THERMAL RADIATION ON THE GROUND FROM LARGE AERIAL BURSTS CAUSED BY TUNGUSKA-LIKE IMPACTS.

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Introduction: The impacts of cosmic bodies from tens to hundreds meters in size can produce aerial bursts and leave no craters on the ground. This occurred in the 1908 Tunguska event in Central Siberia when a comet or an asteroid 50-100 m in diameter entered the atmosphere and released its energy at altitudes 5-10 km [1]. Thermal radiation from the Tunguska fireball ignited a forest in an area of about 200 km^2 [2]. Numerical simulations [3, 4] show that the thermal energy delivered to the ground by radiation peaks at about 1 kJ/cm^2 at the explosion epicenter. Larger impactors can produce higher thermal irradiance. Estimates [5] for grazing impacts of bodies about 1 km in size (rare events with extremely small entry angles to horizon) show that thermal radiation can ignite dry wood or other inflammables and melt soil in a strip some hundreds km long and a hundred km wide.

Large aerial bursts can melt soil and therefore their record may be preserved in glassy objects. It was suggested that layered tektites found in Southeast Asia might be the record of a melt sheet produced by a large aerial burst [6, 7]. A similar origin was ascribed to the Libyan Desert Glass [8, 9]. Some tektite properties are well explained by airbursts and inconsistent with the traditional view that layered tektites are crater ejecta [10]. The purpose of this work was to calculate thermal fluxes on the ground from aerial bursts created by impacts of cometary bodies entering the atmosphere at various angles to horizon.

Numerical Procedure: The hydrodynamic method SOVA [11] was used for the simulations of a flight through the atmosphere, meteoroid disintegration, and the following burst. Cometary impactors were treated as cylindrical (with a diameter equal to a height) water-ice bodies. A nonuniform grid had the best resolution of 20 cells across the impactor radius. Tabulated equations of state were used for air [12] and water [13]. As the size of a fireball in a plane perpendicular to a trajectory is smaller than the atmospheric scale, it was assumed that the flow has axial symmetry and the meteoroid moves through an exponential atmosphere with a scale height equal to $H/\sin\alpha$ km, where H=7.5 km. Cooling and heating of air and vapor due to radiation was calculated by solving an approximate equation of radiation transfer in radial direction [14] Radiation fluxes at some points on the ground were calculated at some instants of time by solving the equation of radiation transfer along 400 rays intersecting the area of heated air and vapor. The whole range of photon energies was divided into 20 groups [14]. In each group Rosseland's absorption coefficients were used [15]. Atmospheric visibility was assumed to be 40 km.

Numerical Results: Numerical simulations were made for the impacts of relatively small comets which decelerate in the atmosphere, release their kinetic energy and produce explosions at altitudes of 5-10 km. Impact velocities V were 20 and 50 km/s, comet diameters D from 40 to 200 m and incidence angles α from 15º to 90º (vertical impact). Larger bodies have smaller α. Calculated maximum radiant exposure at the ground is shown in Fig. 1.

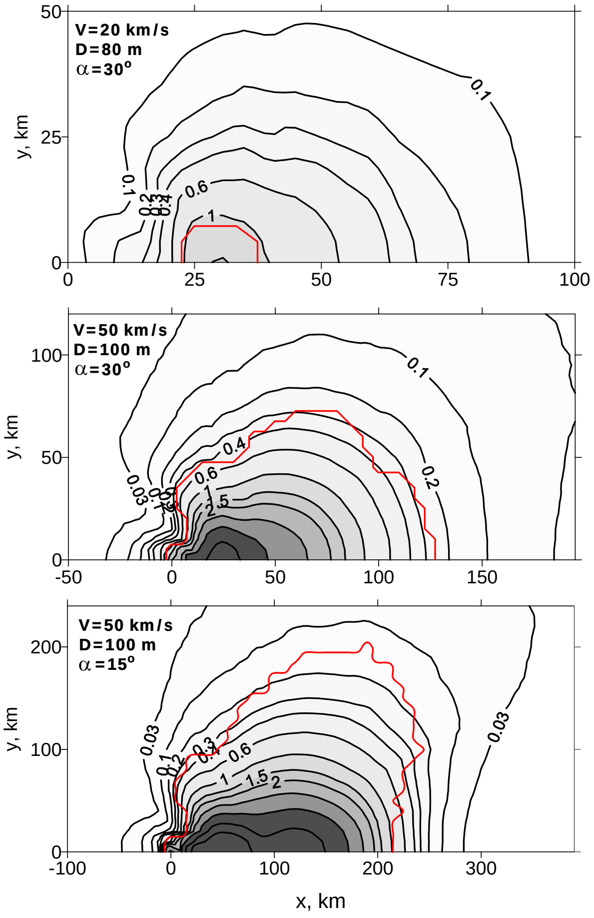

Fig. 1. Isolines of maximum radiation energy absorbed by a unit area at the ground in kJ/cm^2. The red curves confine areas where soil melting can start.

The *x*-axis is a projection of the meteoroid trajectory to the Earth's surface. The coordinates start at the point where the trajectory intersects the surface. The maximum absorbed energy means that the unit area is oriented in that direction which provides maximum.

If the absorbed thermal energy is above 0.1 kJ/cm^2, dry forest materials can be ignited. At 1 kJ/cm^2 rock melts and vaporizes. However temperatures of irradiated soil depend on values and duration of radiation fluxes. The maximum radiation fluxes on the ground as functions of time are shown in Fig.2 for impact velocities 20 and 50 km/s. The duration of that part of a radiation impulse when the fluxes are sufficiently high is of the order of 10 s. For longer times the temperatures of air and vapor diminish due to cooling by radiation. Full energy absorbed by all the ground area varies from about 10% of the meteoroid energy if V=20 km/s, D=40 m, and α=90º to about 40% for V=50 km/s, D=200 m, and α=15º

The temperature of irradiated solid material can be assessed by solving the heat-conduction equation in a solid half-space. This equation was solved numerically for an array of points on the ground, assuming that the surface absorbs the maximum radiation flux from the burst and emits infrared radiation as a blackbody. The heat-conduction coefficient of soil was taken to be 2.5 W/m K and specific heat capacity 1 J/g K. Contours where the temperature reaches 2000 K and the soil begins to melt are shown in Fig. 2 by red. To the periphery of the area bounded by the red contour, melting can start only if the soil surface is inclined at some angle to the horizontal plane and faces to the fireball. The melt area depends also on weather and would be smaller for low visibility. The thickness of melted layer, to a first approximation, is proportional to the square root of irradiation time and the temperature conduction coefficient. Such an estimate gives the thickness of a heated layer about one-half cm. Accurate numerical simulations of glass formation must include vaporization, viscous flow of a melted layer along a tilted surface, and cooling at the end of a radiation impulse.

Conclusions: Small comets entering the atmosphere at high velocities can produce aerial explosions at altitudes 5-10 km. The radiation fluxes on the ground increase with increasing meteoroid velocity and can reach 10 kW/cm^2 after the impacts of long-period comets. The area where soil melts enlarges with increasing meteoroid diameter and decreasing incidence angle. For V=50 km/s, D=200 m, α=30º , and fine weather conditions melting starts in the area of about 10000 km^2. Natural impact glasses could be produced in these cases.

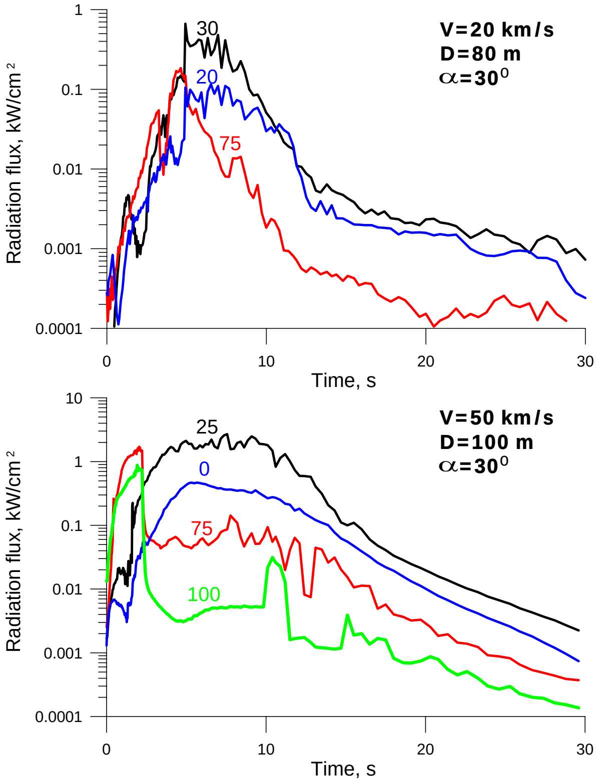

Fig 2. Calculated radiation flux at several points in *x*-axis. The *x*-coordinate of these points in km is plotted at the respective curves.

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