Airburst Consequence Modeling Using Artificial Ablation

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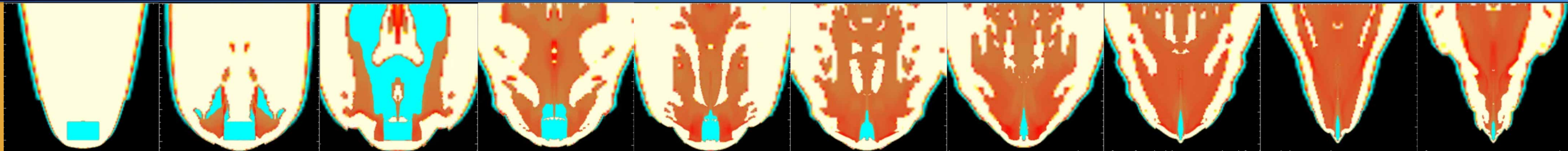
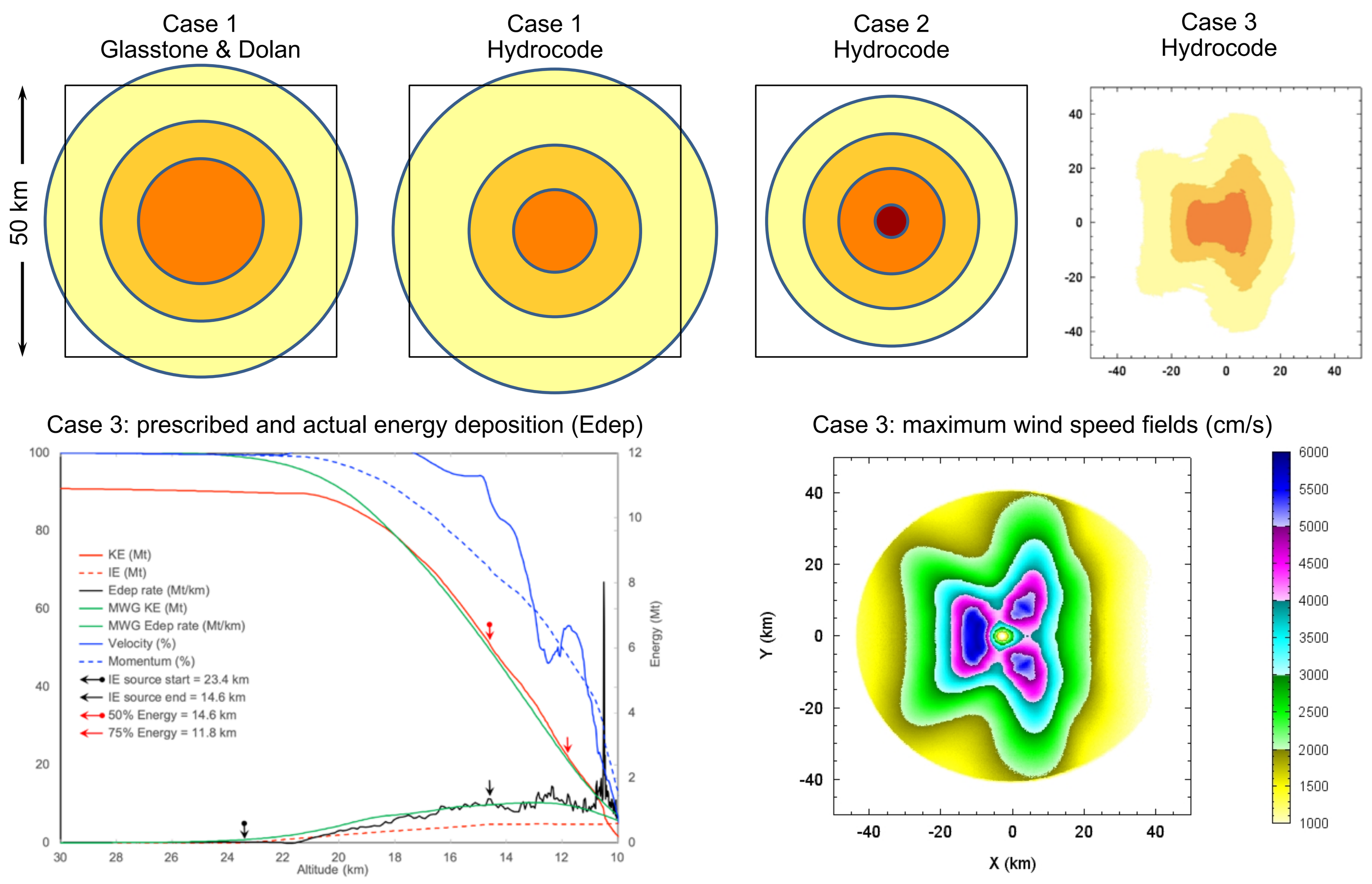


Above: 12-megaton asteroid test of artificial ablation method for Modeling Working Group Case 2: frames are every 0.1 second

Tunguska-like collisional airbursts dominate the current impact risk. The most likely NEO disasters are airbursts, and surface damage calculations are required for risk quantification. Hydrocode simulations are often initialized using entry models that include implicit assumptions about how energy is transferred from exploding asteroids to the atmosphere. Artificial ablation is a method of allowing the transfer of energy to be part of the hydrocode run itself, reducing the number of assumptions and therefore generating better damage maps and risk estimates.

Energy-Loss Edep Insertion Method

CTH simulations contributed to model intercomparison for the Near-Earth Object Modeling Working Group Airburst Blast Propagation Workshop, NASA Ames Research Center, Nov. 18-19, 2019. Three cases were defined. Asteroid properties in CTH were tuned to match energy deposition curves (Edep) prescribed by the Fragmentation Cloud Model (FCM) for collisional airbursts by holding initial mass and kinetic energy constant while tuning density, strength, and external energy sourcing. The global kinetic energy loss of the asteroid (including the ablated portion and cloud entrained into the wake) was used as a proxy for energy deposited into atmosphere (Edep).

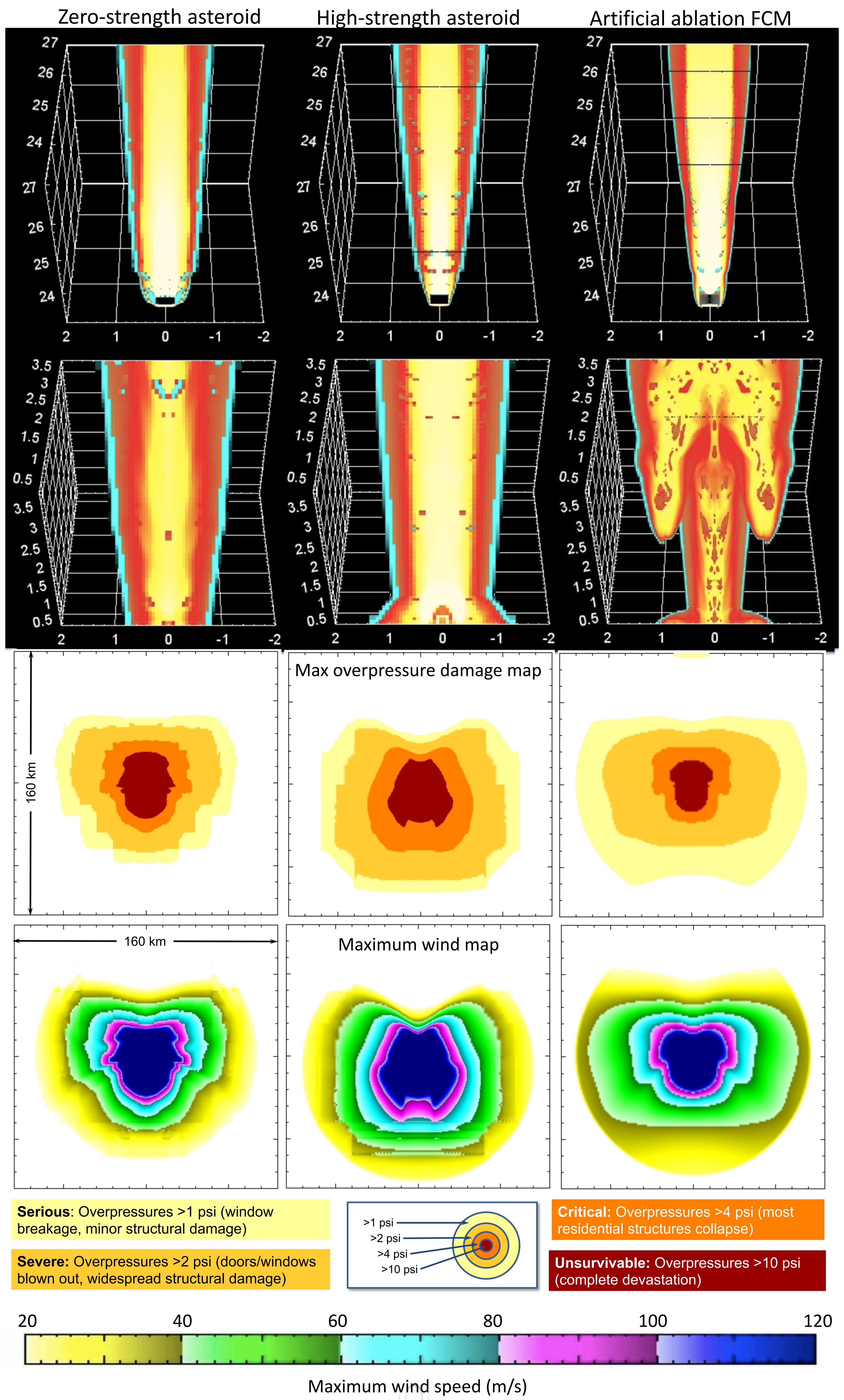


Case 1: Point source blast, 12 Mt, 9.45 km altitude.
Case 2: Vertical entry of 70-m asteroid, 15 km/s, 12 Mt KE, prescribed Edep.
Case 3: Same as Case 2 but 45° oblique entry, different prescribed Edep.

Artificial Ablation Edep Insertion Method

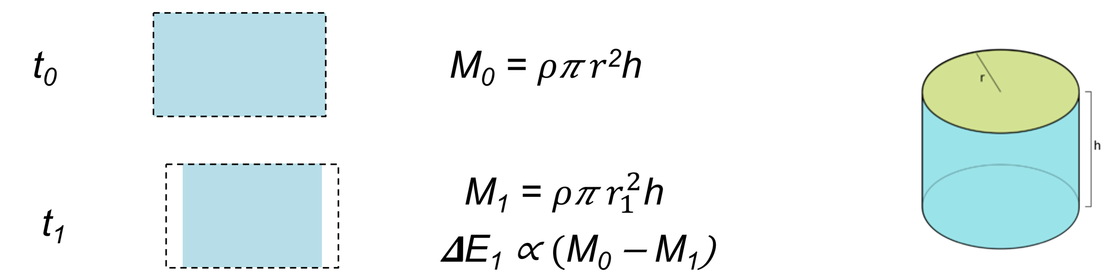
Most of the ablated portion of the asteroid is entrained into the high-velocity wake directly behind it. Mass can be removed from the asteroid at a prescribed rate to match the pre-calculated Edep. One way to do this is to change the physical properties of the asteroid by externally sourcing a small amount of energy in stages, causing a sequence of specified portions of its mass to calve off at a specified altitudes. Edep is ambiguously defined, so a better way is to remove mass at a rate consistent with FCM mass loss.

End-to-End Entry and Effects Simulations



Aritificial Ablation Edep Insertion Test

The simplest way to test this method is to use a cylinder or box shape in a 2D axisymmetric simulation for the asteroid and remove mass at discrete altitudes that match that prescribed by FCM (either by its own mass loss assumption or by its resulting Edep). Frames from a test are shown above.



3D Full-Domain "End-to-End" Tests

The center panel shows the results of three tests using the properties of the 250-megaton mean asteroid prescribed by the PDC 2021 exercise, with an impact velocity of 15.2 km/s and an entry angle of 45°. To minimize insertion error into a relatively course mesh, the asteroid was box-shaped and all three dimensions were exact multiples of the finest cell size. For test purposes, SESAME water was used so that energy required to ablate it by vaporization was only a small fraction of the kinetic energy. The first column is a zero-strength projectile that hits the surface as a vapor jet. The second column is a high-strength projectile that strikes the surface as a solid object. The third column uses artificial ablation based on the highest-strength (10 MPa) FCM mean asteroid model, using the first three fragmentation events to ablate 80% of the mass at altitudes of 25.1, 22.2, and 19.1 km. Below 19.1 km the remaining solid fragment carries a negligible fraction of the initial kinetic energy. The top two rows show time steps at 0.5 and 3.0 s, respectively, in a 45° plane that contains the entry path through a 40×80×160 km half space. Shortly after impact the mesh unrefines to allow the shock to propagate across the surface to create maps of maximum overpressure (3rd row) and maximum wind speed (4th row). These end-to-end runs allow the entry and shock propagation to be performed as a single calculations for demonstration purposes, but separate runs allow higher-resolution entry simulations.

Edep is Ambiguous and of Limited Usefulness

There is no unique agreed-upon definition of energy deposition (Edep). In FCM the different impactor components (various clouds and fragments) contribute to Edep when they pass the altitude at which they lose their increment of KE, even though at different times. My Edep sums all impactor KE losses from everywhere and attributes them to the altitude of the leading fragment at that instant. In reality, Edep is spatially and temporally distributed. It is considered to be a function of the Eulerian altitude coordinate z, but KE is actually lost into a rapidly-moving and deforming medium—the atmosphere—and is advected downward on time scales that are commensurate with deposition time. Edep is useful for inter-comparison of various airburst scenarios but, unlike artificial ablation, does not contain enough information about mass and velocity fields to be uniquely capable of initializing hydrocode simulations for modeling surface blast effects.

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