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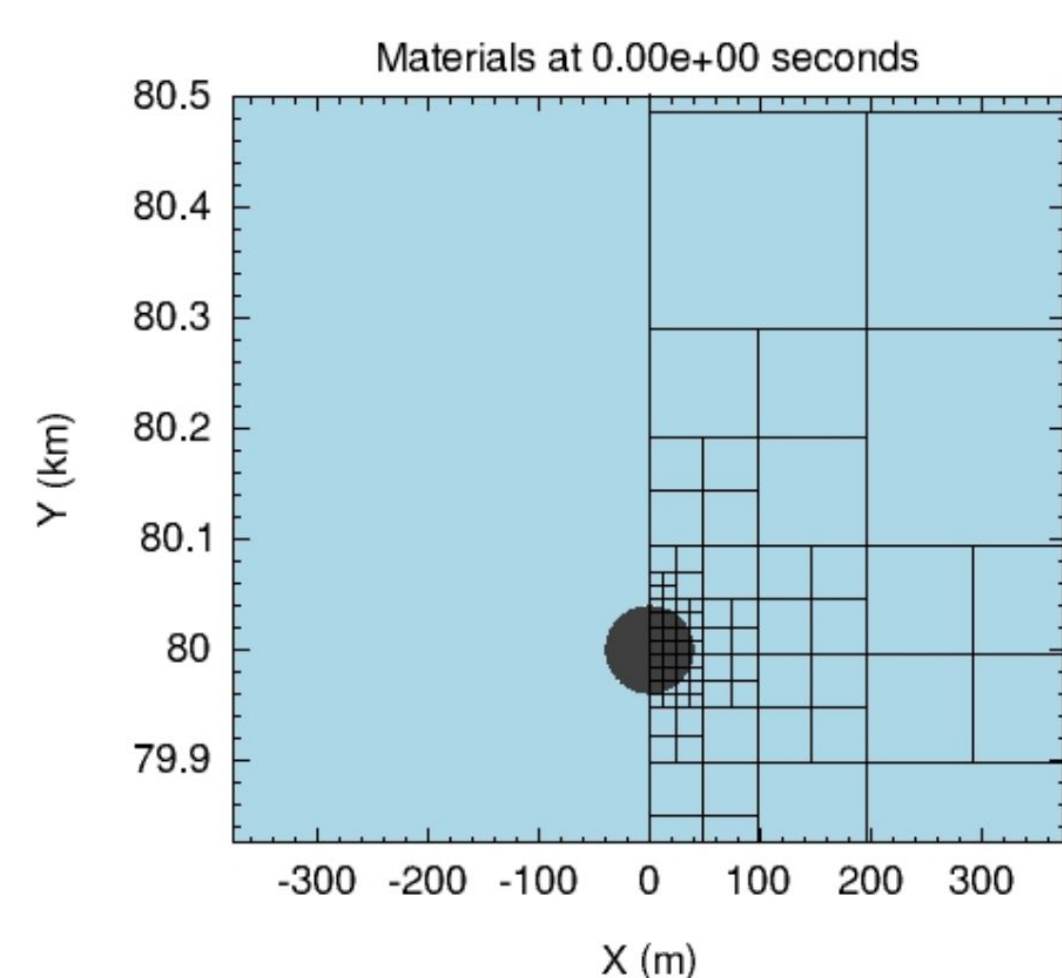
Motivation

Near-Earth object (NEO) impacts pose a significant risk to the Earth, with potential consequences ranging from localized destruction to global-scale environmental disruptions. A critical aspect for NEO impacts is the likelihood that an incoming projectile detonates in the atmosphere during entry versus penetrating through the atmosphere to impact the Earth's surface. When a projectile detonates in the atmosphere as an airburst, the environmental effects depend on the detonation altitude and the amount of energy deposited into the atmosphere. When a projectile impacts the surface, the catastrophic effects can depend and potentially be mitigated by how much disruption of the projectile occurred in the atmosphere prior to surface impact. Prior work has shown that material strength and density can have a significant effect on projectile disruption during entry [1-4].

Using a suite of 2D numerical hydrocode models, we examine how material strength affects the disruption of NEO projectiles as they enter the Earth's atmosphere and influence the likelihood of airburst detonation or surface impact.

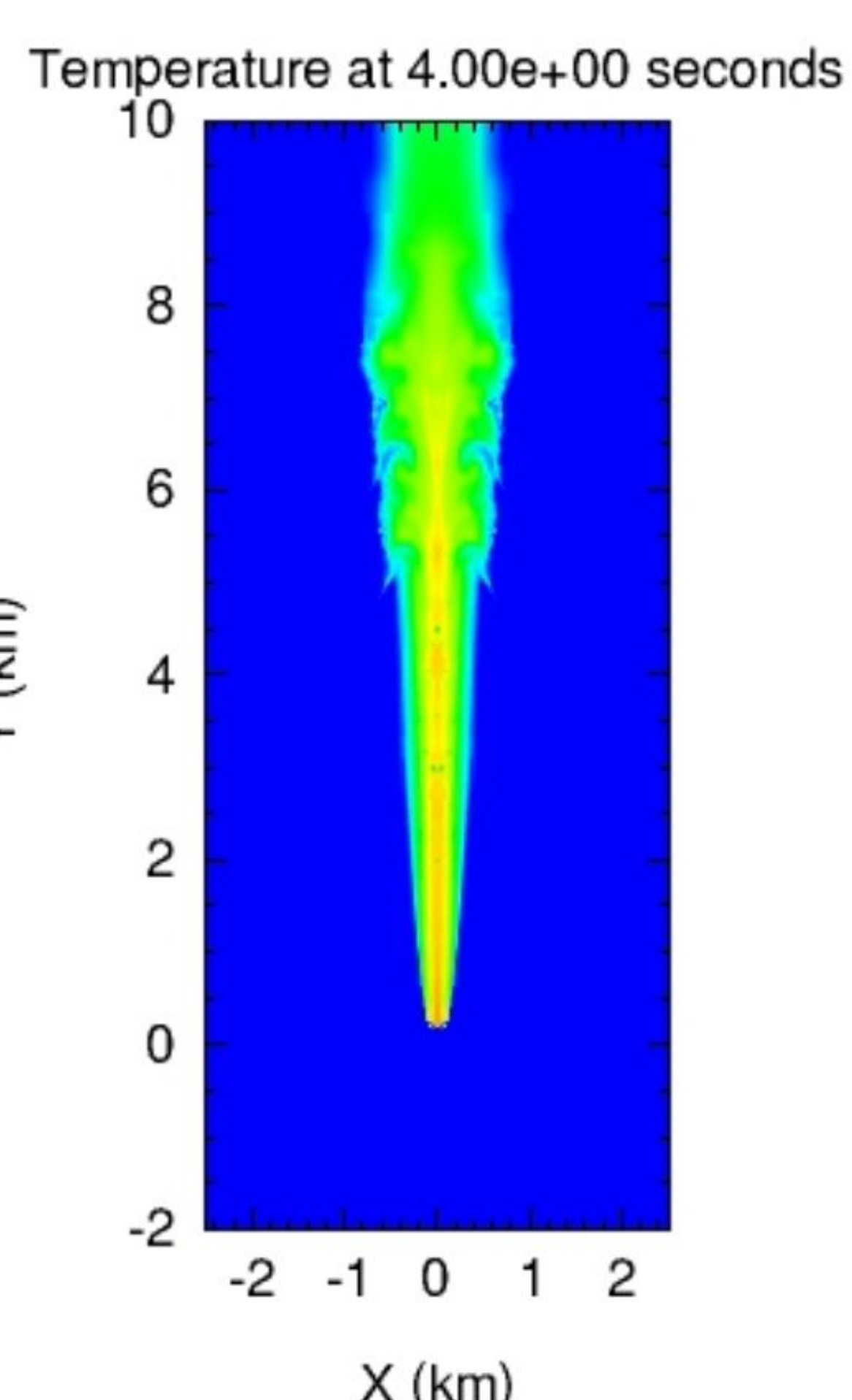
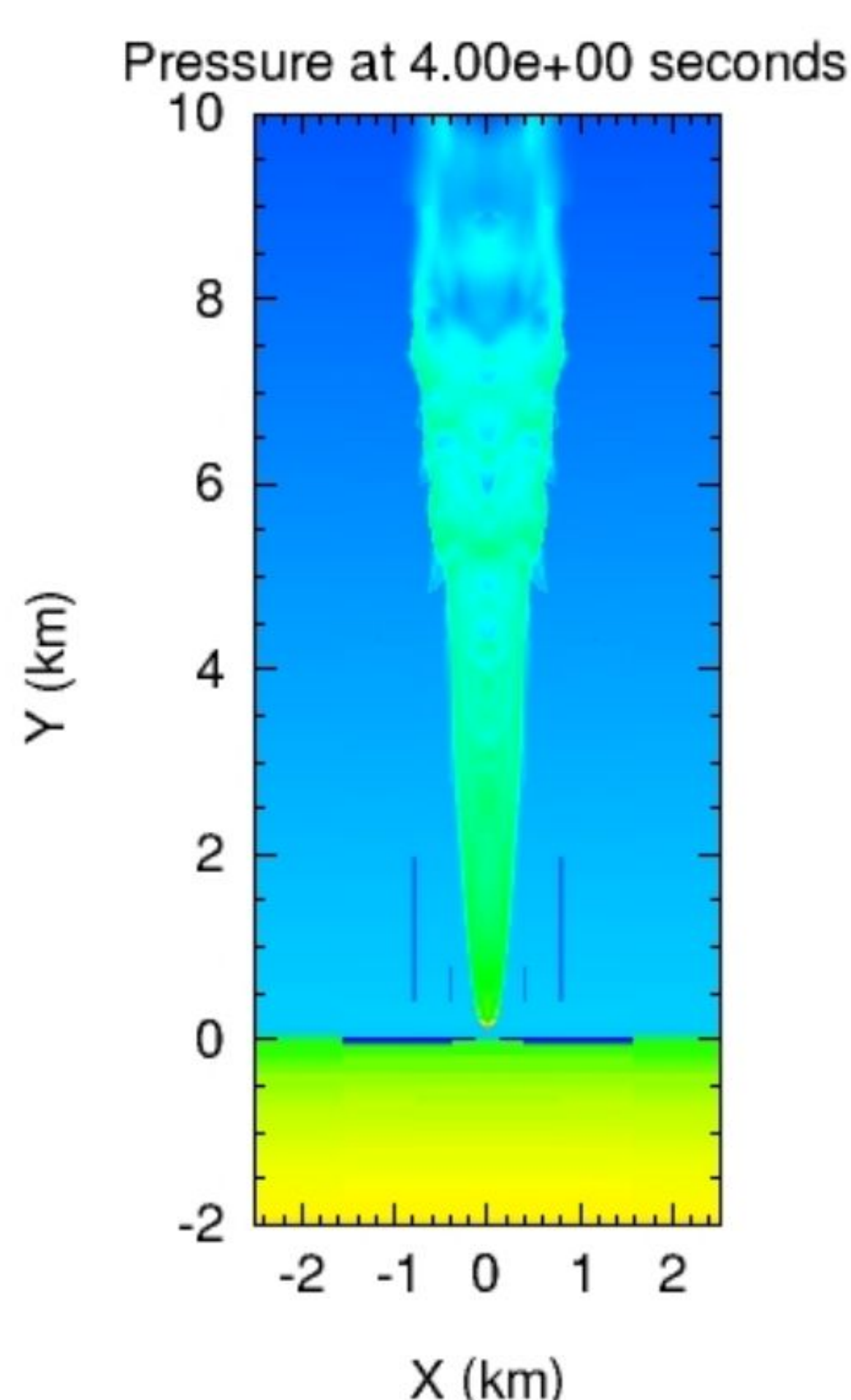
Methods

We utilize the numerical hydrocode CTH [5] in 2D axisymmetric geometry. **We model material strength using the updated ROCK strength model [6,7]** which utilizes a damage and temperature-dependent yield strength [8]. The damage parameter represents bulk fragmentation and accumulates based on plastic strain. Projectiles are modeled as pyrolite using updated parameters [9] for the M-ANEOS package [10]. The Earth's atmosphere is modeled using a SESAME table for air [5]. Adaptive mesh refinement is utilized to resolve the projectile to 20 cells per projectile radius [11].



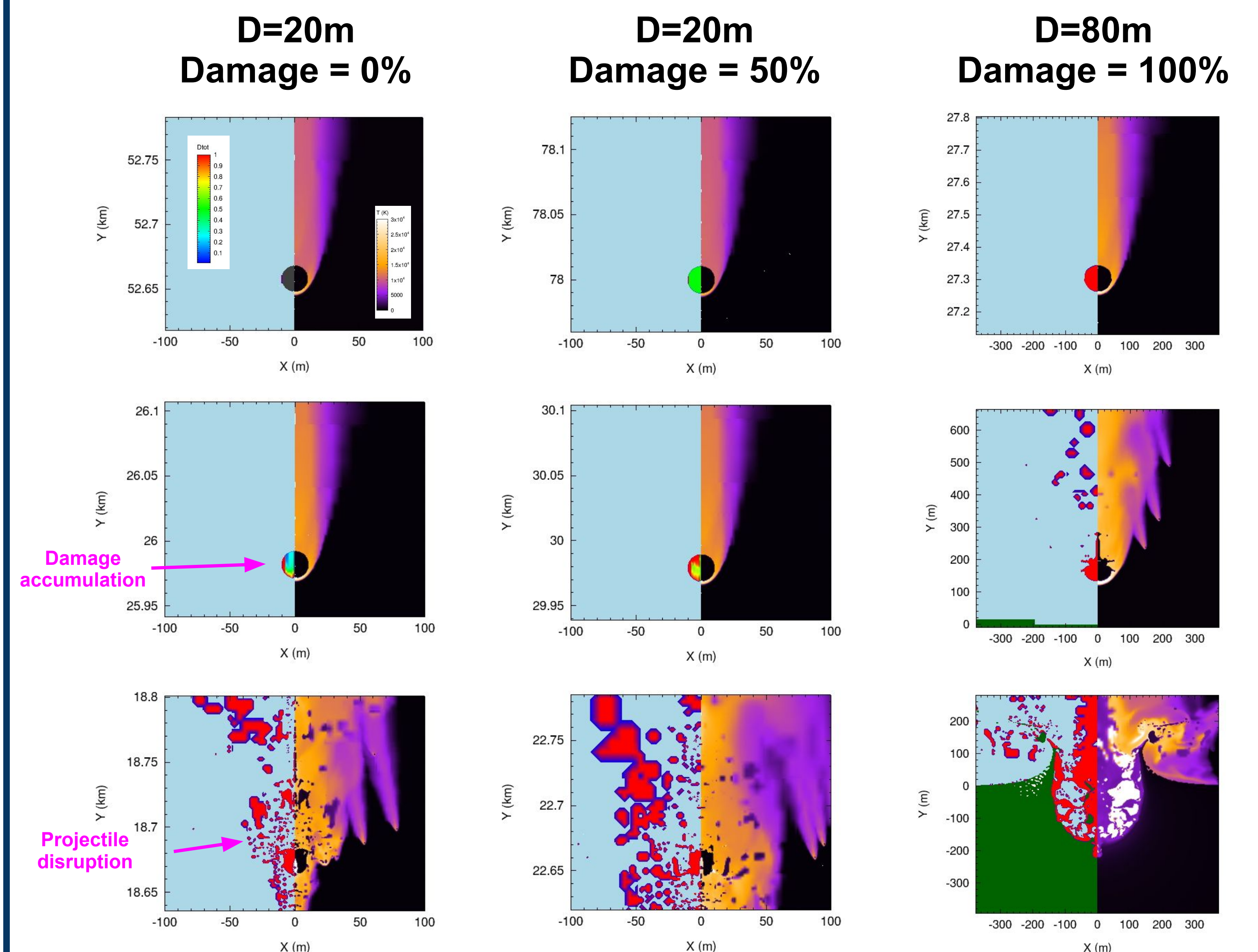
(left) The projectile is shown at its starting location of 80km altitude with an adaptively refined mesh.

(below) Pressure and Temperature profiles immediately prior to surface impact after the projectile has traveled for 4s through the atmosphere.



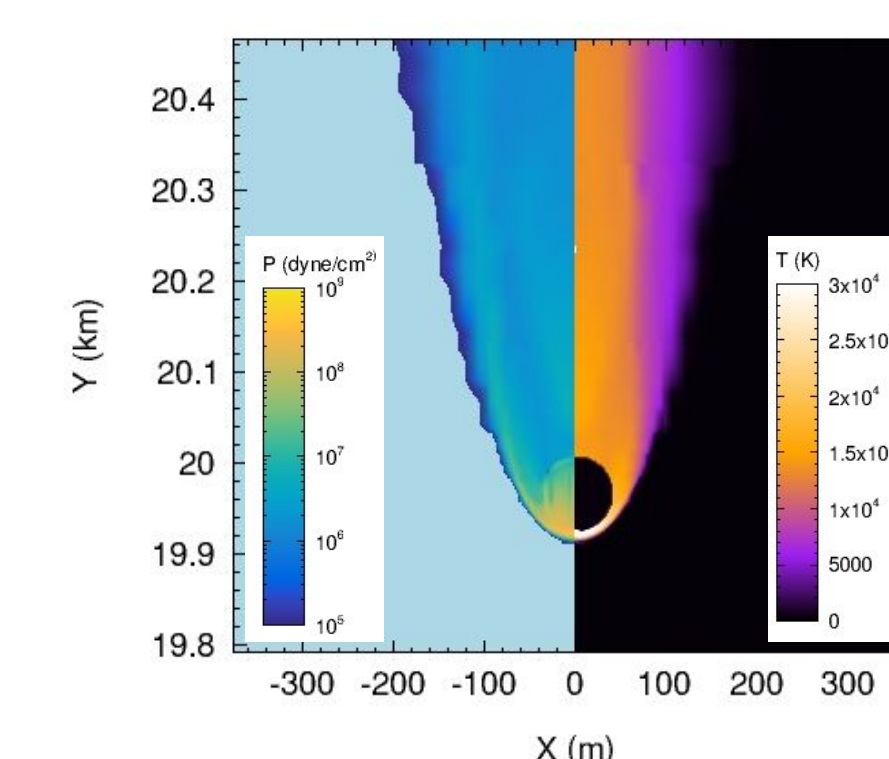
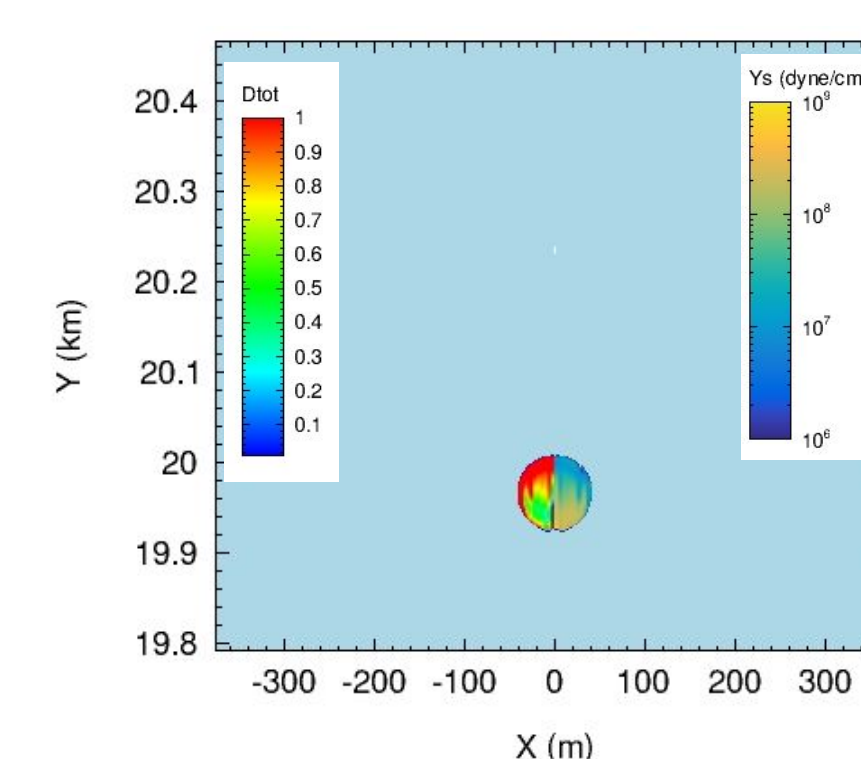
As test cases, **we examine projectiles 20m, 80m, and 300m in diameter**. The 20m projectile is similar to the expected size for Chelyabinsk (airburst height of 28.4km), and the 80m projectile is similar to the expected size for Tunguska (airburst height of 5.74km) [8]. **We vary the initial strength by adjusting the initial material Damage parameter** between 0 (completely intact), 0.5, and 1 (completely fractured). We also test impacts of strengthless projectiles to examine the effects of the strength model on projectile disruption.

Strength-dependent Disruption



Disruption Altitudes for v=20km/s impact

Material	Diameter	Strength	Detonation Altitude
pyrolite	20 m	intact (0% Damage)	14 km
pyrolite	20 m	50% Damage	22 km
pyrolite	20 m	100% Damage	32 km
pyrolite	20 m	no strength (hydro)	50 km
pyrolite	80 m	intact	surface
pyrolite	80 m	50% Damage	surface
pyrolite	80 m	100% Damage	surface
pyrolite	80 m	no strength (hydro)	26 km
iron	20 m	intact	surface
iron	20 m	no strength (hydro)	40 km



For an 80m projectile snapshot, the pressure and damage dependent yield surface (Y_s) is shown to decrease when damage is high (left) and increase where pressure is high (right)

Results

1. Projectiles had lower detonation altitudes with increasing material strength (lower initial damage).
2. For 80m projectiles (Tunguska scale), only the strengthless projectile detonated in the atmosphere; however, inclusion of porosity or lower density projectiles may allow for higher detonation altitudes of projectiles with strength.
3. For iron projectiles, the small 20m projectile with strength impacted the surface. Drastically different surface effects could occur for iron projectiles, which poses a mitigation difficulty given the similar albedos of iron and OC meteors.

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