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GLOBAL IMPACT DISTRIBUTION OF ASTEROIDS AND AFFECTED POPULATION

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EXTENDED ABSTRACT

Introduction

The asteroid threat is a global concern because asteroids can hit the Earth in any region. This conclusion is supported by historical infra-sound microphone recordings that capture bolides (NASA 2014) and the geological crater record (EDEIS et al. 2006). The tools and results in this paper expand the global impact distribution into the future and analyze it in the context of global population data. Potential impacting asteroids are retrieved from the NEODyS risk list and their impact sites are calculated (Universita Di Pisa & European Space Agency 2014). This work is based on a large sample size of 261 virtual impactors. The tools presented here can be employed to analyze individual threatening asteroids that will be discovered in the future to support asteroid threat decision-making.

Method and Results

The Asteroid Risk Mitigation Optimization and Research (ARMOR) tool projects the impact probability of observed asteroids onto the surface of the Earth. The process to accomplish this starts with the ephemerides and orbital data that are available from ESA's asteroid risk list (Universita Di Pisa & European Space Agency 2014). OrbFit is a freely available software package by SpaceDys that is used to find virtual impactors (VIs) of an asteroid given its ephemeris and orbital uncertainty information. Additionally, global impact probability and orbit determination uncertainty are provided for each VI. The data are passed to ARMOR. Utilization of a simplified line of variation (LoV) method (Milani et al. 2005), allows the establishment of potential impact sites in the form of an impact corridor. The LoV method was simplified by assuming that the weak direction of the orbital uncertainty region coincides with the direction of the velocity vector of the VI in its immediate vicinity. This process was repeated for 70 asteroids yielding 261 VIs.

Validation of the ARMOR tool was done by employing case studies of asteroid 2011AG5 and 2008TC8. In the case of 2011AG5 successful cross-validation with other predictive software tools was accomplished. Additional details on this case are provided in (Rumpf 2014). Asteroid 2008TC3 was discovered shortly before entering the Earth's atmosphere. Its entry point was predicted and the resulting bolide was observed by eye witnesses, satellite and infra-sound sensors (Chesley et al. 2014). For validation, ARMOR used the nominal orbital solution for 2008TC8 and predicted the atmospheric entry point as well as the ground track (Figure 1). The predicted nominal entry point agreed to within 0.39º longitude and 0.12º latitude at 65.4 km altitude. Furthermore, the shape of the ground track agreed well with the literature. The validation results demonstrated sufficient accuracy of ARMOR for the problems addressed in this paper.

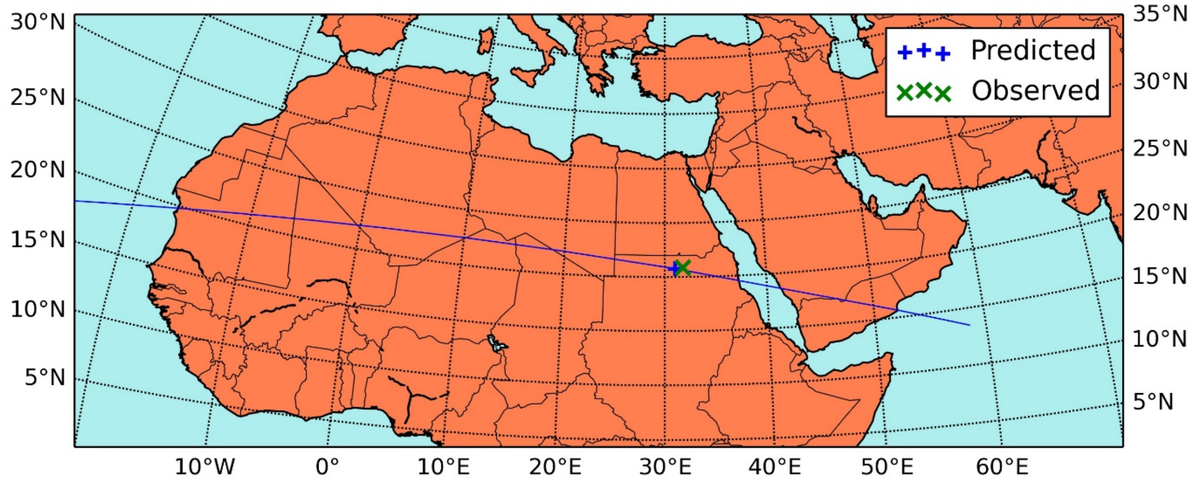

Figure 1: Observed and predicted entry point for asteroid 2008TC3. The blue plus sign marks the point of the nominal entry solution while the green cross gives the solution of the observed entry point at the same altitude of 65.4 km.

For each VI, the spatial impact probability distribution was obtained by centering a Gaussian distribution on the impact corridor center line with a width corresponding to the orbit determination accuracy (line of variation width). Each impact probability distribution was assigned a cumulative impact probability equal to the global impact probability of that VI. All 261 impact probability corridors were superimposed to obtain a global representation of the asteroid impact probability distribution (see Figure 2). The data represents the currently known situation until the year 2100.

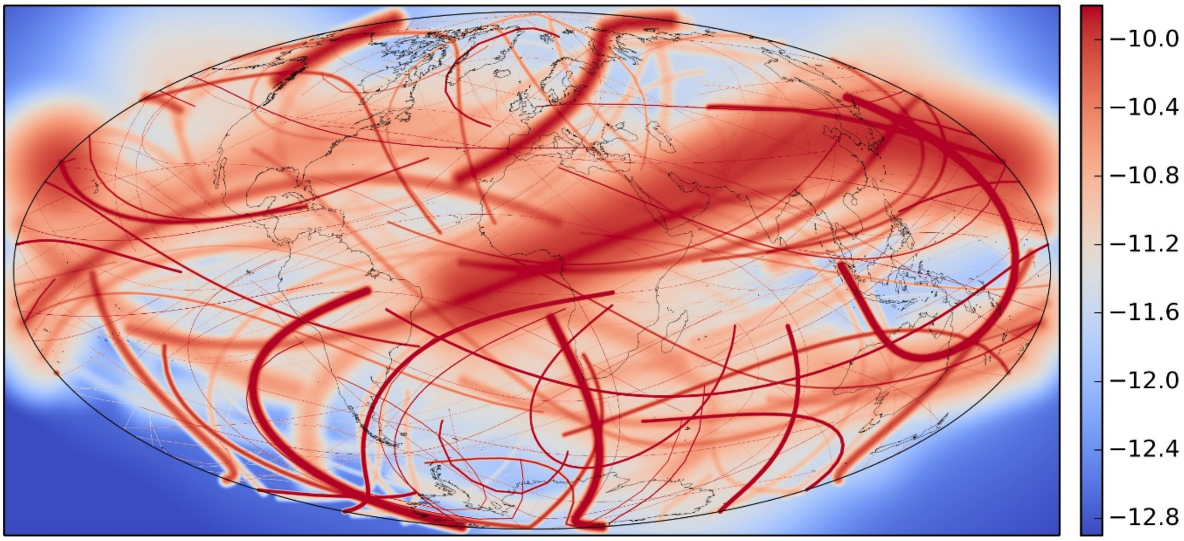

Figure 2: Visualization of 261 impact probability corridors using a logarithmic scale. The map is dominated by high impact probability VIs while lower probability VIs are barely visible.

The hammer projection was used because it provides an equal area representation for the entire projected surface. This is important because it permits the probability corridor to run over the globe with constant width.

Global population data were needed for further analysis. The data were provided by (CIESIN et al. 2005). Figure 3 shows the population distribution as estimated for the year 2015 on a logarithmic scale.

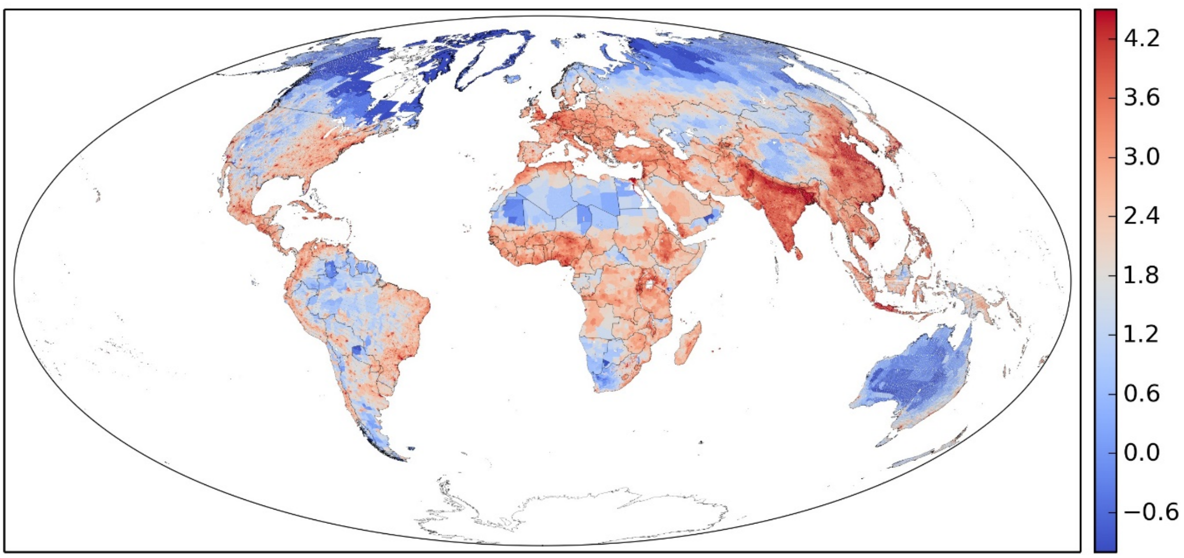

Figure 3: World population distribution data shown using a logarithmic scale in population per pixel.

To understand which part of the world's populations are potentially affected by the asteroid threat and to provide a visual representation of this risk, the global impact probability distribution shown in Figure 2 was multiplied with the population data in Figure 3. The result is shown in Figure 4. It is a risk representation assuming that the population affected by an impact dies (vulnerability is one). In all coloured regions, populations are potentially affected and the colour coding shows the level of risk in that region.

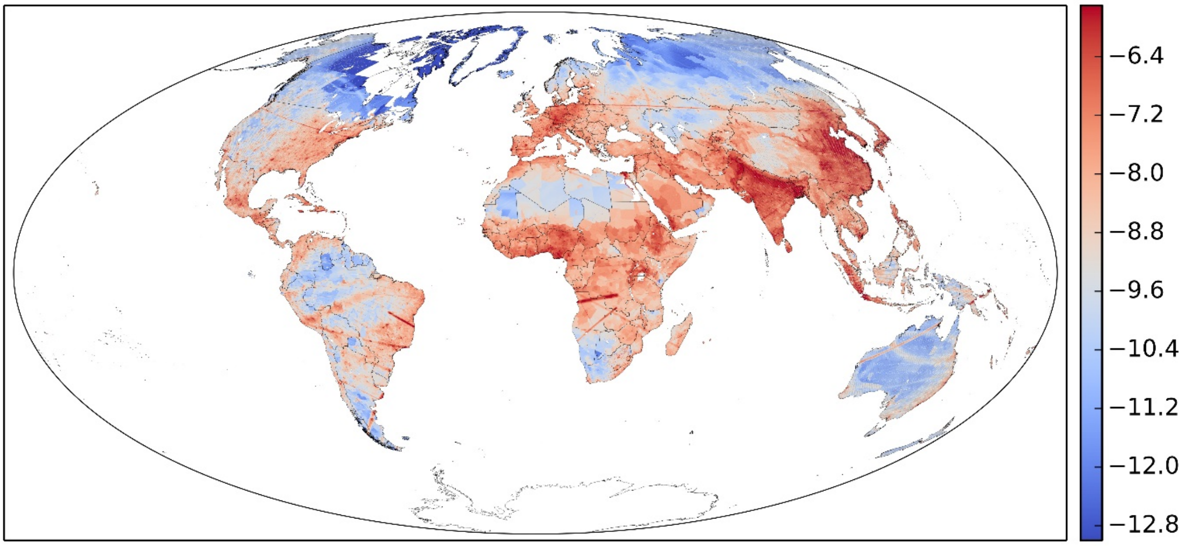

Figure 4: World population distribution that is potentially affected by the asteroid threat. The map uses a logarithmic colour coding. This map is also referred to as the risk distribution.

Discussion

The 261 impact corridors shown in Figure 2 appear to be distributed randomly across the globe. This result is coherent with historical records of geological impact features as well as global bolide recordings. It is concluded that every region on the Earth can potentially be affected by an asteroid hit. In general terms, regions that exhibit a higher population density are associated with an elevated risk with respect to the asteroid hazard because their potential losses are higher. This conjecture is confirmed in a comparison to Figure 4 which shows the affected population distribution across the globe. Regions that show higher risk correlate with regions of higher population density in Figure 3. India and China are amongst the most populous regions in the world and also show the highest risk. Other regions that show a clearly elevated risk are Europe, central Africa, the eastern part of the United States and the coastal regions of South America. All these regions are also densely populated.

The set of individual asteroid impact probability distributions determines the currently known risk of a region until the year 2100. High impact probability asteroids skew the risk map towards their ground tracks. This effect is visible in Figure 4 where the continents feature individual high probability impact corridors that have the capacity to raise the risk even in scarcely populated regions of the world, such as continental South America. Considering that the asteroid risk lists maintained by ESA and NASA are of a dynamical nature, the risk landscape changes with the discovery of new high impact probability asteroids and the exclusion of asteroids that were previously considered. The results presented here, therefore, represent a snapshot in time of the asteroid hazard.

The results presented here, do not account for the physical entry process that an asteroid experiences during its passage through the atmosphere nor the physical effects that an asteroid impact on the ground produces. Inclusion of physical asteroid strike effects will likely alter the risk distribution significantly. For example, it is expected that coastal regions will show a higher risk due to their vulnerability to tsunamis caused by oceanic impacts. Physical asteroid strike effects are a subject that will be addressed in the future. However, to demonstrate global vulnerability to asteroid impacts the method presented here suffices.

The demonstrated accuracy of ARMOR (see Figure 1) is sufficiently high to allow for the treatment of individual asteroids in the future should the need for such an analysis arise due to the detection of an asteroid that shows a high probability of impact. ARMOR will be able to identify high risk regions along the ground track of the asteroid and will, thus, help raise preparedness for a possible impact. Furthermore, knowledge about high risk areas allows the design of a deflection mission that avoids steering the asteroid towards one of these regions.

Conclusions

The presented software tools are capable of addressing the asteroid hazard in the context of global vulnerability as well as individual impact risk. The potential impact corridors of 261 virtual impactors were identified. They visualize the global nature of the asteroid threat. Population density is a significant determinant of local asteroid impact risk. The risk landscape will change when physical impact effects are considered or individual asteroids with a high impact probability are included in the analysis. The demonstrated accuracy of ARMOR allows for the possibility to treat individual asteroids in the future in the context of asteroid hazard response and deflection mission design.

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