INTERNATIONAL ACADEMY OF ASTRONAUTICS

Planetary Defense Conference

5-9 May 2025

Stellenbosch, South Africa

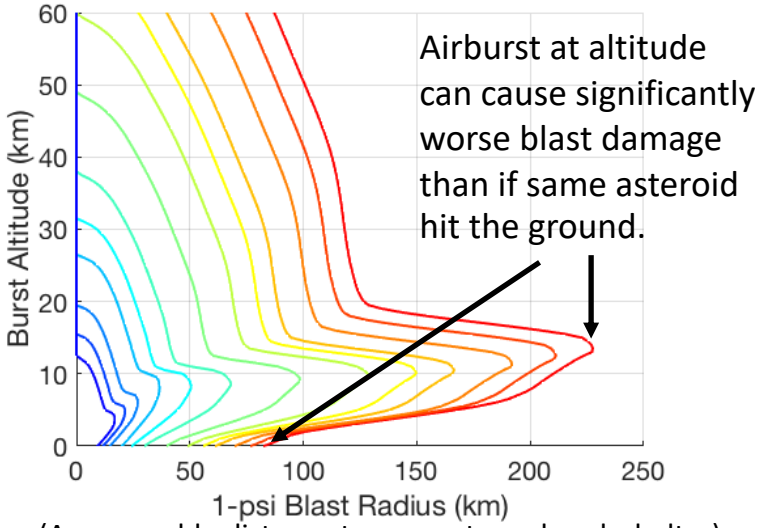
Coupled Radiation-Hydrocode Predictions of Thermal and Blast Damage for PDC25



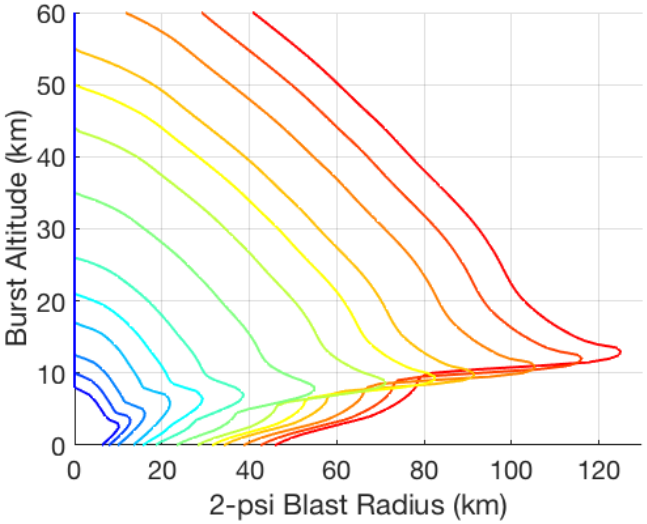
Darrel Robertson[1], Amal Sahai[1,2],
Ashley Coates[1], Eric Stern[1], Lorien Wheeler[1]
[1]NASA Ames Research Center
[2]Analytical Mechanics Associates

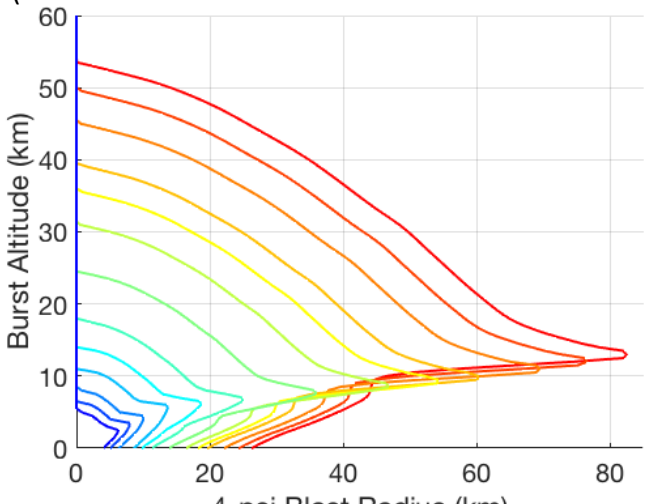
Point Source Blast Pressures

Current curves in PAIR: Interpolation between Glasstone & Dolan (<5Mt) and Aftosmis (>250Mt)

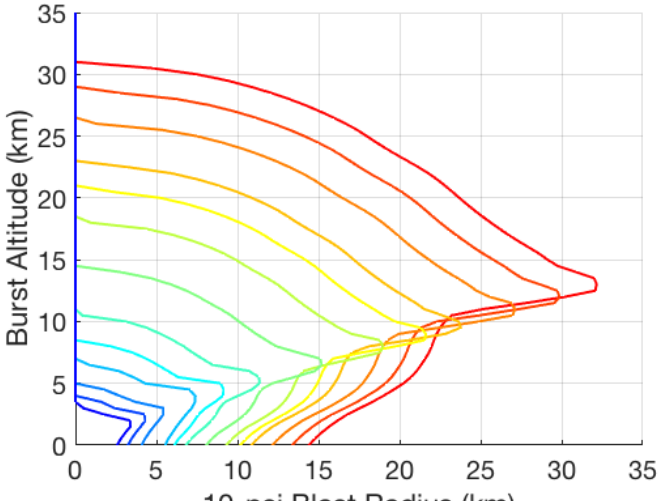


(A reasonable distance to evacuate and seek shelter)

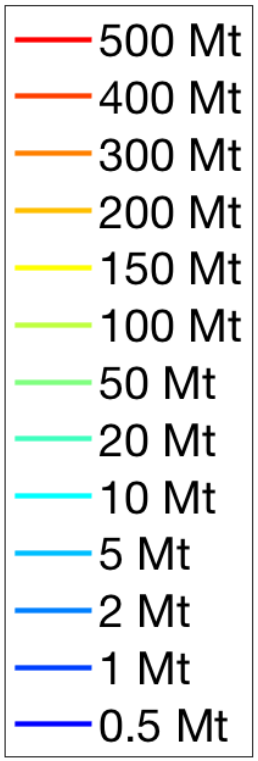




(Will destroy houses)

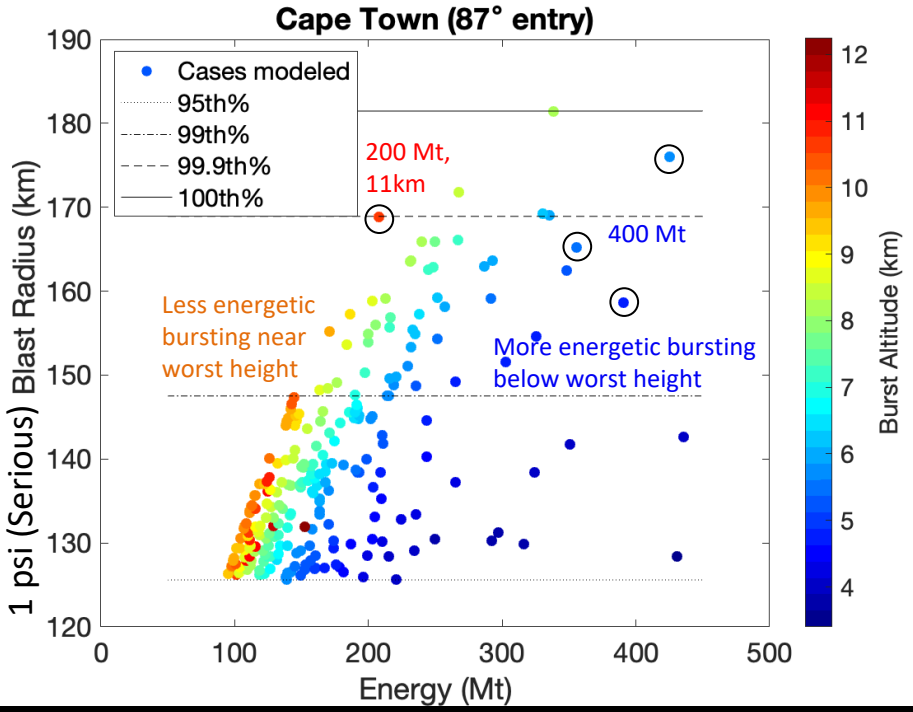


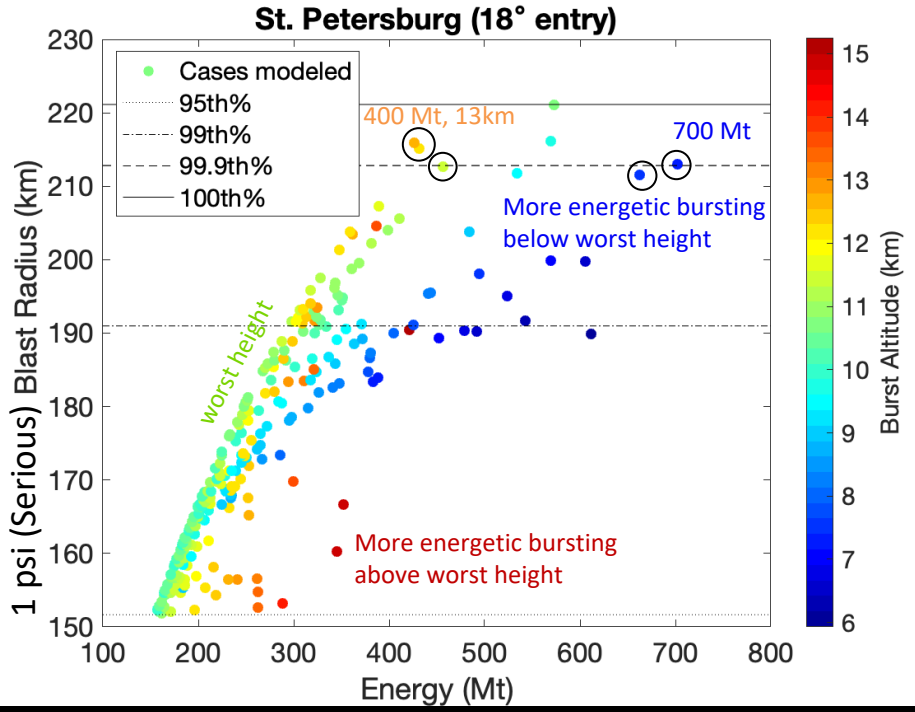
(~100% fatal)



Blast Hazard vs. Energy

PDC25 Scenario

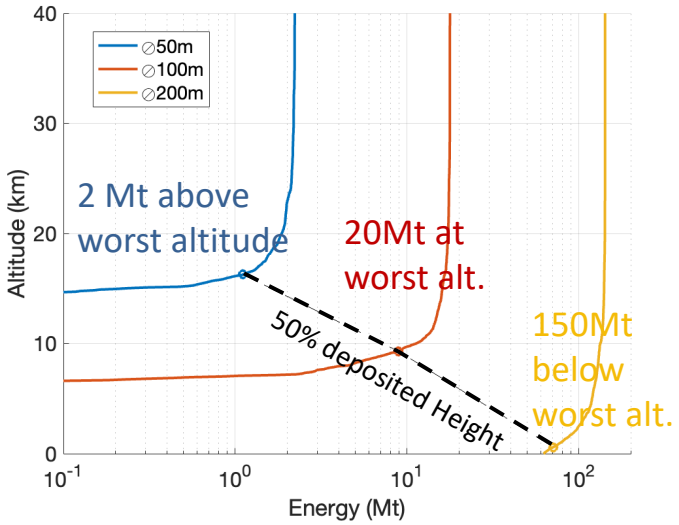


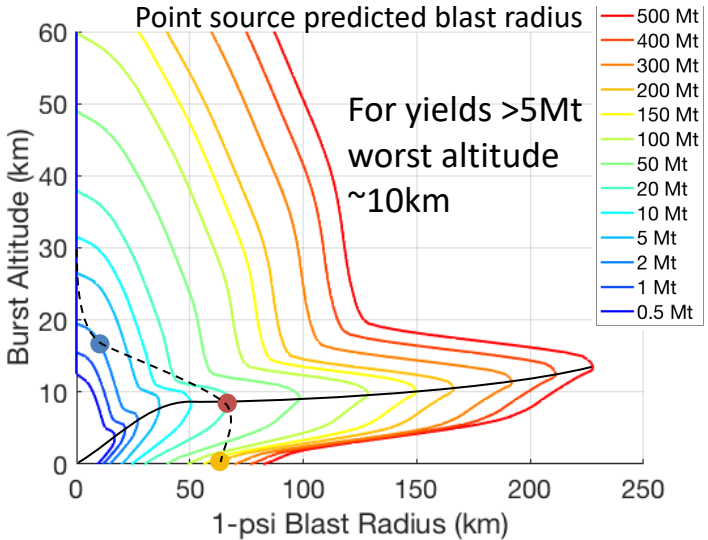


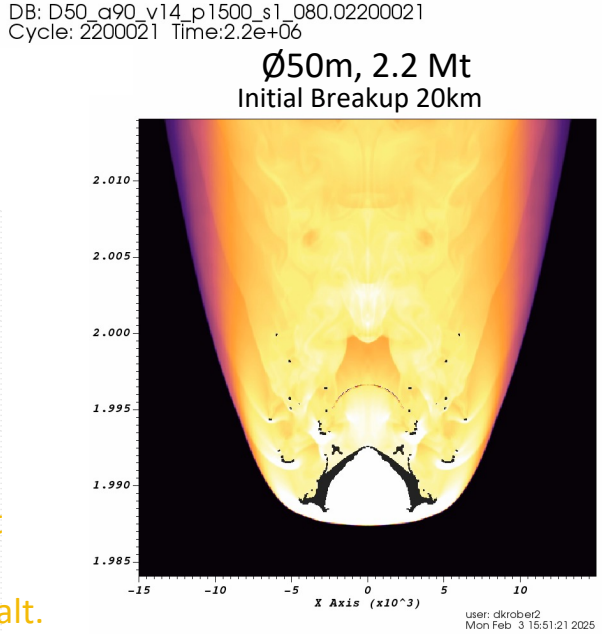
- Using spherical blast at single Height-of-Burst
- Can obtain same blast radius from a smaller burst near the worst height or from a larger ground impact.
- See presentation by Lorien Wheeler for point source trends for PDC25 scenario
- See presentation by Michael Aftosmis for comparison with 3D simulations using energy deposition along trajectory.

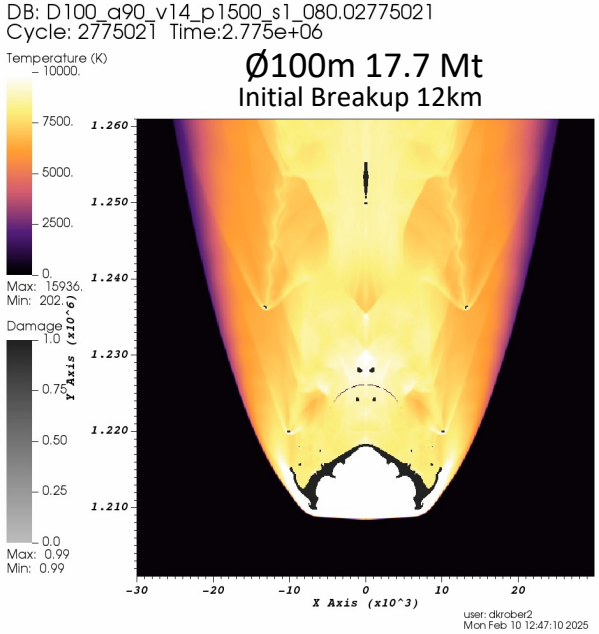
Cape Town (Vertical)

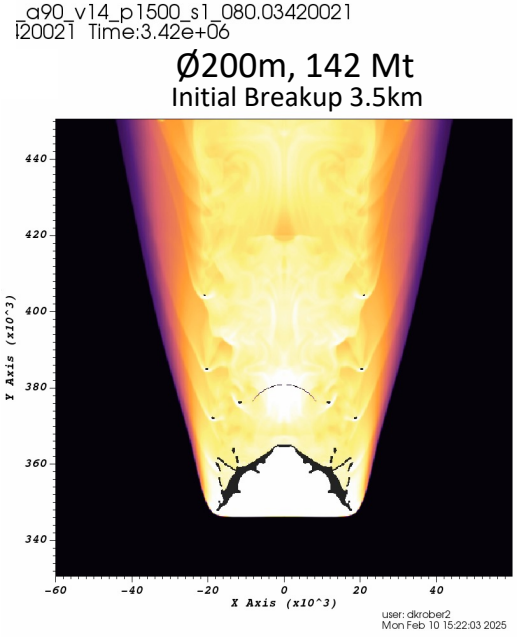
Asteroid
ρ_{bulk} = 1500 kg m^{-3}
ρ_{lock} = 2000 kg m^{-3}
σ_{shear} = 1 MPa
Friction coef = 1
Damage on plastic strain

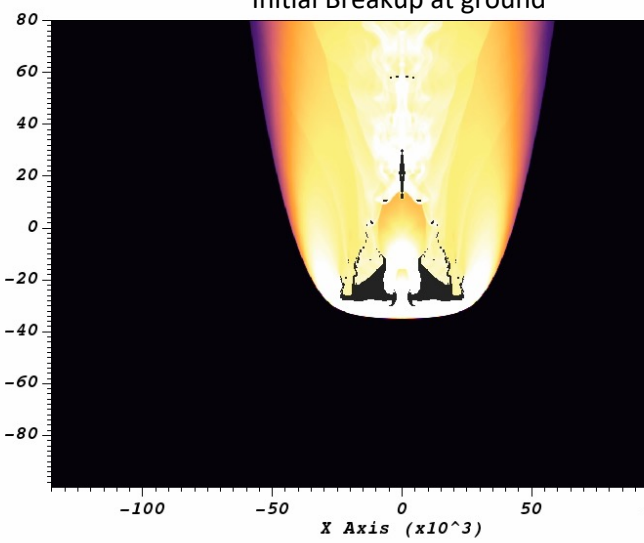








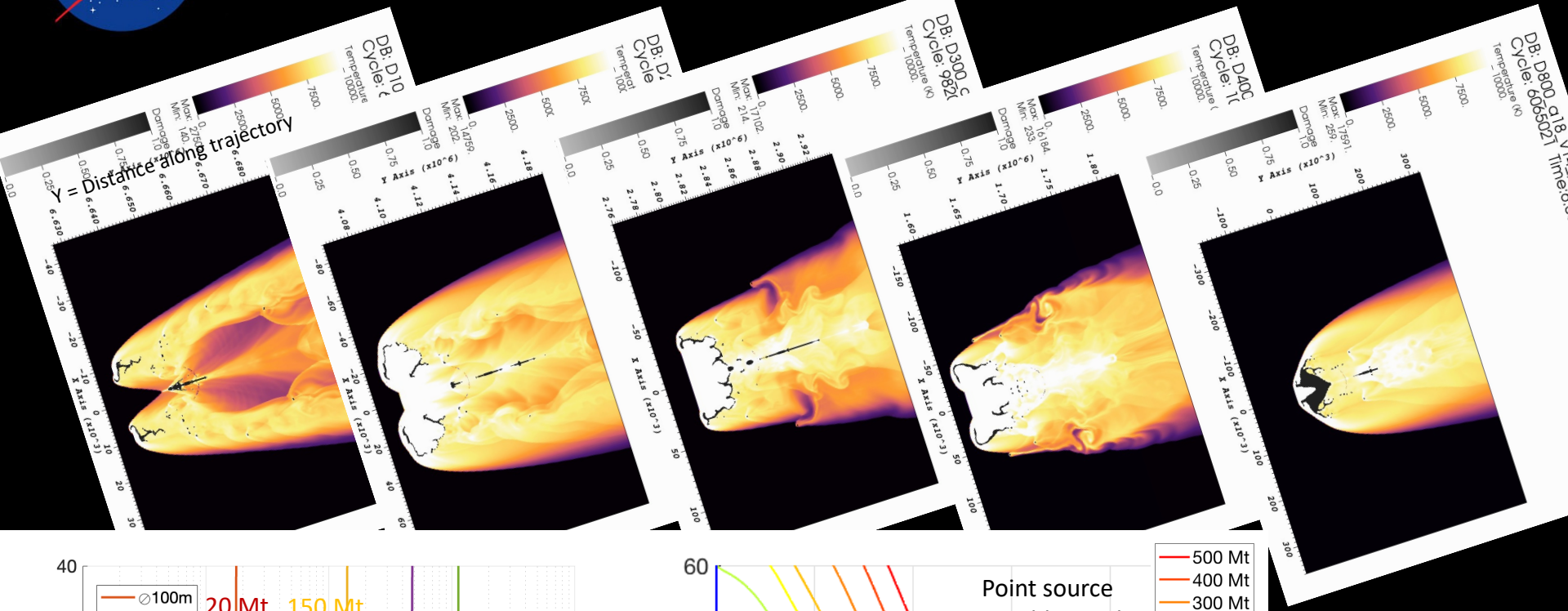


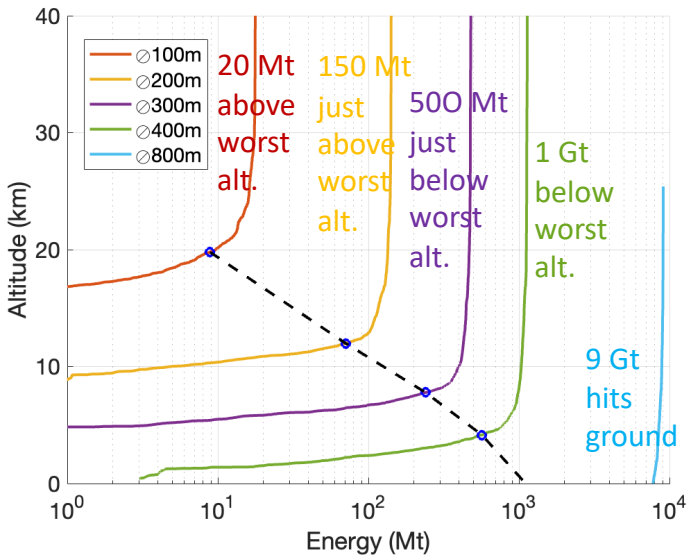


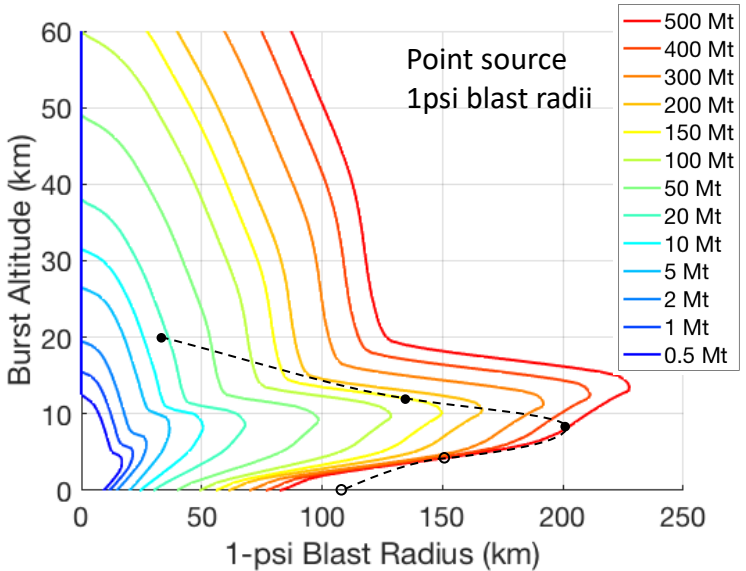
St. Petersburg (18°)

Altitude = Y sin(18°)
= 0.31 Y

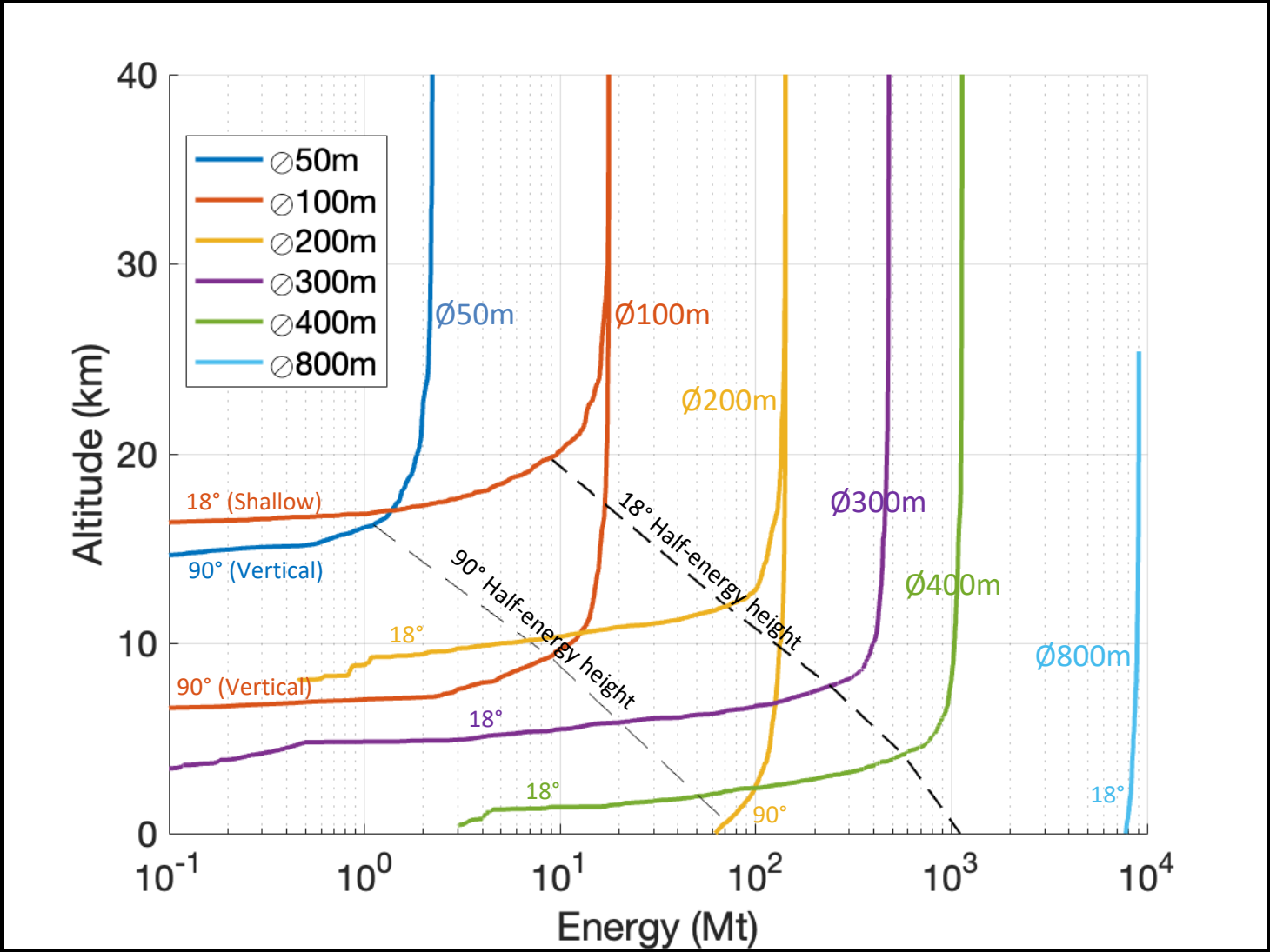
Ø100m 17.7 Mt | Ø200m, 142 Mt | Ø300m, 479 Mt | Ø400m, 1.136 Gt | Ø800m, 9.09 Gt





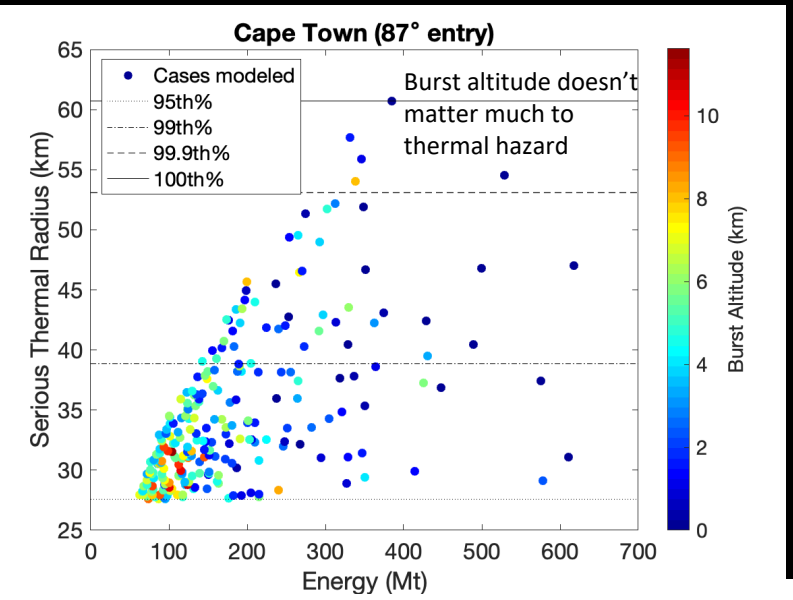


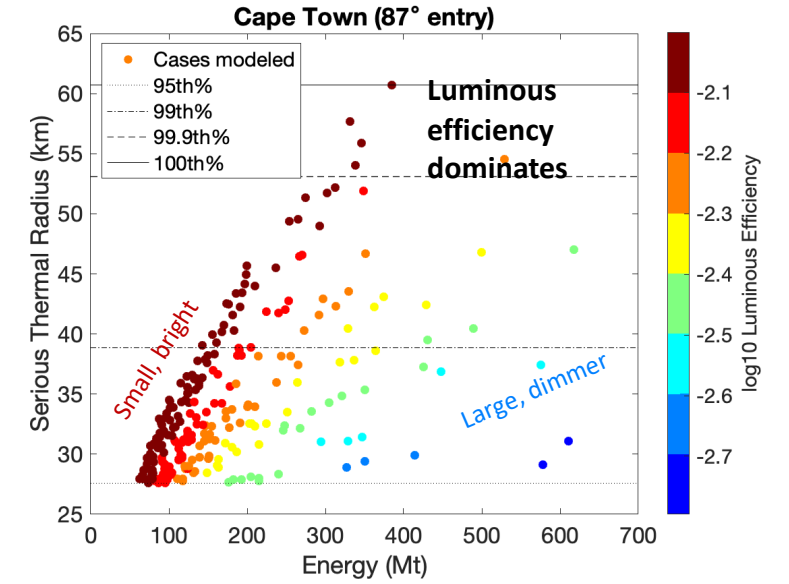
Effective Height of Burst



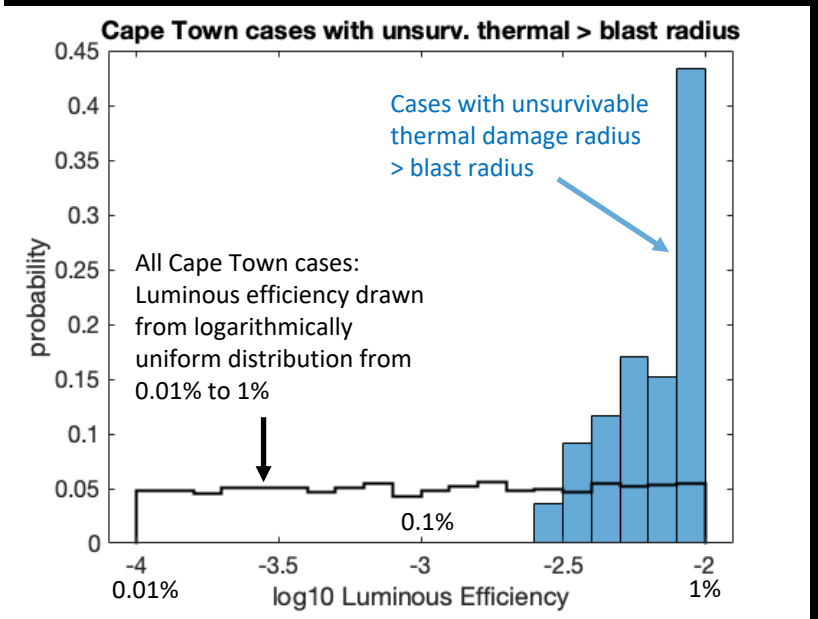
Thermal Hazard vs. Energy

PDC25 Scenario: Cape Town



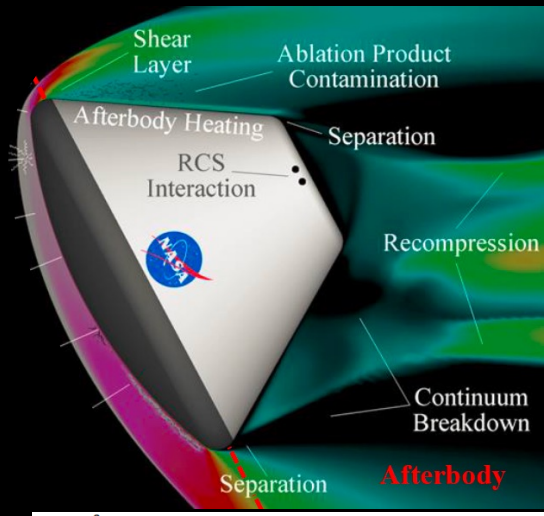


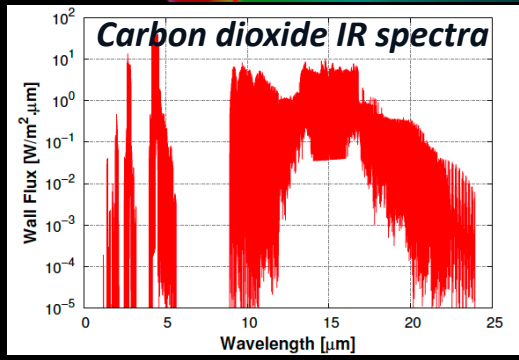
- For a luminous point source the altitude has little affect in current models.
- Dominated by the luminous efficiency (Energy emitted as light / Initial kinetic energy of asteroid).
- Currently a relatively wide range in potential luminous efficiencies.
- Possibility may be underestimating the maximum luminous efficiency for ground impact cases.
- Highlights need for accurate radiation models in simulations to determine actual distribution of luminous efficiency and sensitivity to asteroid and impact properties.
- Expected luminous efficiency will increase with energy



Radiation Solver

- Radiation propagates in all directions every point in space affects every other point within line of sight.
- Photons of different wavelengths differently emitted and absorbed by different media at different temperatures.
- Full radiation solver cost = N cells x N directions x N frequencies. This is extremely computationally expensive.
- Common approximation of radiation uses thermal diffusion. Reduces problem to a local one. Good for localized heat transfer such as from a bow-shock to a spacecraft or asteroid, but cannot model long range propagation of radiation through near-transparent ambient air to the ground.
- To accurately predict the heat transfer to the ground and the wildfire ignition risk need to use a full radiation solver.
- NASA's new high-fidelity, computationally efficient, radiation solver NERO provides speed-up of 100 to 1000 over legacy solvers NEQAIR and HARA. Validated on Orion spacecraft, Mars Sample Return Lander, Dragonfly space probe.
- Coupled ALE3D hydrocode to NERO radiation solver. Running duty cycles with 10 – 50% of time in the flow solver and 50 – 90% of time in the radiation solver. Expensive but now feasible, which was not case with legacy radiation solvers.

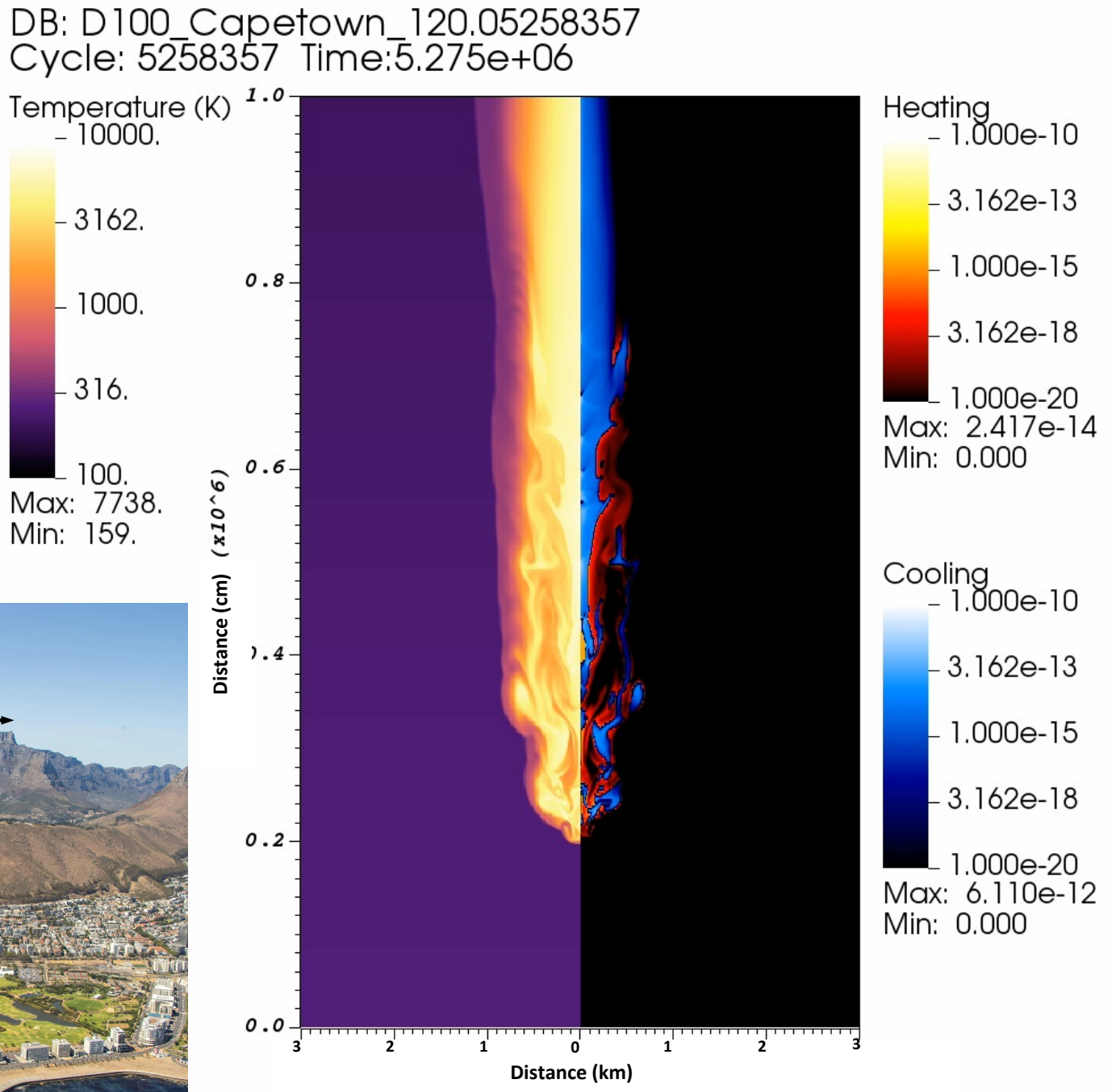




Ø100m Airburst

- Atmosphere to 70km
- Resolved asteroid
- Coupled radiation/flow





Ø100m Airburst



DB: D100_Capetown_NoNero_120.05914693
Cycle: 5914693 Time:7.26501e+06

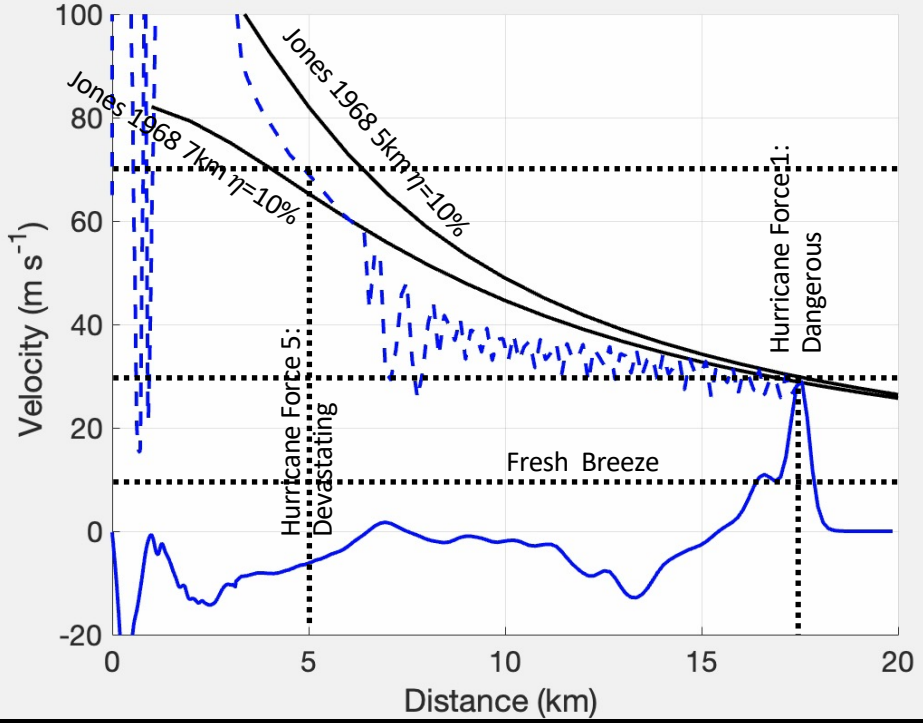
Temperature (K)
10000.
3162.
1000.
316.
100.
Max: 7632.

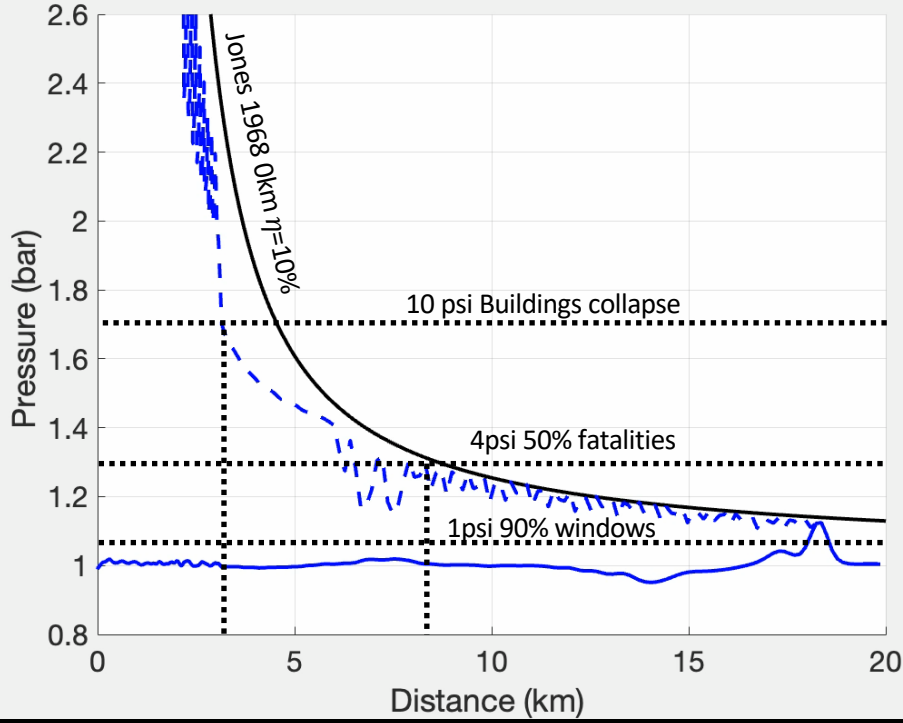
Windspeed
10 km s^{-1}
Escape Velocity
1 km s^{-1}
100 m s^{-1}
Hurricane Cat. 5
10 m s^{-1}
Fresh Breeze
1 m s^{-1}
Calm

Altitude (km)
50
40
30
20
10
0

20
10
0
10
20
Distance (km)

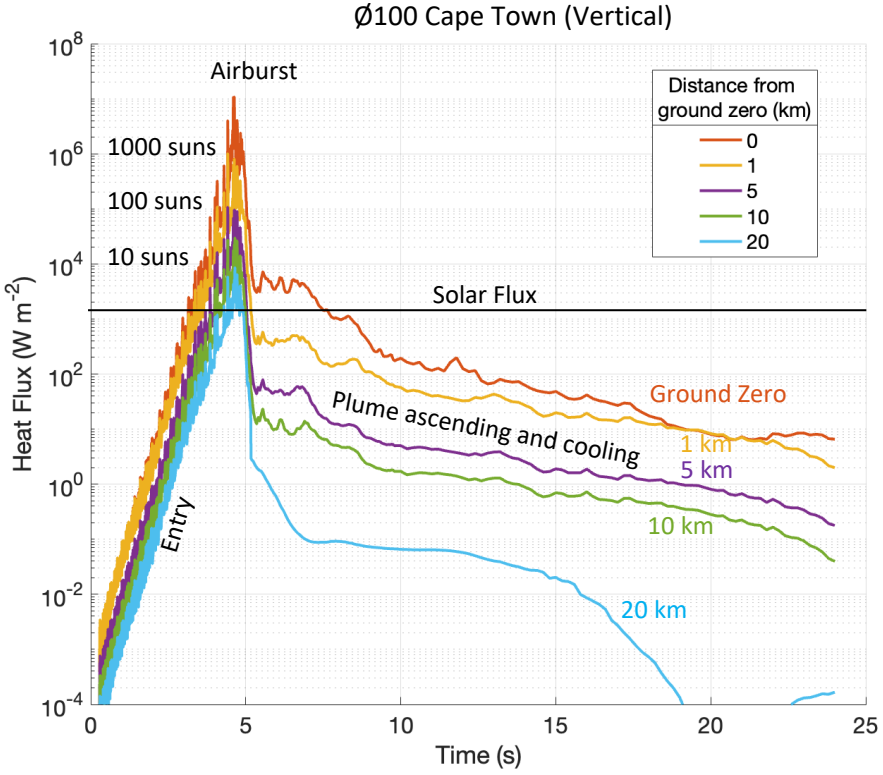
Ø100m Airburst Blastwave

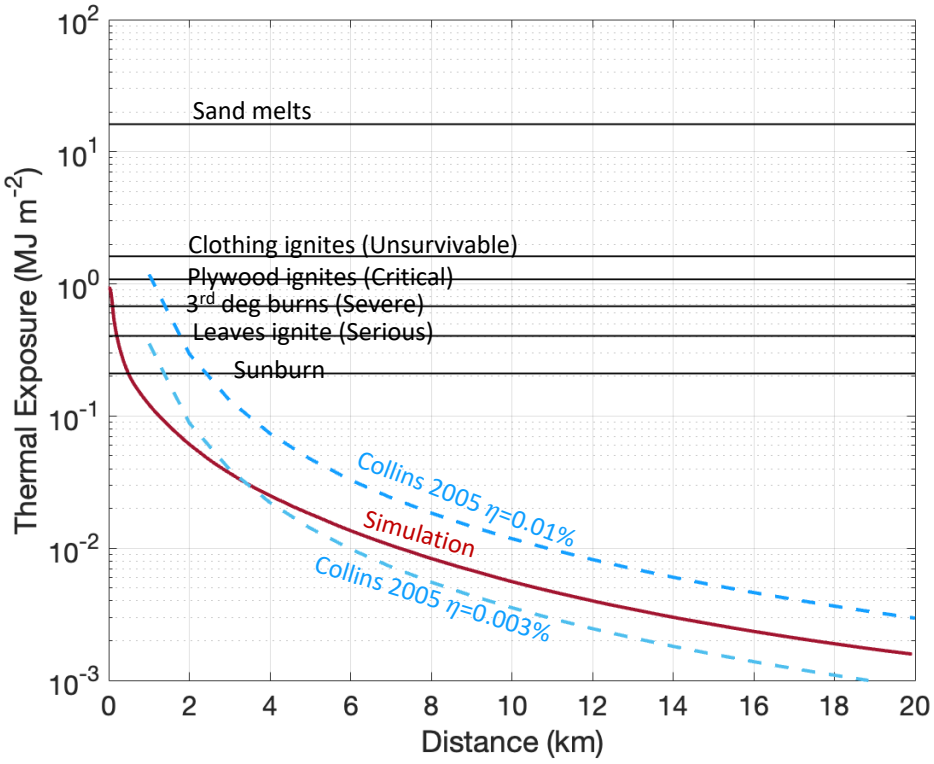




Ø100m Airburst Radiation

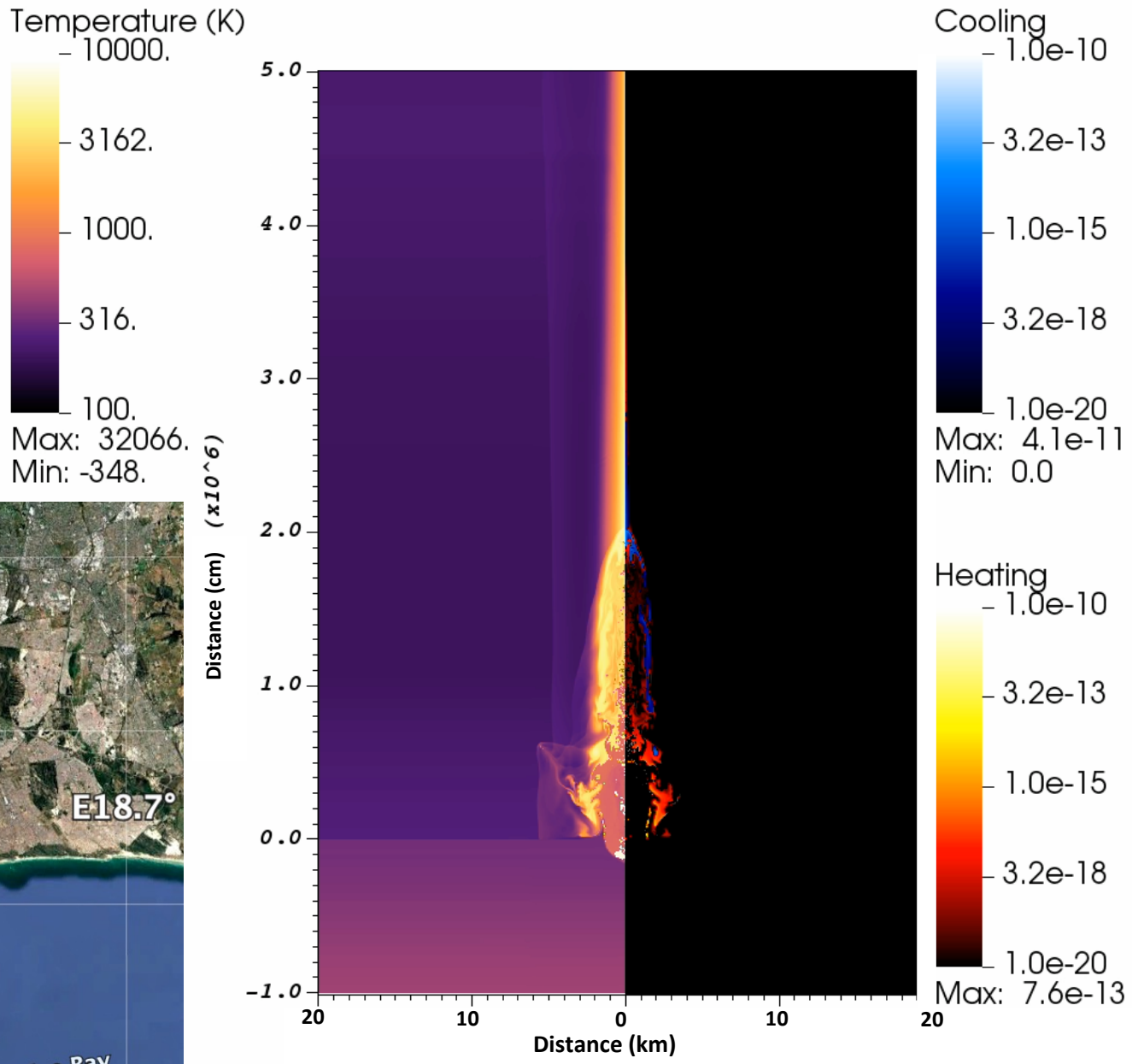
- Flash may blind and vaporize top layer of skin, but won't catch on fire unless directly underneath. (See flash vaporization of leaves in nuclear test Operation Doorstep (Upshot-Knothole Annie) but did not cause forest fire)
- Effective luminous efficiency <0.01% (lower bound in PAIR).
- RADIATION << DANGEROUS THAN BLAST FOR THIS CASE





Ø300m Ground Impact



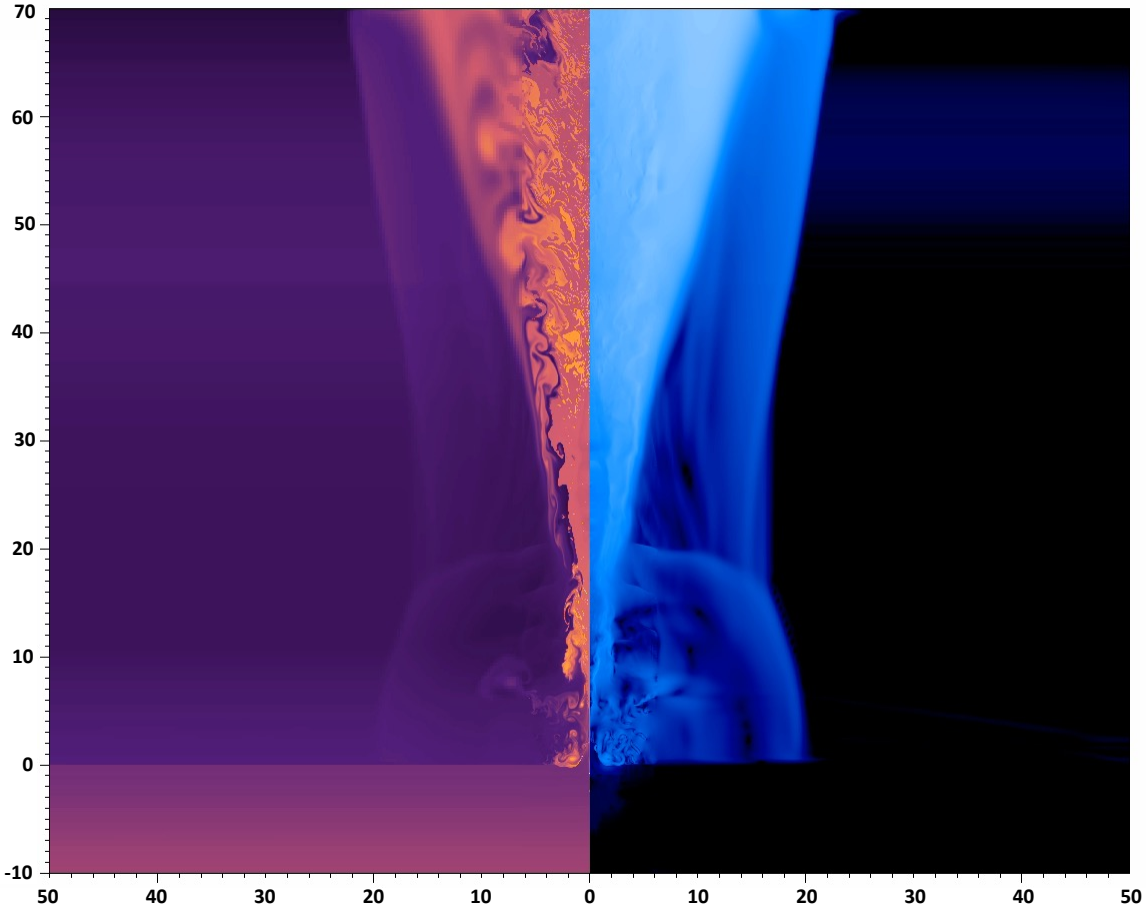


Ø300m Ground Impact Blast

DB: D300_Capetown_NoNero_120.20736691
Cycle: 20736691 Time:4.6e+07

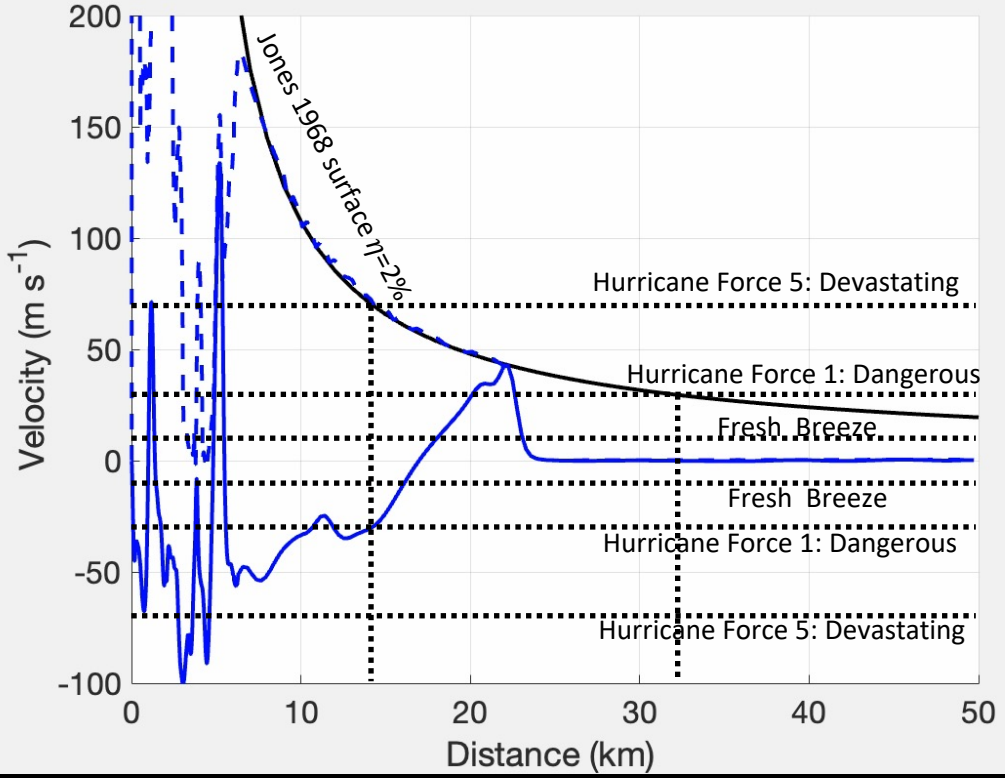
Temperature (K)
10000.
3162.
1000.
316.
100.
Max: 28564.

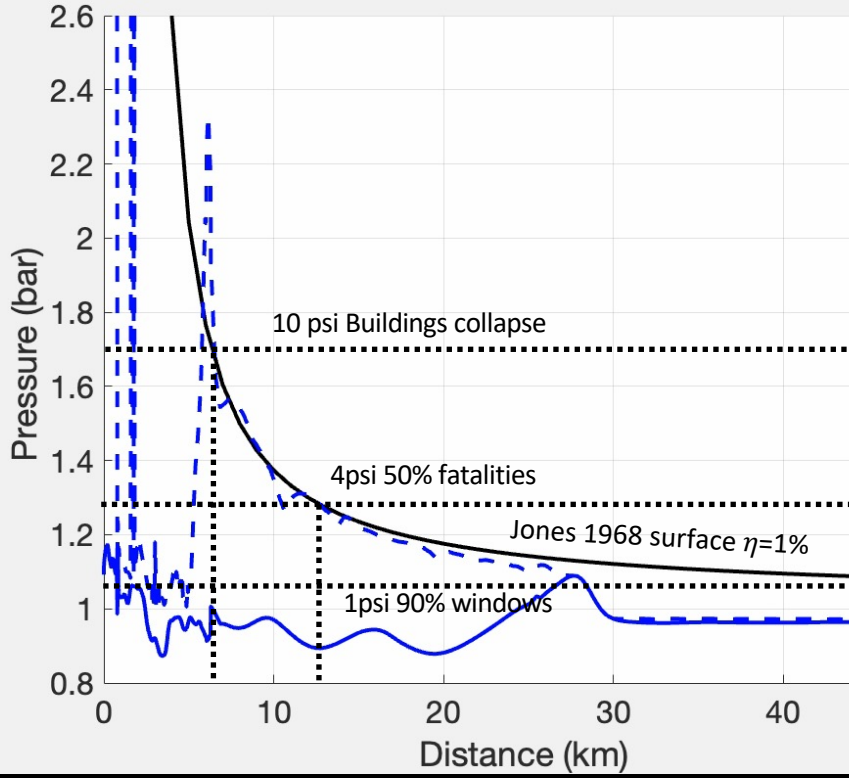
Windspeed
10 km s^{-1} Escape Velocity
1 km s^{-1}
100 m s^{-1} Hurricane Cat. 5
10 m s^{-1} Fresh Breeze
1 m s^{-1} Calm





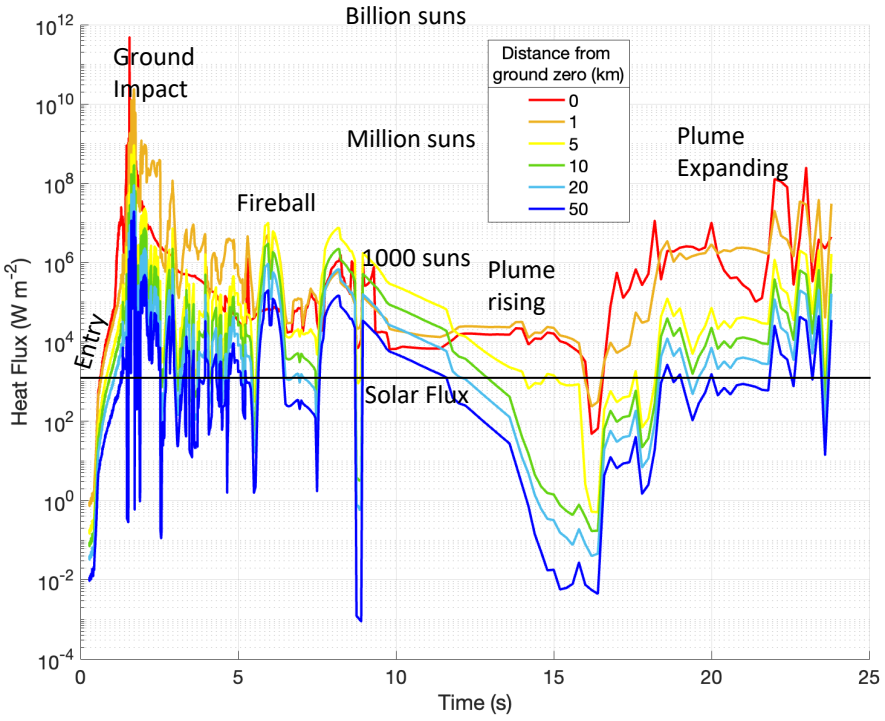
Ø300m Blast

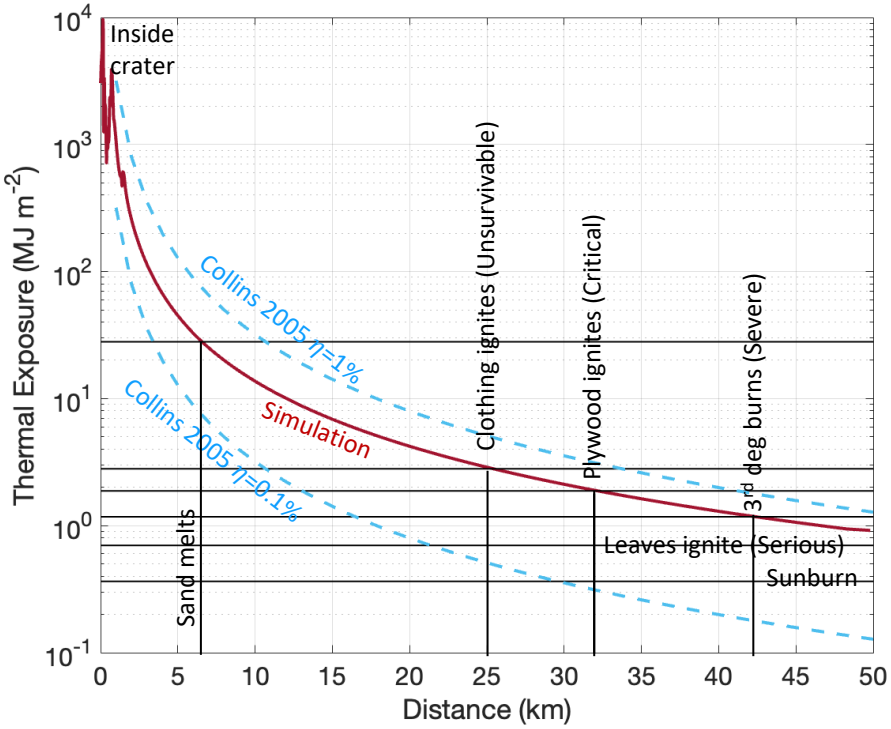

Velocity (m s^{-1})
Distance (km)
Jones 1968 surface η=2%
Hurricane Force 5: Devastating
Hurricane Force 1: Dangerous
Fresh Breeze
Fresh Breeze
Hurricane Force 1: Dangerous
Hurricane Force 5: Devastating


Pressure (bar)
Distance (km)
10 psi Buildings collapse
4psi 50% fatalities
Jones 1968 surface η=1%
1psi 90% windows

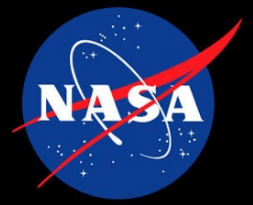
Ø300m Ground Impact Radiation

- Heat inside crater obviously extreme, but temperatures in 10's of thousands Kelvin from fireball can ignite wildfires in excess of 50 km away.
- Late time heat from expansion of plume in upper atmosphere has minimal effect here but slightly increases luminous efficiency at longer distances. May be significant for km size asteroids
- Effective luminous efficiency ≈0.7% (close to upper bound in PAIR).
- RADIATION MORE DANGEROUS THAN BLAST FOR THIS CASE, PARTICULARLY <30km





Improvements



- Currently only air (Oxygen, Nitrogen molecules, atoms, and ions). Rock/rock vapor modelled as transparent. Adding carbon, iron, silicon.
- During entry move heating/cooling with asteroid (or using asteroid centered mesh) will enable heat flux to not need updating so frequently (improving duty cycle ratio).
- ALE3D/NERO currently run serially. Running in parallel will enable significant speed-up.
- Updating NERO to run on GPUs

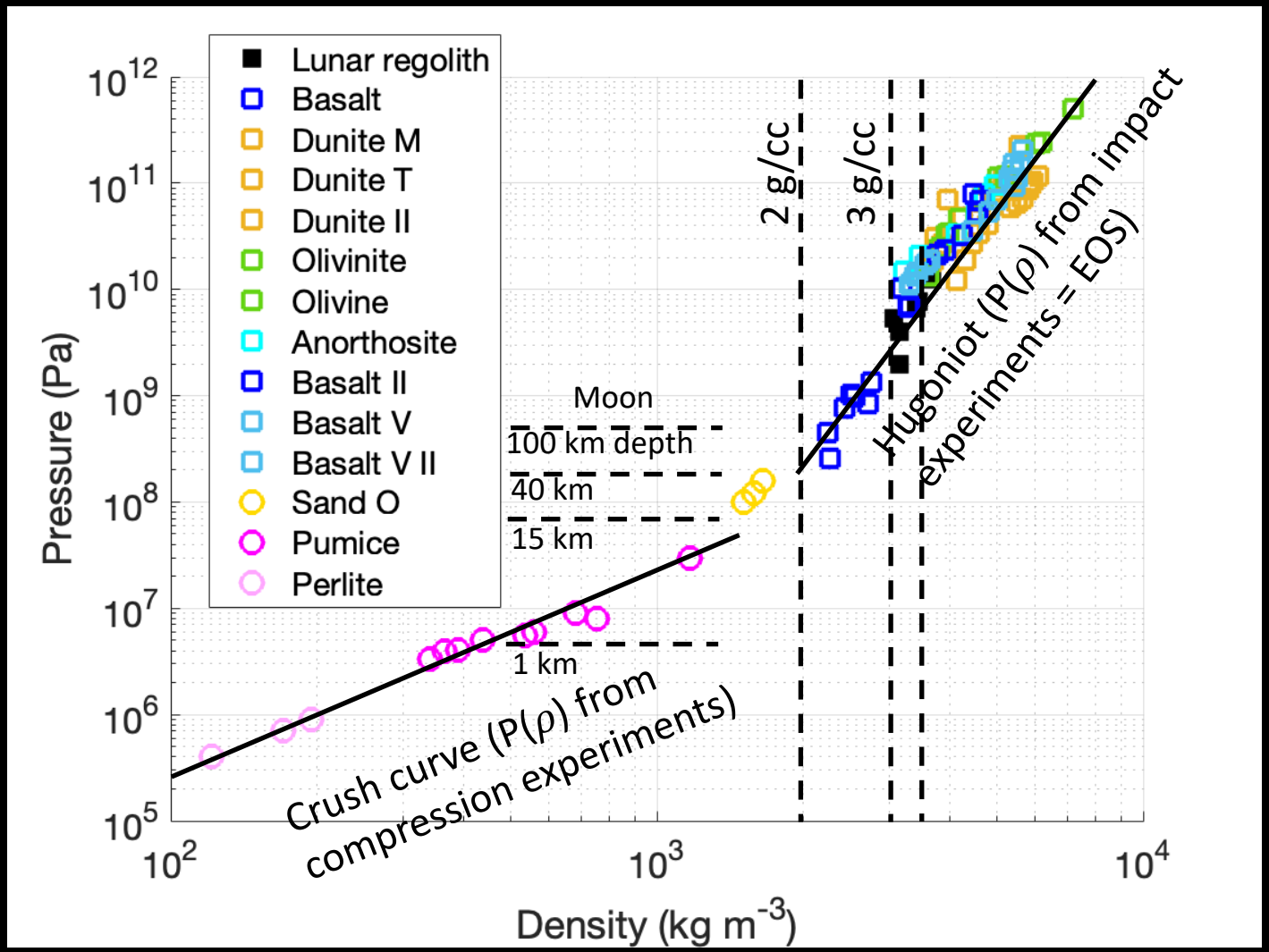
Acknowledgements

- Funded by NASA Planetary Defense Coordination Office under the Science Mission Directorate
- Resources supporting this work were provided by the NASA High-End Computing (HEC) Program through the NASA Advanced Supercomputing (NAS) Division at Ames Research Center.
- Simulations used the ALE3D hydrocode and visualizations by VisIt software. ALE3D and VisIt developed and supported by Lawrence Livermore National Laboratory under the Department of Energy.



BACK UP

Crush Curve



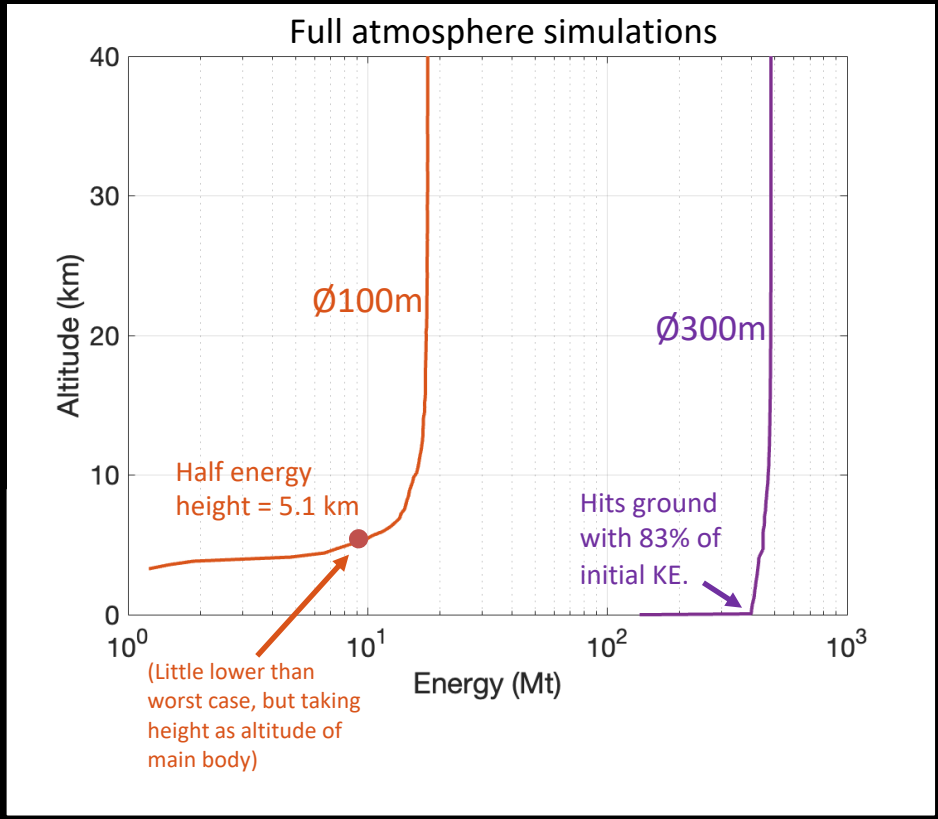
Porosity, ϕ=1-ρ/ρ_g

P = (1-ϕ)$P_s(\rho_g)$

Volumetric strain $\mu=\rho/\rho_g - 1$

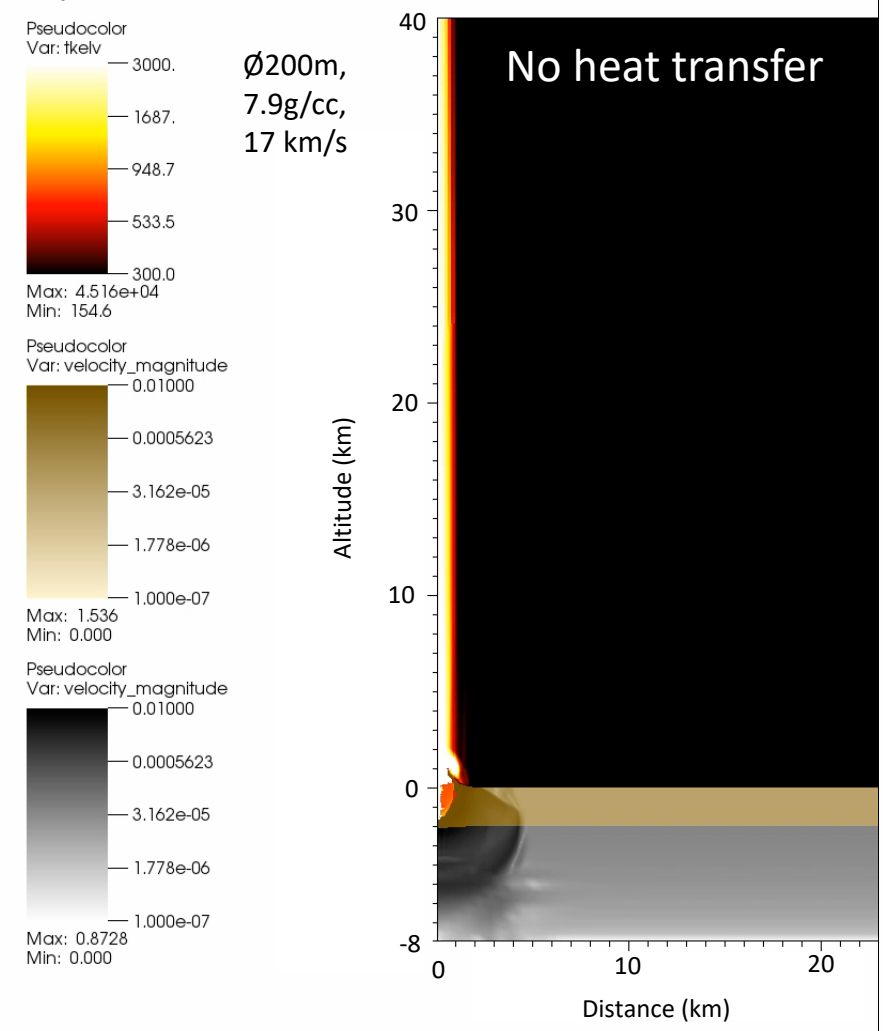
$P_s=K\mu$

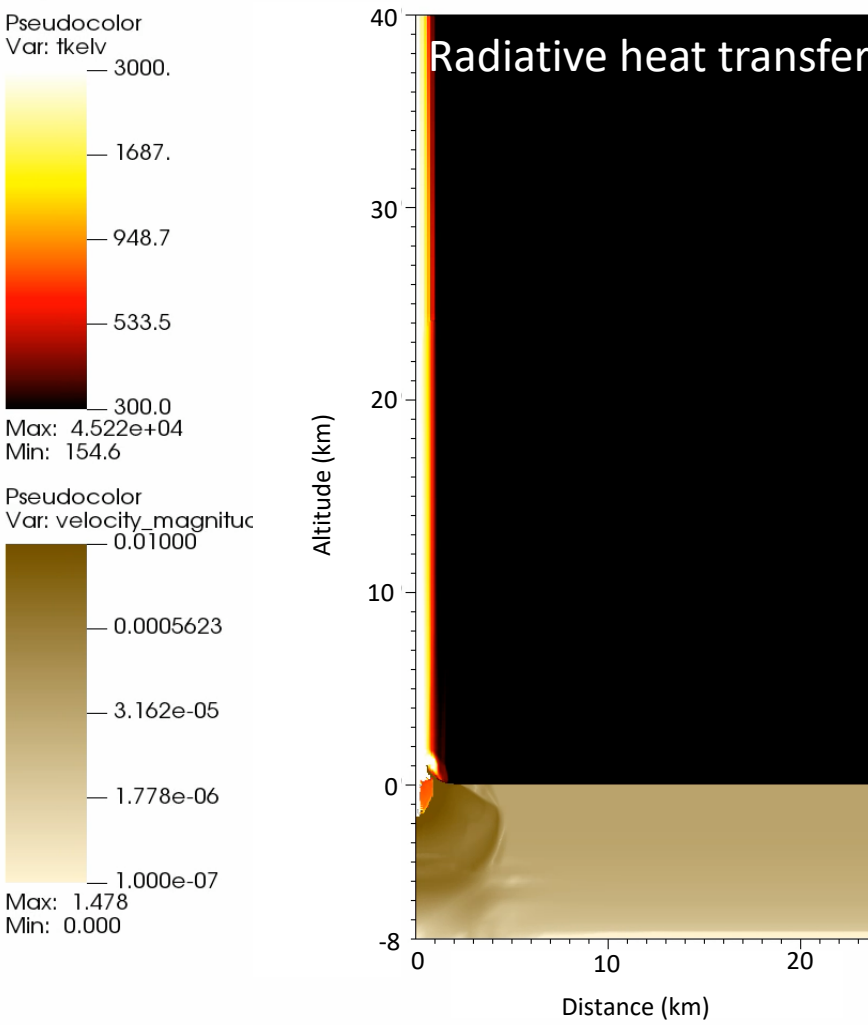
Blast


Full atmosphere simulations
Altitude (km)
40
30
20
10
0
10^0
10^1
10^2
10^3
Energy (Mt)
Ø100m
Ø300m
Half energy
height = 5.1 km
Hits ground
with 83% of
initial KE.
(Little lower than
worst case, but taking
height as altitude of
main body)

Radiative Transfer

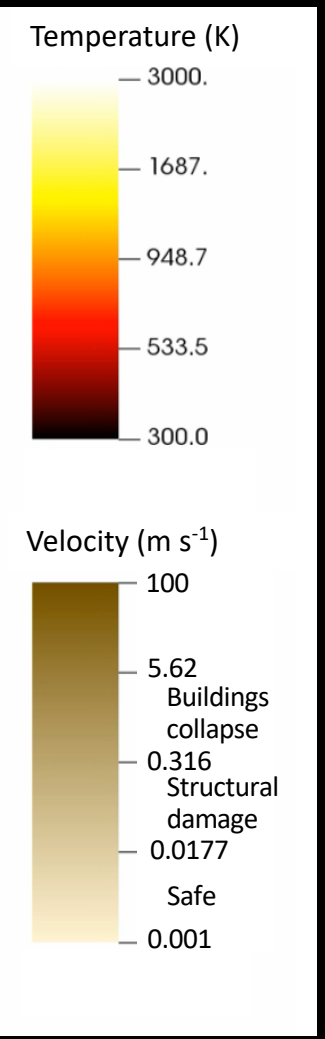
- ALE3D hydrocode loosely coupled to radiative transfer code NERO
- Test case of 1GT impact into continental crust

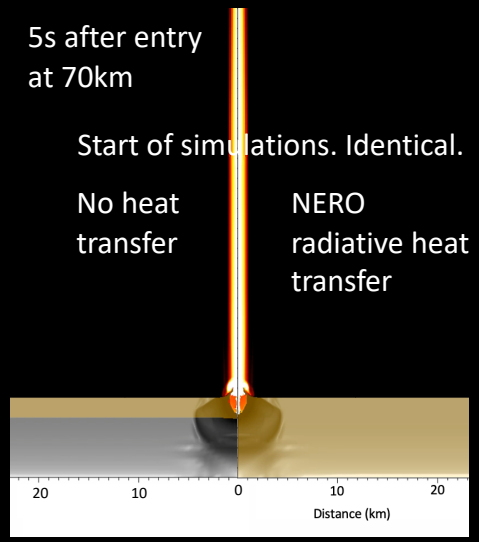


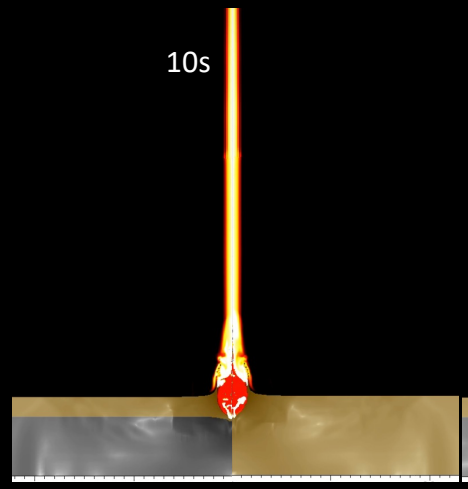


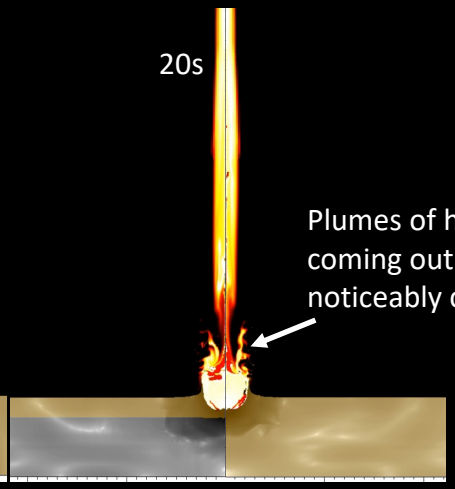
Comparison with/without NERO

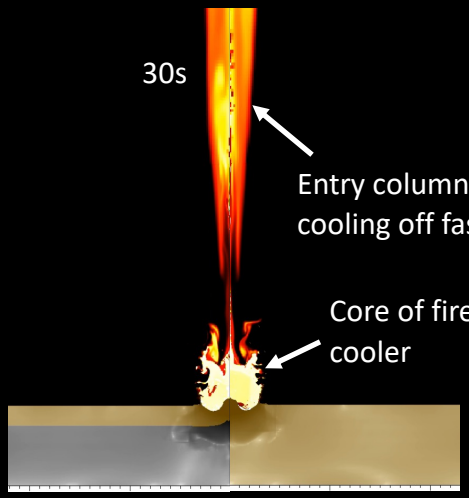
Ø200m, 7.9g/cc, 17 km/s (PDC2019)

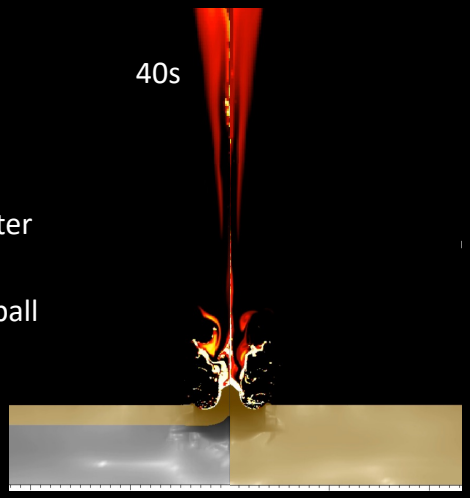


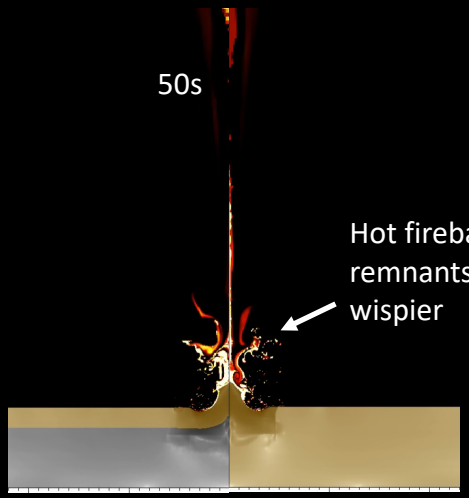












- Overall flow minimally affected
- Temperatures noticeably cooler with radiation cooling the hot regions