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COMPARISON OF DAMAGE FROM HYDROCODE SIMULATIONS OF AN ASTEROID AIRBURST OR IMPACT ON LAND, IN DEEP, OR IN SHALLOW WATER

Darrel Robertson[1], Lorien Wheeler[2], and Donovan Mathias[3]
[1]*Science and Technology Corp. NASA Ames Research Center, Moffett Field, CA 94035, USA*
phone +1 650 604 1331, email Darrel.K.Robertson@NASA.gov
[2] *CSRA, NASA Ames Research Center, Moffett Field, CA 94035, USA*
phone +1 650 604 0785, email Lorien.Wheeler@NASA.gov
[3] *NASA Ames Research Center, Moffett Field, CA 94035, USA*
phone +1 650 604 0836, email Donovan.Mathias@NASA.gov

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Extended Abstract—

If an asteroid is discovered to be on a collision course with Earth and there is insufficient time for a deflection effort to make it miss Earth completely, should it be redirected to a land or ocean impact? While distance from densely populated areas should obviously be maximized, the differing ability of air blast, seismic waves, and tsunami waves to cause damage at distance does not make the choice between land and ocean impacts an immediately obvious one. More broadly this work is a step towards improving damage models from asteroid impacts.

This extended abstract follows the hypothetical scenario of the 2017 IAA Planetary Defense Conference where a 100–250m diameter asteroid is on a potential impact course with Earth. A hydrocode was used to simulate impacts into the most sparsely populated areas along the eastern end of the hypothetical impact corridor—specifically in the Gobi Desert, in the shallow waters of the Sea of Japan, and in the deep waters of the Japan Trench in the Pacific Ocean.

Airburst

The lower end of the size range with a stony asteroid corresponds to ~100 MT (megaton of TNT equivalent), which will likely burst in the air. The simulation in Figure 1 uses a vertical 100 MT energy deposition profile and calculates the pressure felt on the ground as a function of distance from ground zero. The blast wave is seen to be very similar to what would be calculated from a point source or a nuclear explosion as shown in Figure 2

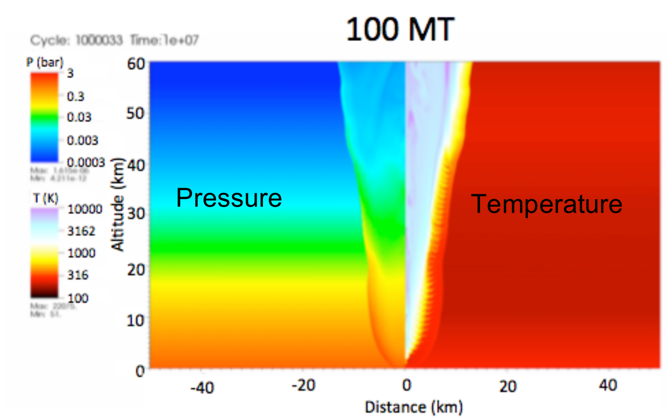

Figure 1: Hydrocode simulation of 100 MT airburst

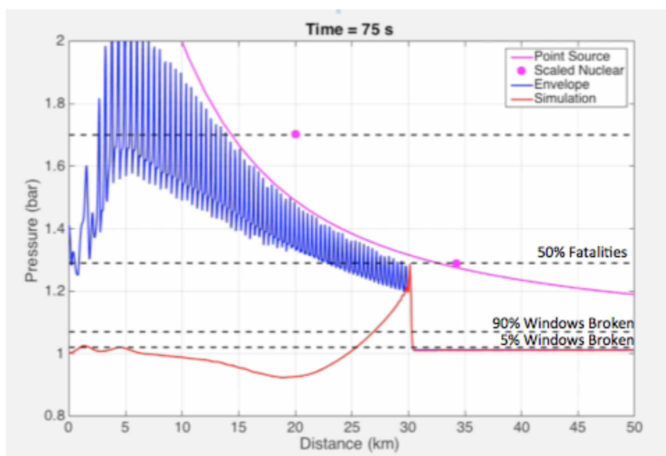

Figure 2: Simulated blast wave is similar to nuclear explosions

At the larger end of the size range, a density of ~4 g/cc corresponds to ~1GT. Such an asteroid is likely to bring a significant fraction of its energy down to impact the ground. Nevertheless, if all of the energy was transferred into a blast wave it would flatten buildings out to 30 km (10 psi), cause ~50% fatalities out to 60 km, and still break most windows 200 km away.

Land Impact

To examine the limiting case with almost all of the energy transferred to the ground, the vertical impact of a 1GT iron asteroid was simulated as shown in Figure 3

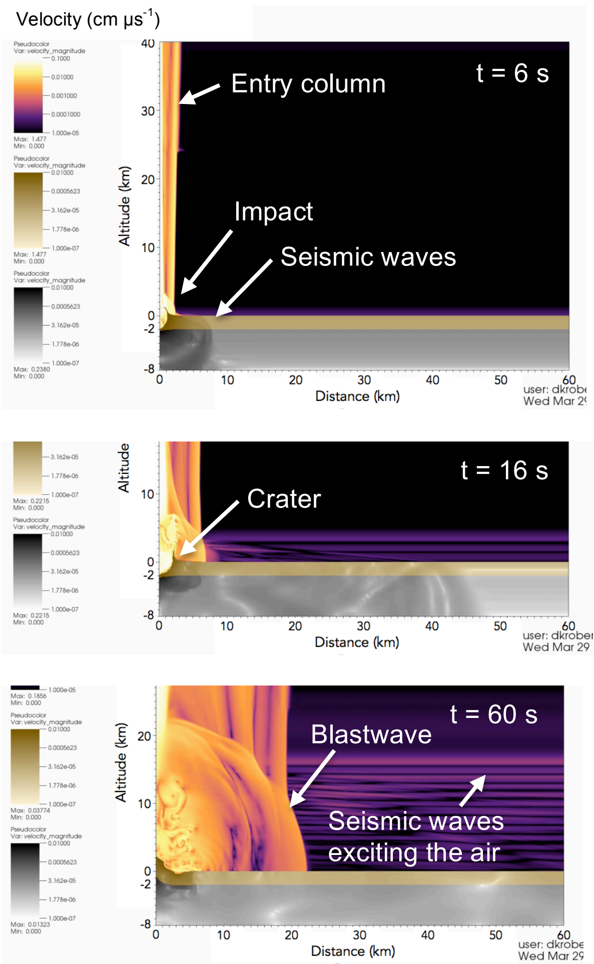

Figure 3: Simulation of 1GT vertical impact into 2km sandstone over granite showing velocities in materials.

In this case, much less energy, compared to the airburst, was transferred to the blast wave in the air yielding overpressures of 4 psi only out to 12 km and 1 psi out to 30 km.

The seismic waves through the ground create an earthquake. The intensity of an earthquake correlates with observed damage and can be measured from peak ground velocities. For this simulation, as shown in Figure 4, the decay of intensity with distance corresponds to a magnitude ~8 earthquake in an earthquake-prone region or a magnitude ~7 in a region with few earthquakes.

Thermal radiation from the entry column and impact fireball was calculated assuming air becomes opaque at 3000 K, and the heat flux on vertical surfaces was calculated as a function of distance, shown in Figure 5. 5 km away this is enough to melt sand whereas 50 km away will likely just cause sunburn.

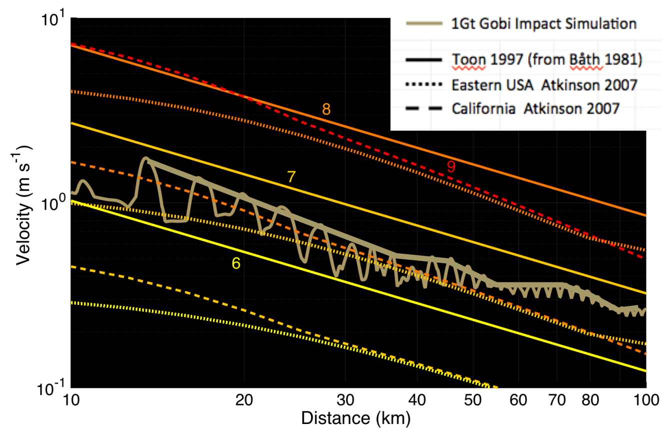

Figure 4: Decay of ground shaking with distance from epicenter.

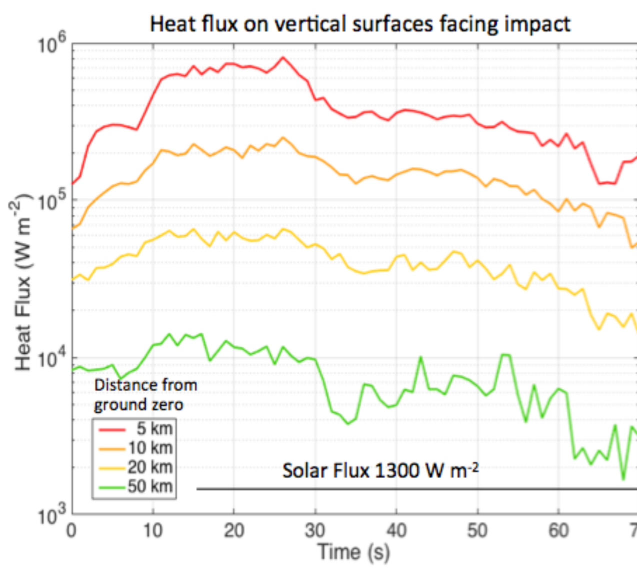

Figure 5: Heat flux vs. time and distance from thermal radiation from hot entry column and impact fireball.

Deep-Water Impact

The deep-water impact into the Japan Trench in the Pacific Ocean creates a tsunami wave train from oscillation of the cavity and central jet. As a deep-water wave, it suffers dispersion as it propagates, as seen in Figure 6. As it reaches shallower waters on the continental shelf, the amplitude was seen to suddenly decay instead of increasing from shoaling. This appears to be due to reflection off the comparatively steep slope before the shelf as the decay essentially mirrors the bathymetry. Waves reaching the shore are very minor and the steep shelf has greatly protected the coastline.

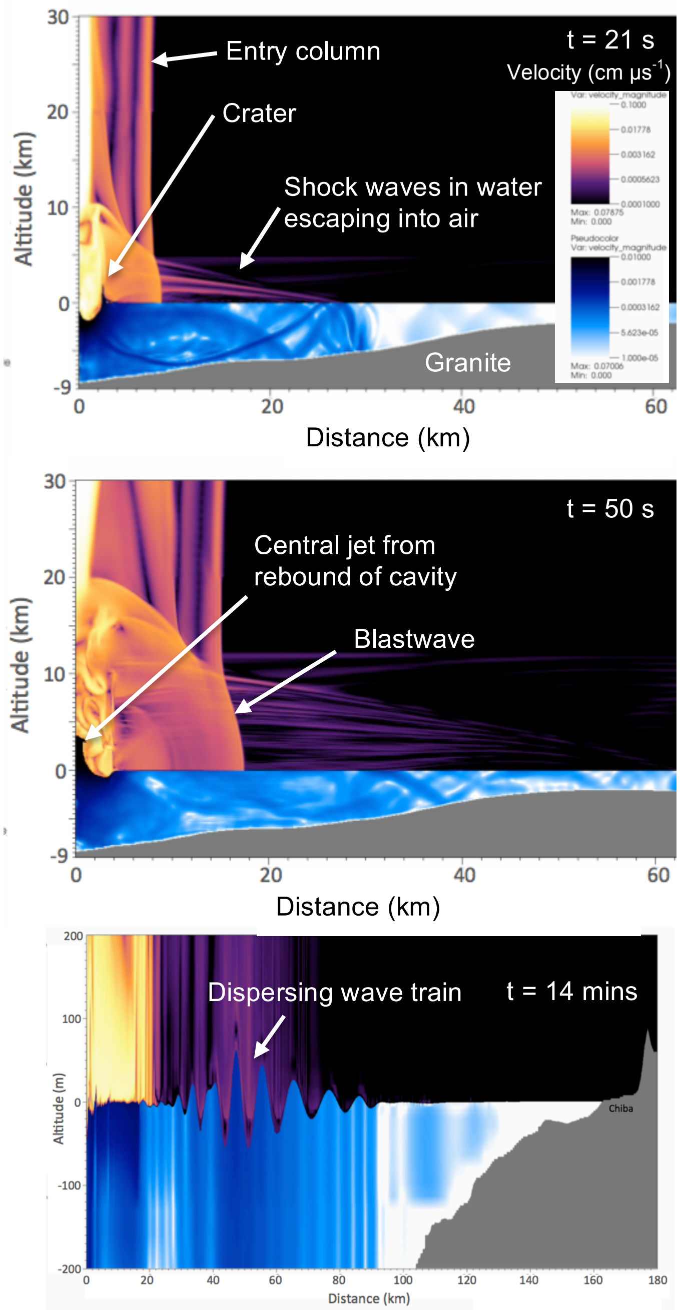

Figure 6: 1GT impact into Japan Trench showing material velocities.

Shallow-Water Impact

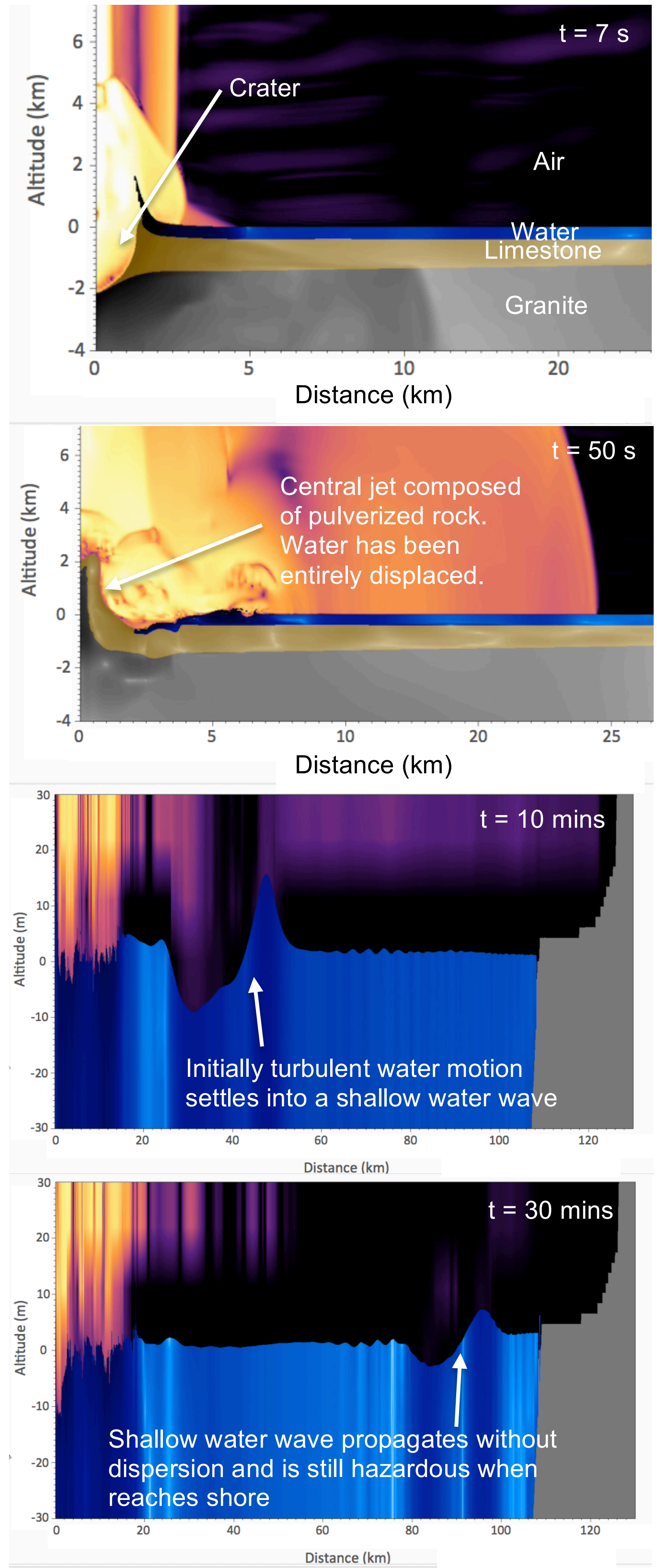

Figure 7: 1GT impact into Japan Sea showing material velocities.

The impact into the Sea of Japan as seen in Figure 7 creates a shallow-water wave that propagates without dispersion. This results in a 5-m high, 10-km long tsunami wave reaching the coastline, which would be expected to cause a significant amount of damage.

Conclusions:

Impact onto land can be good choice if it can be kept away from populated areas or critical resources. An impact into the Gobi Desert might be such an example, but would need to be investigated in more detail taking into consideration the exact location and cost of mines, oil wells, and other infrastructure in the area.

Impact into deep water may also be a good choice if far enough from land. Deep-water waves are dispersive so they decay in amplitude much faster than shallow-water waves. The steep shelf of the Japan Trench also reflected most of the incident wave back out to sea. A less steep slope may allow more of the incident wave to cross the continental shelf and reach the shoreline. A higher-resolution simulation of the exact behavior of the wave reaching the shelf would be advisable to add confidence that the wave will actually dissipate. It would also be advisable to create a better model of the undersea sediments and rock to alleviate potential concerns of the impact triggering an undersea landslide that could potentially create a larger tsunami than the impact induced waves.

Impact into shallow water is inadvisable. Although much of the tsunami energy is dissipated in initial turbulence, once a shallow-water wave is set up it propagates efficiently. For the smaller end of the range of asteroid sizes in this scenario, this wave is unlikely to be significantly larger than a bad storm surge. At the larger size ranges, however, it could create a wave that would still be potentially very hazardous when reaching the coastline of the Japan Sea.