TUNGUSKA EXPLOSION – FINAL REMARKS. N. Artemieva[1,2] and V.Shuvalov[2], [1]Planetary Science Institute, Tucson, AZ 85719, artemeva@psi.edu, [2]Institute for Dynamics of Geospheres, Moscow, Russia, shuvalov@idg.chph.ras.ru

Introduction: Tunguska explosion in Russian Siberia in 1908 [1] has drawn substantial attention over the past 100 years. Although experiments [2], analytical models [3], and recent numerical simulations [4-8] have demonstrated that a lot of related effects may be explained by an atmospheric disruption of a tens of m in diameter asteroid (or comet), ridiculous non-scientific speculations still flourish. In this paper we present distal effects related to the Tunguska plume and discuss the possibility of finding Tunguska material. Combined with other papers [6,7,10], this study allows us to say "The Tunguska enigma is solved".

Model in use: We are using SOVA hydrocode [9] complemented by special routines to model particle interaction with gas/vapor. Projectile entry is modeled in 2D geometry [10]; plume evolution – in 3D.

Projectile parameters. We model a 45º -impact of a spherical 50-m-diameter projectile with chondritic composition at U=20 km/s (impact energy equals 10 Mt of TNT). During the entry, the projectile is strongly deformed, transformed into a debris jet and later – into a gaseous high-velocity jet, which is totally decelerated at the altitude of ~6 km [10]. At this point we interpolate the 2D data into the 3D mesh and transform all projectile material into particles.

Particle size distribution in the plume is not totally clear. Theory [11] suggests that ablated materials recondense as nano-metre-sized smoky particles. However, unique observations of meteoroid dust from the atmospheric disruption of a large meteoroid [12] revealed substantially larger particles of a few µm. We explore two variants: the "fine" plume with particles from 1 to 10 µm, and the "coarse" plume with particles up to 10 cm in diameter.

Evolution of the plume is shown in Fig.1. Projectile material mixed with hot air is buoyant and quickly moves upward along the rarified wake. Within the first minute the plume is formed. Similar plumes have been observed (and modeled) during the Shoemaker-Levy 9 fragments interaction with Jupiter. In three minutes the cloud reaches 400 km in diameter (Fig. 1C). Then it collapses and spreads quickly along denser atmospheric layers (Fig. 1D). Two parts of the plume may be identified –a narrow "stem" below the altitude of 80 km and a huge "cap" above it. The "stem" contains ~90% of the projectile's initial mass.

Deposition of stem material under local conditions: At least a part of extraterrestrial (ET) particles in the stem is located in the lower atmosphere and deposited under the influence of local winds – see Fig.2. A particle's final position is defined by its size: particles smaller than 0.1 mm may be transported thousands km away (i.e. the local wind model is not suitable in this case). Larger particles tend to drift to the west and south from the epicenter. We use standard distribution of winds typical for the Tunguska site, which may be not valid for the particular day of the Tunguska event because of the intensive fires on the surface.

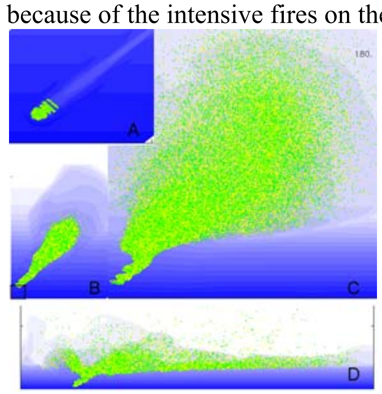

Fig.1 The Tunguska plume evolution. The atmosphere is blue, the projectile particles are green and yellow. A) total deceleration of the projectile, particles are produced, the frame is 20×20 km; B and C) 1 and 3 min later, a small square in the bottom left corner corresponds to the A-frame, 400×400 km); D) 10 min later, the plume collapse, 1500km×400 km.

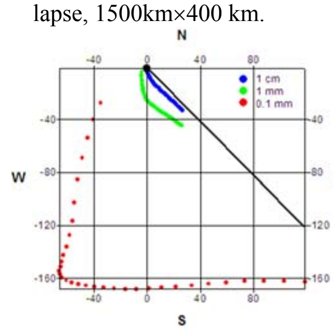

Fig.2 Deposition of the plume lower part (stem) under local winds. Black line shows the trajectory (SW-NE), black circle – the epicenter. Particles smaller than 0.1 mm are dispersed farther than 200 km from the epicenter.

Plume collapse and global distribution of ET-material: Quick spreading of the particle layer at the altitude of ~100 km is obvious (see Fig. 1D). This spreading may be attributed to the strong winds in the upper atmosphere caused by the plume collapse. Further propagation of this layer depends on the global circulation at high altitudes and is beyond the scope of our study. Assuming world-wide distribution of the "cap" particles, the average concentration of extra-terrestrial material on the surface may be of about 0.03 kg/km^2. Even if the cloud is diffused exlusively within the polar region of the northern hemisphere the value is still low, i.e. comparable with the annual flux of cosmic dust onto the Earth (0.1 kg/km^2).

Water in the plume and white nights in Europe: The plume rise causes substantial re-distribution of atmospheric gases. In particular, water-vapor is lifted up into the mesosphere, which is normally extremely cold and dry. Three minutes after the "explosion" the value of mesospheric vapor reaches its maximum of 20 ktons, and later decreases to 16 ktons because of the plume collapse – see Fig.3.

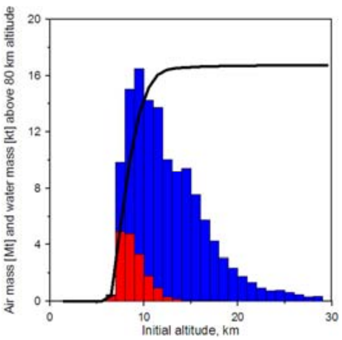

Fig.3 Mass of uplifted gas (blue) and water vapor (red) in the plume as a function of its initial altitude; the cumulative mass of uplifted water (black line). The deepest uplifted layer was initially at the altitude of 6 km (approximately the altitude of the jet final deceleration; 2) tropospheric gases bring 99% of all vapor into the mesosphere.

Noctilucent clouds (or polar mesospheric clouds) are well-known phenomena observed usually at latitudes between 50° and 65° during the summer time. They are concentrated at the altitude of ~82 km and consist of tiny (~40-100 nm) icy crystals. The column mass of water ice contained within PMC ranges from a detectable minimum of 20 $\mu g/m^2$ to a maximum of 200 $\mu g/m^2$[14, 15]. They are visible in the twilight because they reflect the solar radiation while the rest of the sky is in the Earth's shade. It was observed that a space shuttle exhaust releasing ~300 ton of water at the altitudes above 100 km produces PMC [15]. These "technogenic" PMCs reach the polar region within a day and are subsequently visible for about a week.

Tunguska-NLC. Our model shows that the mesosphere is oversaturated with water vapor immediately after the explosion because of the intensive uplift of tropospheric gases. Moreover, within the first half an hour the Tunguska plume reaches 2000 km in diameter and still is at least an order of magnitude more water-rich than a standard PMC (i.e. may be an order of magnitude brighter). Presence of the projectile particles promotes growth of icy crystals. Further evolution of this cloud is defined by the mesospheric winds. It is quite possible (and correlates well with a shuttle-generated exhaust propagation) that this cloud reaches the northern Europe within ~20 hours, creating extremely bright PMC and hence, white nights at lower (~50°) latitudes than their normal occurrence (>60°).

Other distal effects. Seismic effects are equivalent to the 4.5 magnitude earthquake and correlate well with the overpressure on the surface near the epicenter [17]. Registered disturbances in magnetosphere may be attributed to the plume rise-collapse [18].

Conclusions: All observed Tunguska-related effects are typical for 50-100 m bodies entering the Earth's atmosphere at cosmic velocity. These effects are defined mainly by projectile size and the entry angle, not by its structure or composition [10]. Recent speculations about the cometary nature of the Tunguska object [16] are based solely on the presence of water in the mesosphere and may not be valid. Our modeling shows that this water is of tropospheric origin and is not the result of comet vaporization in atmosphere. The type of the Tunguska object can not be defined without geochemical analysis of its material, which has not been found so far. The average concentration of this widely dispersed material is comparable with the annual flux of cosmic spherules onto the Earth. It may probably be detected in the regions with extremely accurate stratigraphic records (glaciers in Greenland could possibly be candidates).

Nowadays Tunguska-sized objects represent the most hazardous cosmic bodies. The probability of such event is quite high, while the size is too small to predict the collision in advance. Damage on the surface may reach thousands of sq.km. Disturbances in ionosphere may destroy modern telecommunication systems and cause a world-wide chaos.

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