Large Aerial Bursts and the Impact Threat

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The most likely scenario for a costly or fatal impact event is not a crater-forming collision, but a large aerial burst. The June 30, 1908 Tunguska explosion is the best known example of an aerial burst, and represents the lowest-energy end member, with the damage at ground level being dominated by air blast. At the high-energy end of the aerial burst spectrum is the Libyan Desert Glass (LDG) event--29 million years ago--for which effects on the ground are dominated by radiative heating. Models of the Tunguska event are consistent with a stony impactor 30 to 40 meters in diameter. The LDG event is consistent with an impact of a stony asteroid 120 meters in diameter or greater.

Estimates vary widely for the total energy released at Tunguska, and range from a few megatons up to 50 megatons. These estimates are based on comparisons between the observed damage to the forest at Tunguska and the criteria for blast effects established by the nuclear weapons literature. The most commonly cited yield is about 15 megatons at an altitude of about 8 km. This value is consistent with a comparison of 1908 seismic records to data recorded from Soviet and Chinese atmospheric nuclear tests. However, we believe that the accepted estimate of 15 megatons for the Tunguska yield is too high, and have downgraded the estimate to 3 or 4 megatons.

Tunguska yield estimates based on treefall are too high because they did not account for topography or forest health. Comparison to nuclear weapon effects is a reasonable approach, but it is important to recognize the limitations associated with using the weapons tables, which apply to living coniferous forests and implicitly assume flat topography. Scientific and popular accounts of the Tunguska event state that the forest was flattened over an area of 2000 km^2. However, old photographs of the destruction reveal that many trees were left standing. These photographs also show that slopes of 15º and greater are typical of the terrain around the impact site. A 15º degree upslope results in a secondary Mach stem that increases the dynamic pressure by a factor of 3 for a weak shock, so the topography at Tunguska would naturally lead to concentrations of blast wave energy far beyond the distance that would be calculated assuming flat terrain.

Another reason to be skeptical of treefall-based yield estimates is that none of them take into account the pre-impact condition of the Siberian forest at the site of the explosion. On result of K.P. Florenskiy's 1961 expedition to the site was that "the region of the forest flattened in 1908 was not on of homogeneous primeval intact taiga," and that "…the region of meteorite impact in 1908 was basically a fire-devastated area… a partly flattened dead and rotting forest was standing in this area…" According to Florenskiy, "…an estimate of the force of the shock wave that is based on the number of flattened trees must necessarily take into consideration the condition of the forest at the time." If the requisite wind speeds are reduced to be consistent with Florenskiy's dynamometer measurements, then the necessary yield is reduced to 3.5 megatons.

Estimates based on seismic and barogram data are also too high. They assume that aerial bursts are point-source explosions. In reality, large impacting bodies couple their energy and momentum along their entire entry path, leading to an extended "line explosion" that results in plume formation as well as enhanced momentum and energy coupling to the ground. Simulations of a 3 megaton aerial burst show that the upward-directed momentum associated with the atmospheric plume generates a reaction impulse that is sufficient to generate the observed seismic records. From a seismic standpoint, a 3 megaton plume-forming event gives the appearance of being a much larger point source explosion.

The LDG event represents a much different aerial burst regime, with different phenomenology. Glass fragments are scattered over an area spanning 6500 km^2 in western Egypt, but the original source area may be much smaller. This silica-rich glass has a reported fission track age of about 29 Ma, and is found primarily on and within Quaternary colluvium and alluvium in the narrow corridors between linear dunes of the Great Sand Sea. Multiple lines of geochemical evidence strongly suggest that it is the product of an impact event, but there is no associated impact structure. We have performed numerical modeling to assess the hypothesis that the source material was melted by radiative/convective heating from the low altitude explosion of a small asteroid or comet.

High-resolution simulations were carried out using CTH with adaptive mesh refinement of the atmospheric entry of a 120-meter-diameter sphere of dunite. With an initial velocity of 20 km/s, the kinetic energy converts to an explosive yield of 108 Megatons. Most of this energy is coupled directly into the atmosphere as the asteroid ablates and explodes before it hits the ground. The resulting fireball contains air and ablated meteoritic material at temperatures exceeding the melting temperature of quartz in direct contact with the surface over a 10 km diameter area for more than 10 s after the explosion. Where the fireball is in contact with the ground, wind velocities exceed the sound speed over this time interval. This model is qualitatively different from a conventional impact, in which the fireball is embedded within the ejecta curtain and does not come into contact with the surface. The combination of high temperatures and high-velocity shear flow leads to strong coupling of thermal radiation, with melting and stripping of ablated silica melt that subsequently quenches to form the LDG.

Based on these simulations and comparisons to observations, Tunguska-class (blast-dominated) aerial bursts recur on time intervals of about 100 years. LDG-class (radiation-dominated) aerial bursts recur on time intervals of about 10,000 years. Aerial bursts represent a small fraction of the total impact risk, but are by far the most likely class of event expected to cause property damage or take lives. The next significant impact event on Earth will almost certainly be an aerial burst.

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