AIRBURSTS: WE WILL SHOCK YOU!

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Introduction: An 'airburst' happens if a meteoroid loses almost all its energy in atmosphere, cannot strike the ground with high velocity to produce an impact crater, although strong shock waves generated during the entry may reach the surface and shock it dramatically. The entry of relatively small (~20 m in diameter) Chelyabinsk meteoroid in February, 2013 caused substantial economic problems, severe injuries, and panic among local people. If the Tunguska-like event occurred not in Siberia but above Moscow or any other megalopolis, the city and its population would be totally demolished. Impacts of small (<100 m) asteroids are much more probable jand may occur any time in the nearest future. Current estimates of airbursts effects [1] either utilize oversimplified analytical models or interpolate the effects observed after powerful nuclear explosions [2]. To assess hazardous consequences of small (1-200 Mton TNT) impacts in a wide range of scenarious we combine numerical modeling of the related physical processes with available observations of natural and technogenic catastrophes.

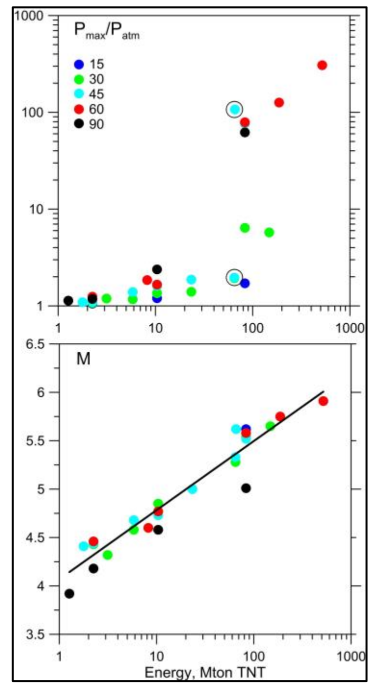
Methods: We use hydrocode SOVA [3] to model the atmospheric entry of a cosmic body (asteroid or comet, hereafter cosmic body, CB) and the interaction of generated shock waves with the surface. Details of the atmospheric entry model are presented in [4]. When the CB is totally transformed into a debris-vapor jet, 2D distributions are interpolated into 3D mesh. Due to computer capacity restrictions, 3D resolution is much lower, but the method allows to conserve the total energy and the momentum in the system. Calculated distriburions of overpressure on the ground allow us to estimate the energy of seismic waves and earthquake magnitudes.

Results: We have modelled the atmospheric entry for ~60 different scenarios. Values of maximum pressure, wind speed and total area subjected to overpressures of a certain value (0.2, 0.1, 0.05, and 0.02 of the standard atmospheric pressures) have been calculated and could be presented now as 'scaling laws'.

Pressure and winds on the surface: The shape of severely damaged area is almost circular for entry angles >45°; it is transformed into a butterfly with its 'wings' being perpendicular to the trajectory plane if impact angles are < 45° (e.g., Tunguska); highly oblique impacts (<20°) result in elongated 'wings' (e.g., Chelyabinsk). Relatively short overpressure pulse is followed by a long low-pressure pulse (60-90% of the standard atmosphere). Maximum overpressure jumps by an order of magnitude at entry energies of ~100 Mt TNT (see upper plate), when the airburst regime is transformed into the impact regime. Gas velocities are negligible below the epicenter, then increase quickly to 'hurricane' values and decay with distances in the same manner as pressure values.

Comets versus asteroids: Effects on the surface after cometary impacts are in general similar to those after asteroid impacts. If energies are the same, maximum pressures and winds are lower after a cometary impact although the total area of moderate damage (overpressure of 2%) is larger.

Earthquakes: Magnitudes of equivalent seismic sources vary from 4.0 (a 30-m-diameter comet at 20 km/s) to 5.9 (a 100-m-diameter asteroid at 50 km/s). Dependence of magnitudes on the angle and the velocity (for fixed energy) is rather small and irregular (bottom plate). Seismic efficiency calculated by Guttenberg-Richter equation ranges from 1.5×10^{-5} to 6×10^{-5}.



Overpressure on the surface (top plate) and earthquake magnitude (bottom) as a function of energy. Different colors show different impact angles.

Discussion: The low resolution of 3D simulations may lead to underestimates of maximum pressure and velocity values by 5-20%. Much larger effects could take place if the surface is uneven: high walls can cause shock waves interference and localized pressure peaks. Our models show that reliable estimates of affected areas and local effects require precise knowledge of CB's properties which are usually poorly known (or even totally unknown). It means that the results have to be treated as 'rough' estimates prior to the impact, but can be used to evaluate CB properties after the impact.

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