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High-Fidelity Modeling of Asteroid Ocean Impacts: Understanding Tsunamis Generation and Atmospheric Responses

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Near Earth Objects (NEOs), such as asteroids on an Earth-impact trajectory, are low probability, high consequence natural hazards. To understand the consequences of Earth-impacting NEOs we rely on numerical simulations to model potential damage. In this study we investigate asteroid ocean impacts, focusing on the primary and secondary hazards such as tsunami wave generation and atmospheric effects. Our main objective is to develop a methodology that transitions the local, early-time effects

of an asteroid impact - captured using a high-fidelity hydrocode - into models capable of simulating secondary hazards over extended timescales and large distances.

We employ ALE3D, a multi-physics hydrocode utilizing an Arbitrary Lagrangian-Eulerian (ALE) scheme, to simulate impacts of asteroids with diameters of 75m, 125m, and 200m into water depths of 1km and 3km. This hydrocode effectively models asteroid fragmentation, water crater formation, complex thermodynamic behaviors, vaporization, and the conversion of impact energy into wave energy, all on microsecond time scales. Once the initial impact effects are captured, the simulation data is linked to a Boussinesq tsunami propagation model, FUNWAVE, and a Weather Research and Forecasting model, WRF. These models are used to calculate secondary hazards, such as tsunamis and atmospheric response, on a regional scale over hundreds of seconds.

This research aligns with the 2023-2032 Planetary Science & Astrobiology Decadal Survey's recommendations to establish an operational capability for threat assessment and rapid information dissemination through a national planetary defense pipeline. Given the limited historical data on NEO impacts, theoretical numerical models offer valuable insights for hazard assessment and emergency response planning. If an asteroid is detected early enough, these models can inform decisions on reconnaissance or mitigation missions. By comprehensively modeling these cascading hazards, this study enhances our understanding of the risks posed by ocean impacting NEOs and informs the development of effective mitigation strategies.

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