Modeling Catastrophic Geologic Events

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LDRD
LABORATORY DIRECTED RESEARCH & DEVELOPMENT

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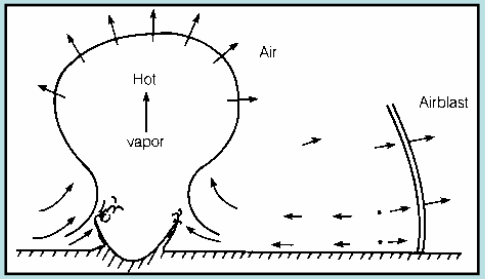
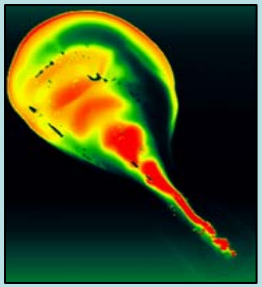
LDRD projects: Planetary impact physics

Making use of advanced supercomputing to discover *emergent* phenomena that were not anticipated from first-principles reasoning.

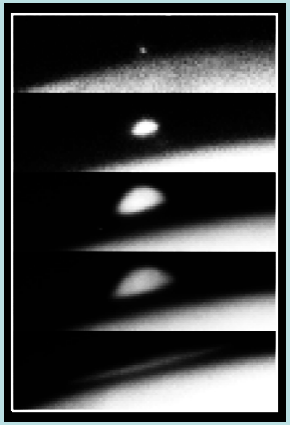
Evolution of our understanding of atmospheric effects of impacts



1989 textbook



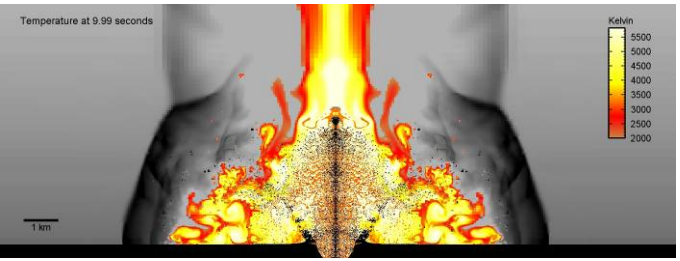
1993 Sandia simulations



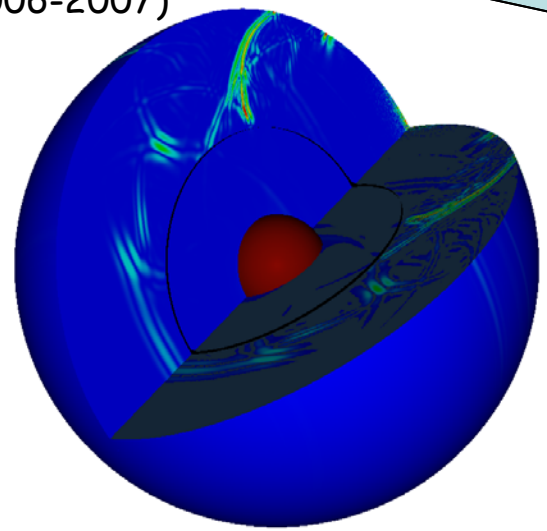
1994 Jupiter comet impact

1997 book cover

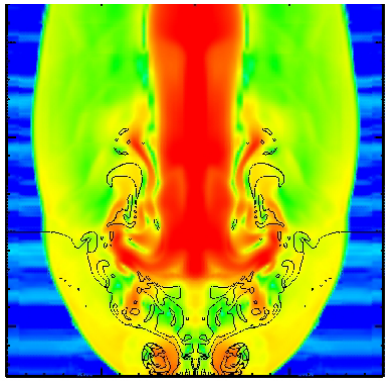
Desert Glass (2006)



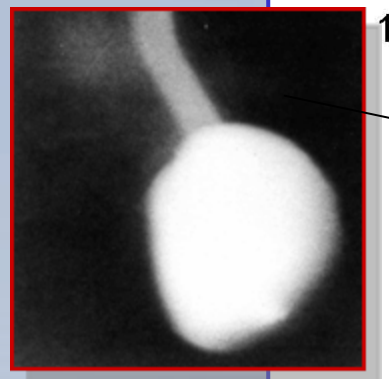
Great Dying (2006-2007)

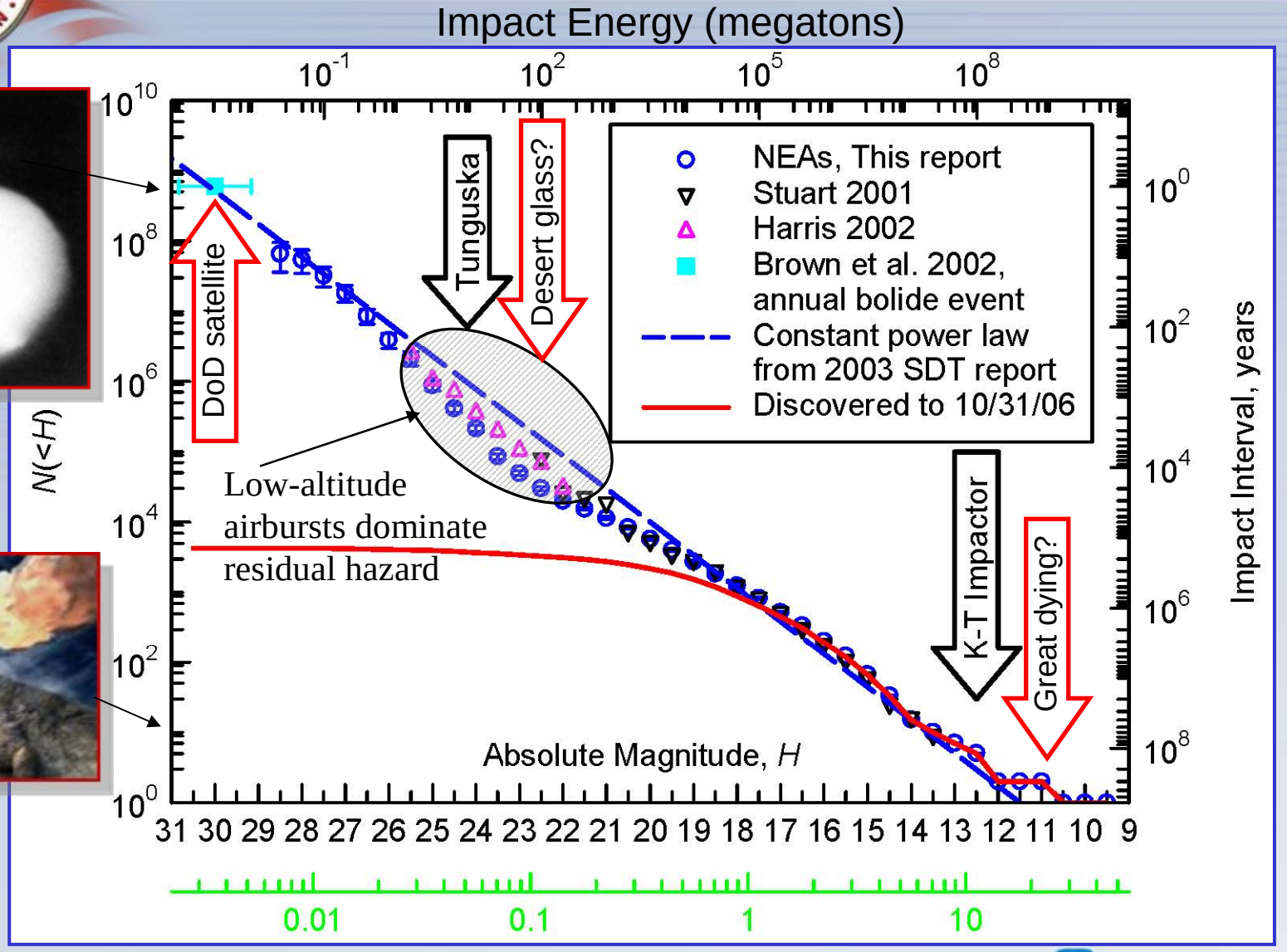


Low-altitude airbursts (2007)

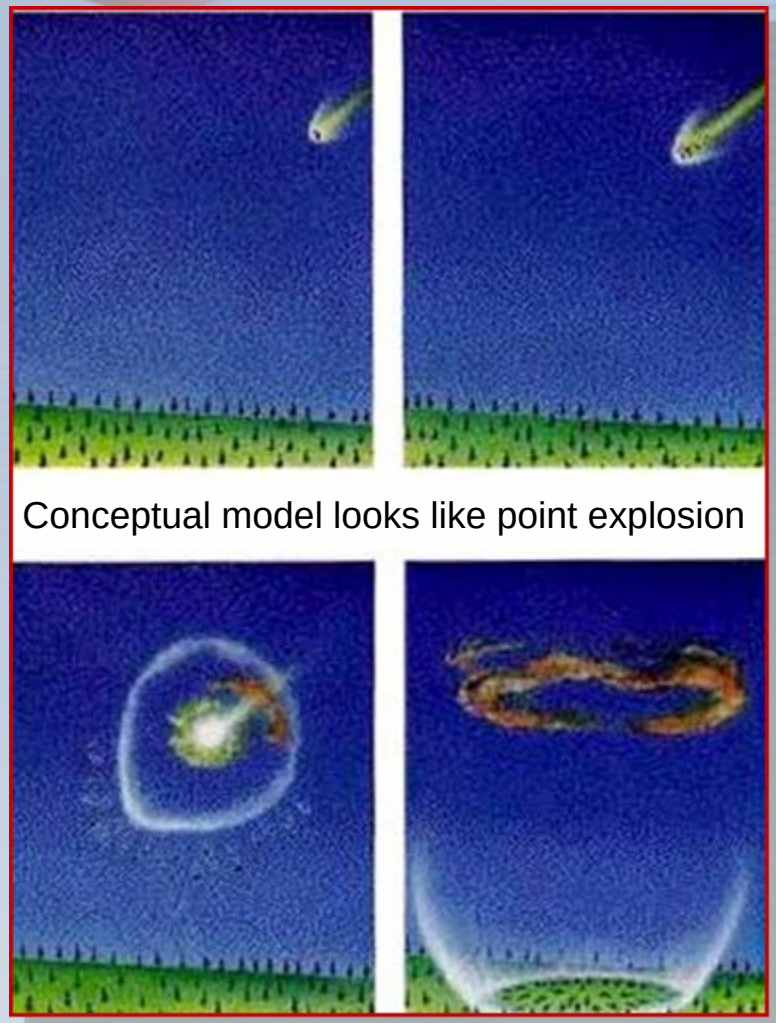


Power law spans 10 orders of magnitude





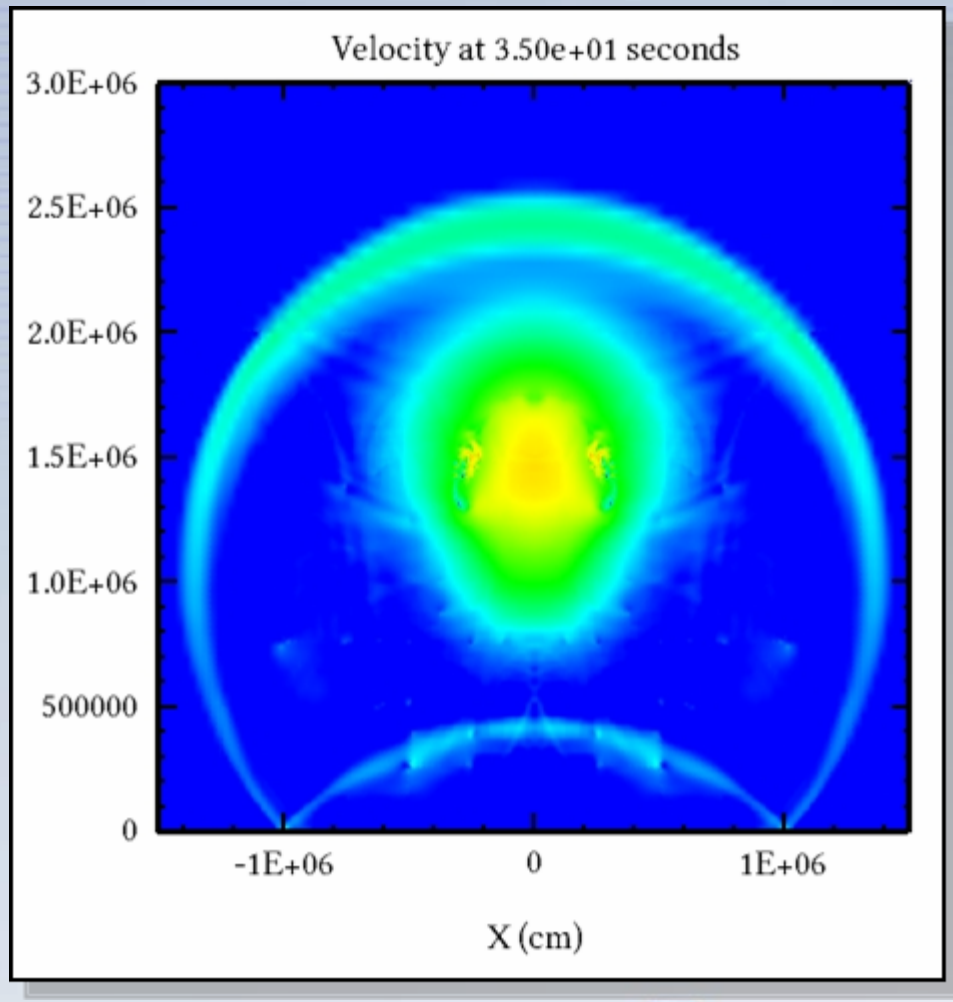
1908 Tunguska explosion: The canonical airburst event



Conceptual model looks like point explosion

5 Megaton explosion at 10 km altitude

Hydrocode runs support simple concept



Airburst impact hazard estimate hinges on question: What was the yield of Tunguska?

Consensus estimate: 10 – 20 Megatons

New analysis lowers estimate to:
3 -5 Megatons

1. Treefall pattern and distribution
2. Barograph data
3. Seismic data
4. Nuclear weapons effects
5. Pancake model

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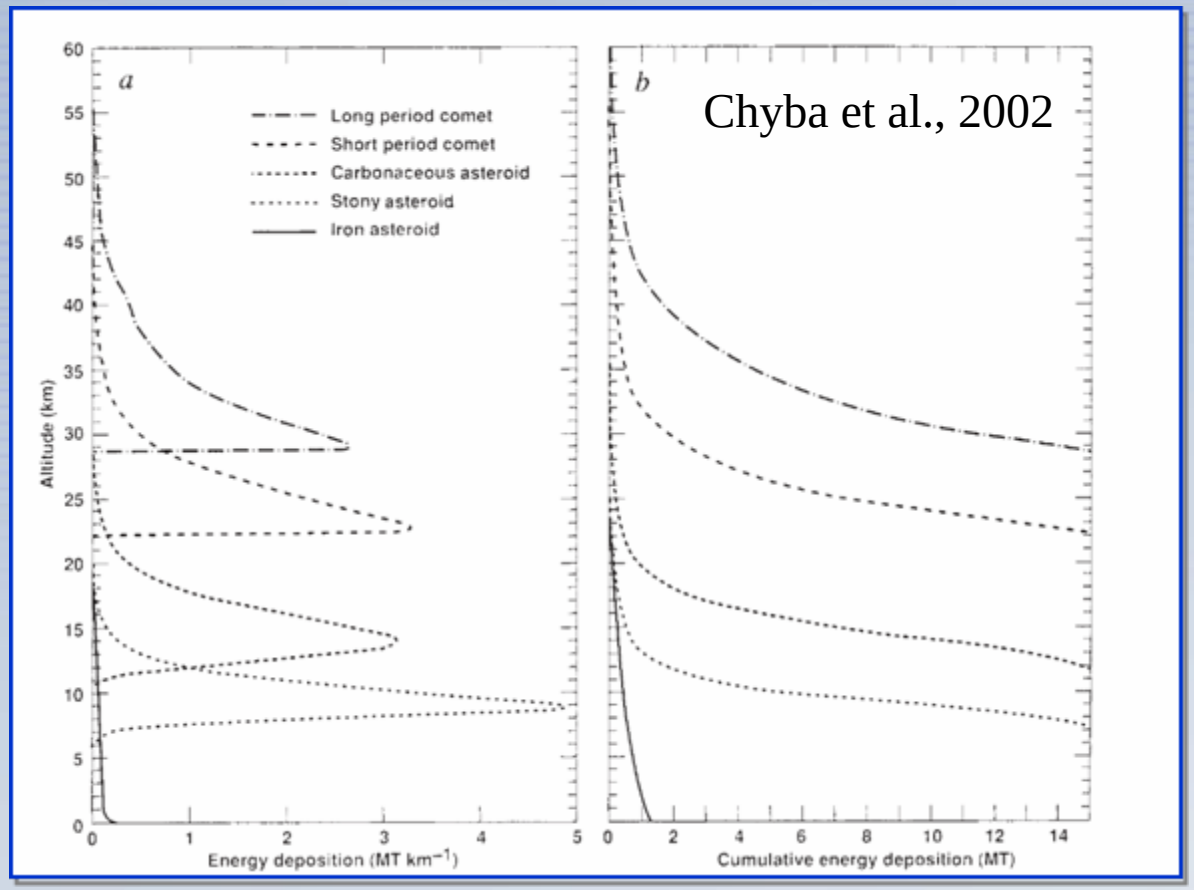
Pancake model: Earth's atmosphere protects us from low-altitude airbursts

In 1993, Chyba, Thomas & Zahnle published "The 1908 Tunguska explosion: atmospheric disruption of a stony asteroid" in *Science*. They attributed the event to a 10-20 Mt explosion at an altitude of about 10 km, based on a simple calculations involving ablation, aerodynamic drag, and mechanical deformation called the Pancake Model.



Chyba et al., 2002

A stony asteroid deposits essentially all of its kinetic energy above 7 km. In this model the energy deposition curve is sharply peaked because of the mutually-reinforcing effects of atmospheric drag and deposition. Subsequent modeling has been based on point-source explosions and nuclear weapons effects.

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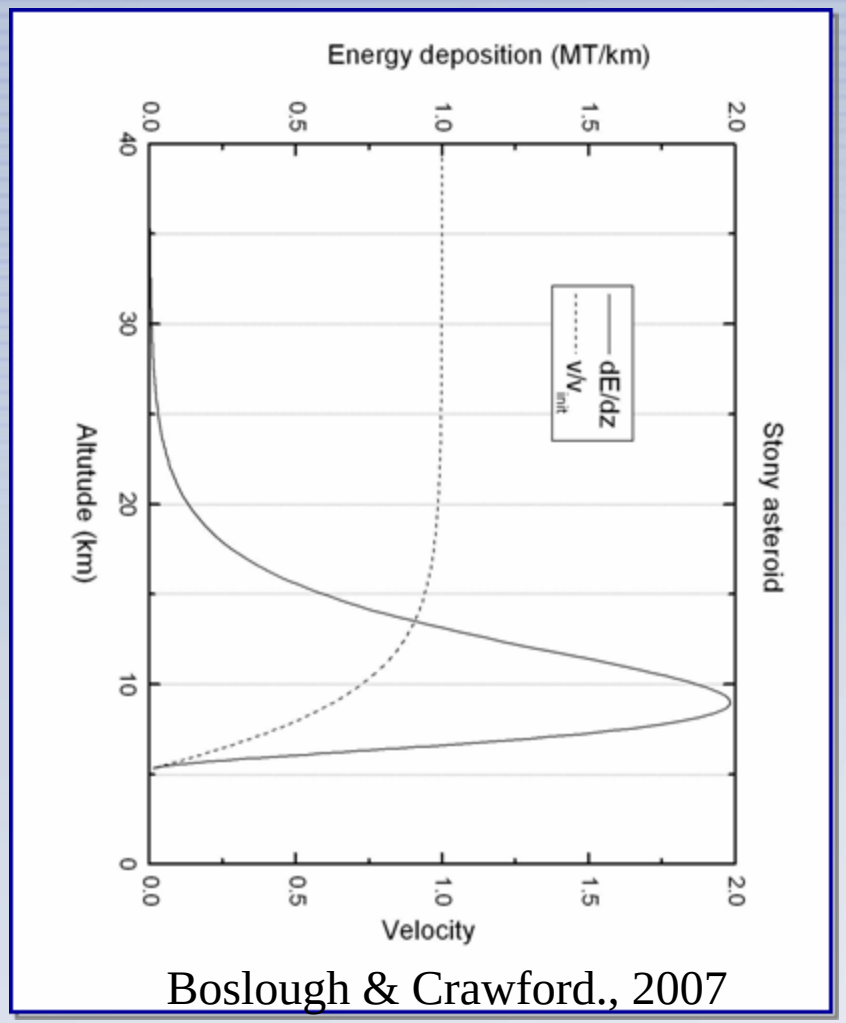
Pancake model revisited: Earth's atmosphere is actually penetrated by hot vapor jet

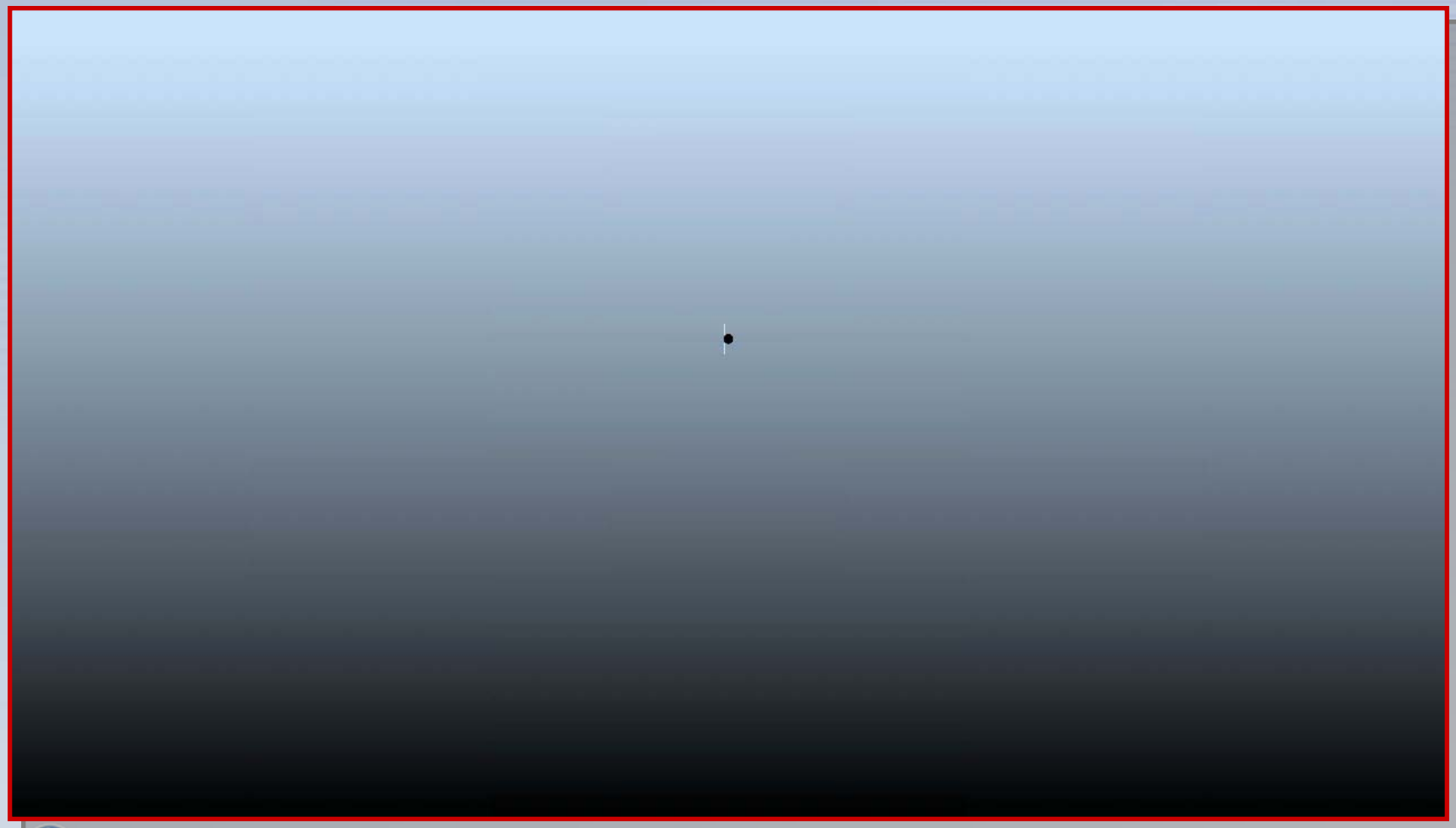
Revisiting the pancake model demonstrates that at the altitude of maximum energy deposition, the asteroid still has most of its mass and more than half of its initial velocity. When it explodes its mass is converted to a hot vapor jet which continues downward at hypervelocity. The "point source explosion" model is therefore a poor approximation.



Boslough & Crawford., 2007

Movies: Difference between explosion and impact

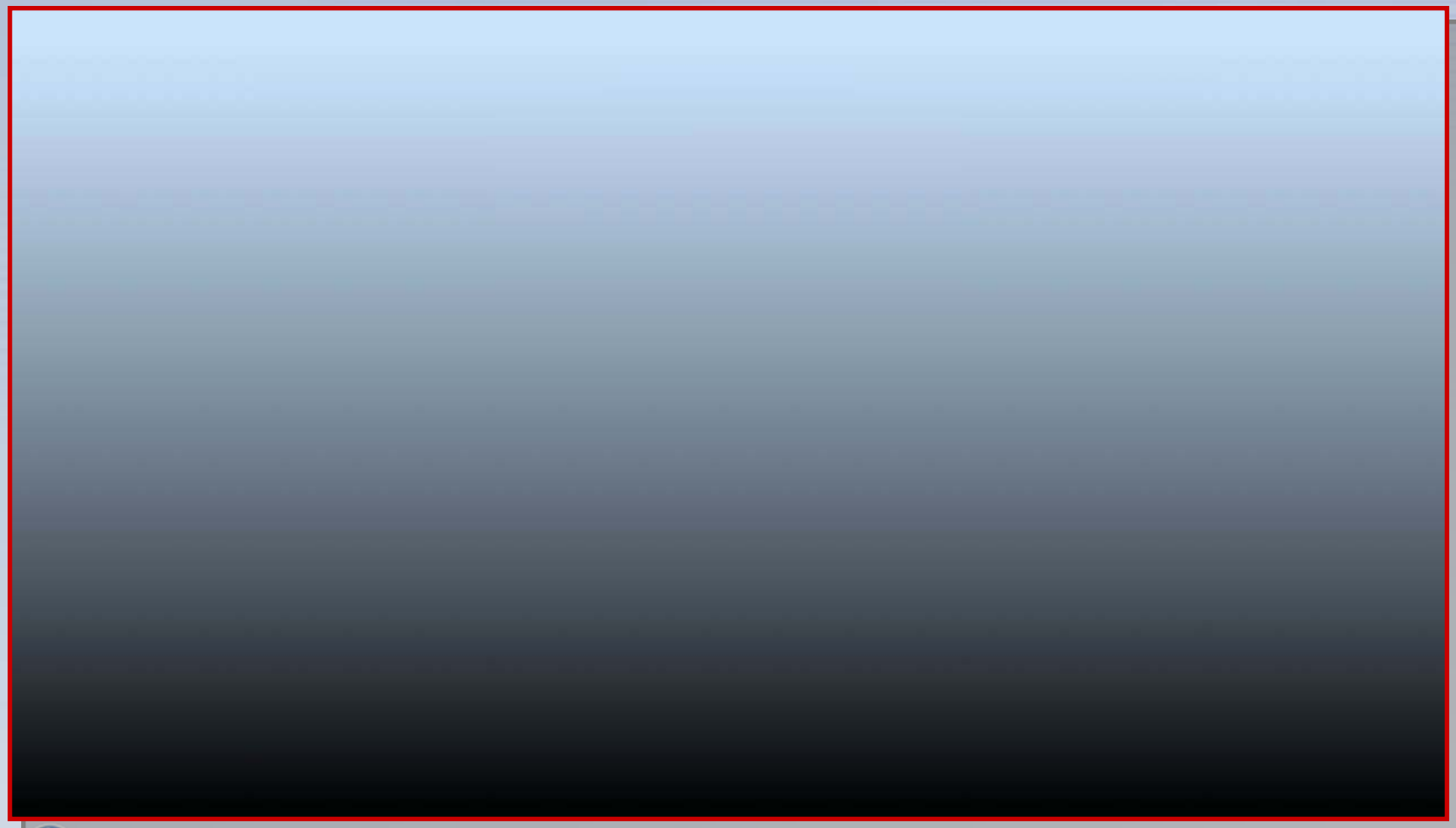
5 megaton point explosion at 5 km altitude



Box dimensions: 8.4 x 15 km

Movies: Difference between explosion and impact

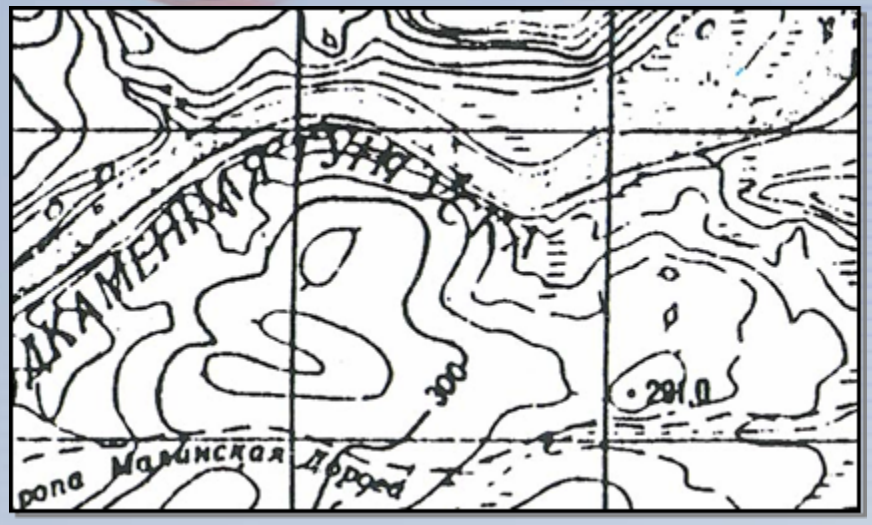
5 megaton impact airburst at 5 km altitude



Box dimensions: 8.4 x 15 km

Previous Tunguska yield estimates assume: Flat terrain and healthy forest

Terrain was not flat



Forest was not healthy

"…the region of the forest flattened in 1908 was not one of homogeneous primeval intact taiga…" "…the region of meteorite impact in 1908 was basically a fire devastated area…" "…a partly dead and rotting forest was standing in this area…" "…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 that time."

(K.P. Florenskiy's report on 1961 expedition)

DAMAGE CRITERIA FOR FORESTS

58-62 m/s: Up to 90% of trees down (35-37 m/s)*

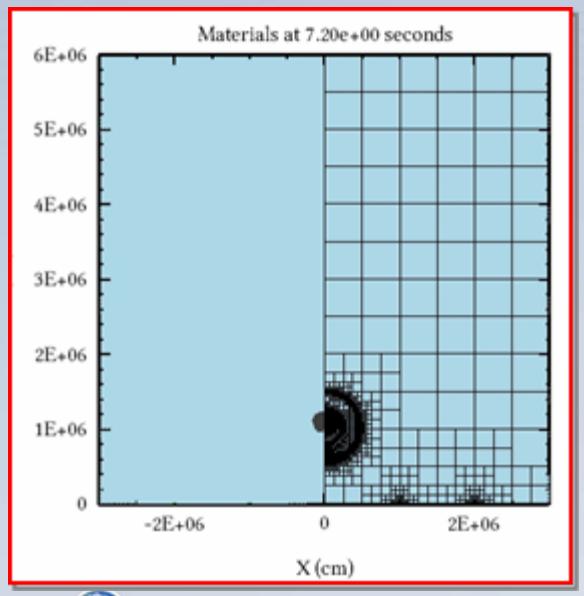
40-44 m/s: About 30% of trees down (24-26 m/s)*

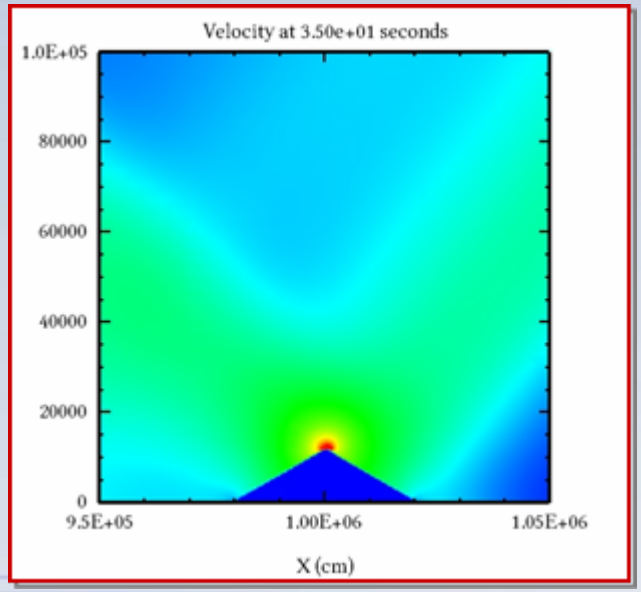
Assumes living coniferous forest, flat terrain

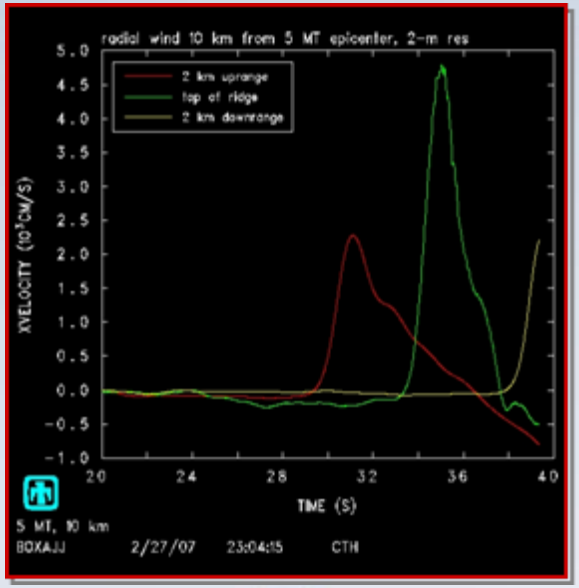
(Glasstone & Dolan, 1977, The Effects of Nuclear Weapons)

***Florenskiy's dynamometer experiments reduce felling moment by 67% and wind speed by 40%.**

Weak trees blew down along ridge lines







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Impact-induced vortex rings

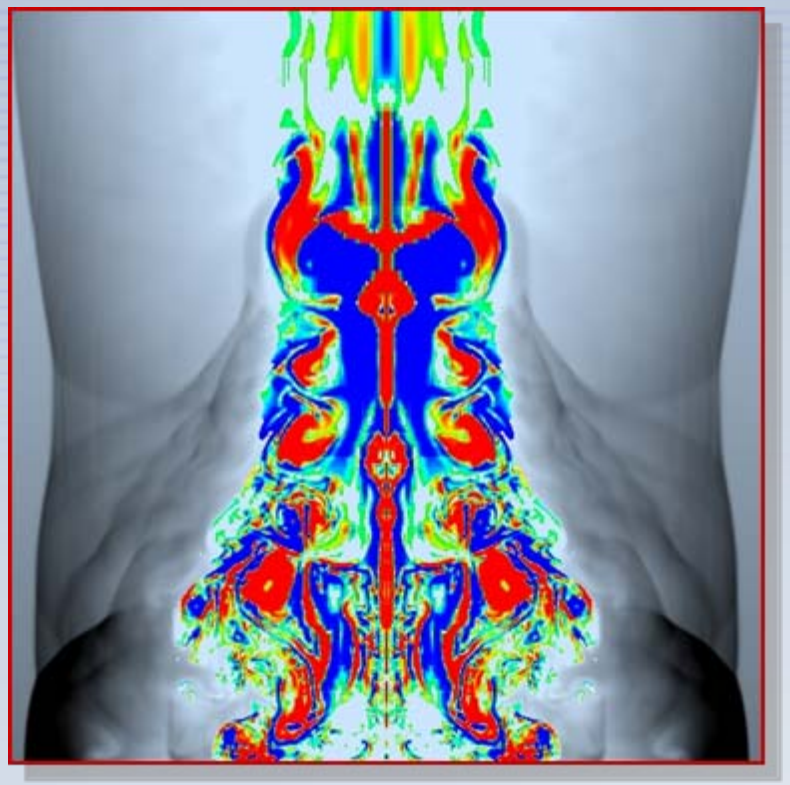
5 megaton impact airburst at 5 km altitude

Box dimensions: 3 x 4 km

Airburst contribution to impact hazard: Conclusions

- Tunguska yield estimates of Chyba et al. may be too high by factor of 3-4.
- Tunguska-class events are more frequent, but less damaging than conventional estimates (because of yield over-estimate).
- Momentum coupling to atmosphere, solid earth and tsunami is higher because of plume ejection.
- Radiative coupling based on nuclear weapons effects literature is underestimated (impact fireball moves downward, nuclear fireball moves upward).
- Small cratering events are large airburst events with incandescent fireball in contact with surface over hundreds of square kilometers for tens of seconds. This may explain anomalous glass and glass-coated clasts in the geologic record.

Vorticity from 5 Mt asteroid impact



Large ring vortices reduce drag, enhance downward flow, and increase coupling of energy to surface of the Earth.