EFFECTS OF THERMAL RADIATION FROM IMPACT PLUMES.

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Introduction: Plumes that are formed upon the impacts of asteroids and comets and consist of rock vapor and air can have high temperatures. It seems that the thermal radiation from the plumes can be strong enough to be dangerous for people, can ignite fires and even melt rocks. The Chixculub impact of an asteroid 10–15 km in size generated global wildfires, and the 1908 Tunguska airburst caused by the entry of an object about 50 m in diameter generated a forest fire within a radius of 10–15 km [1]. It has been suggested that the layered (Muong-Nong-type) tektites from SE Asia and the Libyan Desert Glass had been formed by melting under radiation from aerial bursts produced by the breakup and atmospheric deceleration of cosmic objects [2–4]. Even the radiation from the 2013 Chelyabinsk bolide (an asteroid 20 m in diameter) caused temporal flash blindness of eyewitnesses [5]. Radiation fluxes on the ground from the impact plume produced by the Chixculub impact (assuming a vertical impact) and by a hypothetical impact of a 300-m asteroid (similar to the asteroid Apophis) have been calculated in numerical simulations [6, 7]. In a general case, thermal radiation damage can be estimated using an analogy with nuclear explosions and approximations of luminous efficiency of hypervelocity impacts [8]. In this study we have carried out 3D numerical simulations of impacts of stony and icy objects from 300 m to 3 km in diameter, entering the atmosphere at various angles, and calculated radiation fluxes on the ground.

Numerical simulations: The simulations of impacts were carried out using a hydrodynamic model, equations, and a numerical technique described, e.g., in [8]. We assumed that the cosmic object has no strength, deforms, fragments, and vaporizes in the atmosphere. After the impact on the ground, formation of craters and plumes was simulated taking into account internal friction of destroyed rocks and a wake formed in the atmosphere. The equations of radiative transfer, added to the equations of gas dynamics, were used in the approximation of radiative heat diffusion or, if the Rosseland optical depth of a radiating volume of gas and vapor was less than unity, in the approximation of volume emission. We used temperature and density distributions obtained in the simulations to calculate radiation fluxes on the Earth's surface by integrating the equation of radiative transfer along rays passing through a luminous volume. We used tables of the equation of state of dunite, quartz (for impactor and target) and air, and tables of absorption coefficients of ordinary chondrite vapor and air (see refs. in [8]).

Results: If an asteroid or comet hits the ground, the main source of radiation is vaporized material of an asteroid and a target in the impact plume. The vapor heated to temperatures 2000-2500 K reaches heights about 300 km if the asteroid diameter D=1 km and above 600 km if D=3 km. Luminous efficiency η (fraction of impactor kinetic energy emitted as thermal radiation) decreases with decreasing impact angle θ because for smaller θ less energy is transferred to the impact plume. For instance, for D=1 km, η=13% if θ=60° and η=8% if θ=30°. Duration of a thermal pulse from its beginning to its maximum τ is 100-150 s if D=1 km, in this case dry leaf litters can be ignited if maximum radiation flux density Q is 2-3 W/cm^2 [9]. The average radius R of the area of potential fire ignition is 800-1000 km. If D=3 km, τ =200-250 s and live pine needles are ignited at Q~3-4 W/cm^2 [9], R is about 1700 km.

A thickness of a melted layer of rock is determined by the coefficient of thermal diffusivity. For its typical values of 0.01 cm^2/s a layer thinner than 1 cm can be melted by thermal radiation from the impact plume at distances from about 100 km (for D=1 km) to several hundred kilometers (for D=3 km) from a crater. A layer of molten quartz can be thicker, a few centimeters thick, because radiation free paths in quartz are relatively large, about 1 cm [10]. The impact plume expands upward and falls back onto the atmosphere. As a result, a layer heated to temperatures about 2000 K is formed at altitudes around 200 km. This layer radiates only slightly because of low density of air but can substantially influence electromagnetic properties of the ionosphere.

Conclusions: Direct thermal radiation from impact plumes produced by asteroids and comets with a size larger than or equal to 300 m can be dangerous for people, animals, plants, and economic objects. Fires can be ignited on the ground within a radius of roughly 1000 times the body's diameter (for $D\leq$1 km), and rocks melted by thermal radiation could be found around impact craters on the Earth and terrestrial planets.

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