NUMERICAL MODEL OF IONOSPHERIC DISTURBANCES GENERATED BY TUNGUSKA AND CHELYABINSK IMPACTS. V.V. Shuvalov[1] and V.M. Khazins[1], [1]Institute of Geosphere Dynamics, 38 Leninsky prosp, bld.1, Moscow, Russia, shuvalov@idg.chph.ras.ru.

Introduction: Ionospheric disturbances are considered to be one of hazardous consequences of a meteoroid impact. The purpose of this study is to model large-scale atmospheric perturbations induced by well-known Tunguska (1908) and Chelyabinsk (2013) impacts.

Methods: The disruption and deceleration of a meteoroid in the atmosphere followed by propagation of shock waves to long distances have been modelled using a two-step model described in [1].

Results: Fig.1 demonstrates the initial stage of plume formation for three models of the Chelyabinsk airburst. In the first scenario a 19-m-diameter asteroid consisting of dunite (ϱ=3,300 kg/m^3) penetrated through the Earth's atmosphere at a velocity of 20 km/s and an angle of 19^o to horizon. In the second scenario a vertical impact of a similar meteoroid was considered. In the third scenario a point source with energy of 500 kt TNT (the same as meteoroid's energy) at an altitude of 20 km was modeled. At 30 s flow fields (density distributions are show in Fig. 1) considerably differ from each other. The difference is still clearly seen 150 s after the impact. However, in 360 s the flow fields look quite similar; the shape of the energy release curve does not influence strongly the late stage of atmospheric disturbances evolution.

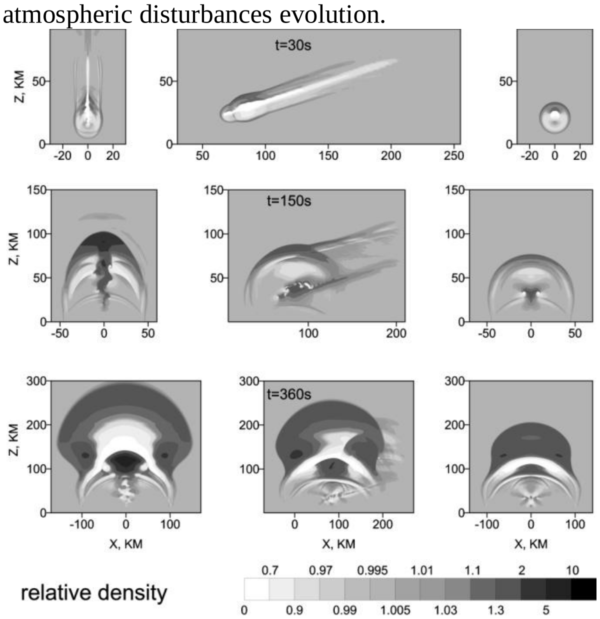

Fig.1 Distributions of relative density $\rho/\rho_0(z)$ 30, 150, and 360 s after the Chelyabinsk impact. Left column shows a vertical impact: right column -– a point source at an altitude of 20 km; central column – the most realistic scenario.

To estimate a degree of atmospheric disturbances at each point of space we used a non-dimensional value $\varepsilon=\max(\mathrm{abs}(\rho/\rho_0-1))$, where $\rho_0(z)$ is density of undisturbed atmosphere at an altitude z. In other words, ε is the maximum (through time) deviation of local density from its equilibrium value . Fig.2 shows ε-distributions for the all three scenarios. Distributions do not differ dramatically from each other: the size of a region with ε>5% is about 3,000-4,000 km; at distances up to 500 km disturbances exceed 20%. The trajectory inclination in the first scenario results in a small downrange shift and in a total decrease of the disturbed region. To estimate an influence of weather conditions the third run (point explosion) was performed with two different atmospheric models (CIRA and MSIS-90). The results show that a difference between the three scenarios is approximately the same as a difference which could be induced by the weather conditions.

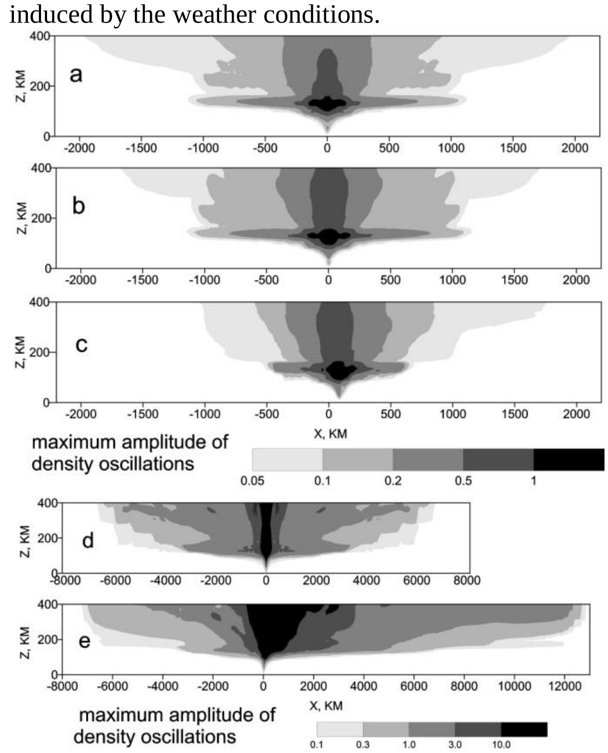

Fig.2. ε-distributions for different Chelyabinsk (a – spherical explosion: b – a vertical entry: c – a 19 degree entry) and Tunguska (d – spherical explosion: e – a 45 degree entry) models.

Fig.3 shows a comparison between deviation dI of the total electron concentration obtained in numerical models versus observed data [2].

A flow field resulting from the Tunguska impact considerably differs from the Chelyabinsk case. The difference is explained by a strong influence of a meteor wake (a hot rarefied channel formed in the atmosphere behind the entering high-velocity meteoroid).

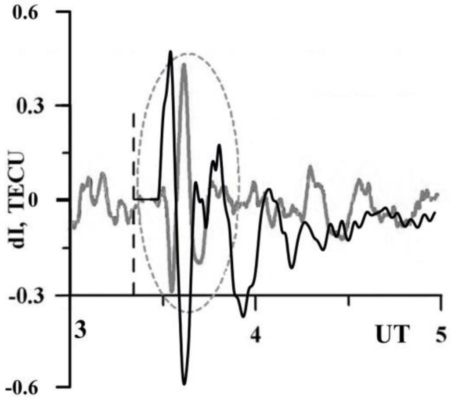

Fig.3. Total electron concentration after the Chelyabinsk airburst. The gray line shows observational data (Perevalova et al., 2015): the black line shows numerical results (this work).

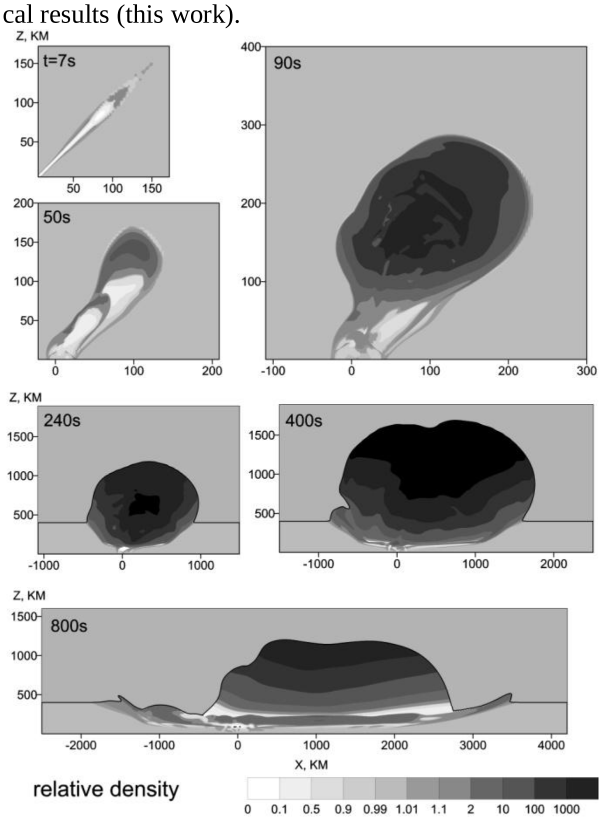

Fig.4. Distributions of relative density $\rho/\rho_0(z)$ 7, 50, 90, 240, 400, and 800 s after the Tunguska impact.

Hydrostatic equilibrium is broken in the wake, and a mixture of hot air and vapor accelerates upwards along the wake. As a result, an atmospheric plume is formed which rises along the wake and transports dense air from a lower part of the atmosphere to high altitudes up to several thousands of kilometers. Fig.4 illustrates some results of numerical simulation of an 80-m-diameter cometary impact at45^o with a velocity of ; 30 km/s. At an altitude of about 1500 km the plume is decelerated by gravity and begins to fall back generating large scale oscillations.

The late stage of a flow field evolution is shown in Fig.5. Plume oscillations generate shock waves expanding up and down.These waves transform the plume energy into heat. The heated atmospheric region expands laterally generating shock wave propagating horizontally. The results for the Chelyabinsk impact are also shown in Fig.5 for comparison.

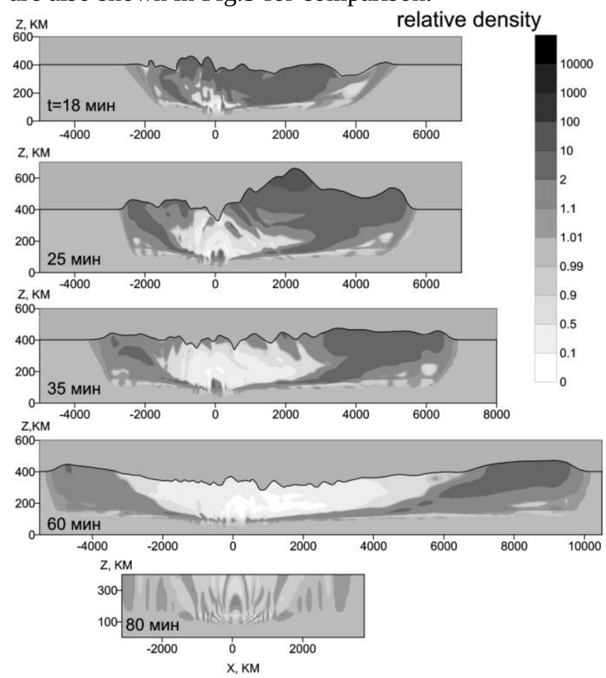

Fig.5. Distributions of relative density $\rho/\rho_0(z)$ 18, 25, 35, and 60 min after the Tunguska impact (four top images) and 80 min after the Chelyabinsk impact (bottom image).

Conclusions: In both Chelyabinsk and Tunguska impacts the atmospheric disturbances are concentrated at altitudes above 100 km. Below 100 km the disturbances are strongly attenuated due to a sharp decrease of atmospheric scale height and related abrupt increase of atmospheric density. Contrary to the Chelyabinsk case, atmospheric disturbances induced by the Tunguska impact are much more powerful than the disturbances induced by a spherical explosion with the same energy (see fig.2) due to the influence of the meteor wake.

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References: [1] Shuvalov et al. (2013), Solar System Research,47(4), 260-267. [2] Perevalova et al. (2015), Geophys. Res. Lett., 42, 6535-6543.