Numerical Modeling of Asteroid Ocean Impact:
Preparing Pipeline for Future Scenario Modeling

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Modeling asteroid ocean impacts using multi-physics hydrocode

Values based on PDC 2023 hypothetical impact exercise epoch 1

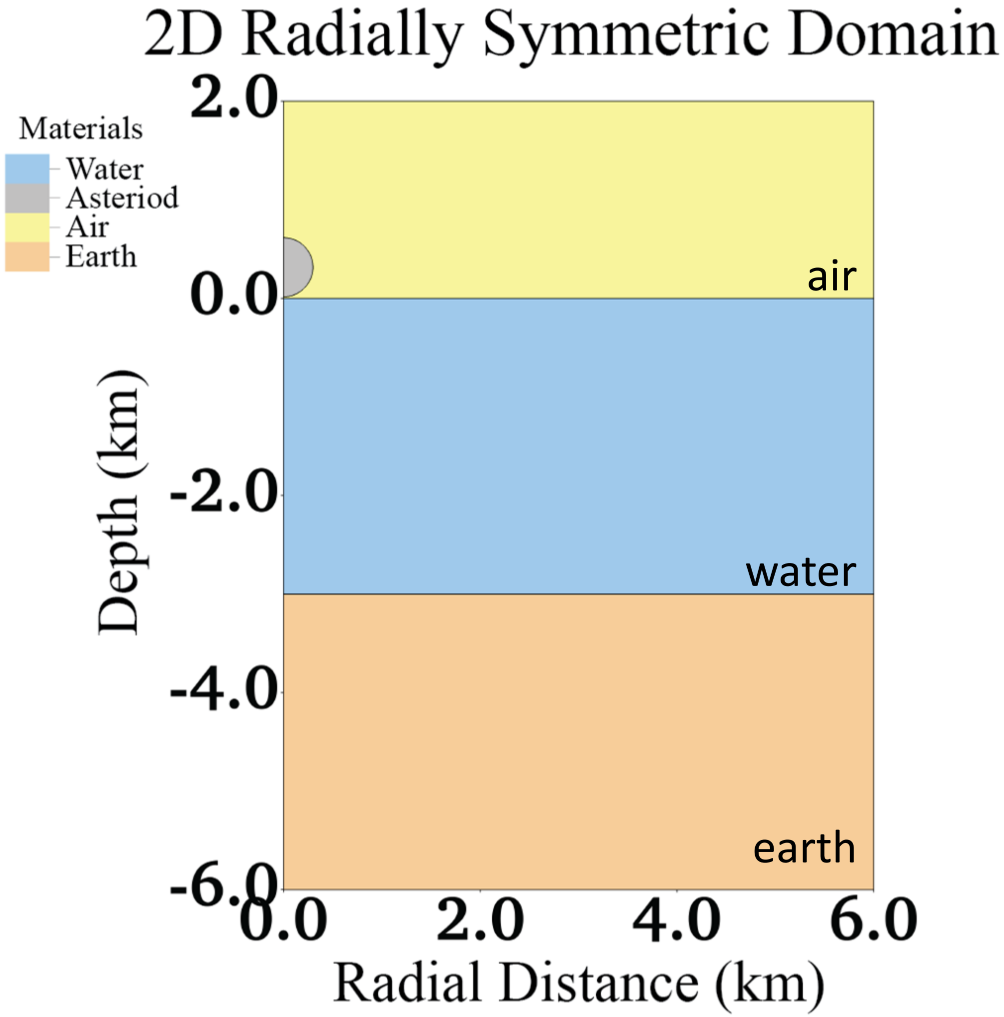
- Impact of near earth objects (NEOs) are low probability high consequence hazards. The initial impact can have a variety of secondary hazards that are dependent on geographical location.

- We focus this work on water impacts with special interest on tsunami wave generation/propagation and atmospheric affects

Key Parameters	Value
Asteroid diameter	600 m
Asteroid density	2.12 g/cm^3
Asteroid porosity	20%
Asteroid velocity	12.67 km/s

Multi-physics hydrocode (ALE3D)

Arbitrary Lagrangian-Eulerian scheme



- Asteroid impact and crater formation
  - Initial mesh element size: 5 – 15 m
- Material details:
  - Livermore Equation Of State (LEOS) data tables used to determine thermodynamic properties of air, water, and earth
  - Granite asteroid uses GEODYN material model
- Adaptive mesh refinement (AMR) applied to the area around the asteroid and material interfaces

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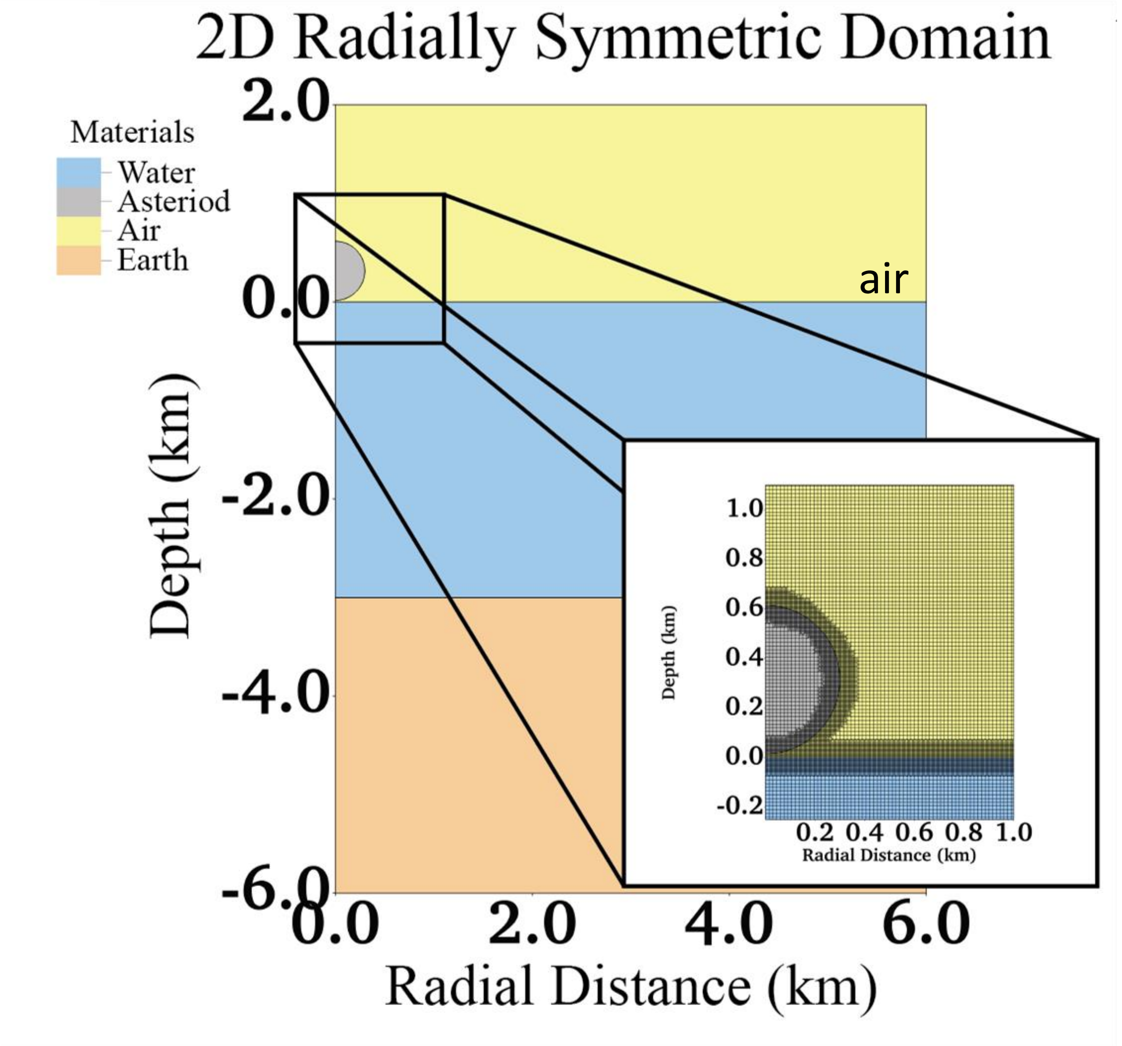

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Pipeline for consequence calculations

Linking high-fidelity hydrocode to atmospheric and tsunami models

Multi-physics hydrocode (ALE3D)

- Arbitrary Lagrangian-Eulerian (ALE) scheme
- Δx = 5 – 50 m, $\Delta t = 10^{-6} - 10^{-4}$ s
- Crater formation, vaporization, conversion to wave energy, and asteroid pulverization

ALE3D

Weather Research & Forecasting (WRF) model

- Δx = 1 km, Δt = 2 – 6 s
- Includes cloud microphysics

WRF

Boussinesq solver

- Δx = 100 m, Δt = 0.5 s
- Tsunami propagation and dispersion

Computational Fluid Dynamics (CFD) model

- Inundation of coastal areas and forces on structures

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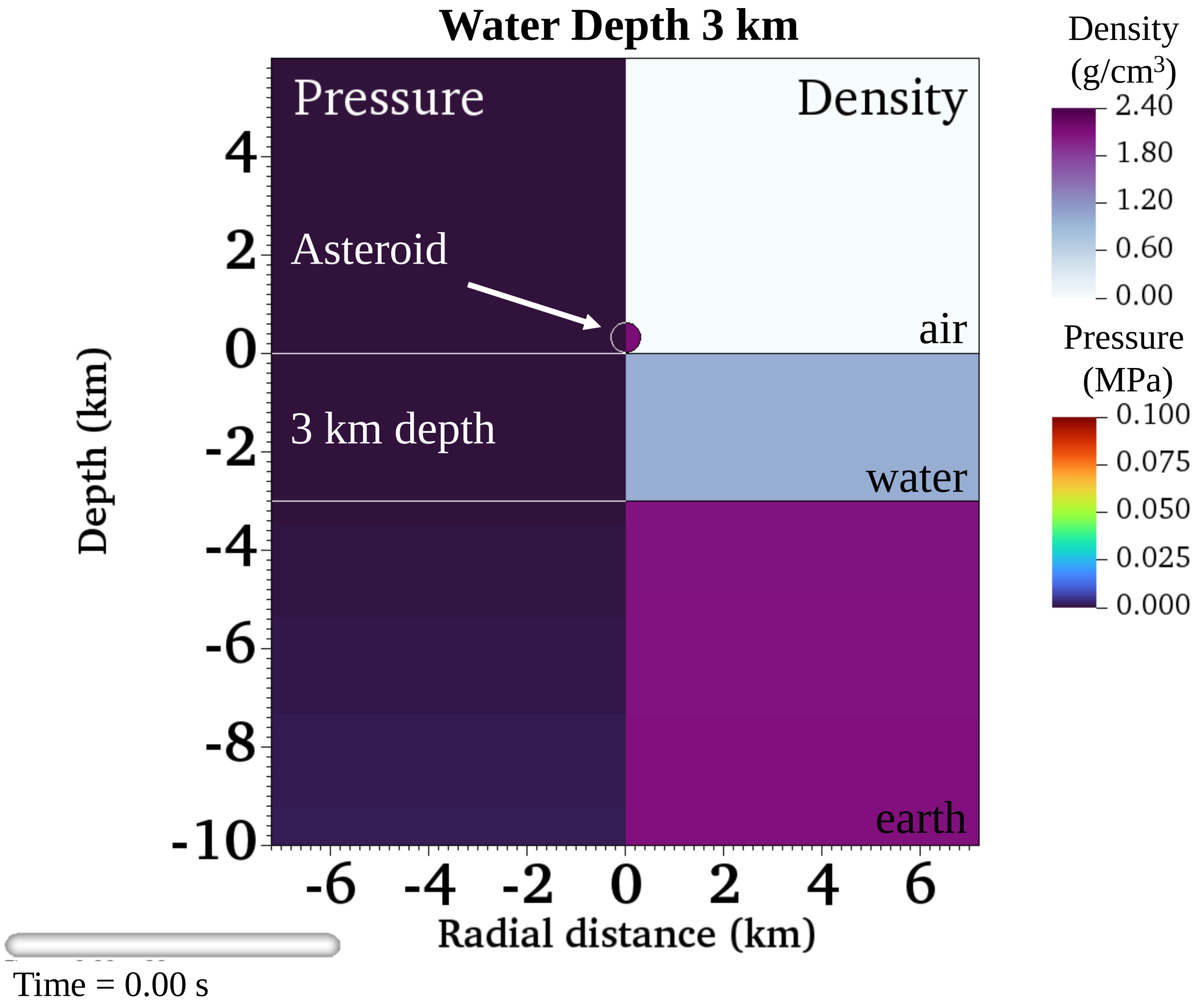
- Simulation starts with asteroid just above water



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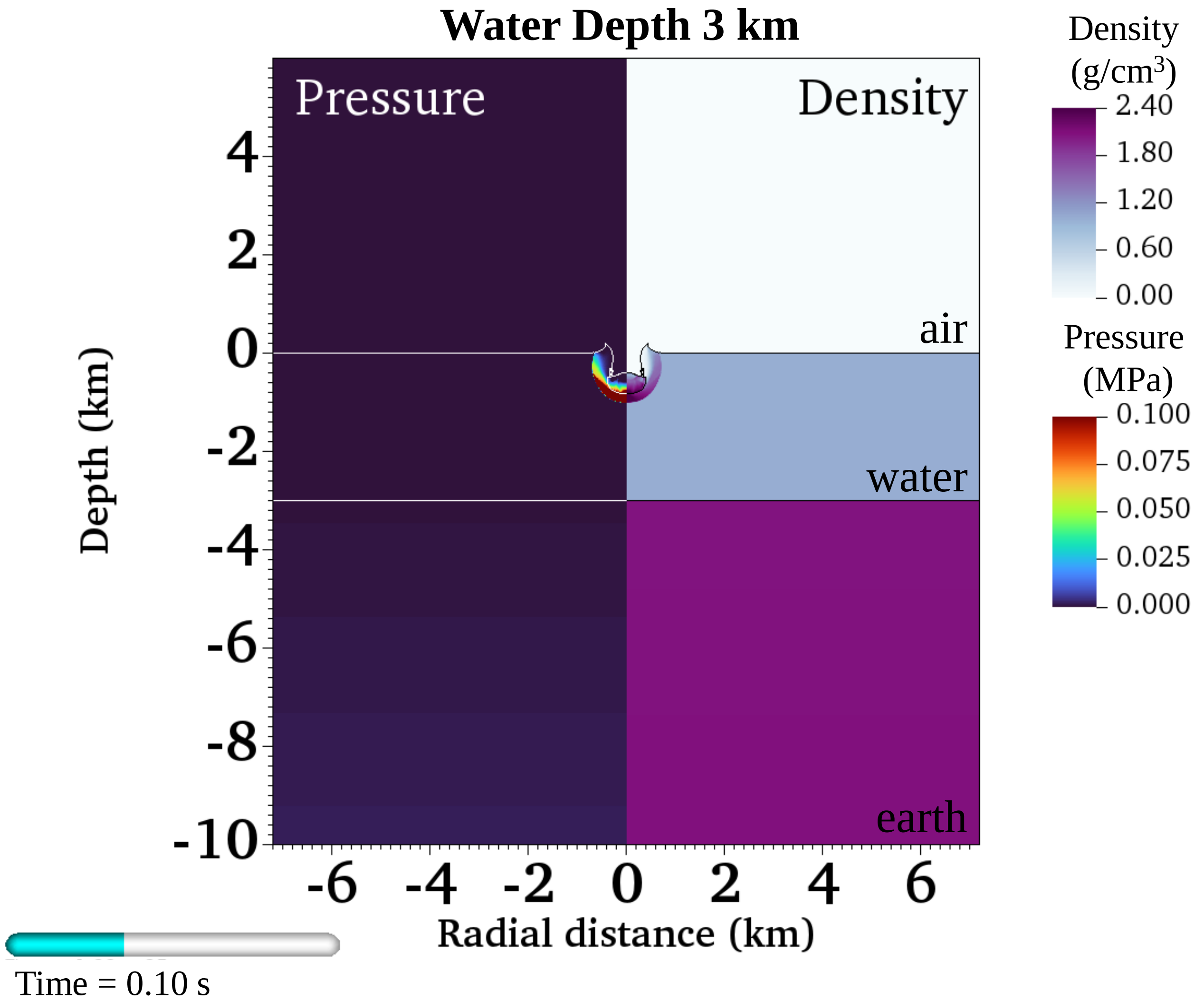

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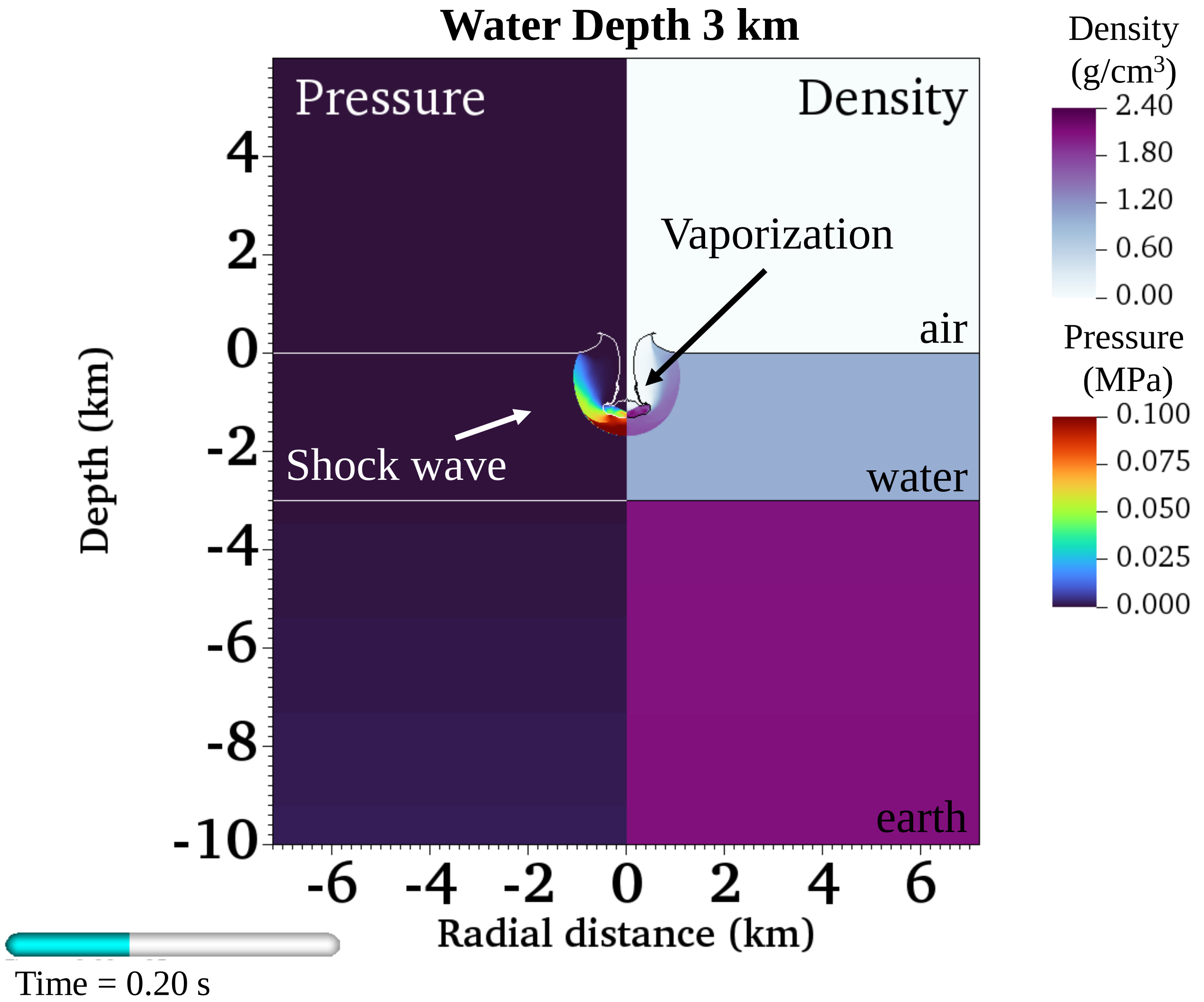

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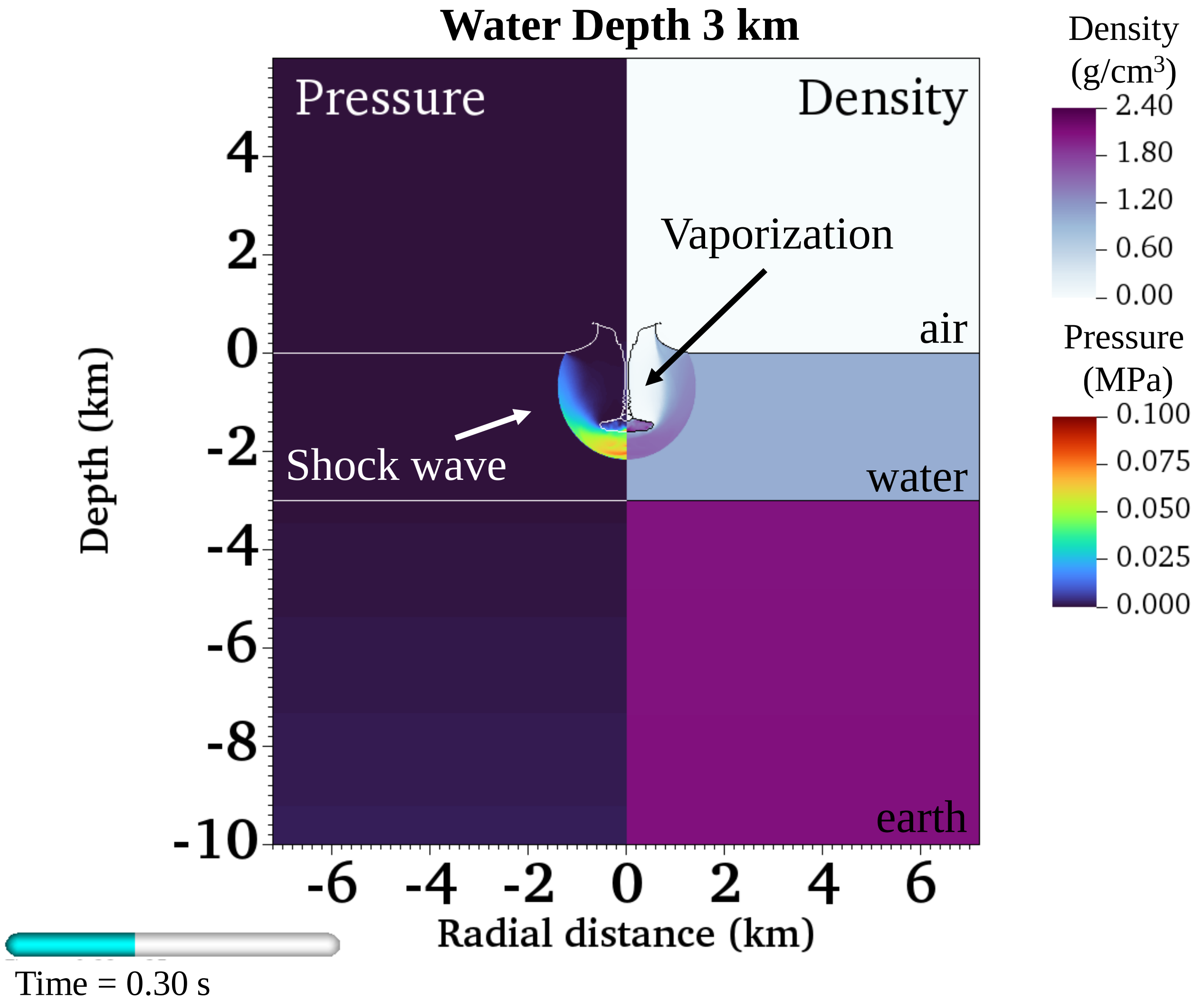

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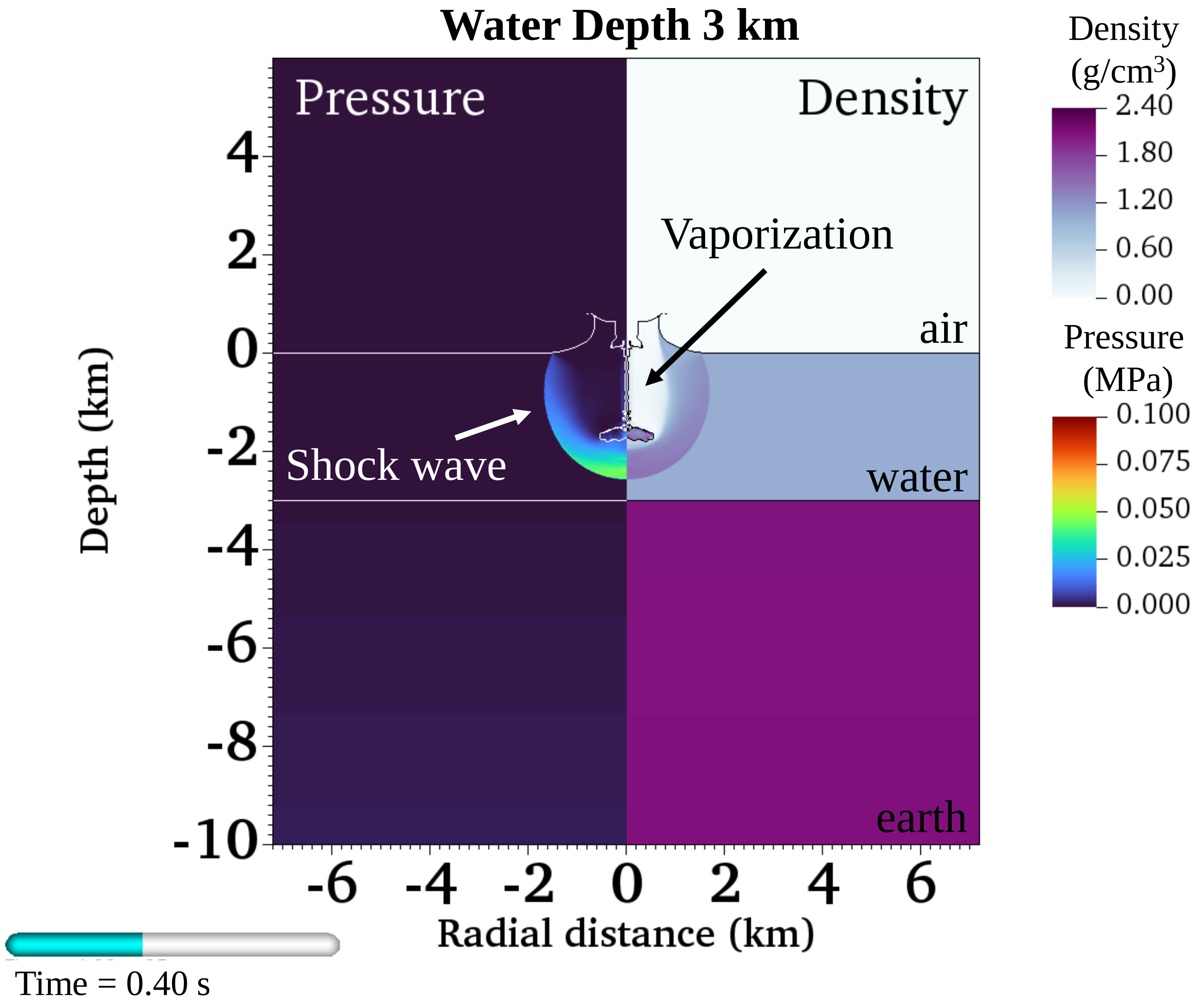

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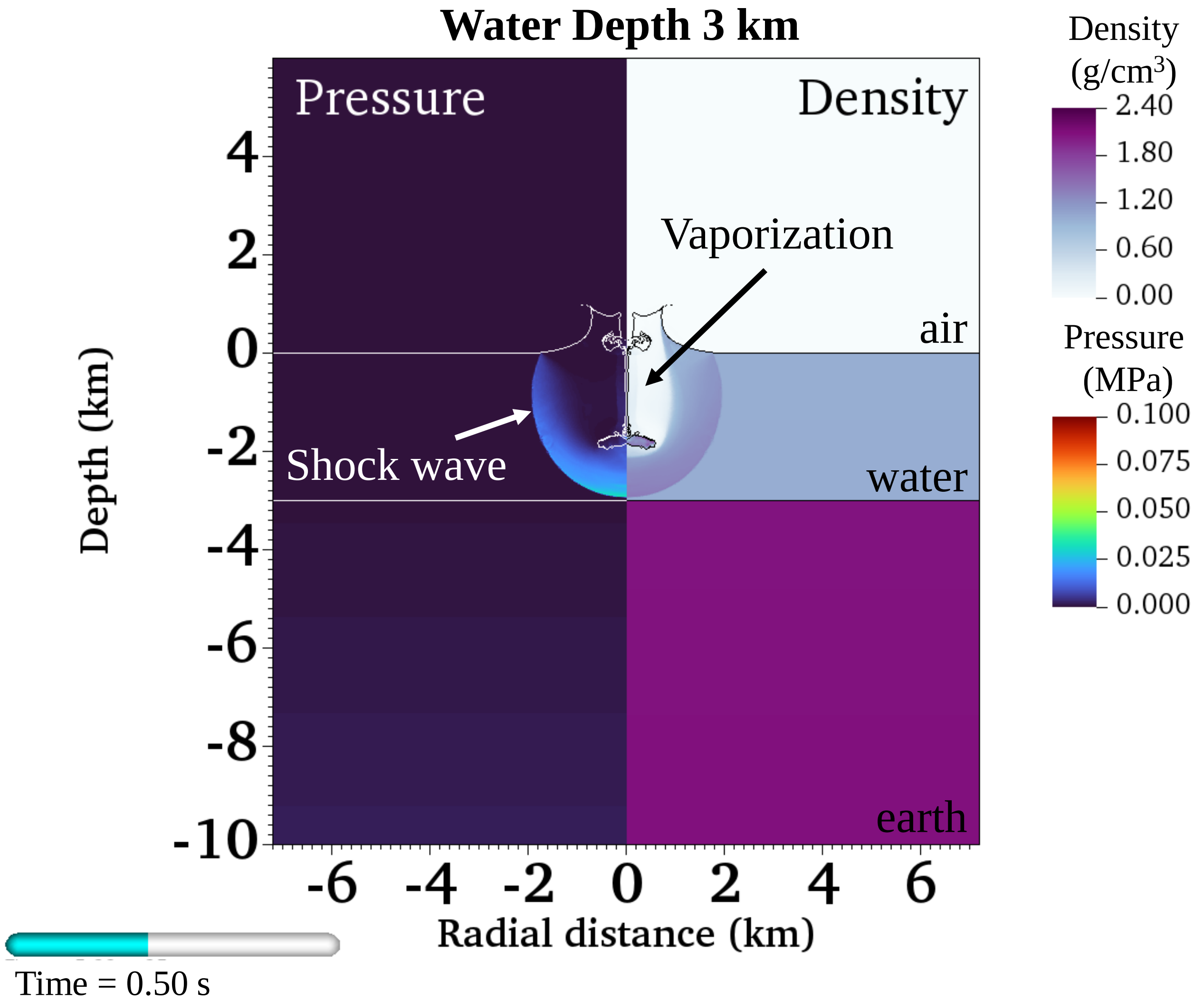

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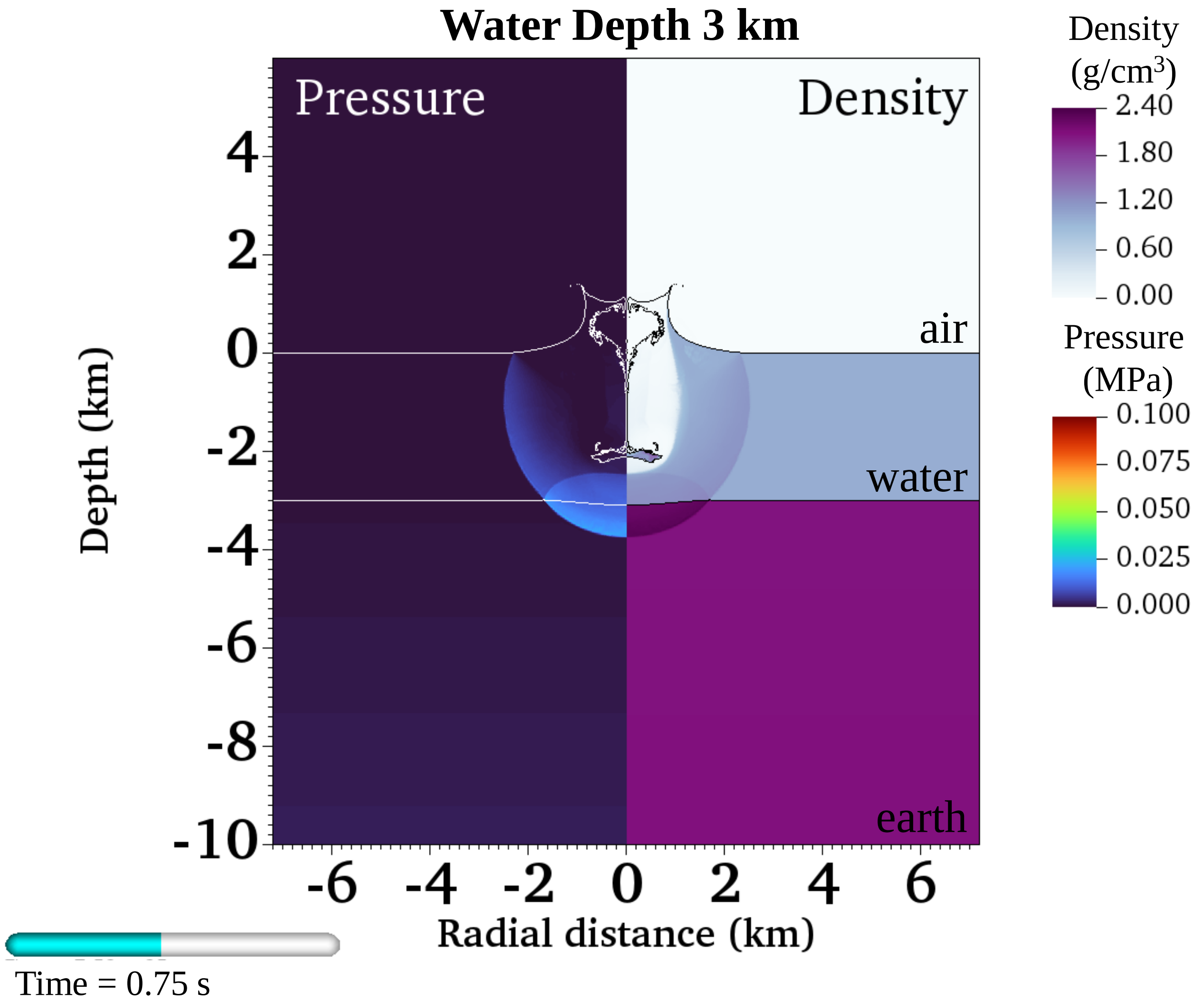

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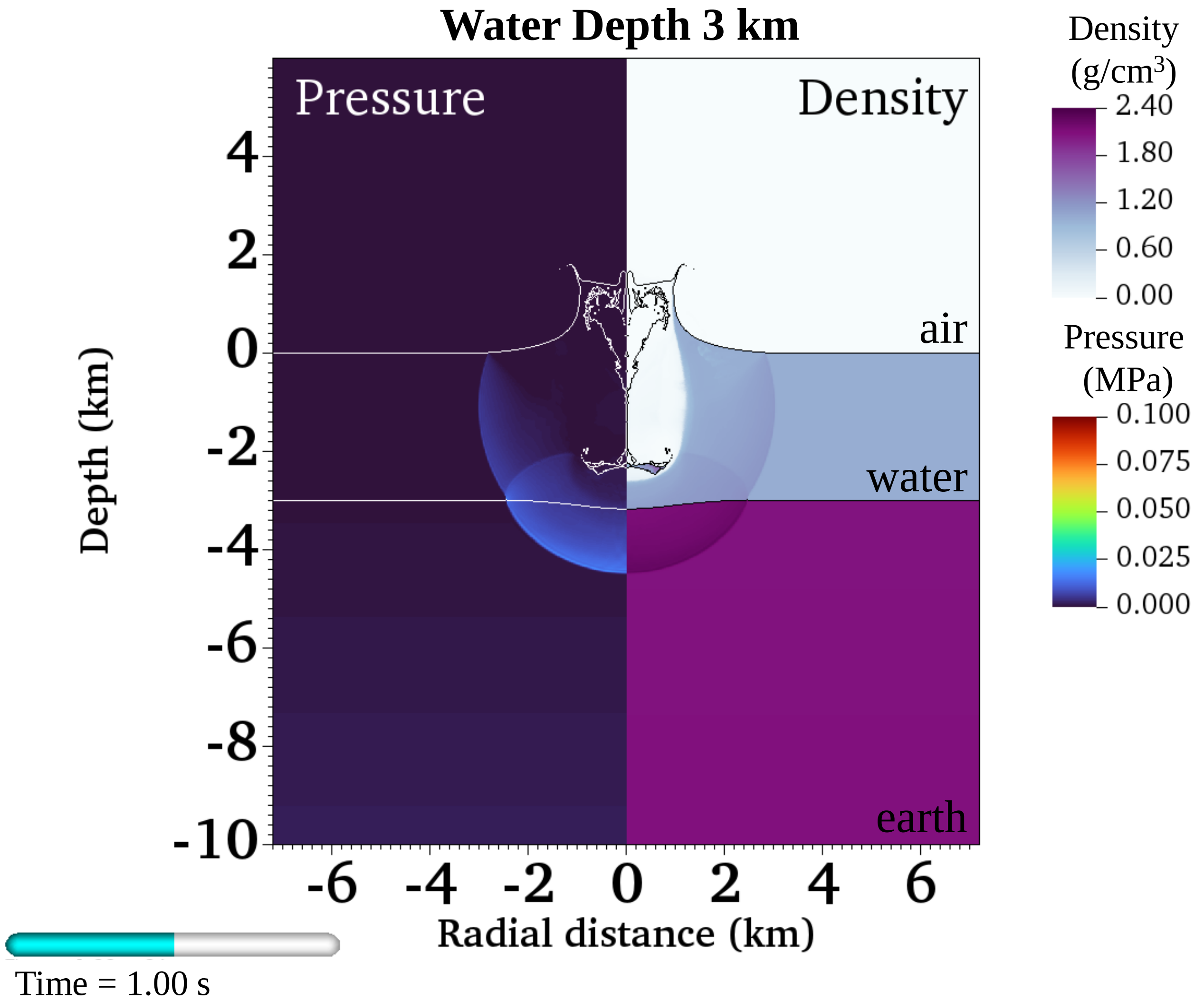

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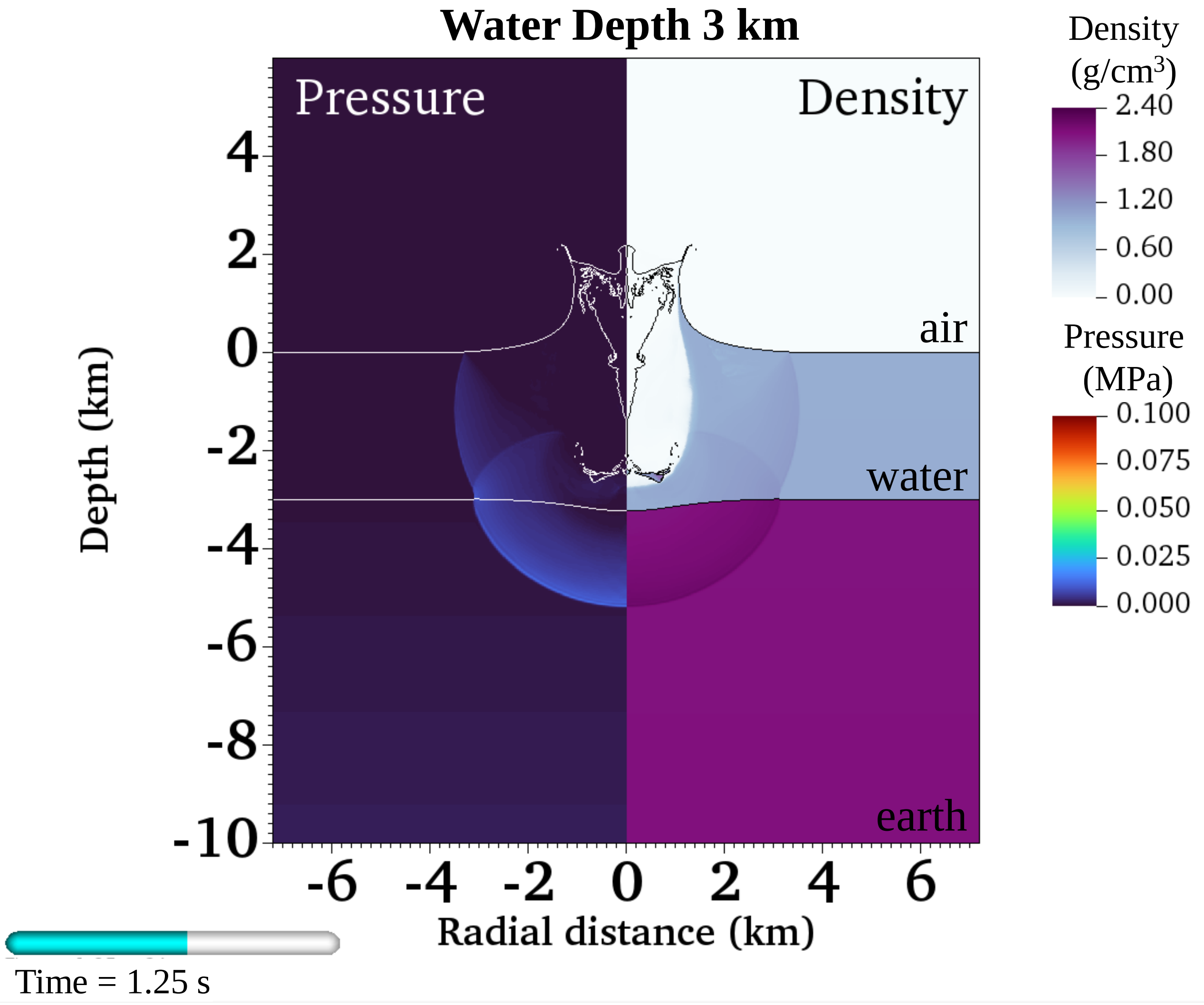

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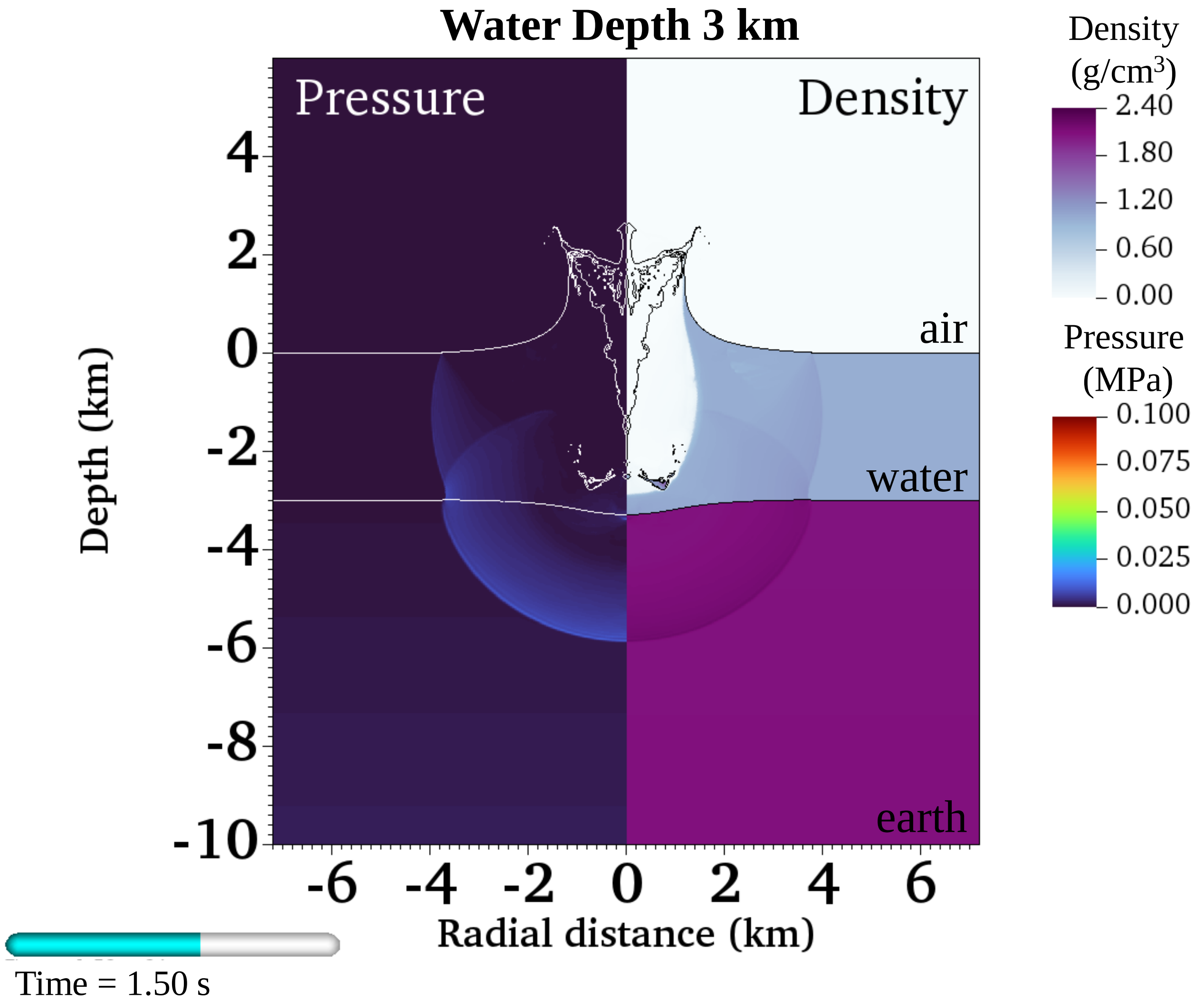

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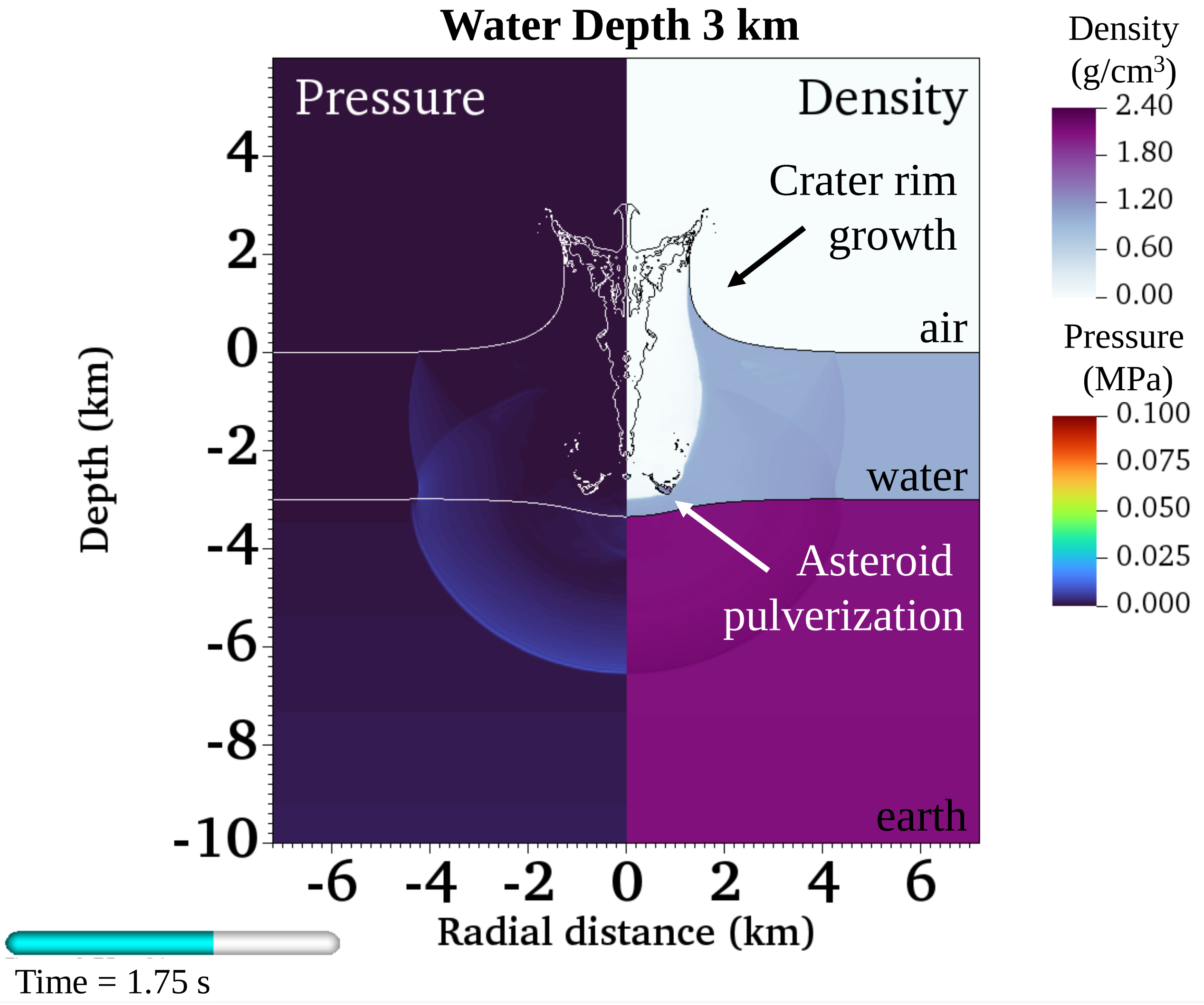
- Asteroid pulverizes into smaller pieces



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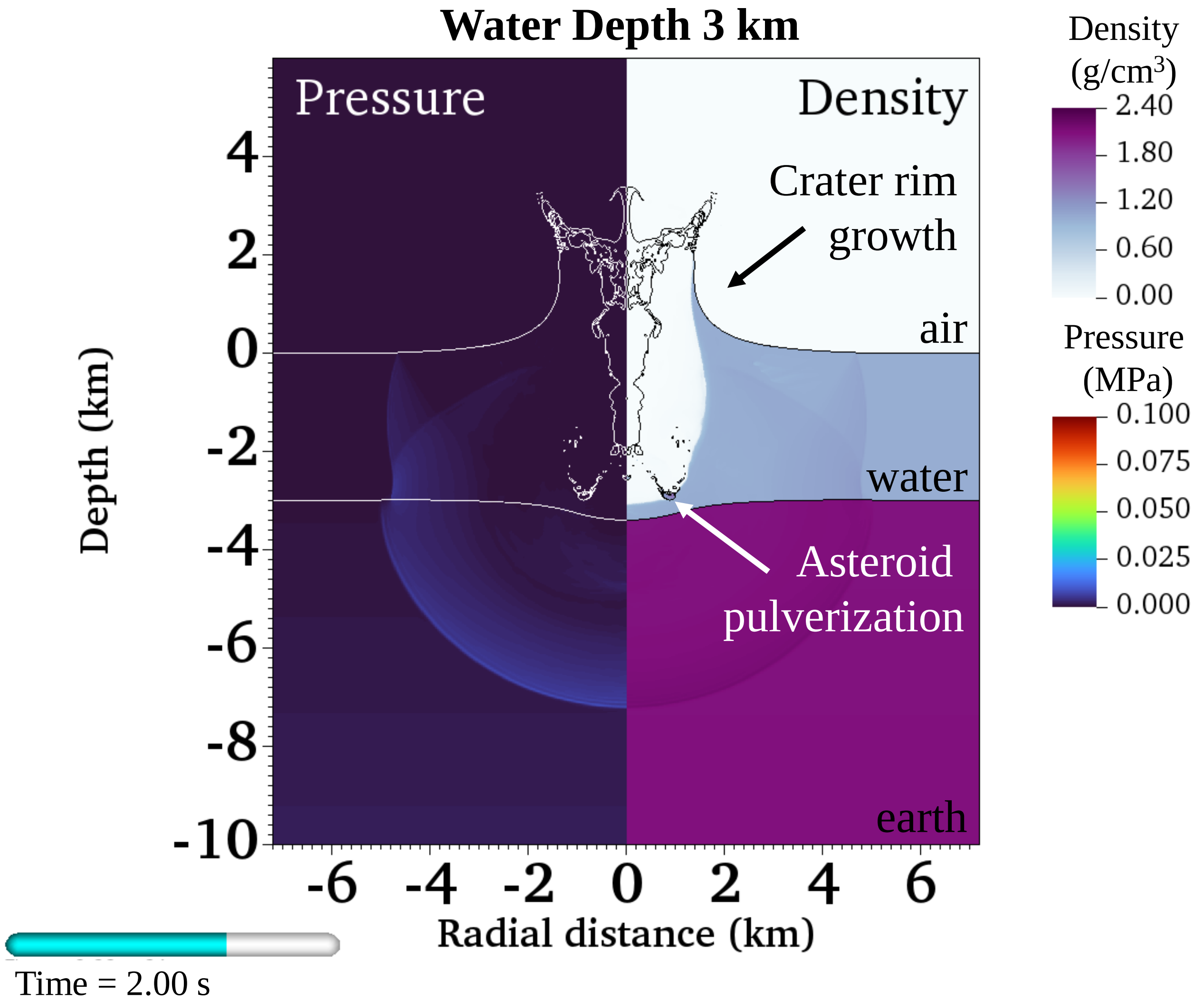

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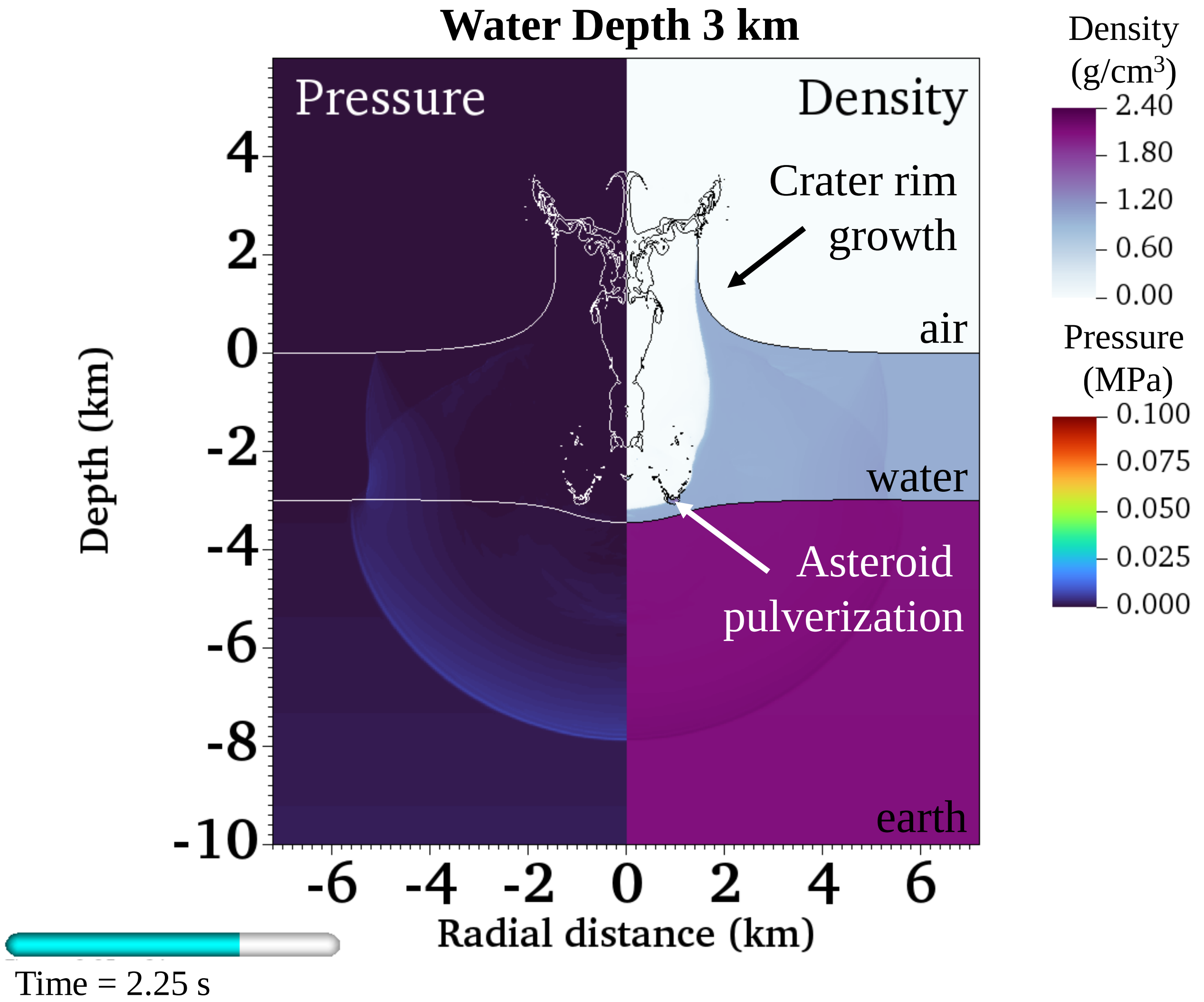

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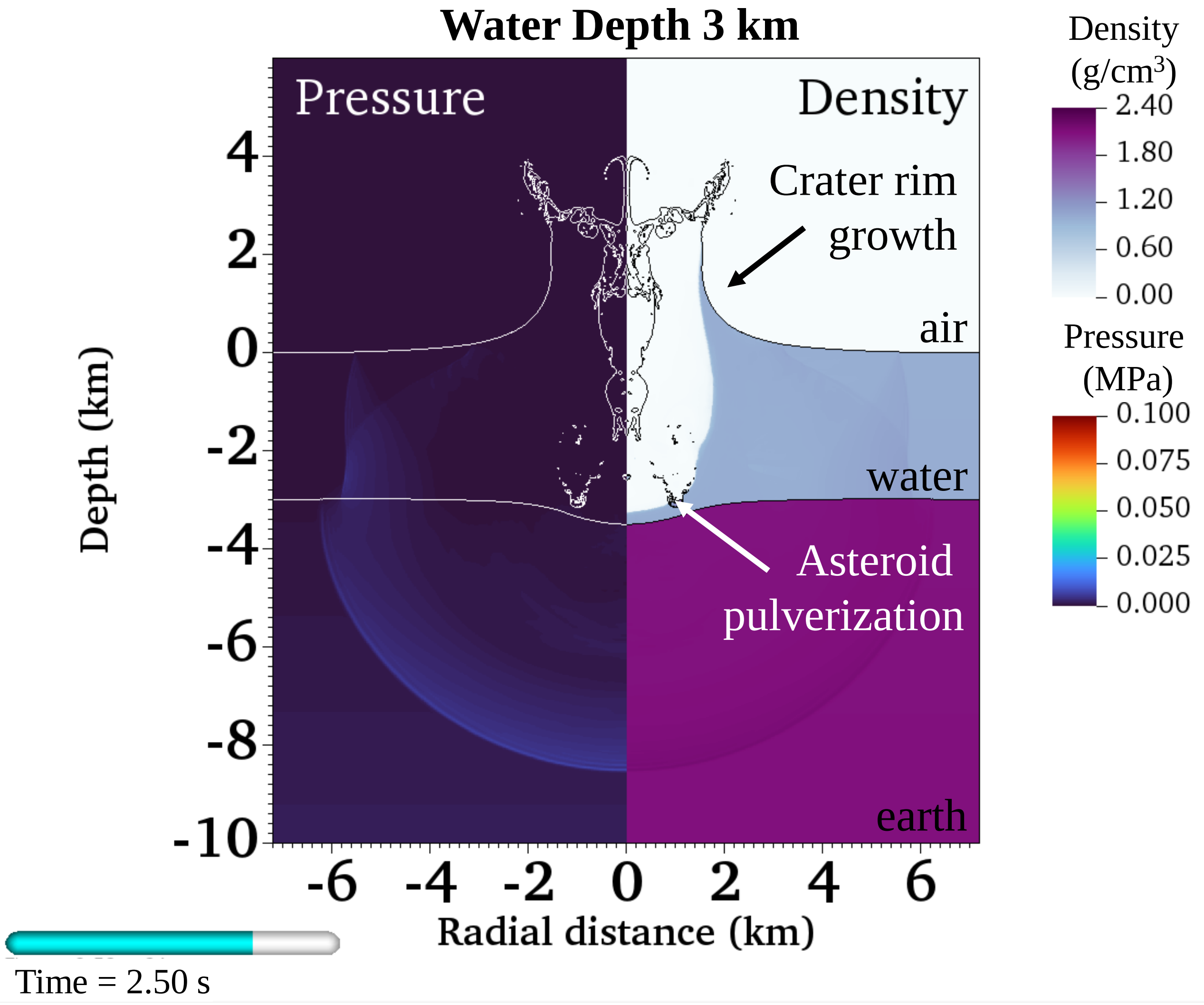
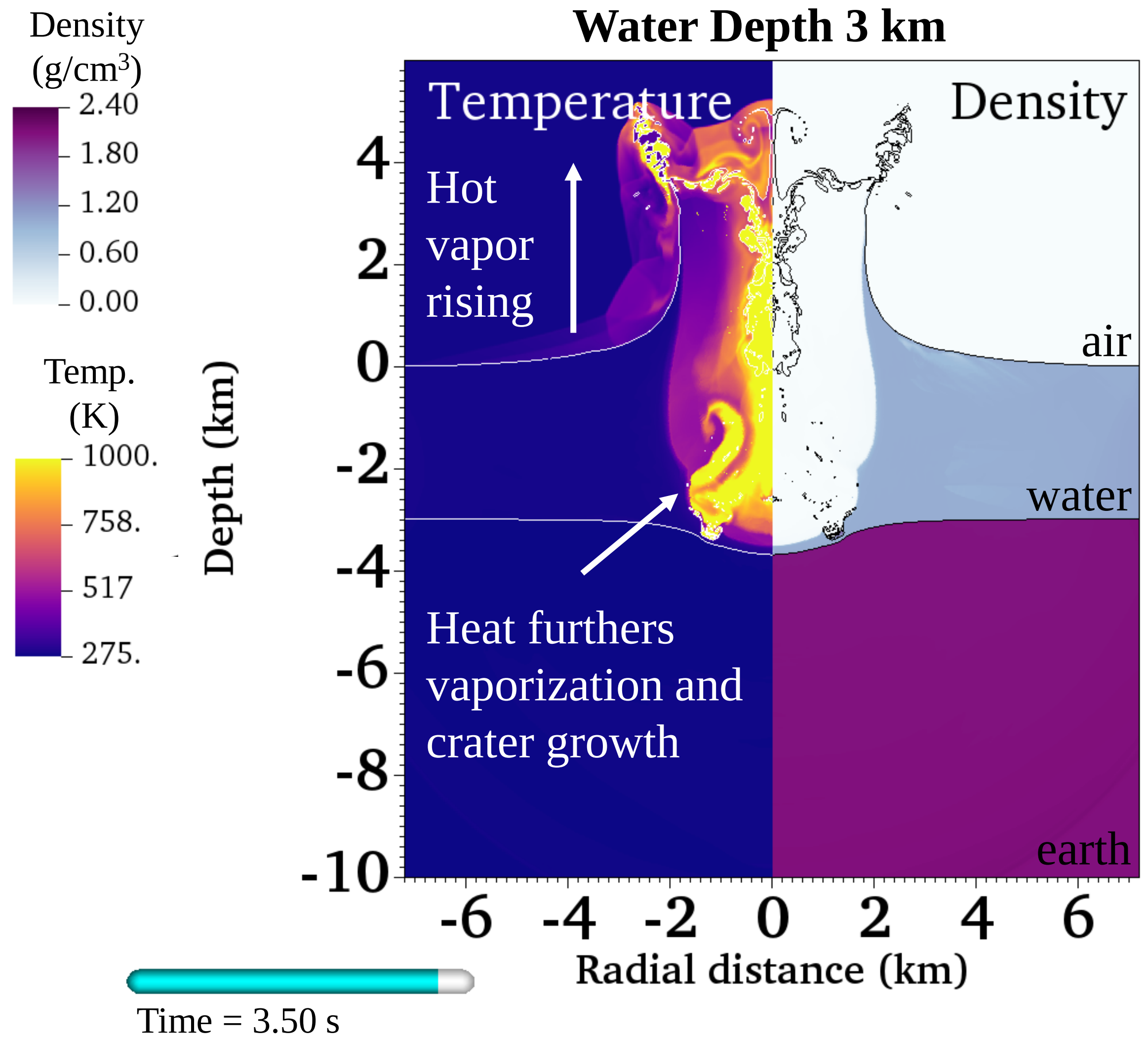
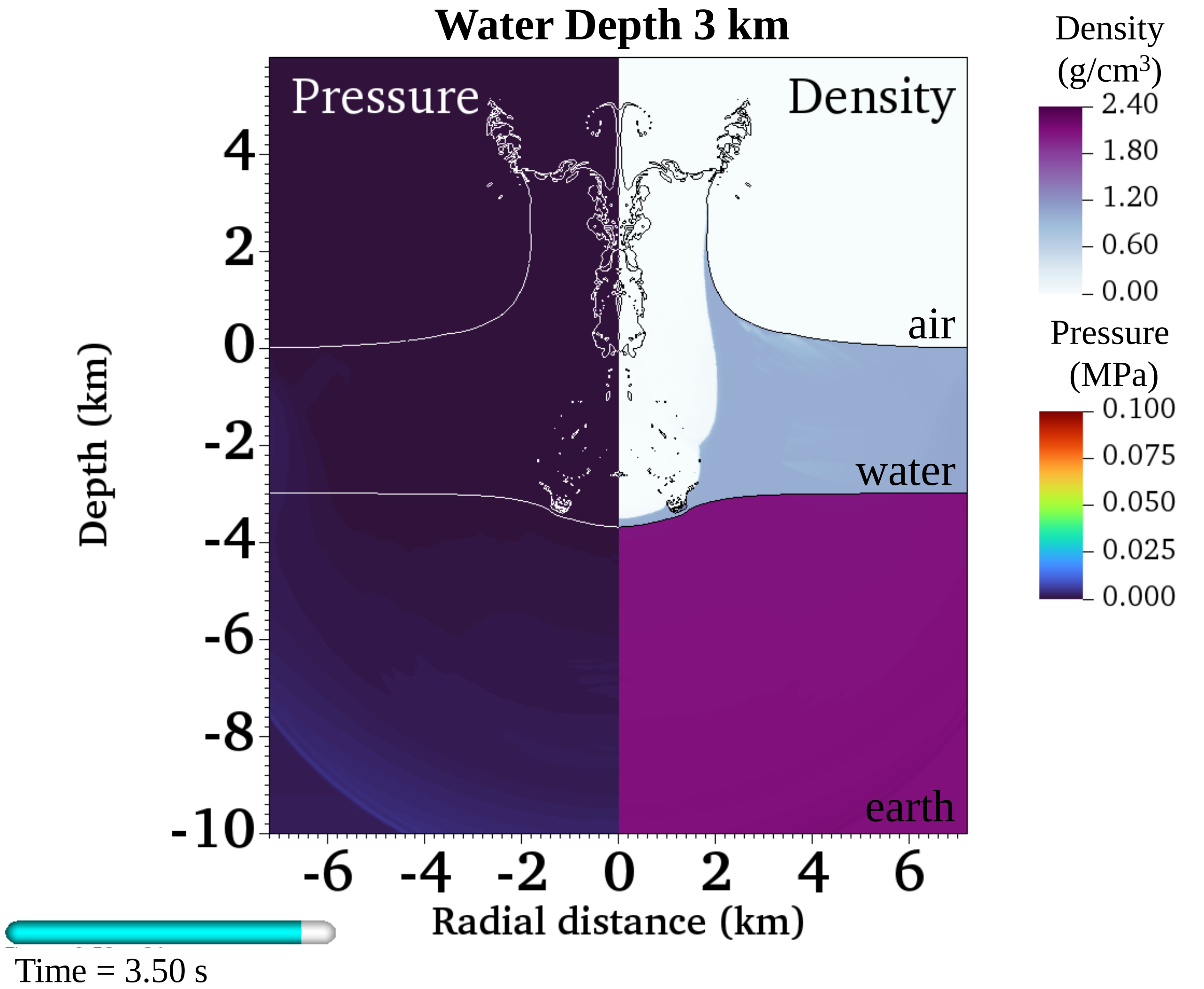


Hot vapor plume moves up into atmosphere

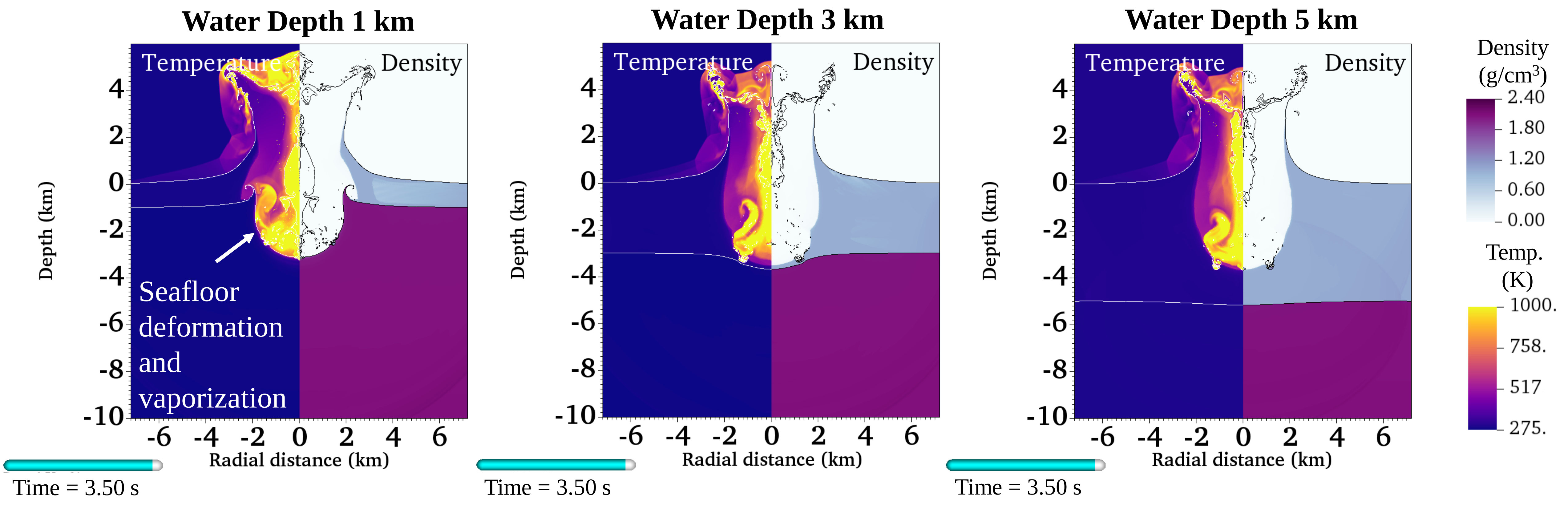
Linking necessary for modeling cloud formation atmosphere effects on longer time scale





Impact in shallow water deforms and vaporizes seafloor

Changing vapor to include steam and dust



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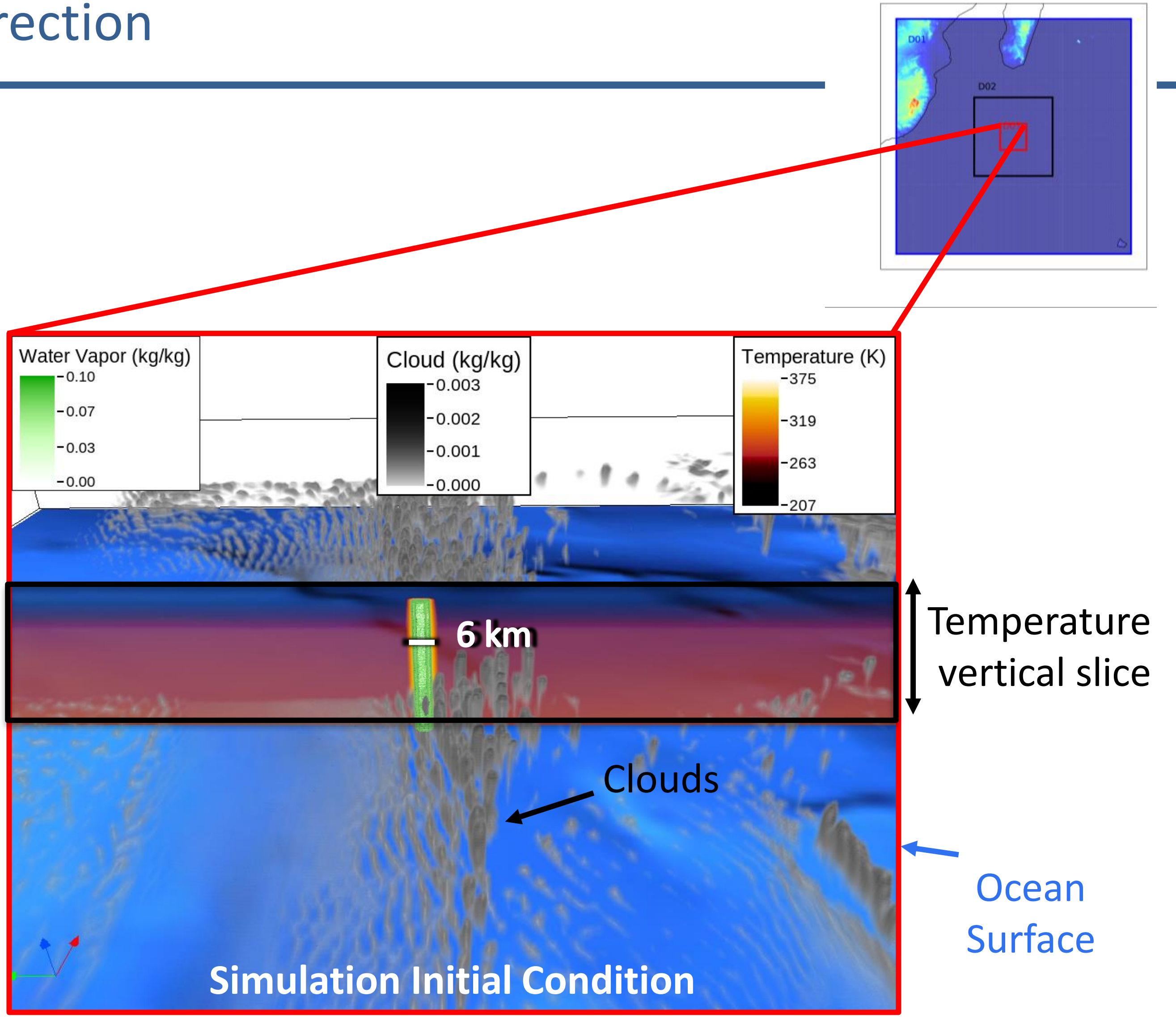
Future linking to Weather Research & Forecasting (WRF) model

Modeling workflow potential and future direction

- Model applies historic atmospheric meteorology data of real cloud coverage
  - Near South Africa, south of Madagascar
  - 9:00 am local time on June 3, 2022
- Simulated change in temperature shows
  - Atmospheric gravity waves
  - Cooling due to cloud formation at late time
- Results give insight into post-impact weather and potential global radiative effects



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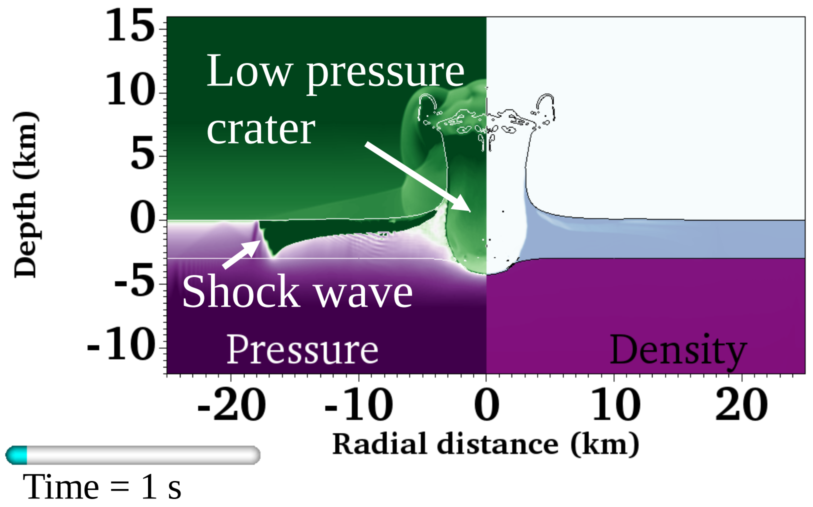
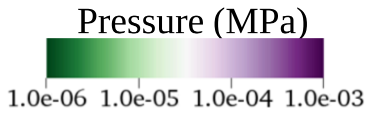
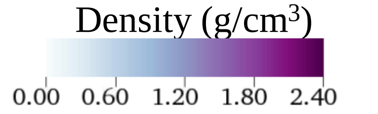
Pressure difference causes seafloor rebound

Damped oscillation and crater infill creates the initial tsunami wave train







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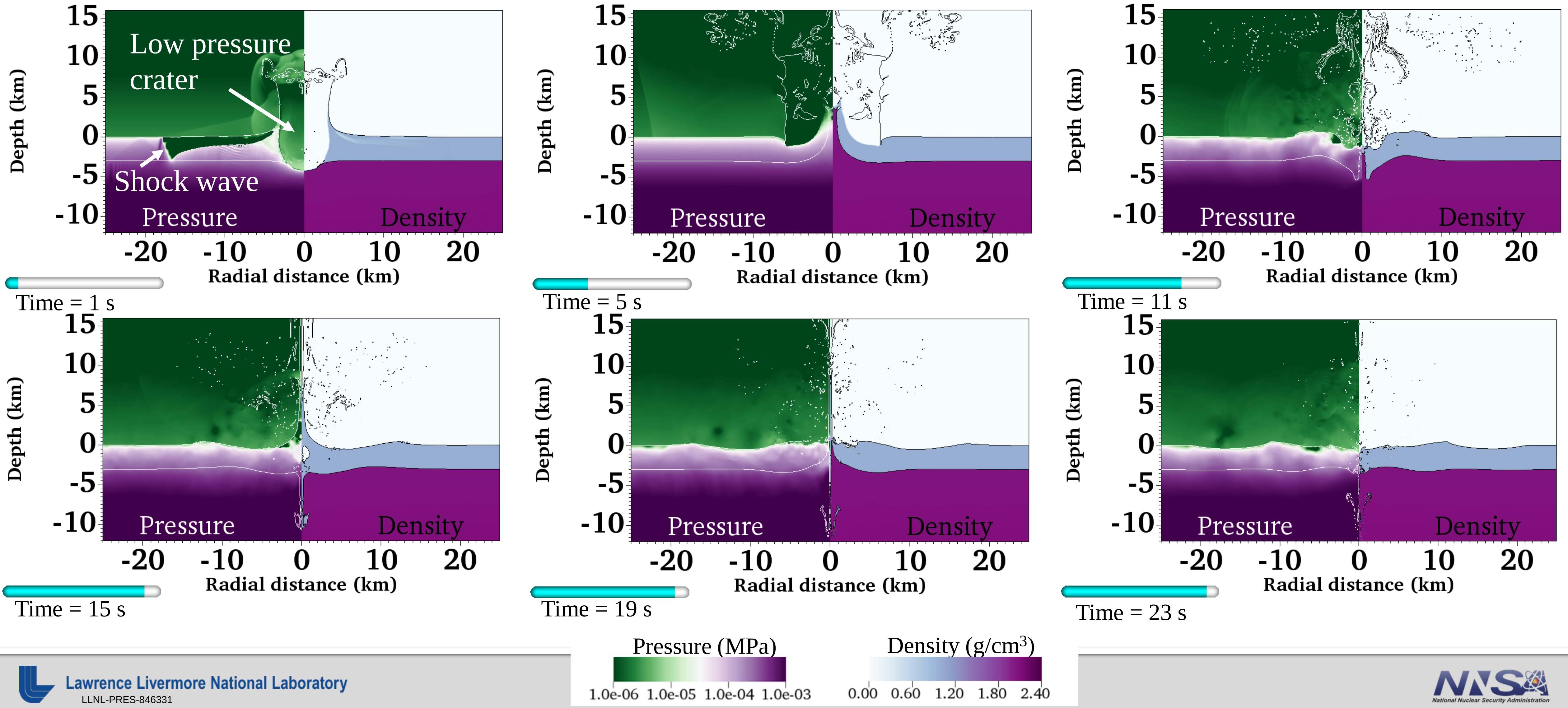
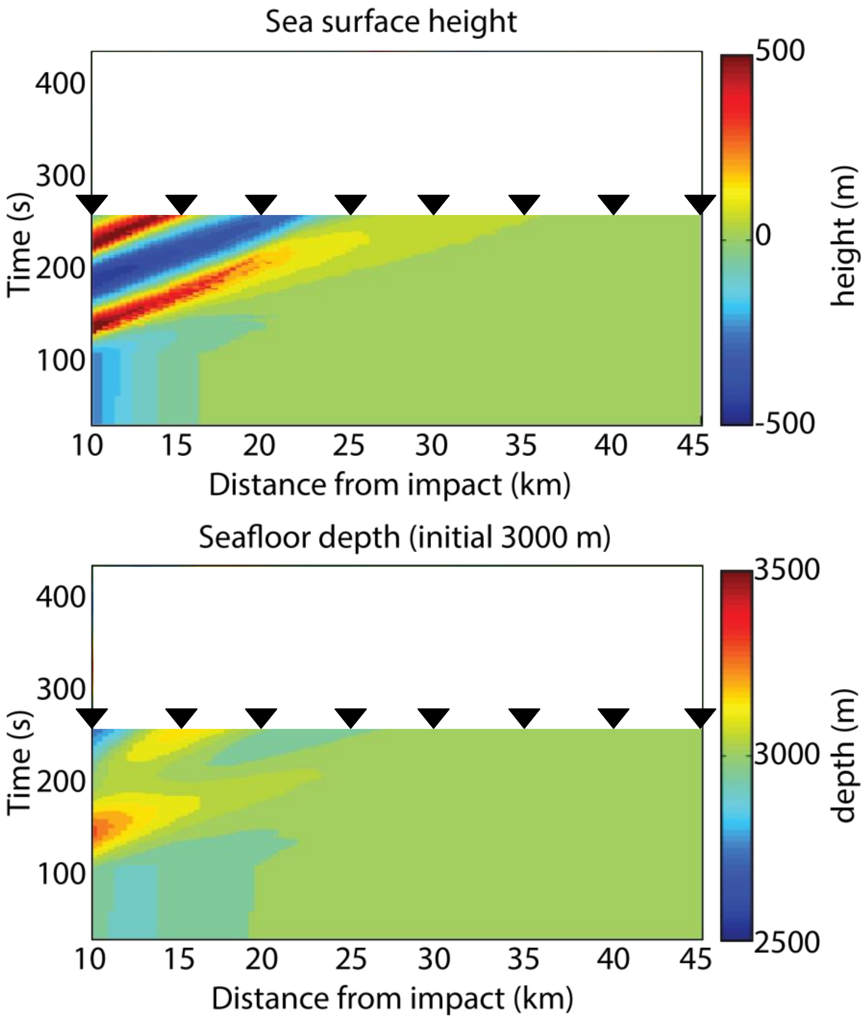
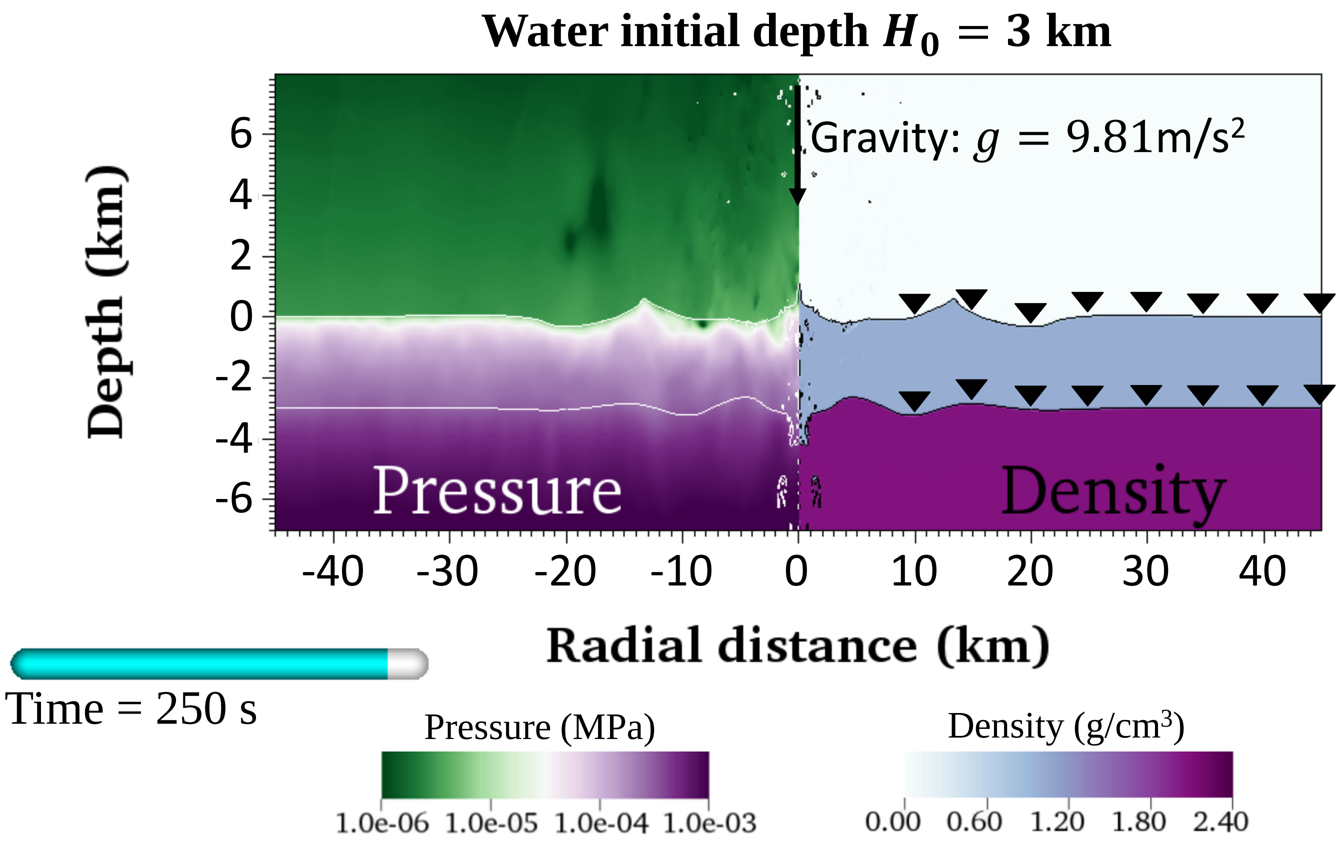


Complex nature of seafloor rebound and tsunami generation

Tsunami waves generate and propagate while seafloor is continuing to deform
Tsunami wavelength within deep-water limit dispersion will occur





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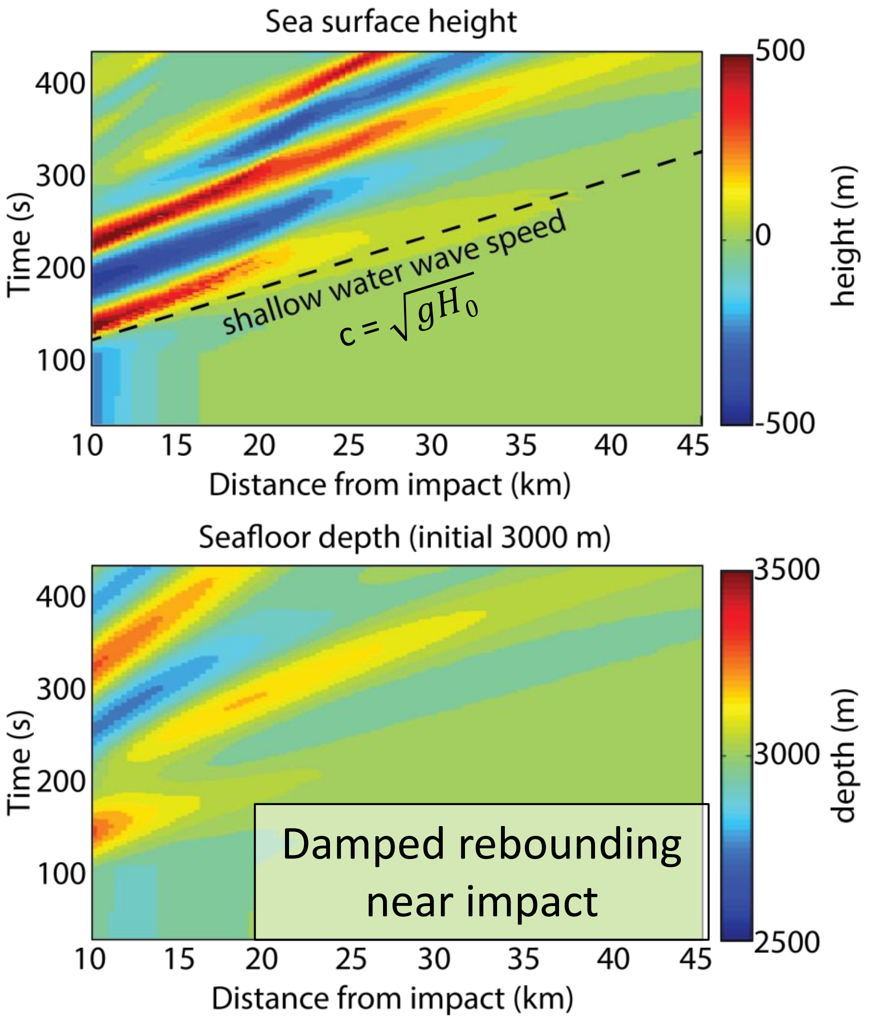

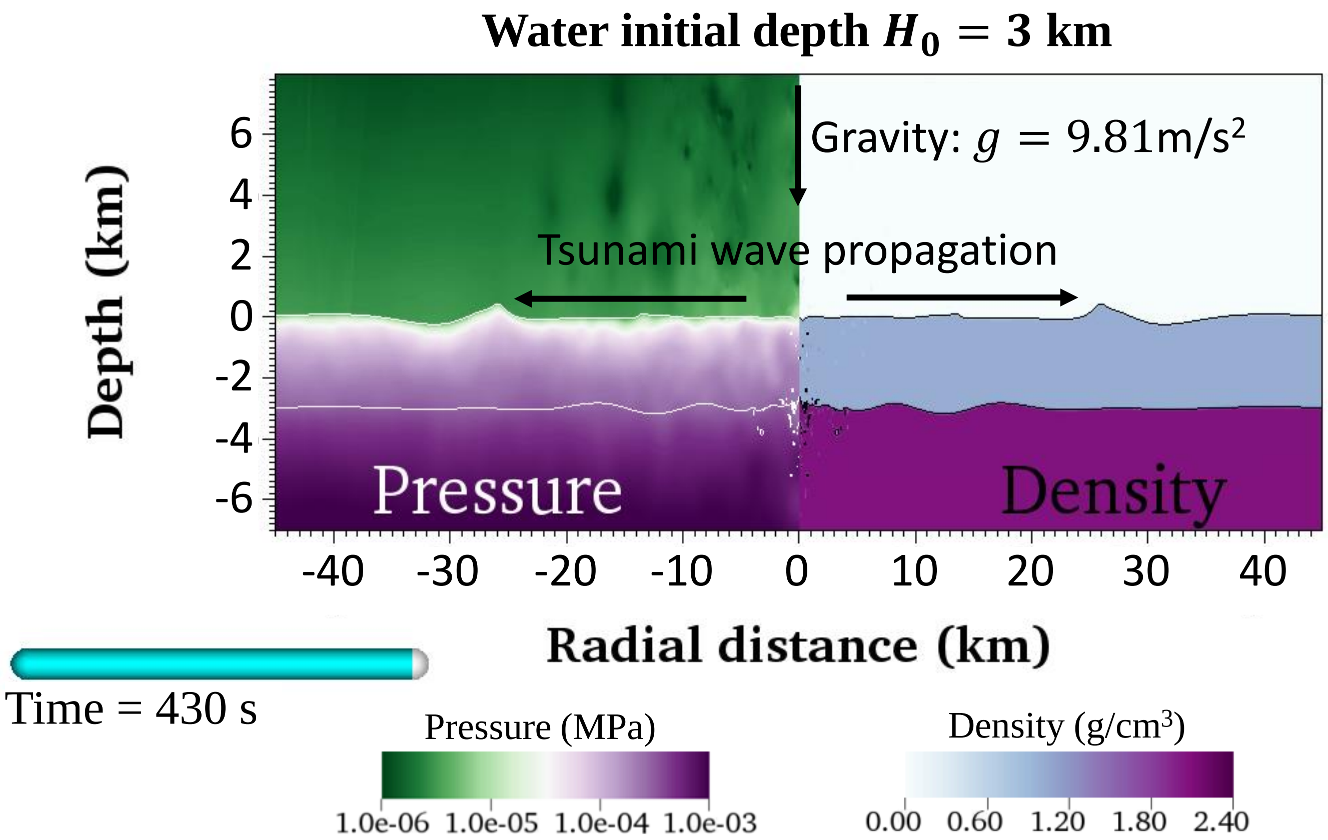

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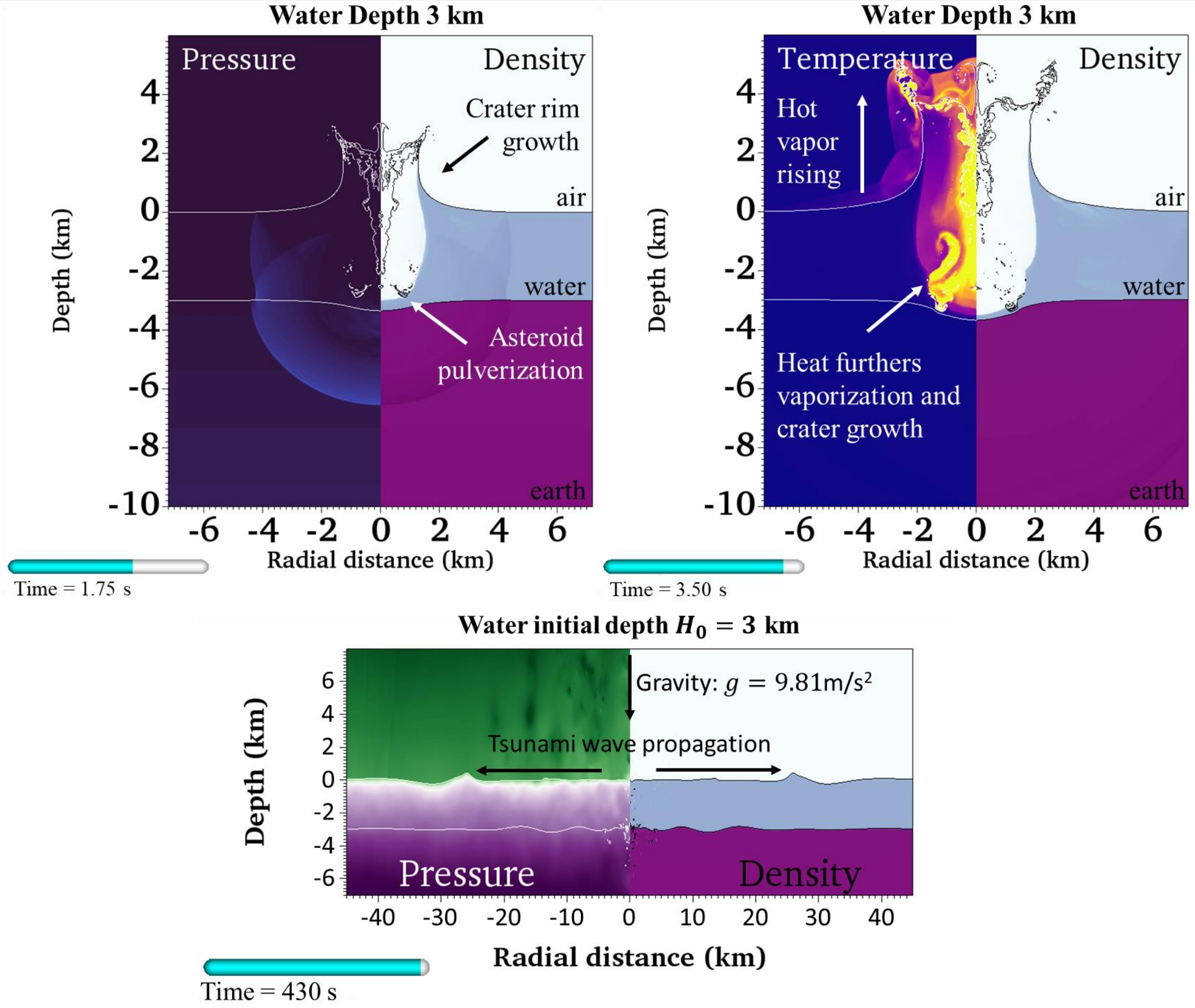
Looking forward

- Numerical models can assess potential hazard and lead to recommendations for emergency response
- Complexity of thermodynamic and elastic behaviors captured in hydrocode
- Timely and credible consequence calculations could factor into the decision to fly reconnaissance and/or mitigation missions.



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