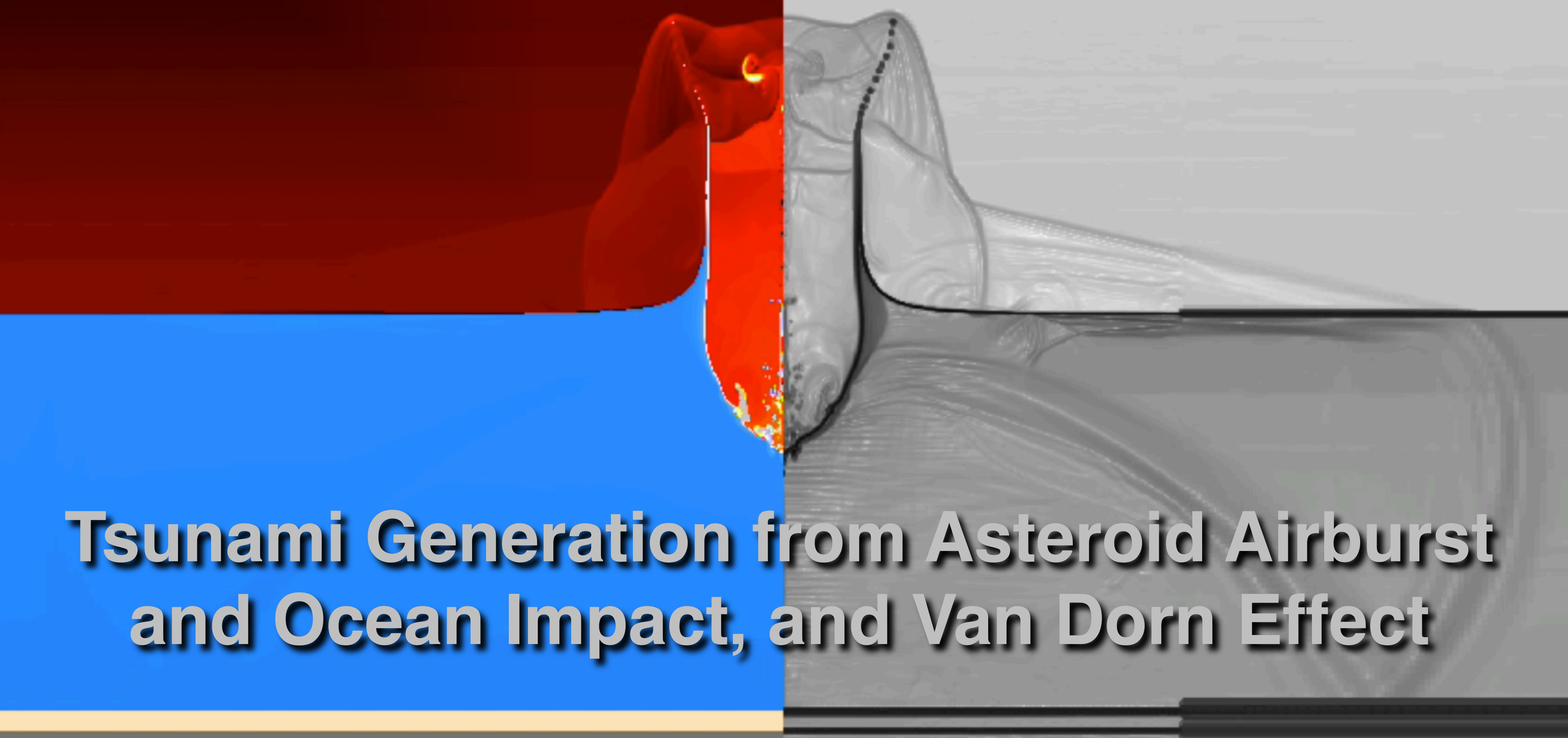
Second International Workshop on Asteroid Threat Assessment:
Asteroid Generated Tsunami and Risk Assessment, August 23-24, 2016



Tsunami Generation from Asteroid Airburst and Ocean Impact, and Van Dorn Effect

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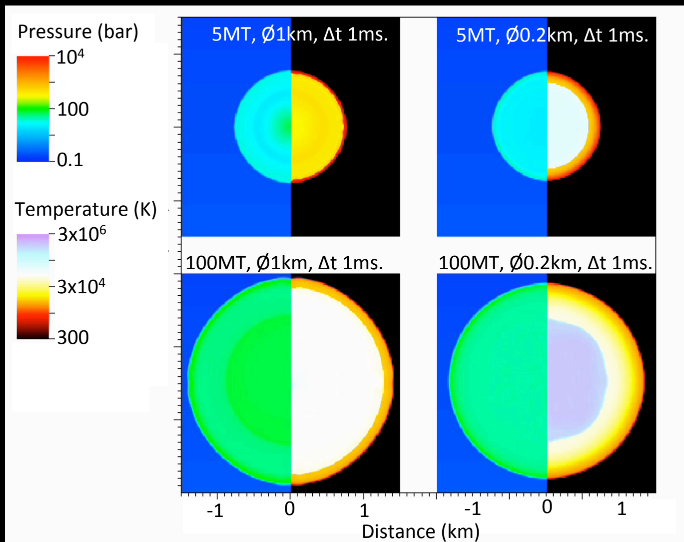
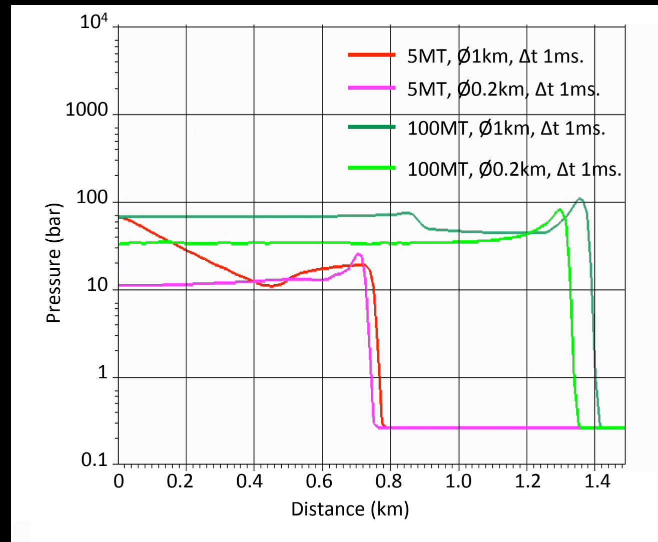
Tsunami Workshop

First workshop on asteroid threat assessment demonstrated significant differences in expert opinions on threat from asteroid induced tsunami. Goal: Calculate tsunamis generated from asteroid airburst and ocean impact for use in long range propagation and hazard analysis to determine danger of asteroid impact tsunami.

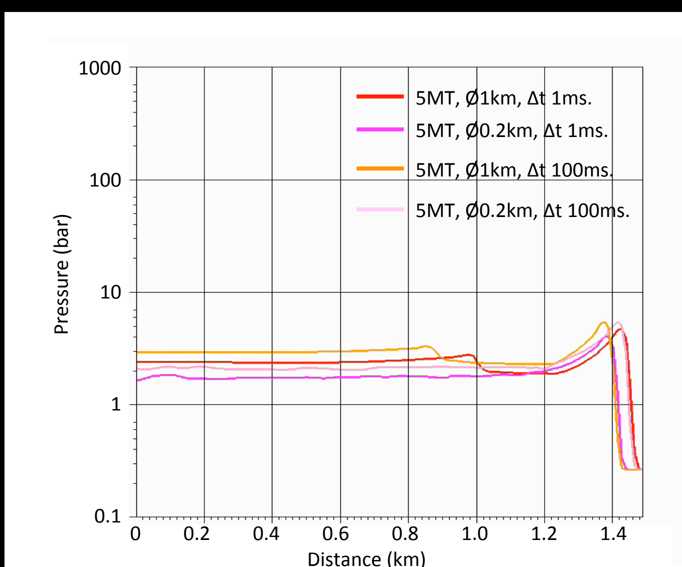
- Airburst blast propagation
  1. Variation of 5 & 100 MT compact source volume and energy deposition duration
  2. Static burst of 5 MT, 100 MT sources at 10 km altitude
  3. 5 & 100 MT vertical entry moving-line from Fragment-Cloud model (Wheeler) with peak dE/dh at 10km
  4. Static burst of 250 MT at 10km over water
- Water impacts
  5. 5, 100, 250 MT iron asteroid deep ocean impact cases neglecting atmospheric passage
  6. 100 MT deep ocean impact including atmospheric passage
  7. Tsunami propagation including bathymetry and interaction with continental shelf and shoreline.

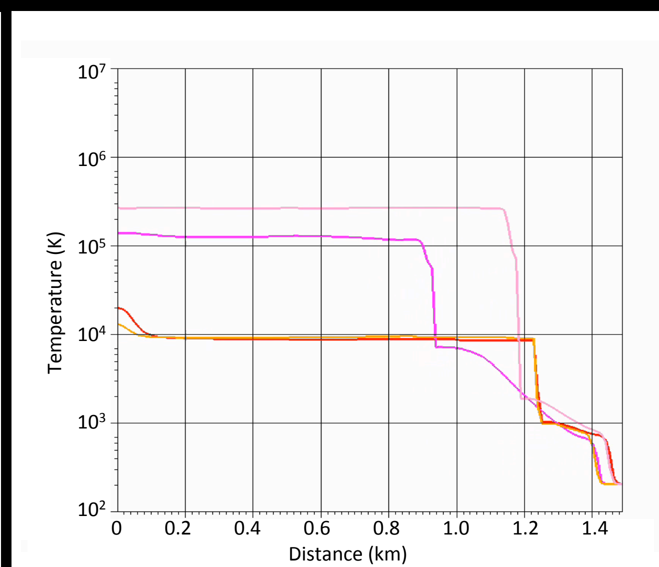
1. Compact Source Time/Volume Variation





Test #	Yield (MT)	Diameter (km)	Δt (ms)
1	5	1	1
2	5	0.2	1
3	100	1	1
4	100	0.2	1
5	5	1	100
6	5	0.2	100

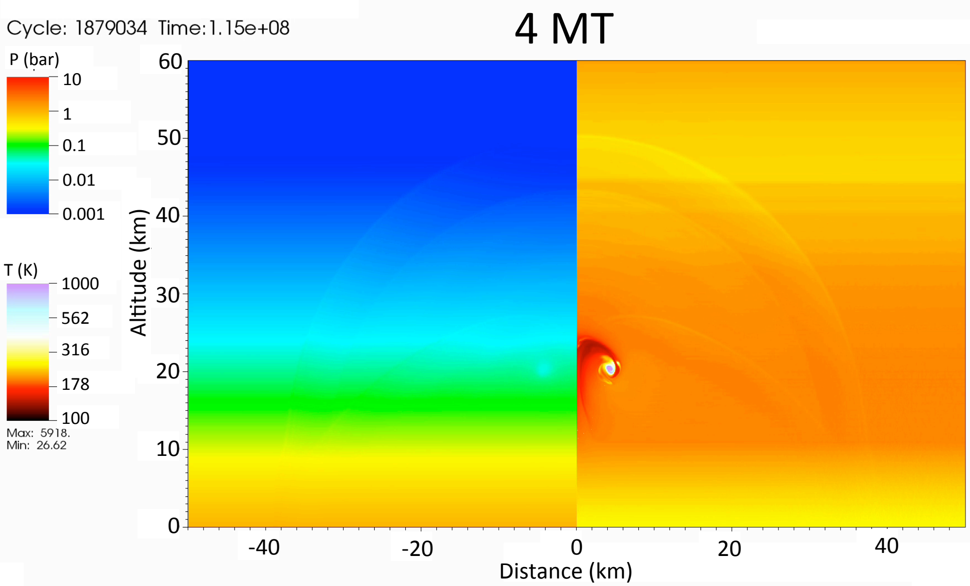


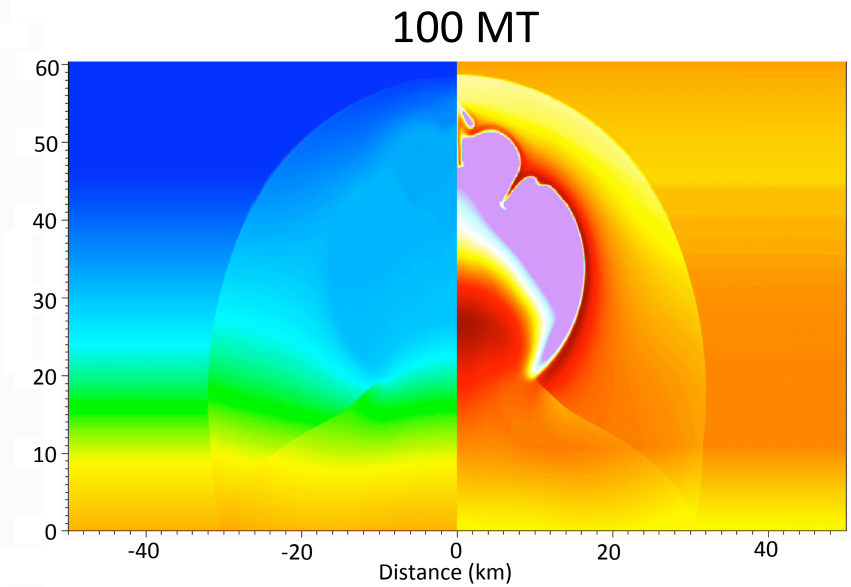


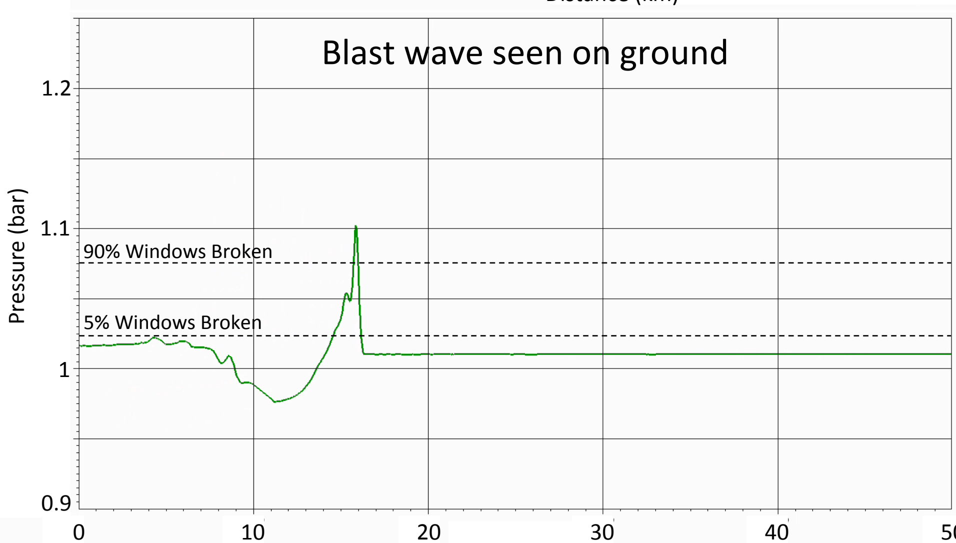
- A relatively short distance from the source they shock-up to very similar blast wave profiles
- Might be more important for entry profiles where velocity from imparted downward momentum will depend on volume of air.

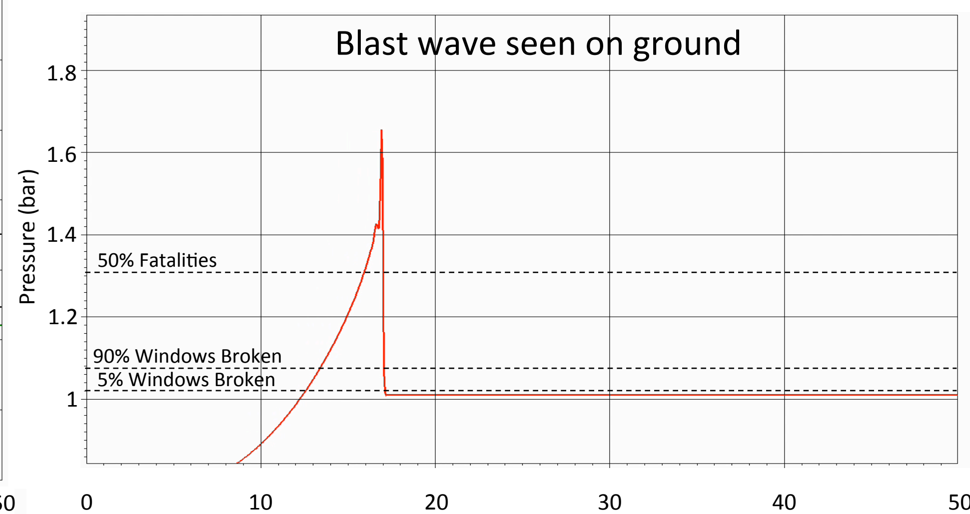
2. Static Compact Airburst

- Propagation from 4MT and 100MT static point sources
- Energy sourced directly into air



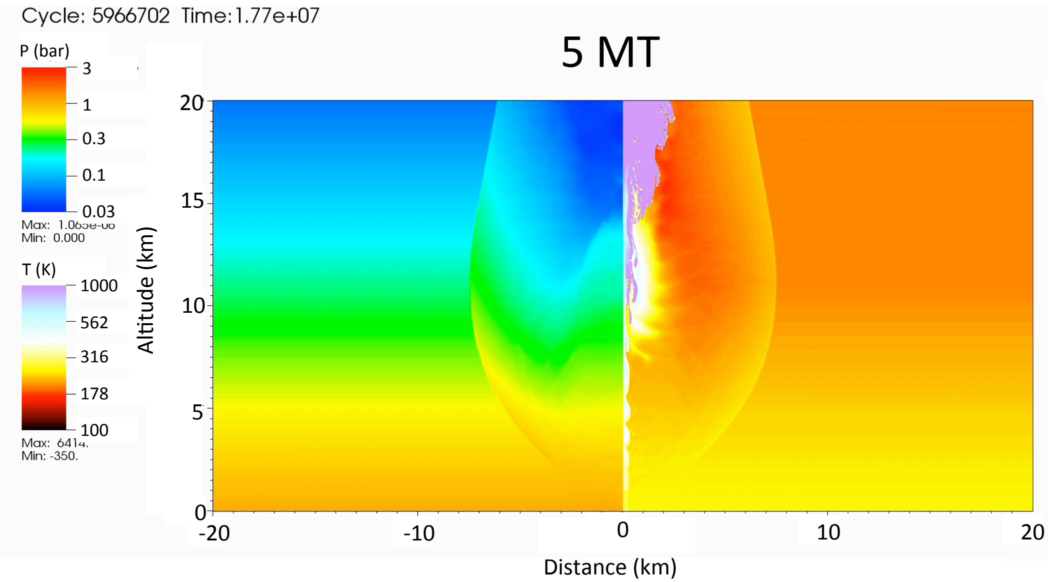


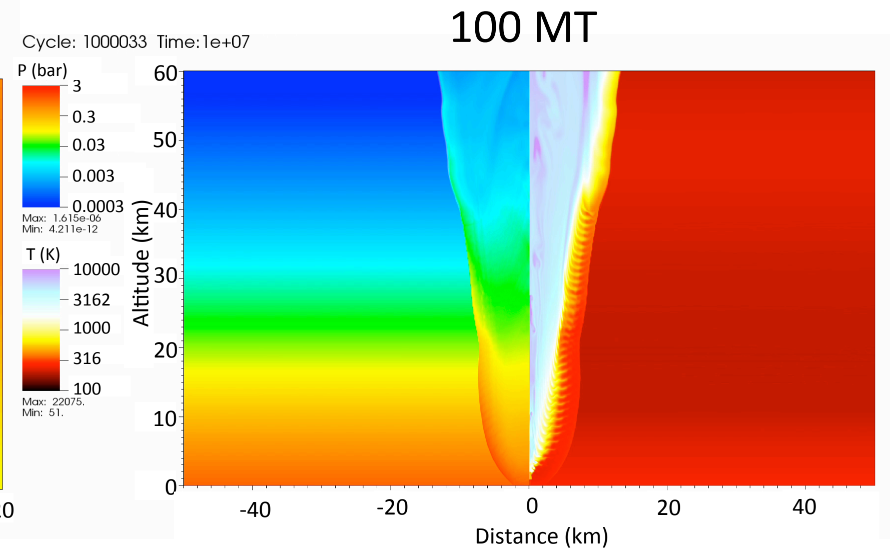


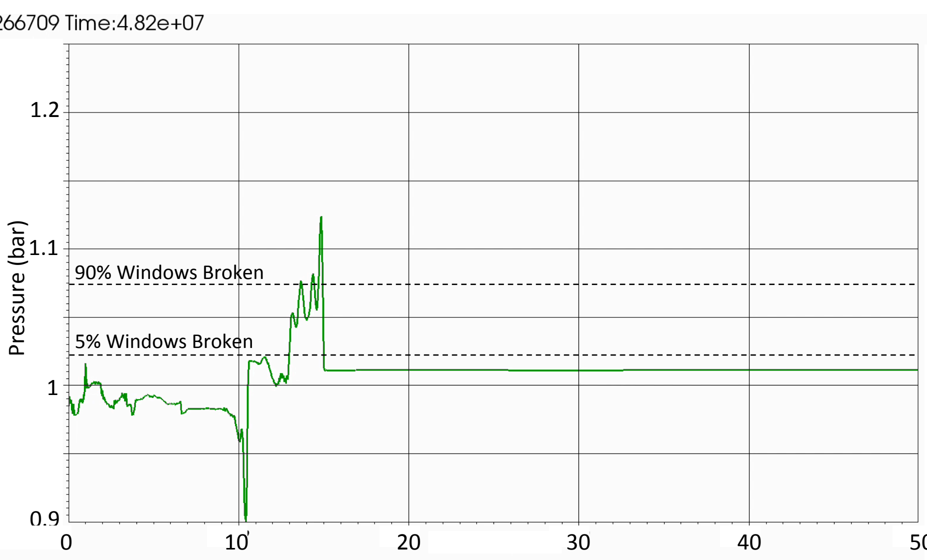


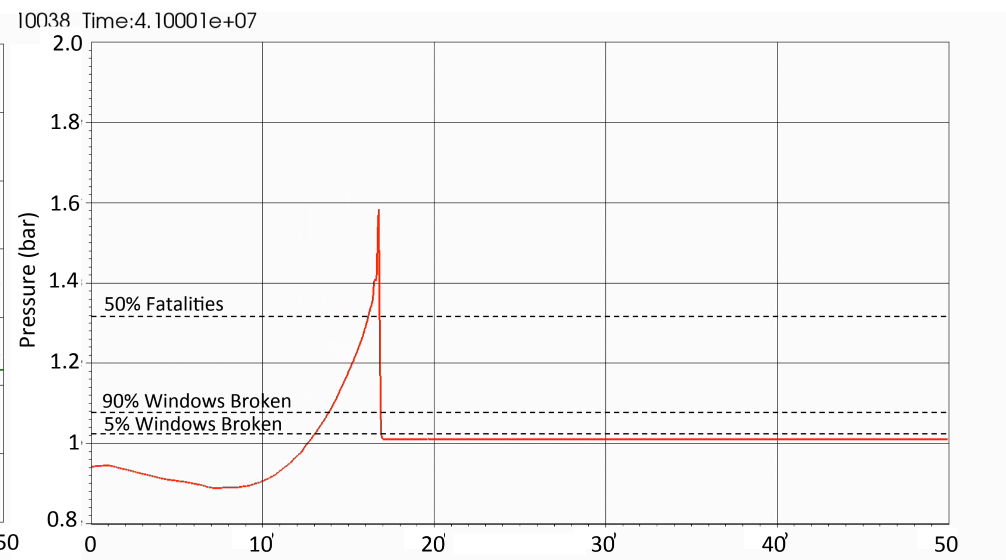
3. Blast from Asteroid Entry

- Energy sourced directly into air in 1km cylinders
- Downward velocity from momentum deposition into Ø500m air block
- Times from entry profile

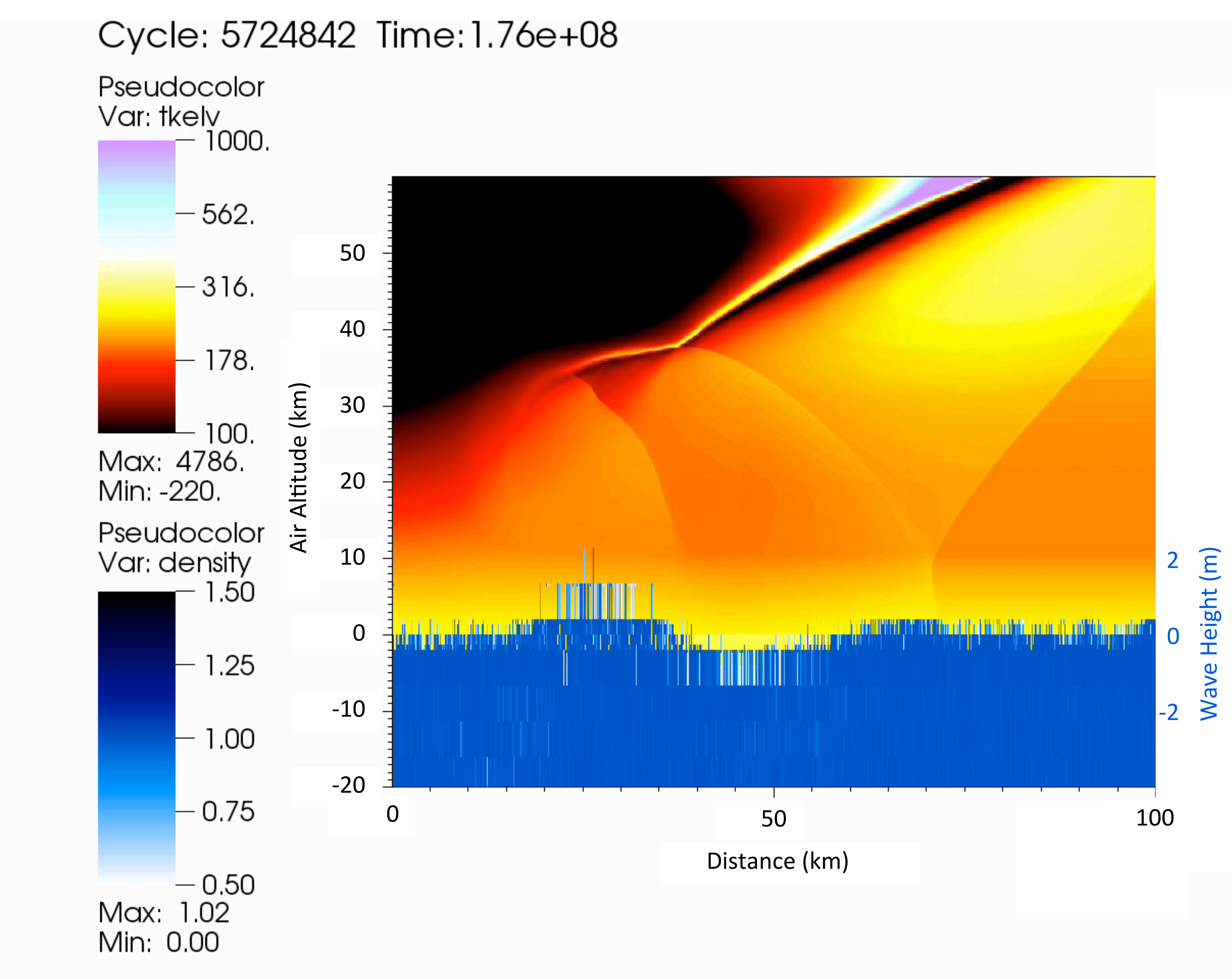






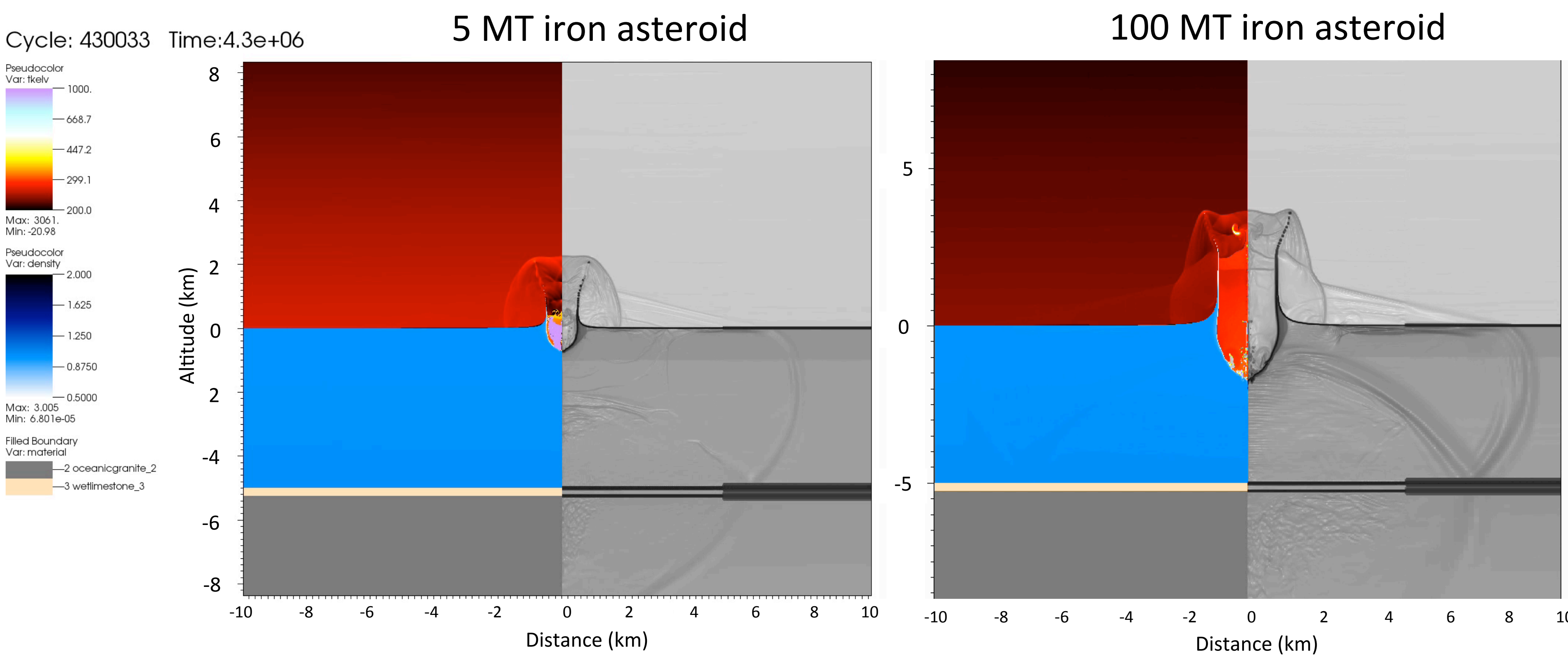


4. Compact airburst over water 250 MT, altitude 10km



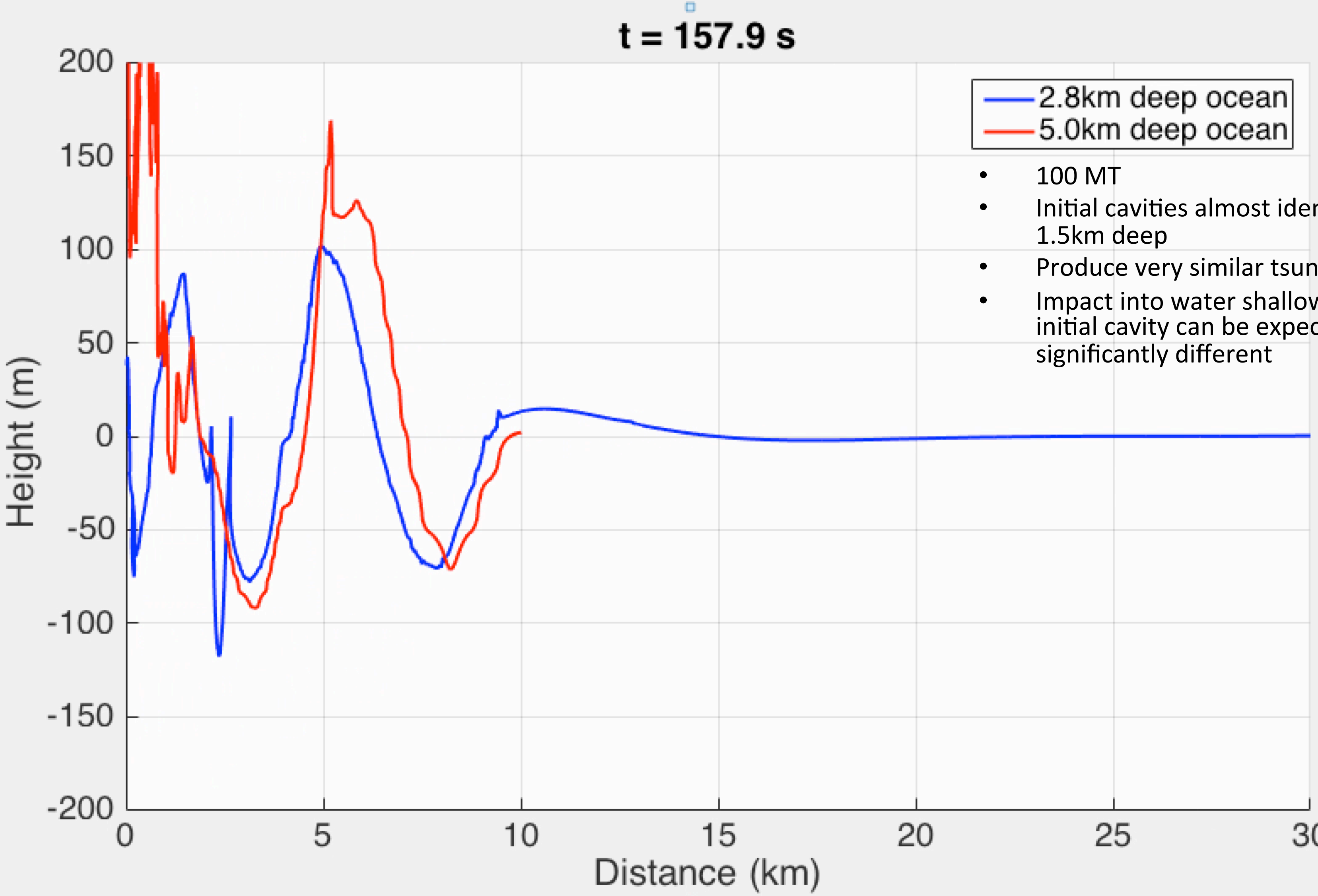
- Creates tsunami 1m high and 20km long when 50km from ground zero
- 4km deep ocean

5. Deep Ocean Impact



- 5km deep ocean, 250m loose sediment, oceanic granite
- Energy distribution…
- Crater size…

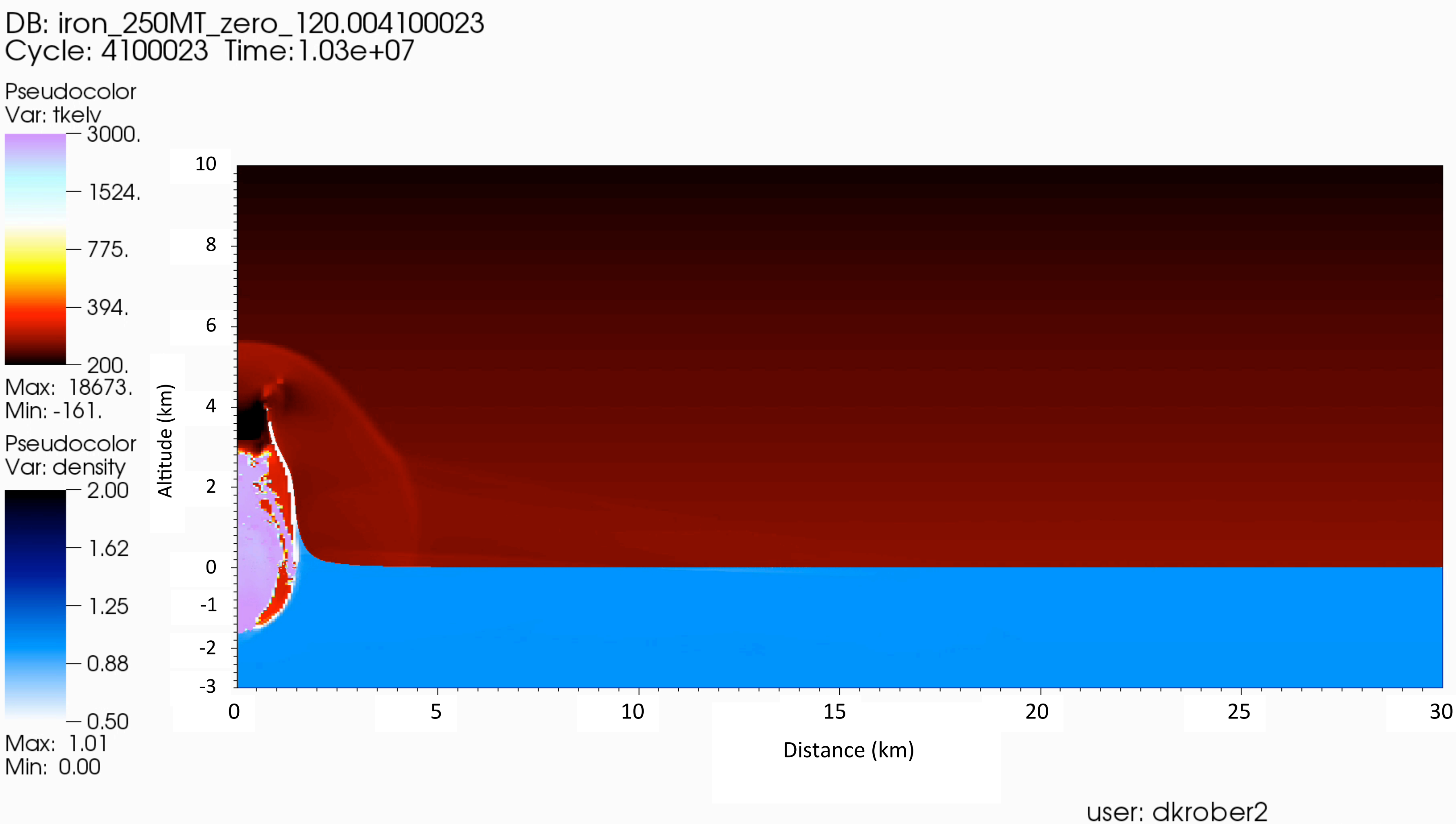
3 vs 5 km Deep Oceans



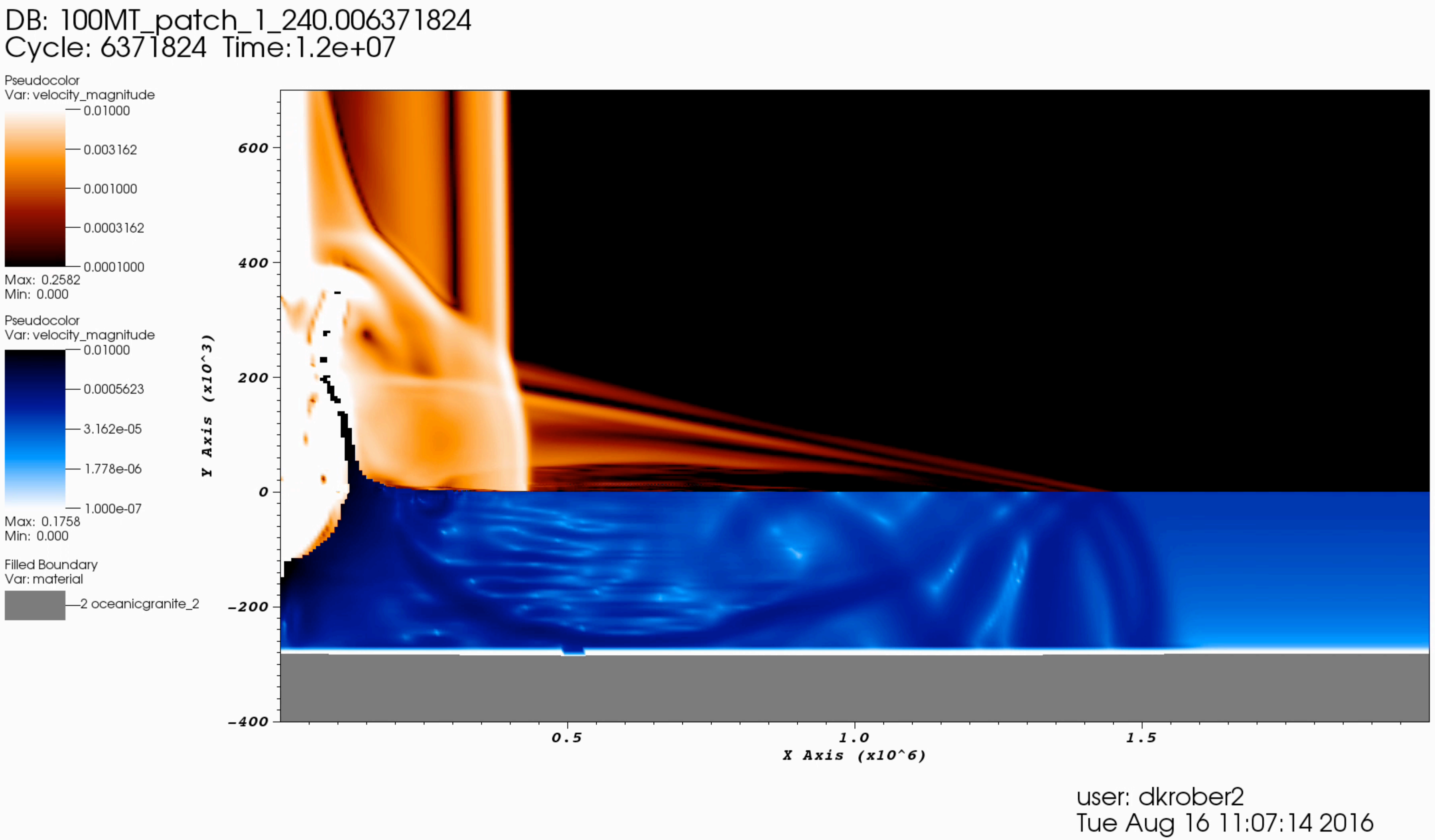
- 100 MT
- Initial cavities almost identical 1.5km deep
- Produce very similar tsunami waves
- Impact into water shallower than initial cavity can be expected to be significantly different

250 MT

- 3km deep ocean. Hard ocean floor

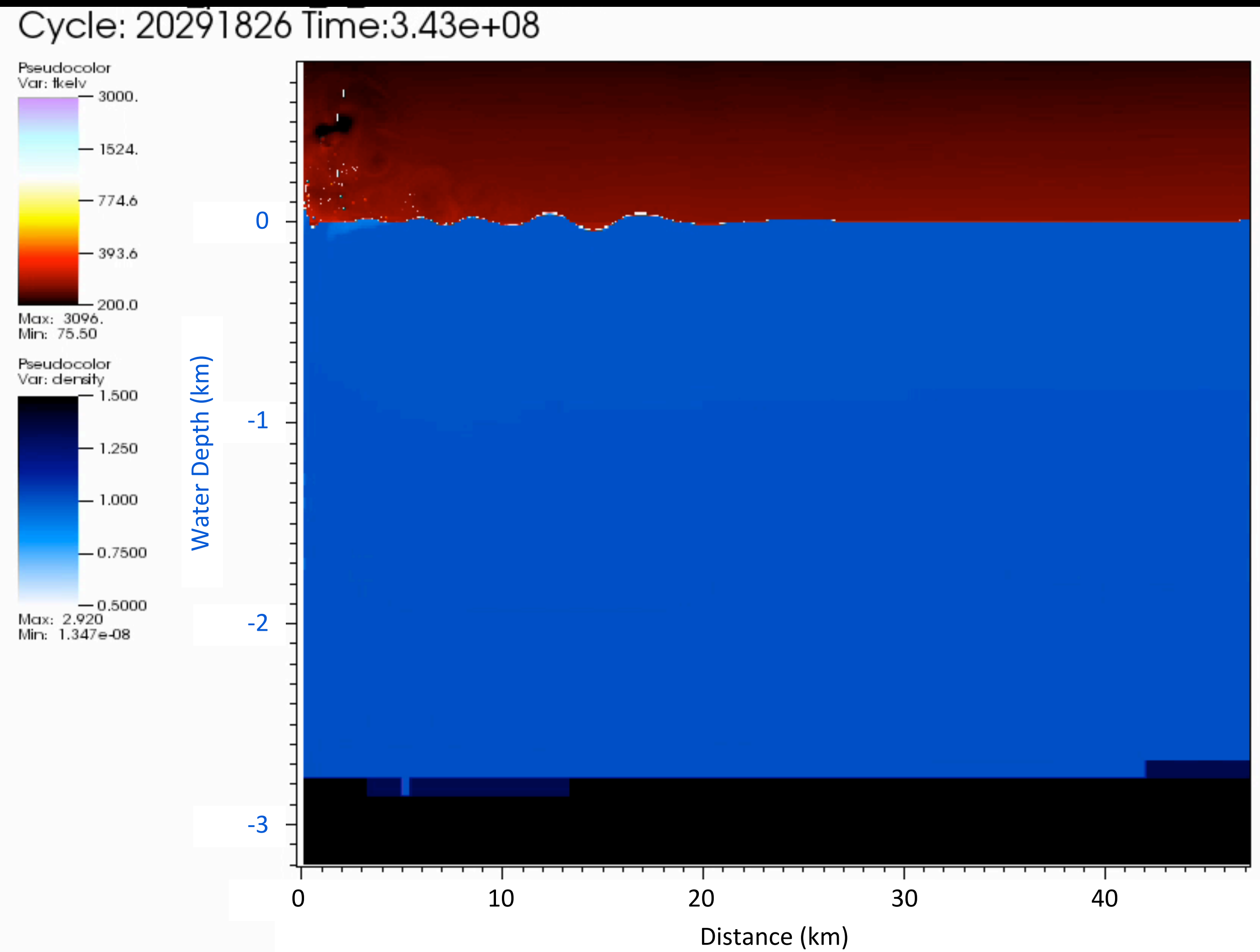


Including Atmospheric Passage

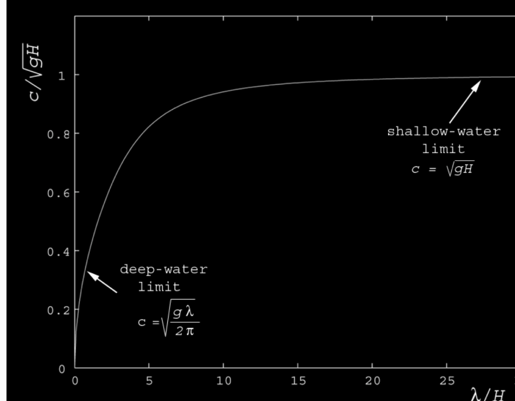


6. Continental Shelf

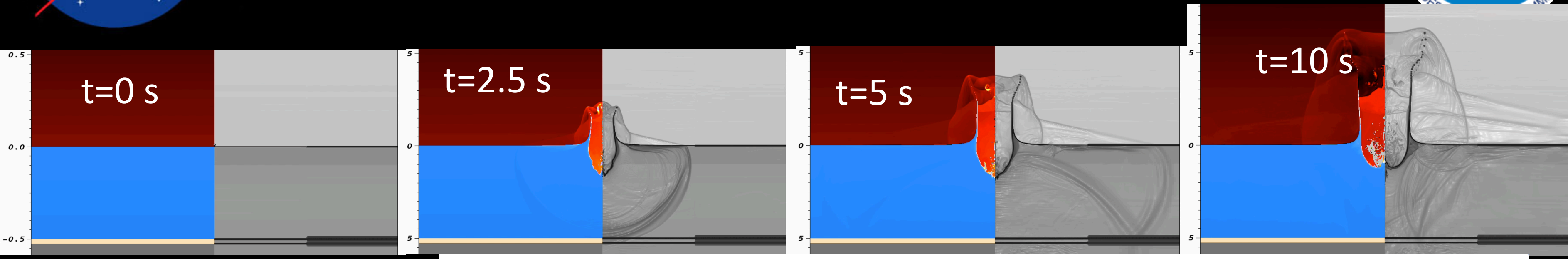
- Van Dorn predicted that when tsunami waves from asteroid impacts encounter the continental shelf they would break, dissipating significant amount of energy.

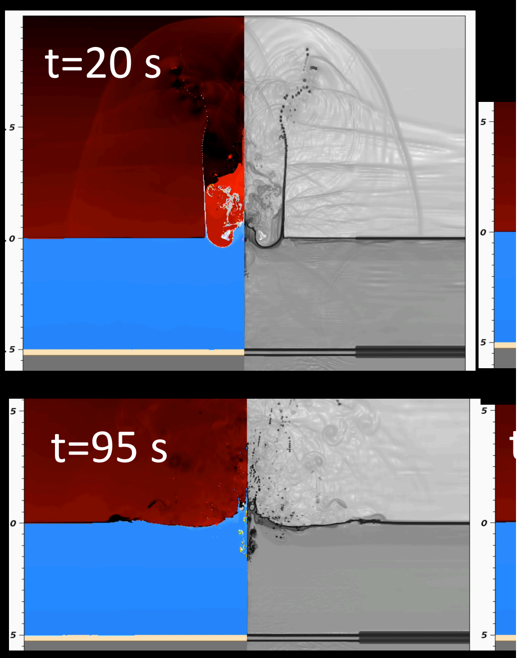


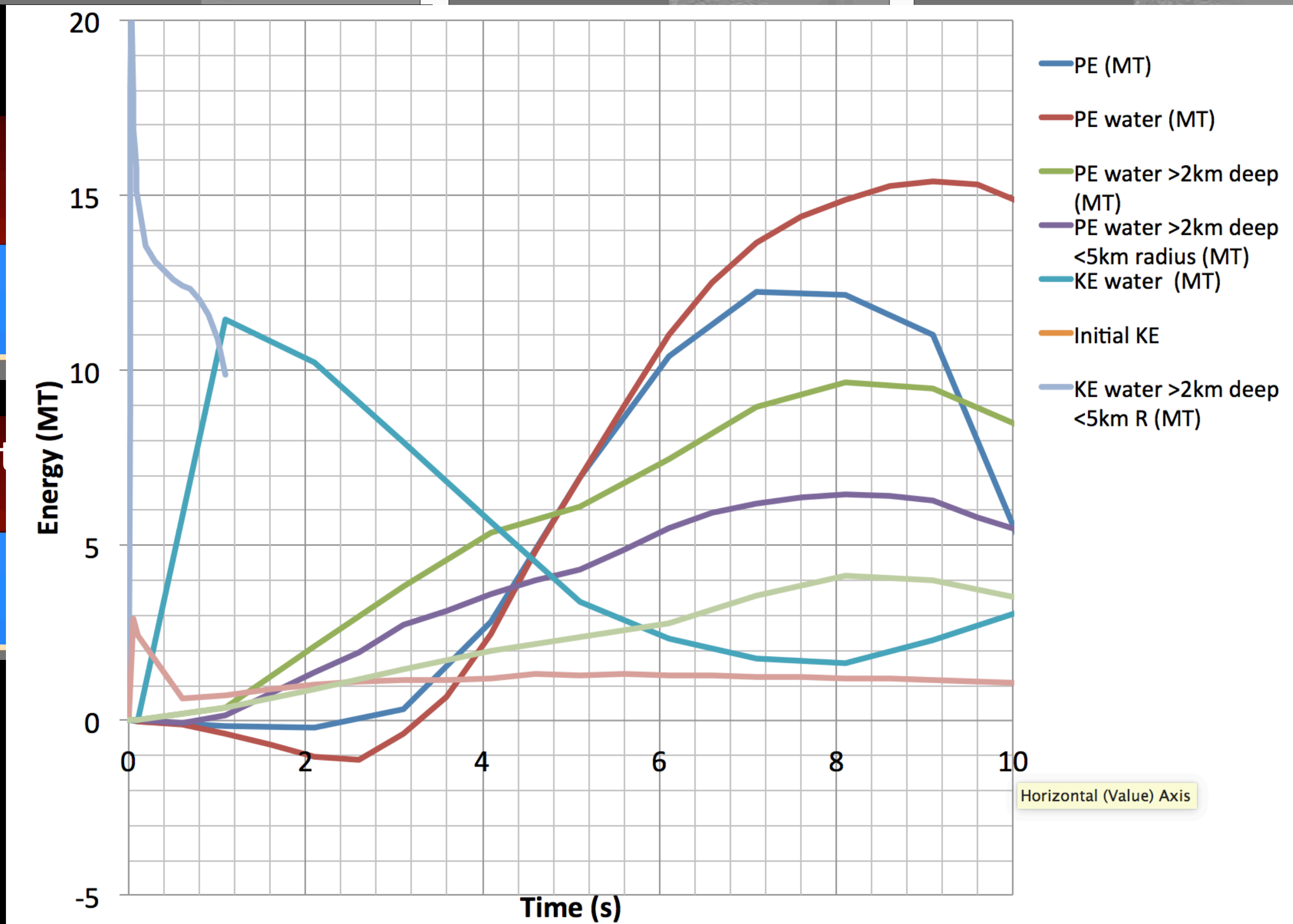
- 100 MT initial energy.
- Creates 1 MT tsunami wave train
- Waves appear to be deep not shallow water



Energy Distribution

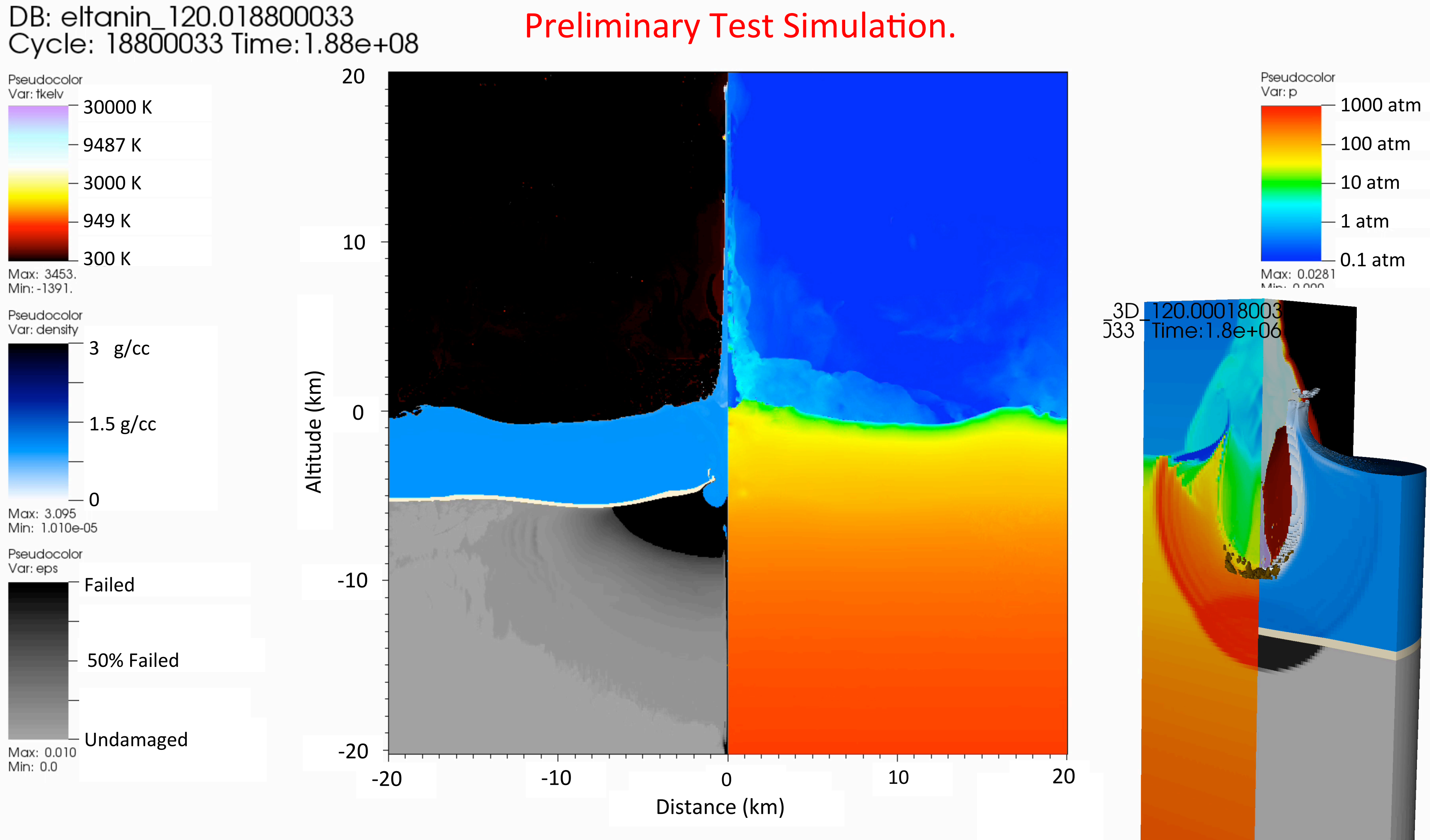






Eltanin (10GT)

- 2.1 Million years ago in South-East Pacific Ocean
- Only known impact into deep Ocean Basin
- Evidence of mega-tsunami debris on coasts of Chile and Antarctica as well as drill cores from Bellingshausen Sea.
- Current estimates Ø750m rock at 12 km/s vertical (10 GT) or 18 km/s at 45°.
- 5000m deep ocean, 250m sediment, basalt crust.



Conclusions and Future Areas of Interest

- Airburst
  - In the simulations explored energy from the airburst couples very weakly with the water making tsunami dangerous over a shorter distance than the blast for asteroid sizes up to the maximum expected size that will still airburst (~250MT).

  Future areas of investigation:
  - Low entry angle airbursts create more cylindrical blasts and might couple more efficiently
  - Bursts very close to the ground will increase coupling
  - Inclusion of thermosphere (>80km altitude) may show some plume collapse effects over a large area although with much less pressure
- Ocean Impact
  - Asteroid creates large cavity in ocean. Cavity backfills creating central jet. Oscillation between the cavity and jet sends out tsunami wave packet.
  - For deep ocean impact waves are deep water waves (Phase speed = 2x Group speed)
  - If the tsunami propagation and inundation calculations are correct for the small (<250MT) asteroids in these simulations where they impact deep ocean basins, the resulting tsunami is not a significant hazard unless particularly close to vulnerable communities.

  Future work:
  - Shallow ocean impact.
  - Effect of continental shelf and beach profiles
  - Tsunami vs. blast damage radii for impacts close to populated areas
  - Larger asteroids below presumed threshold of global effects (Ø200 – 800m)