3D EFFECTS OF TUNGUSKA EVENT ON THE GROUND AND IN ATMOSPHERE. N. Artemieva[1,2] and V. Shuvalov[1], [1]Institute for Dynamics of Geopsheres, Moscow 119334, Russia. [2]Planetary Science Institute, Tucson 85719, AZ.

Introduction. Tunguska explosion in Russian Siberia in 1908 [1] continues to be the subject of intensive (yet boring) scientific studies and ridiculous (yet attractive for public) non-scientific speculations one hundred years later. Although 40-year-old experiments [2], analytical models [3-4] and recent numerical simulations [5-8] clearly demonstrated that a lot of related effects (butterfly-like fallout, white nights in western Europe, and absence of extra-terrestrial material near the impact site) may be explained by atmospheric disruption of tens-meter-diameter asteroid (or comet), new hypotheses arise every year. In this paper we apply 3-D numerical modeling for a cosmic body entry into the Earth's atmosphere to reproduce the most famous Tunguska effects: tree fall near the impact site, seismic signal, as well as plume evolution and material dispersion in the upper atmosphere.

Numerical methods and starting conditions. We use the hydrocode SOVA [9] complemented by standard equations of state for air and chondritic material. The results of two-dimensional simulations of meteoroid entry, similar to [10], are used as initial conditions for the 3D model. Spatial resolution varies from 40 m near the surface up to a few km in the upper atmosphere. Although starting conditions are the same, two separate runs are used the reproduce the effects on the surface and in the upper atmosphere.

We consider two variants: a 45º -impact of a spherical 50-m-diameter projectile with chondritic composition at U=20 km/s and a 30º -impact of 80-m-diameter projectile at 15 km/s (impact energy equals 10 and 20 Mt of TNT equivalent respectively). The falling body is treated as strengthless. At the altitude of about 35 km the projectile begins to deform under increasing aerodynamic loading. At 20 km a typical pancake-like structure forms, at 15 km the projectile transforms into a debris jet, then into a gaseous jet consisting of vapor and shock-heated air. The fact that the disruption and total evaporation of the projectile occur at high velocity, which is close to pre-entry velocity, is an important feature. The projectile decelerates only after its total evaporation and transformation into a gaseous jet. At the altitude of ~6-8 km above the surface we interpolate 2D distributions into 3D mesh with the resolution of 40 m (see **Fig. 1a**). It takes another 10-20 s for the shock wave to reach the surface, while all extraterrestrial materials become buoyant and accelerate along the wake into the upper atmosphere (see **Fig. 1b**).

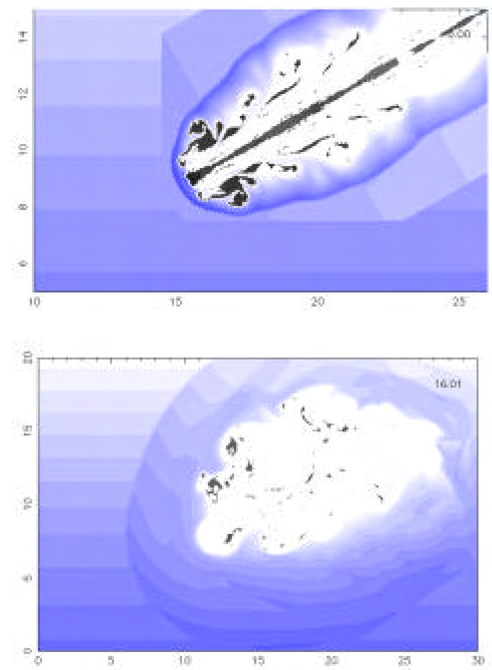

Fig. 1 a) 3D modeling starting conditions for a 30-degree impact. Atmosphere is in blue with color intensity corresponding to gas density, Chondritic material is shown in dark gray. Interpolation between 2D and 3D mesh is still visible. b) 16 s after the beginning of simulations, the shock wave reaches the surface, while ET-material (gray color) is floating at the altitude of 5-10 km.

Forest fallout: Interaction of a bow shock wave with the ground (treated as a rigid boundary) results in a gas flow along this surface (stormy winds) and slow decay of the shock at distances of about 20-30 km from the epicenter. **Fig.2** shows distributions of maximum pressure and maximum horizontal velocity for a 45° impact (10 Mt of TNT). Maximum pressure exceeds standard atmospheric pressure 1.5 times within the 5-km-diameter area and remains high enough (10% above standard) within the area larger by an order of magnitude (50-km-diameter). However, the taiga fallout is caused by dynamic loading, i.e. winds, rather than by static pressure. Nuclear weapon tests in early 60-ies allow us to estimate critical values for winds: minimal action occurs at the speed below 25 m/s, some damage (30%) at winds of 40-45 m/s, and maximal effect (90% damage) at speeds exceeding 55-65 m/s. According to our model, there are no strong winds in the epicenter: the speed is less than 30 m/s approximately within the same area as maximum pressure. This is in good agreement with survived trees ("telegraph forest", where almost all dead trees remain standing upright like "telegraph poles" with their crowns torn off). Maximum wind speed (contours in magenta color, > 50 m/s) occurs in two spots, resembling the famous butterfly wings. There is no fallout outside the area where the wind speed is below 20 m/s (yellow contours). The total modeled damaged area is around 1700 km^2, i.e. a bit less than available data. This discrepancy may be due to specific conditions near the Tunguska site, trees' weakness because of local soil, swamps and permafrost, intensive wildfires. Some observed peculiarities in the actual fallout (strips, deviations from radial direction) may be explained by the local landscape, assumed absolutely flat in the model.

The second variant with larger initial energy of 20 Mt TNT renders higher static and dynamic pressures and a patchy structure on the surface. Thus, additional adjustment of entry parameters are needed to reproduce the fallout at other impact angles.

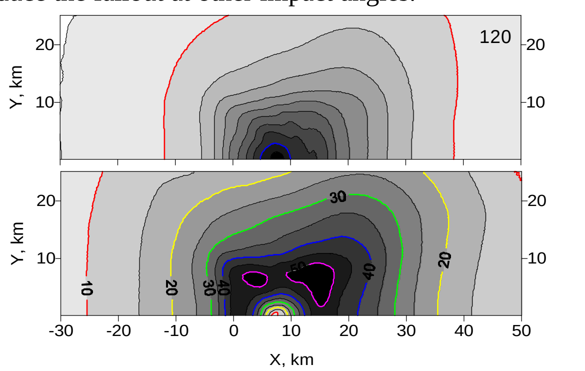

Fig. 2. Distribution of maximum pressure (upper plate) and maximum horizontal velocity (bottom plate) near the impact site. A half of the field (positive Y) is shown. The body came from the right along the X-axis. Blue contour on the pressure map corresponds to the pressure of 1.5 bar, red – to the pressure of 1.1 bar. Numbers on the speed map show horizontal velocities. The forest between two blue contours is totally damaged. Yellow contour restricted the devastated area.

Plume evolution: Strong material motion along the wake results in formation of a well defined bubble at the moment of about 30–40 s. Further the plume expands ballistically; 80 s after the impact disturbed region reaches the altitude of 600 km (**Fig. 3**). The downward motion of ejected gas begins approximately 3 min after the impact. The falling mass is decelerated at different altitudes because of different densities and sizes of re-entering particles. However, the bottom boundary of the falling plume is almost horizontal and is located at the altitude of ~100 km, around the boundary between strongly stratified (below 100 km) and weakly stratified (above 100 km) layers of the Earth's atmosphere.

Discussion: For the first time the Tunguska surface effects and ET-material dispersion have been reproduced in 2D-3D numerical model of a falling cosmic body without any substantial simplifications (such as atmospheric explosion, vertical entry, etc). Although we cannot properly resolve fragments smaller than a cell size in this model, only cm-m-sized fragments may move differently from an average hydrodynamic flow. Eventually, a few of them can survive the entry process. It means that we still cannot totally eliminate the probability of finding some fragments not far from the Tunguska impact site (but they would be really large fragments, not dust). Most probably, we have to look for Tunguska-related materials thousands km away from the Tunguska impact site, dispersed over huge area by the plume.

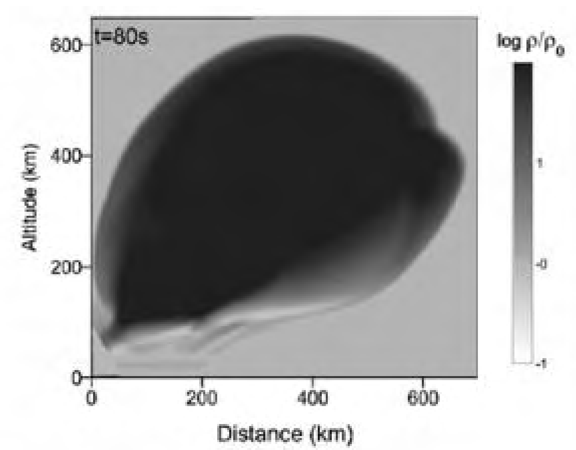

Fig. 3. Tunguska plume in the upper atmosphere 80s after the impact. Relative density is shown.

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References: [1] Vasilyev N. V. 1998. *Planet. Space Sci. 46*, 129–150. [2] Zotkin and Tsikulin. 1966. Sov. Phys. Dokl. 11, 183-186. [3] Chyba C. et al. 1993. Nature 361, 40-44. [4] Hills J.G. and Goda M. P. 1998. PSS 46, 219-229. [5] Boslough M. and Crawford D. 1997. *Annals NY Acad. Sci. 822*. [6] Svetsov V. 1998. *Planet. Space Sci. 46*, 261-268. [7] Korobeinikov V.P. et al. 1998. *Planet. Space Sci. 46*, 231-244. [8] Shuvalov V. and Artemieva N. 2002. *Planet. Space Sci. 50*, 181–192. [9] Shuvalov V. V. 1999. Shock waves 9, 381-390. [10] Shuvalov V. V. and Trubetskaya I.A. 2006. LPSC-37, abstr. # 1075.