chosen over manual specification or fully-random percentage generation for several reasons. First, it is probable that the ~~structural occupancy~~ building distribution of refugees is ~~different than~~ loosely similar to that of local populations~~(approximately 25% of refugees live in makeshift or rubble housing (3RP, 2015)), estimates for this distribution were not sufficiently known and both population sources were distributed equivalently. Any cell with a population density greater than 150 persons per kilometer was assigned an urban distribution while the rest were assigned a rural distribution (OECD, 1994). Each scenario's gridded population was distributed for both daytime and nighttime percentages using the corresponding informationin Table 3.~~, given the implicit understanding that the available building stock in a given region is largely fixed. Secondly, determining

Table 2. Collapse rates and fatality rates by structural type

Structural Class	PAGER-WHE Type	Collapse % by Intensity VI	VII	VIII	IX	FR (%)
Masonry	DS	0	1	14	45	8
	A	2	17	48	90	6
	UFB	0	3	18	43	6
	UCB	0	0	3	10	8
Structural Concrete	C2	0	0	0	2	15
	C3	0	0	2	11	15
	C6	0	1	5	15	15
	C7	0	2	22	45	15
	PC2	0	1	6	15	15
Steel	S1	0	0	0	1	14
Wood	W	0	2	10	20	13

Collapse rates are rounded to the nearest percent.

Table 3. Building occupancy percentages by structural type and time of day, from Jaiswal and Wald (2009b).

Structural Class	PAGER-WHE Type	Urban Daytime	Urban Nighttime	Rural Daytime	Rural Nighttime
Masonry	DS	4	15	0	1
	A	2	15	0	2
	UFB	25	35	15	35
	UCB	5	5	15	25
Structural Concrete	C2	5	0	5	0
	C3	40	25	50	36
	C6	5	0	6	0
	C7	8	0	5	0
	PC2	2	0	2	1
Steel	S1	0	0	1	0
Wood	W	4	10	1	1

Daytime refers to working hour percentages, nighttime to living hour percentages.

the central tendency and variance of refugee fatalities across hundreds of occupancy tables provides a reasonable way to characterize occupancy related fatality variations in the absence of further information.

5 Results and discussion

Fatality estimates for fifteen earthquake scenarios were calculated for this study, covering three earthquake magnitudes on five fault zones in southeastern Turkey. For each earthquake scenario, fatality estimates were produced for non-refugee and refugee populations in both daytime and nighttime building occupancy distributions. Tables 4 and 5 present fatality estimates for all fifteen earthquake scenarios. Table 4 shows baseline fatality estimates produced using the gridded population model without incorporating Syrian refugees. Table 5 shows the median fatality estimates and median absolute deviations resulting from the refugee population model.

5.1 Interpreting Fatality Estimates

The results presented in Tables 4 and 5 were transferred directly from fatality calculations without applying any rounding. Non-rounded values were included to allow for closer comparisons to be drawn between individual scenarios. However, this choice may inadvertently suggest that the values presented are very precise—this is not the case. Every attempt has been made to utilize the best data available, but semi-empirical fatality estimations remain a fundamentally uncertain process and will not be perfectly accurate. Yet, there is ample evidence to suggest that fatality estimations remain a useful procedure for determining disaster scale and response capacity needs (Wyss, 2004; Erdik et al., 2011; Jaiswal et al., 2011b). The U.S. Geological Survey provides the following estimates for response levels at varying earthquake fatality thresholds:

- 1-100 Fatalities: regional response required
- 100-1000 Fatalities: national response required
- 1000+ Fatalities: international response required

It is also stressed that the values shown in Tables 4 and 5 do not represent fatality predictions for future earthquakes. Rather, the fatality estimates are better interpreted as order of magnitude estimates for hypothetical earthquakes of varying size and location. Therefore, the conclusions drawn henceforth are scenario specific—and should be only generalized to other scenarios with appropriate caution.

5.2 Baseline Fatality Estimates

Fatality estimations were first produced for non-refugee populations to provide baseline values. These baseline values, shown in Table 4, help determine how earthquake fatalities in southern Turkey scale vary with earthquake magnitude, location, and time of day. At all five fault locations, increasing earthquake magnitudes from 5.8 to 6.4 corresponded with larger fatality increases (241% on average) compared to subsequent increases when magnitudes were changed from 6.4 to 7.0 (175% on average). These results are expected given the logarithmic relationship between magnitude and intensity.

Nighttime fatalities were estimated higher than daytime fatalities in all fault locations (an average of 160%). This indicates that the building stock distribution occupied during working hours is less susceptible to collapse than the building stock

Fatality estimates prior to including refugee population statistics.

Table 4. Fatality estimates for non-refugee populations

Fault	M_w	Daytime Casualties Daytime Fatalities	Nighttime Casualties Nighttime Fatalities
Pütürge	5.8	27	62
	6.4	91	178
	7.0	202	372
Türkoğlu	5.8	430	657
	6.4	945	1380
	7.0	1514	2187
Kırıkhan	5.8	1268	1886
	6.4	2832	3991
	7.0	4461	6144
Göksun	5.8	773	1119
	6.4	1712	2402
	7.0	2944	4099
Bozova	5.8	646	980
	6.4	1335	1942
	7.0	2111	3055

distribution occupied during nighttime hours. These results are supported by the occupancy patterns seen in Table 3, which shows that populations generally transitioning from vulnerable masonry buildings at night to concrete structures during working hours. Additionally, it is probable that the percentages of population located outdoors is higher during working hours compared to nighttime hours, especially in rural environments. These findings add to the growing volume of research stressing the importance of including temporal elements into natural hazards studies (Chen et al., 2004; Ara, 2014; Aubrecht et al., 2012; Freire and Aub

Every earthquake scenario included in this study produces casualties that would require at minimum regional response. Many of the scenarios, especially at earthquake magnitudes 6.4 and higher, would likely require national or international response. These results indicate consistently high levels of seismic risk across most of southeast Turkey—a region with a deep history of deadly earthquake activity (Ambraseys, 2009). The differences in fatality estimates between fault locations register the relative proximity of each fault segment to areas with high populations. The two fault segments with the highest fatality estimates, Kırıkhan and Göksun, are both located within some of the highest population districts across southeast Turkey.

5.3 Refugee Fatalities

Median fatality estimates and median absolute deviations based on 500 building occupancy iterations are shown in Table 5. The median absolute deviations of refugee fatality estimations, based on adjustments in building occupancy percentages, range from 25-55% of median estimates. These variations may have implications for the severity of a particular earthquake event, but in general, they do not dramatically change the estimated impact levels due to refugee populations. At four of five fault locations, median fatality estimates reach over 100 fatalities for earthquakes above magnitude 6.4. Accordingly, refugee populations are sufficiently large to produce fatality estimates that would require local or regional response. On the Kırıkhan fault, refugee populations are high enough to merit international response. Thus, it is clear that refugee populations in southeastern Turkey should be included in the fatality estimation process.

However, in comparison to baseline fatality estimates, refugee populations constitute relatively small portions of overall fatalities. The relative contributions of refugee and non-refugee populations for each scenario are compared in Figure 6. The Kırıkhan fault scenarios have the highest refugee contributions, with 25-27% of total scenario fatalities coming from refugee populations. The Göksun, Bozova, and Türkoğlu scenarios all have 7-9% refugee fatalities, and the Pütürge has only 1-2% refugee fatalities. These differences reflect the distribution of refugees throughout the study region which is similar, but not identical to existing population distributions. As a result, refugee contributions to total fatality estimates are not tied to baseline fatalities. The relationship is fairly close for the scenarios in this study, but as a general rule, baseline fatality estimates should not be assumed to be good predictors of refugee fatality estimates.

The total number of projected casualties in a particular earthquake scenario depends on the spatial overlap between population, shaking intensity, and structural type distribution. Adjustments in any of these parameters affects the number of projected casualties. This study estimated casualties for fifteen earthquake scenarios representing three earthquake magnitudes at five geographically distributed fault zones . Casualties were calculated for both daytime and nighttime hours and refugee inclusive and refugee exclusive population scenarios, producing a total of four casualty estimates for each earthquake scenario. The results indicate intra-fault, inter-fault, and temporal differences in earthquake casualty projections across the study area, as well as notable casualty increases after refugee inclusion.

Tables 4 and 5 present the casualty numbers for each of the twelve earthquake scenarios. Table 4 provides baseline casualty estimates produced using the gridded population model before Syrian refugee adjustment, while Table 5 updates the estimations using the refugee inclusive population model. It is important to highlight that the values presented in Tables 4 and 5 are not specific casualty predictions for future events, but representations of the order of magnitude that could be expected in events of varying size and location. Therefore, any conclusions drawn henceforth are scenario specific—and should only be generalized to other scenarios with appropriate caution.

5.4 Uncertainty in semi-empirical methods

Ground motions, population estimates, collapse rates, fatality rates, and occupancy patterns are all subject to varying levels of uncertainty in the semi-empirical model. In the context of this study, two particular sources of uncertainty are worth highlighting.

~~Casualty estimates after including refugee population statistics.~~

Table 5. Median fatality estimates for refugee populations

Fault	Mw	~~Total (Day)~~ Median Fatalities (Day)	~~Total (Night)~~ Median Fatalities (Night)	~~New (Day)~~ MAD* (Day)	~~New (Night)% Diff~~
Pütürge	5.8	~~28~~ 0	~~63~~ 0	~~1~~ 0	
	6.4	~~92~~ 2	~~181~~ 2	1	
	7.0	~~205~~ 4	~~377 3~~ 5	~~1.5~~ 1	
Türkoğlu	5.8	~~466~~ 39	~~711~~ 52	~~36~~ 18	
	6.4	~~1022~~ 83	~~1492~~ 108	~~77~~ 35	
	7.0	~~1637~~ 134	~~2363~~ 172	~~123~~ 53	
Kırıkhan	5.8	~~1594~~ 354	~~2371~~ 466	~~326~~ 193	
	6.4	~~3560~~ 774	~~5017~~ 987	~~728~~ 360	
	7.0	~~5607~~ 1195	~~7723~~ 1519	~~1146~~ 510	
Göksun	5.8	~~773~~ 59	~~1119~~ 76	~~55~~ 28	
	6.4	~~1712~~ 131	~~2402~~ 168	~~123~~ 58	
	7.0	~~2944~~ 228	~~4099~~ 291	~~216~~ 97	
Bozova	5.8	~~694~~ 55	~~1056~~ 74	~~48~~ 18	
	6.4	~~1437~~ 116	~~2099~~ 152	~~102~~ 36	
	7.0	~~2285~~ 201	~~3321~~ 258	~~174~~ 65	

*Median Absolute Deviation

1. When compared across all countries, WHE collapse functions have shown tendencies towards overestimating fatalities, with more significant effects in smaller earthquakes (Porter et al., 2008).

2. There are issues with the use of empirical occupancy percentages. Specifically, transit periods are not included and the outdoor population percentages are not accounted for.

~~Consistent trendsRefugees and local populations were disaggregated using a consistent methodology across population scenarios. Accordingly, several of the trends drawn from Table 4~~ A general shortcoming of fatality estimation processes is the difficulty in separating out individual uncertainty terms. As a result, uncertainties are often wrapped together into a total model uncertainty term (Jaiswal et al., 2009). The USGS PAGER implementation of total model uncertainty specifies the probability P of estimated losses e falling between two thresholds a and ~~5 are consistent across every population scenarios and not tied to refugee migration. At all five fault locations, increasing earthquake magnitude from 5.8 to 6.4 resulted in a larger casualty increase (241% average) than the subsequent 6.4 to 7.0 magnitude increase (175% average). This reflects the non-linear relationship between earthquake magnitude , intensity, and building collapse rates. Increases in earthquake ground motions, not magnitude, are the driving force behind increase earthquake casualties. These results are consistent with general~~

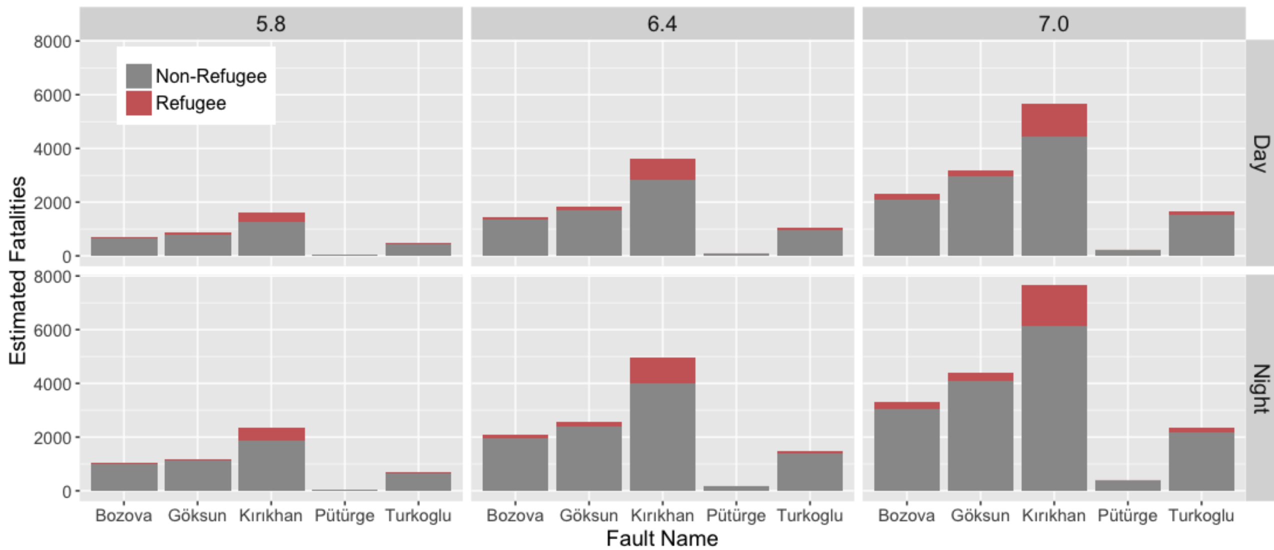

Figure 6. Refugee and non-refugee contributions to total estimated fatalities across all earthquake scenarios. Estimated fatalities are separated by time of day and earthquake magnitude.

~~magnitude–intensity relationships. Areas simulated with PGA values high enough to produce building collapse are highly localized for magnitude 5.8 scenarios compared to larger magnitudes. However, local site conditions or poorly constructed buildings can amplify casualties even in moderate magnitude earthquakes—the 1960 Agadir earthquake in western Morocco resulted in 15,000 casualties despite a moment magnitude of 5.7 (Paradise, 2005).~~ b as Eq. (3).

~~Nighttime casualties were forecasted consistently higher than daytime casualties in all fault locations (an average of 160%). This indicates that the building stock distribution occupied during working hours is less susceptible to collapse than the building stock distribution occupied during living hours. These results follow out of Table 3 which shows populations generally transitioning from vulnerable masonry buildings to concrete structures during working hours. These findings add to the growing volume of research stressing the importance of including temporal elements into natural hazards studies (Chen et al., 2004; Ara, 2014; Aubr~~

$$P(a < e <= b) = \Phi[\frac{log(b) - log(e)}{\zeta}] - \Phi[\frac{log(a) - log(e)}{\zeta}] \quad (3)$$

~~Inter-fault casualty differences reflect the location of particular faults to population centers. The two highest casualty locations, the Krkhan~~ This implementation relies on a hindcasted country-specific residual error term, ζ, defined as the normalized standard deviation of the logarithmic ratio of expected to recorded losses (Jaiswal et al., 2009).

Because fatality estimations are generally considered to be order of magnitude estimates, a and ~~Göksun fault segments, extend over several of~~ b are commonly set to one order of magnitude above and below median estimated fatalities (Jaiswal et al., 2009). Using the ζ value for Turkey (1.52), the ~~highest population districts in all of southeast Turkey. With casualties estimates ranging~~

from hundreds at magnitude 5.8 to thousands at magnitudes 6.4 and 7.0, these scenarios indicate serious consequences in the event of similar earthquake ruptures. The proximity of major cities and other population dense areas to faults strongly contributes to increased earthquake casualty estimates in this region. This has been historically true as well, with earthquakes repeatedly destroying ancient cities near the modern day provinces of Hatay and Adana (Ambraseys, 2009). probability P of actual fatalities in a given scenario falling within one order of magnitude above and below median estimated fatalities is 49%. Thus, there is a 25.5% chance that actual fatalities are greater than one order of magnitude above median estimated values and a 25.5% chance that actual fatalities are less than one order of magnitude below median estimate values. These relationships apply to every scenario in this study.

5.5 Refugee related trends

Examining the new casualty and percent difference statistics in Table 5 shows that the presence of refugees has a non-trivial impact on earthquake impacts. Consistent increases in simulated casualties reflects the widespread presence of refugees amongst Turkey's southeast districts. The varying percentages between fault locations reflects the distribution of refugee populationsacross the study area. Syrian refugee settlement patterns do not directly correspond to those of existing populations. While several previously populated areas in southeast Turkey (Adana and Gaziantep) have sustained similarly large refugee populations , many refugees are settled in less populated provinces like Hatay, Şanlurfa, and Kilis. Kilis represents the extreme end of the spectrum with approximately 120, 000 Syrian refugees settled amidst an existing population of only approximately 130,000 individuals.

Understanding these variations explains the differences in the earthquake casualties by location. Table 5 shows total casualties, which reflects both population sources, and new casualties that reflect the impact of refugee adjustment. The percentage difference statistic measures the relative difference between these two values. The findings show that the Krkhan fault scenarios sustain the largest percent increases in addition to retaining the most overall casualties. However, this pattern is not consistent. The Türkoğlu and Bozova fault scenarios show the second largest percentage increases, but have less total casualties than the Göksun fault scenarios at comparable magnitudes. The Pütürge fault remains the least deadly earthquake location and has negligible percent increases from refugee migration.

It naturally follows that provinces with larger population increases will sustain larger percentages of additional casualties in nearby earthquakes. Yet, it had not been previously shown what casualty magnitude should be associate with current refugee populations. The results from this studyindicate that casualty underestimations range from 1-26%, varying with location. These percentages translate into a wide range of casualty counts. The deadliest of the simulated earthquakes, a moment magnitude 7.0 rupturing the Krkhan fault during nighttime hours equated to 1579 additional casualties compared to the base population scenario estimate, while the least deadly Pütürge scenario only produced one additional casualty after refugee adjustment. For magnitude 6.4 earthquakes and above, refugee inclusion adds hundreds of casualties to the total event values at four of five fault locations, a notable severity increase.

It is noted that our simulations find the refugee related casualty increases at the event level to be close to an average of the province level refugee populations within affected provinces. This implies that, in the absence of additional data, applying a static severity increase in proportion to province migration statistics may be sufficient as a minimum estimate .

6 Conclusions

This study assessed the impact of Syrian refugee migration on earthquake casualty fatality estimations in southeastern Turkey using a semi-empirical loss estimation technique on minimally modeled gridded population datasets created from refugee statistics and Turkish ABPRS district level population data. It was shown that using the refugee adjusted population model in the earthquake fatality estimation process increased casualties in proportion to migrated population exposure. Earthquake scenarios on four of the five fault zones included in this study produced tens to hundreds of additional casualties after the inclusion of refugee data, with a maximum of 1579 extra casualties and a minimum of one extra casualtyrefugee populations in southeastern Turkey are sufficiently large to produce fatality estimates requiring local or national relief—fatalities on the order of tens to two thousand individuals, varying with location and earthquake magnitude. Refugee fatalities estimates were then compared to non-refugee fatality estimates, showing that the relative contribution of refugee populations on total estimated fatalities ranges from 1-27%. While it naturally follows that places with population increases will sustain additional casualties in earthquakesmigration resulting in increased populations results in additional estimated fatalities for earthquake events, it had not yet been shown the degree to which current refugee populations impact loss estimations . determined to what degree current refugee levels would contribute to total fatality estimates.

Because of data limitations, this study incorporated refugees into earthquake fatality estimations with large uncertainties. This creates a number of follow up research opportunities. Dedicated studies investigating the structural conditions, spatial distribution, or migration patterns of refugee populations, among other topics, would improve the efficacy of earthquake risk assessment in countries with high refugee populations. Further work characterizing the vulnerability of refugees is an also important future step in understanding how their presence influences earthquake risk assessments.

Characterizing the expected casualty fatality increases related to refugee migration populations is an important step in loss estimation—even if a basic province-level correction is a sufficient adjustment. Disaster scale underestimations estimation methodologies. Underestimations of disaster scale have the potential to greatly complicate the work of local governments and aid agencies working to respond to earthquake disasters (Jaiswal et al., 2011b). Accordingly, adjusting population models for refugee presence is an important consideration with casualty underestimations in high migration regions reaching hundreds of individuals. These adjustments will only increase in importance as more refugees flee into southeast Turkey alongside the evolving conflict in SyriaThe results of this study help to characterize the scale of potential fatality underestimations in southeastern Turkey and communicate the greater importance of placing natural hazards studies in an appropriate regional context. This study also provided a methodology for making such contextual population adjustments in places where census data remains the de facto standard for environmental hazards studies. These types of approaches will only become more relevant as more refugees flee from the conflict in Syria into southeast Turkey.

~~This study incorporated refugees into earthquake loss estimations at the minimum possible level—considering them equal to that of local citizens. Further work improving the ability to characterize the seismic vulnerability of refugees is an important future step in understanding how their presence influences natural hazard evaluation. Changes in refugees' freedom of movement, reporting requirements, and settlement locations all affect the ability to uniquely incorporate them into earthquake risk analyses. In areas where the relative percentage of refugees amongst local populations continues to increase, understanding where and how refugees are being accommodated should be a fundamental focus for earthquake related studies.~~

7 Data availability

The population models used in this project were constructed with freely available and frequently updated data from the address based population registration system (Turkish Statistical Institute, 2015) and the Turkish Ministry of Interior Directorate General of Migration Management (Republic of Turkey, 2015). The Global Earthquake Model's OpenQuake platform was used to produce all earthquake simulations (GEM, 2016) in this study. The source models used as the basis for these simulations are available from the SHARE initiative (Giardini et al., 2013). Site amplification data used in scenario creation is available from the U.S. Geological Survey's global Vs30 grid (U.S. Geological Survey, 2013), described in Wald and Allen (2007). Building occupancy and collapse rate data from the WHE-PAGER phase I survey is published in Jaiswal and Wald (2009b). Please contact the corresponding author for the R loss estimation code or GIS processing workflows.

Appendix A

The process for determining fragility coefficients is described at length in Jaiswal et al. (2011a), with selected building types presented. A more complete list of coefficients was presented at the summer 2009 WHE-PAGER workshop (Jaiswal and Wald, 2009a).

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Table 6. Fragility coefficients

PAGER-WHE Type	A	B	C	R^2
DS	9.52	-4.89	5.32	0.95
A	10.76	-5.34	4.05	0.91
UFB	3.88	-4.22	4.97	0.94
UCB	2.15	-5.18	5.11	0.95
C2	1.95	-6.14	5.90	0.89
C3	3.42	-5.03	5.62	0.93
C6*	2.55	-5.03	4.91	-
C7*	1.94	-1.91	5.99	-
PC2	0.85	-2.35	5.90	0.95
S1	0.45	-8.71	4.40	0.80
W6*	1.14	-2.66	5.49	-

R^2 denotes uncertainty compared to building performance records. Asterisks indicate building types with fragility coefficients calculated from a single expert estimate.

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Dear Editors & Reviewers:

We appreciate the constructive feedback on our manuscript. We have significantly edited our manuscript in response to reviewer comments. Particular focus has been placed on improving our discussion of relevant uncertainties and framing the results in the context of methodological limitations.

Overview of Major Changes

1. The title of the manuscript has been changed slightly to reflect the manuscript-level terminology change from 'casualty' to 'fatality'.

2. We have substantially edited the entire manuscript for clarity, consistency, and style. Special attention has been made to terminology concerns raised by reviewers, sources of uncertainty, and limitations.

3. We have introduced a major change in how building occupancy for refugees is calculated. The model now simulates a range of potential occupancy patterns for refugee populations to assess the magnitude of corresponding fatality variations. The related methodology, results, and discussion sections have been reworked accordingly.

4. The format of the discussion has been smoothed out. Fatalities are now discussed for non-refugee and refugee populations separately, then compared. Additionally, the comparison between refugee and non-refugee fatalities is now in the form of a new Figure instead of a table. We feel these changes better contextualizes the nature of the study.

5. Two subsections have been added to the discussion. One introduces the interpretation of fatality estimates and the other discusses total model uncertainty. We feel that that the addition of these two sections properly frames the limitations of our results.

Response to Reviewers

Referee 1:

Migration data accuracy concerns:

Concerns were raised over the migration data accuracy. We have included a more substantial explanation of where these statistics come from and what they cover. We have added a statement distinguishing between refugee populations and displaced persons, indicating that the data we used only covers registered refugee populations and may underestimate the total number of Syrians present in our study area. We have also improved the clarity regarding our disaggregation methodology and its relative strengths and drawbacks. (p. 6-7, section 4.1.1)