Asteroid Impact Risk Assessment

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Asteroid Threat Assessment Project
NASA Ames Research Center

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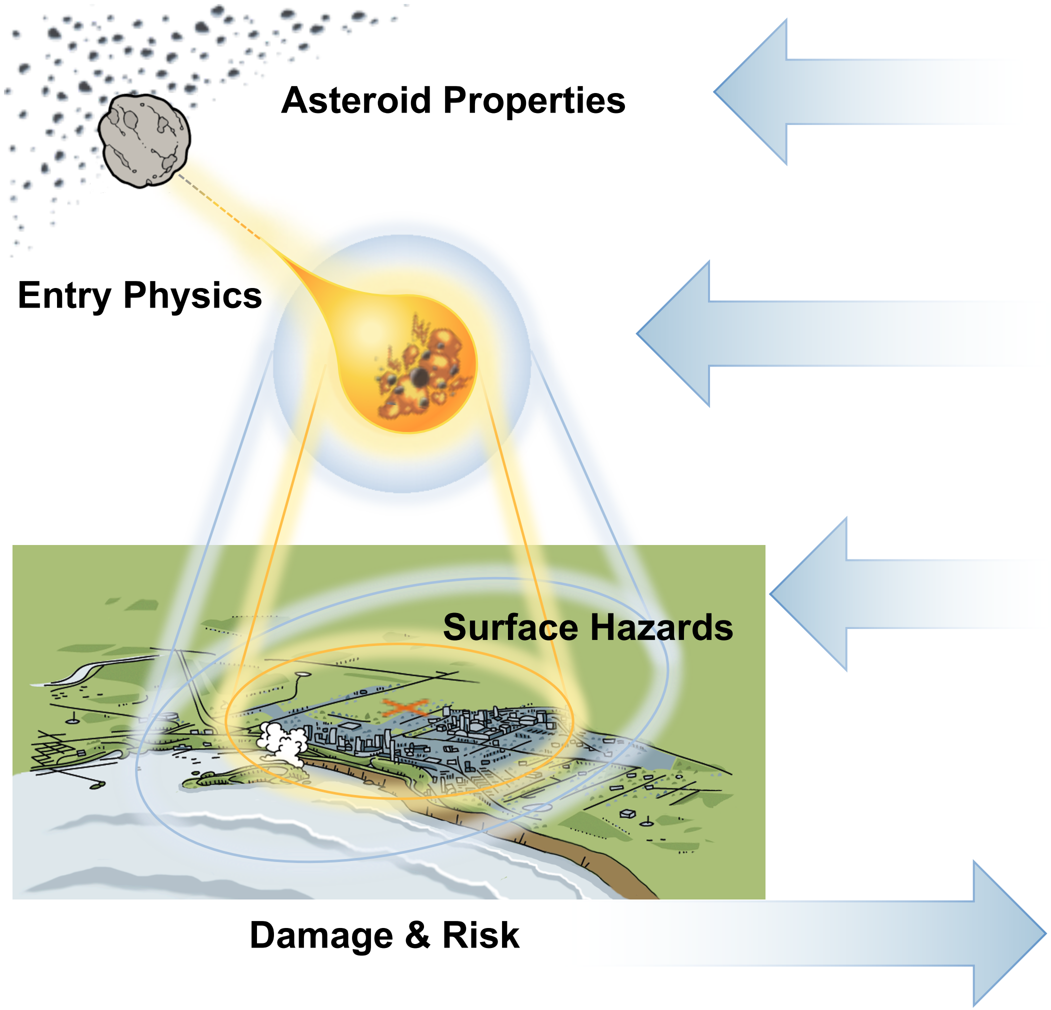


Characterization
- Measurements
- Inference
- Data aggregation

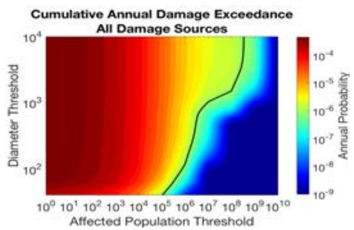
Entry Simulations & Testing
- Coupled aerothermodynamics
- Ablation & radiation modeling
- Arc jet testing

Hazard Simulations
- 3D blast simulations
- Tsunami simulations
- Impact crater simulations
- Thermal radiation models
- Global effects

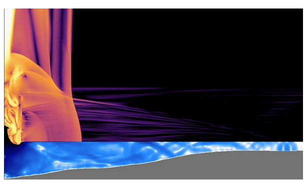
Probabilistic Risk Assessment
- Analytic physics-based entry and damage models
- Probabilistic Monte Carlo simulation using uncertainty distributions

NASA Supercomputing

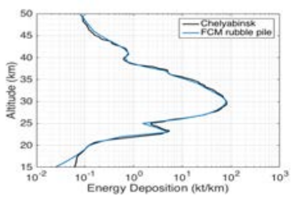
Supercomputing helps address the challenging unknowns of asteroid threat assessment by enabling:



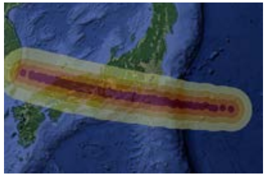
- Analysis of millions of impact cases to assess risk probabilities, including uncertain asteroid properties, entry modeling, local populations, and multiple hazard sources



- High-fidelity simulations to improve understanding of key impact effects and refine probabilistic risk models

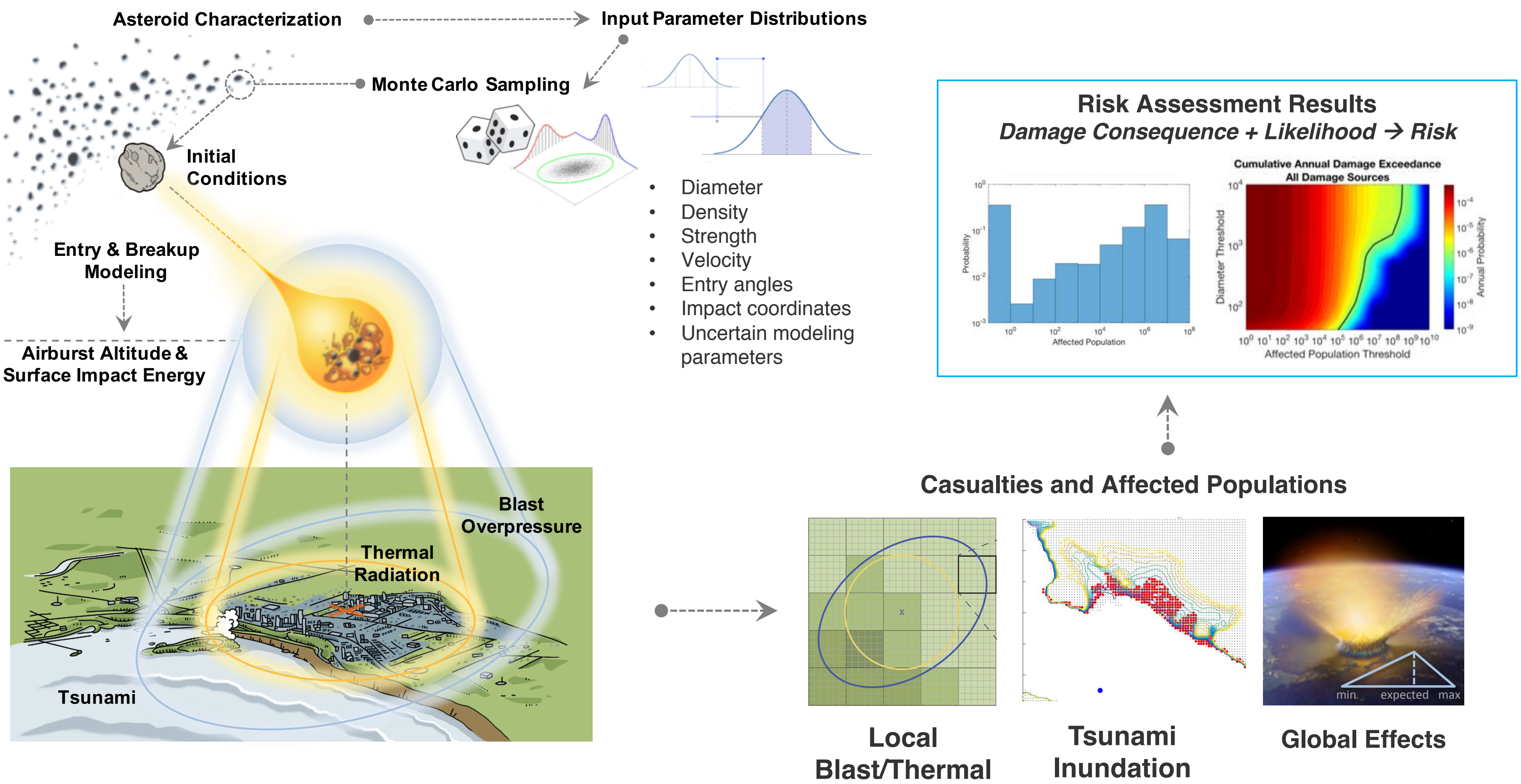


- Inference of asteroid properties from automated entry modeling of observed meteors



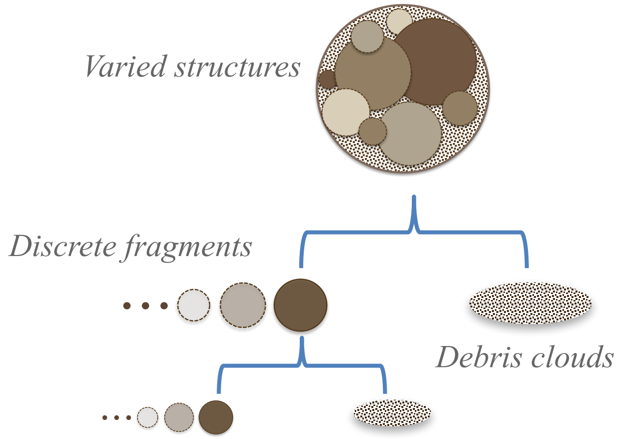
- Rapid-turnaround risk assessment to support mitigation and response planning in the event of a potential impact threat.

Probabilistic Asteroid Impact Risk (PAIR)

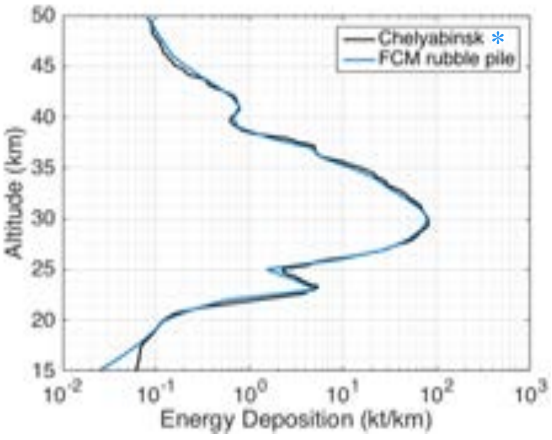


Fragment-Cloud Model (FCM)

FCM Breakup Modeling



FCM Modeling of Chelyabinsk Meteor



Analytic model of energy deposited in the atmosphere during entry and breakup

- Represents breakup process using a combination of discrete fragments and aggregate debris clouds
- Can represent range of asteroid structures and breakup characteristics

FCM results can match observed meteor light curves to:

- Infer pre-entry asteroid properties
- Investigate breakup characteristics
- Guide model refinements

Energy deposition results used to estimate airburst altitudes and ground energies in probabilistic risk model

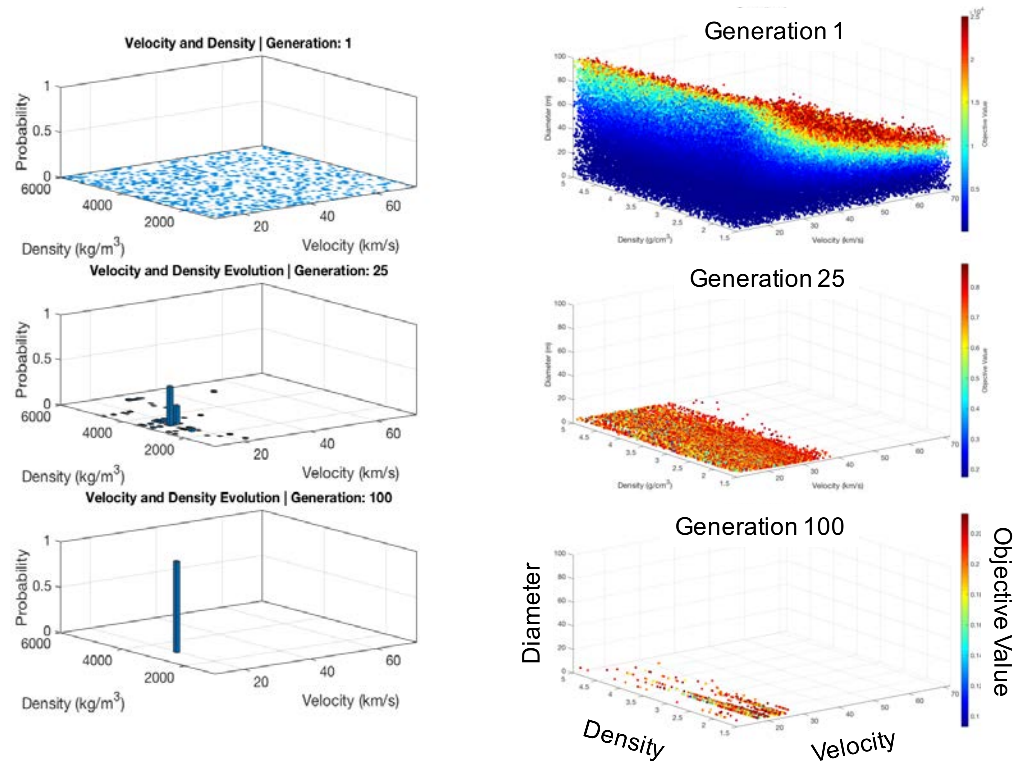
*Chelyabinsk energy deposition curve from: Brown et al., 2013. A 500-kiloton airburst over Chelyabinsk and an enhanced hazard from small impactors. Nature 503 (7475), 238–241.

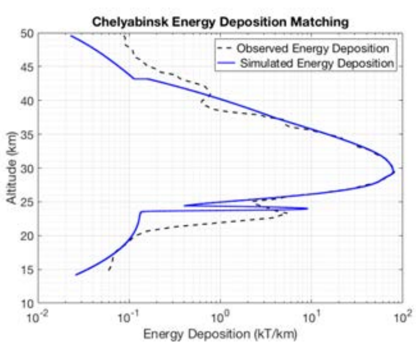
Automated Meteor Inference

Developing automated approach for matching Fragment-Cloud Model (FCM) energy deposition results to observed meteor light curves.

- Automates entry modeling for thousands of asteroid and entry parameter variations.
- Objective function evaluates quality of matches to observed data.
- Genetic algorithm approach evolves selection of the input parameters to produce the best fits.

Sample evolutions of diameter, density, and velocity parameters





Automated fit obtained for the Chelyabinsk meteor energy deposition profile

Modeling & Image Credit: Ana Tarano, Stanford/NASA Ames

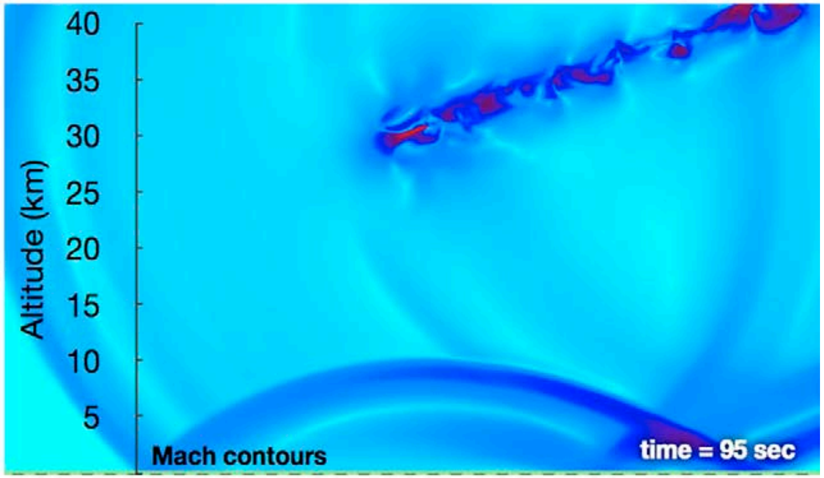
Blast Overpressure Modeling

CFD blast propagation simulations improved ground damage estimates in risk model

- Height-of-burst maps estimate the extent of ground overpressures as a function of airburst altitude, based on nuclear test data
- Yield-scaling based on smaller nuclear sources becomes inaccurate for higher impact energies due to buoyancy effects (KE >10-50 megatons, diameter > 50-80m)
- CFD results provided improved height-of-burst map for higher asteroid impact energies

See demo "Simulating Atmospheric Impacts" by Marian Nemec

Cart3D blast propagation simulation



Image/simulation: Michael Aftosmis, NASA Ames

Simulation vs. nuclear-based (G&D) height-of-burst map

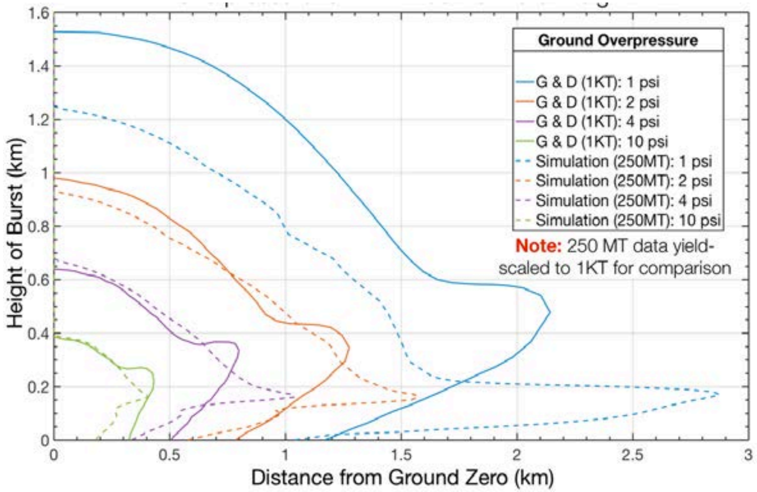
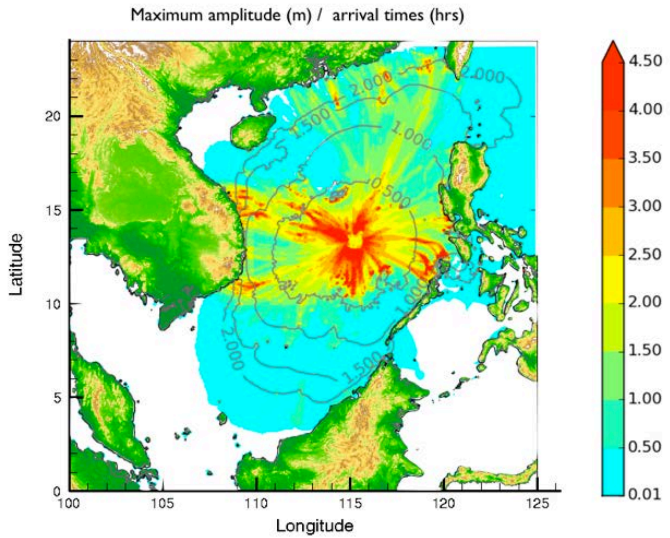
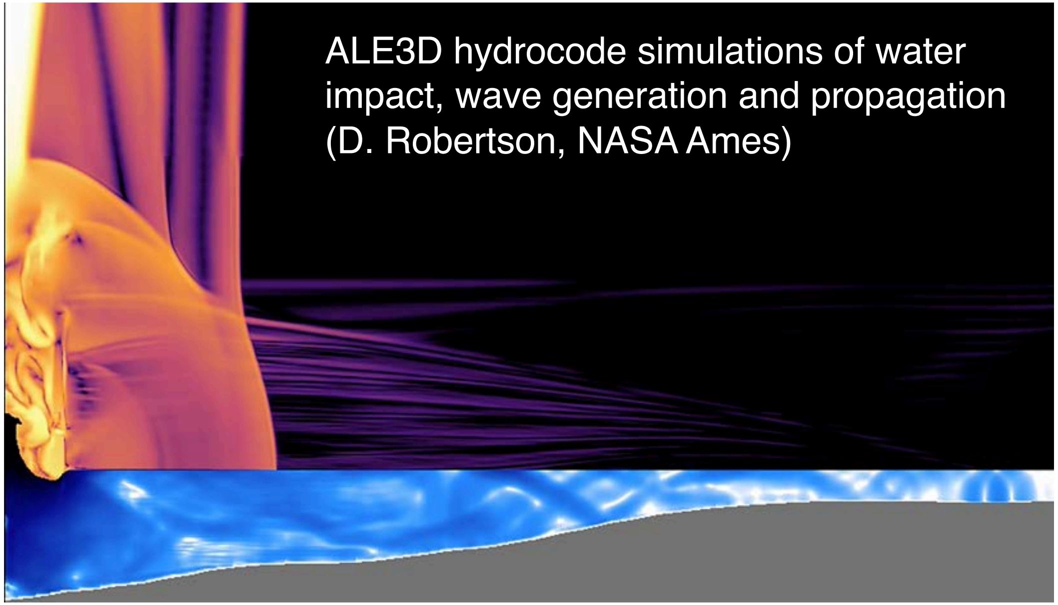


Image: Michael Aftosmis, Ana Tarano, NASA Ames

Asteroid-Generated Tsunami Simulations

- High-fidelity simulations address big unknown of whether asteroid impacts or airbursts of various sizes could cause significant tsunamis
- Recent results show asteroid impacts to pose less tsunami threat than previously thought
- Results used to refine analytic tsunami risk model





ALE3D hydrocode simulations of water impact, wave generation and propagation (D. Robertson, NASA Ames)

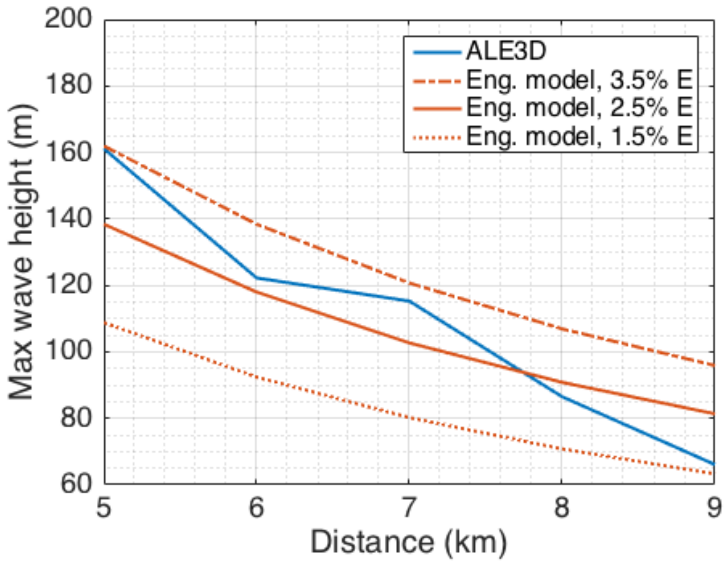
GeoClaw simulations of long-range wave propagation and inundation (M. Berger, NYU)

→ *For more on asteroid tsunami simulation, see demo "Simulating Atmospheric Impacts" by Marian Nemec*

Tsunami Risk Modeling Advancements

- Analytic model estimates wave run-up based on energy impacting surface of the water and propagation distance from impact to shore (Chesley & Ward 2006)
- Improved energy coupling estimates for airbursts and splashdowns based on ALE3D and GeoClaw simulations of wave formation and propagation.
- Supercomputing enables risk model to include inundation of specific coastal topography for millions of ocean impact/airburst cases, enabling damage assessment based on local populations and flood depths.

Comparison of analytic model scaled to match simulation results



Risk model inundation including local topography

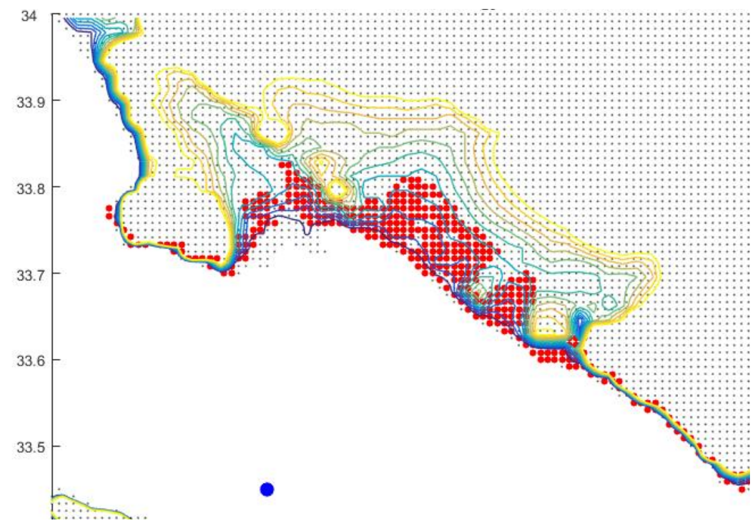
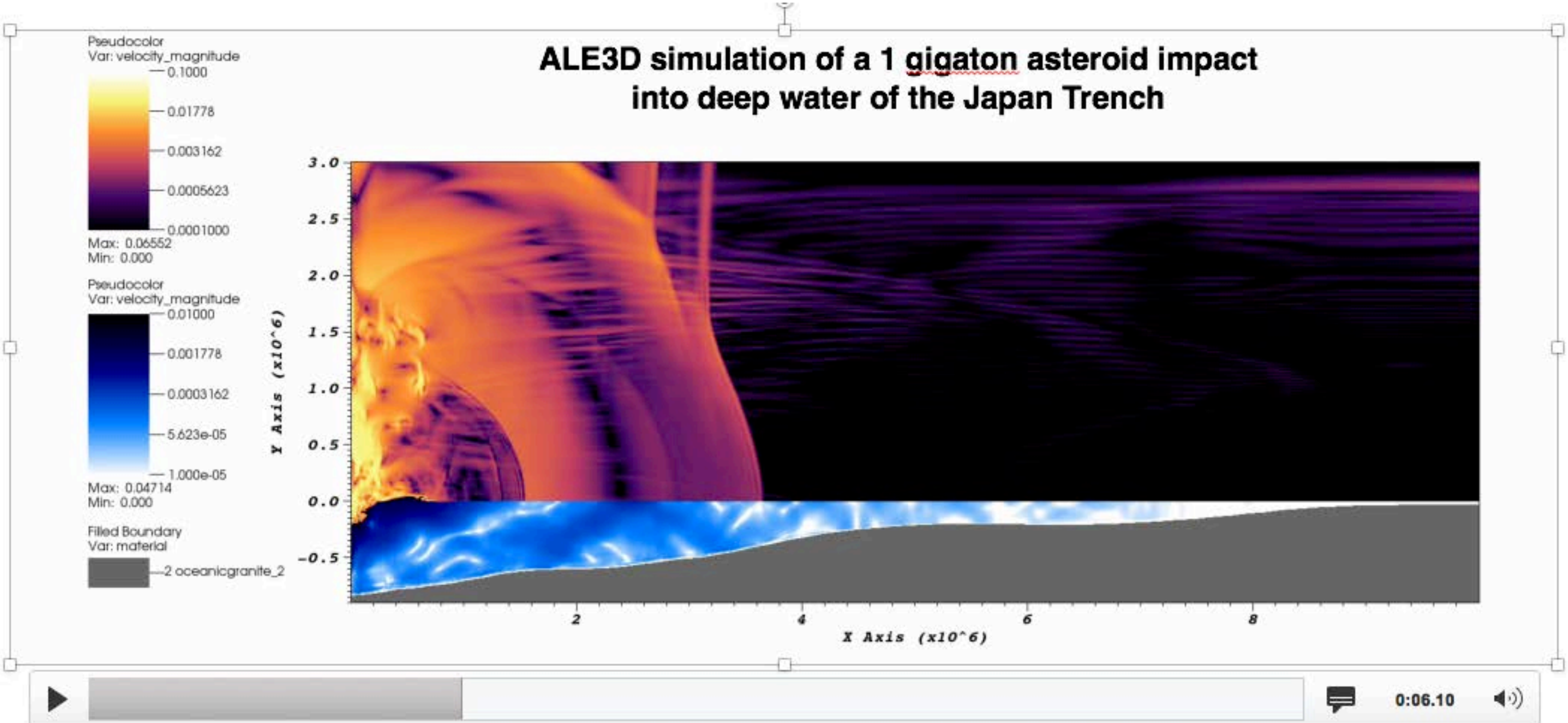


Image: Paul Register, NASA Ames

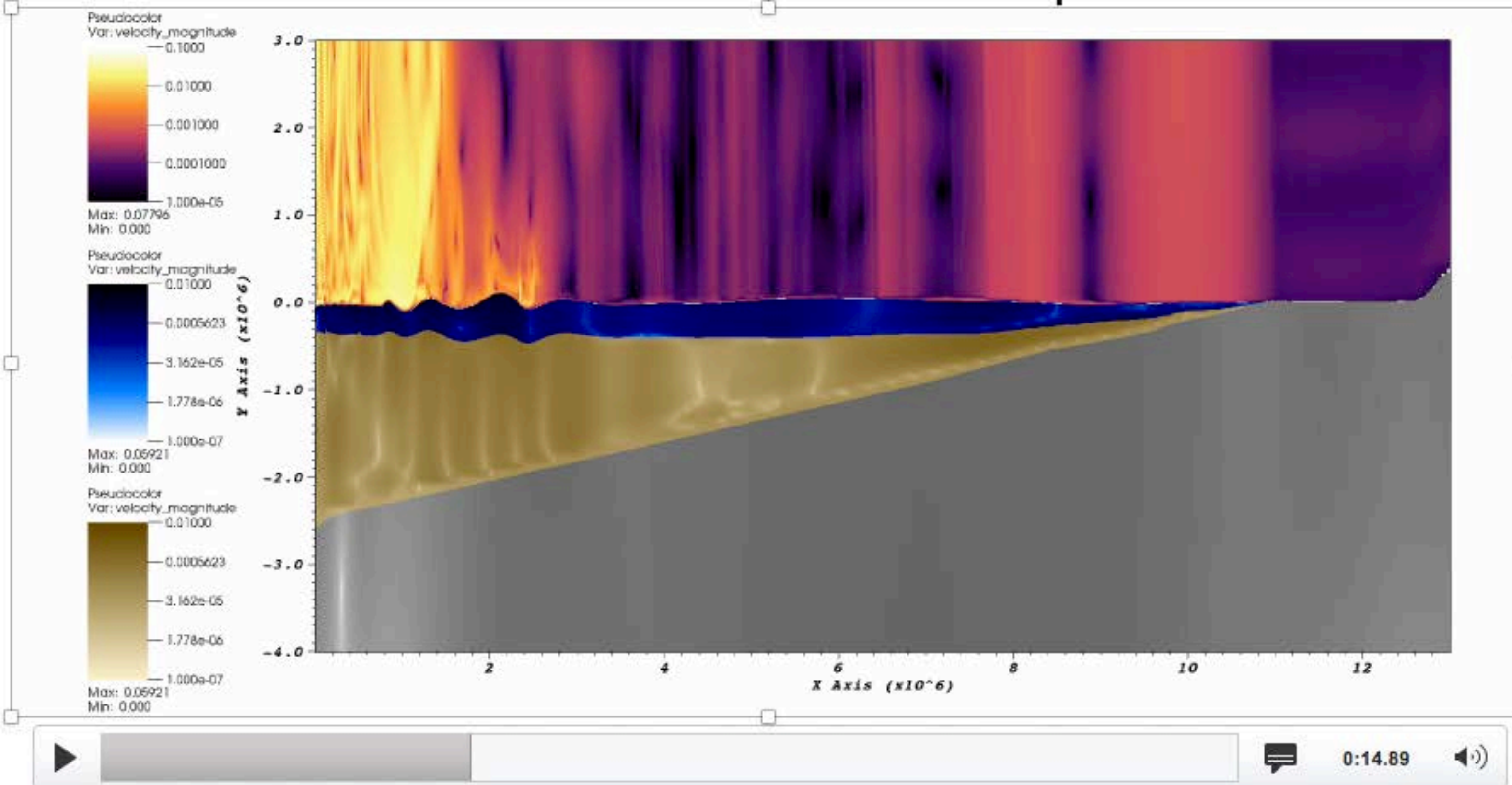
Asteroid-Generated Tsunami Simulations



Simulation & movie credit: Darrel Robertson, NASA Ames

Asteroid-Generated Tsunami Simulations

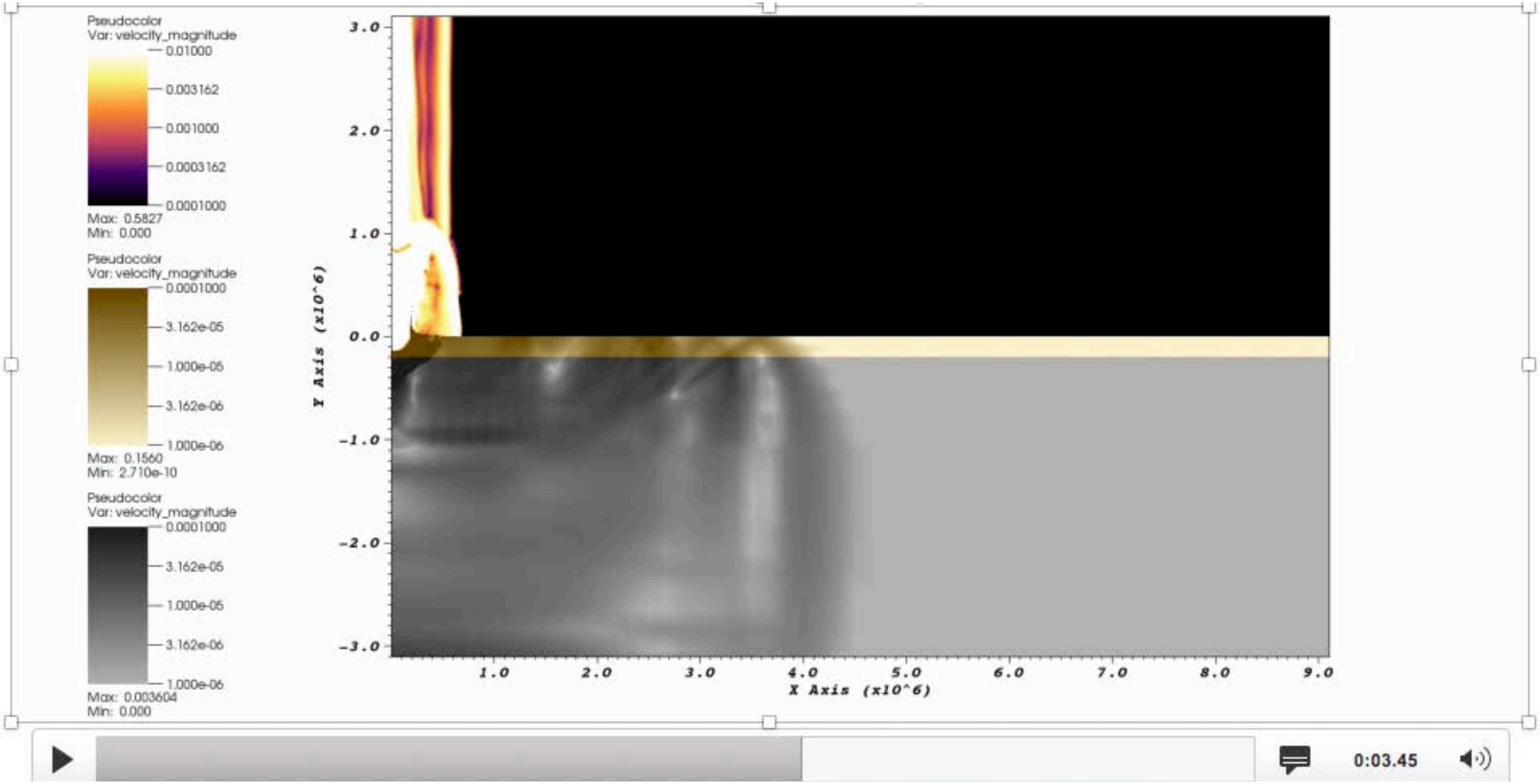
ALE3D simulation of a 1 gigaton asteroid impact into shallow water of the Japan Trench



Simulation & movie credit: Darrel Robertson, NASA Ames

Ground Impact Simulations

ALE3D simulation of a 1 gigaton asteroid ground impact



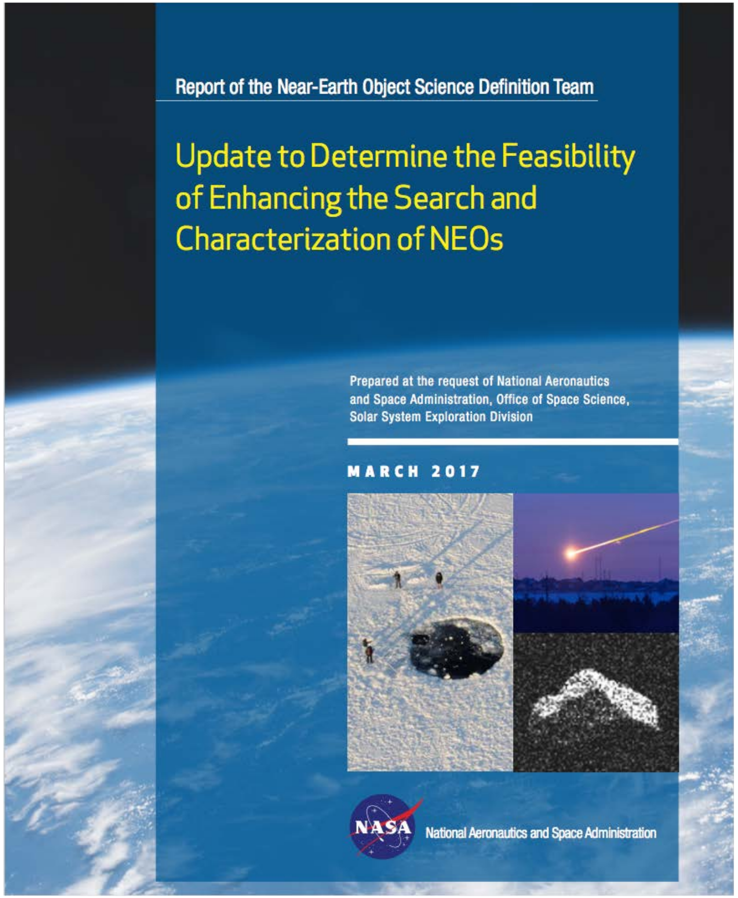
Simulation & movie credit: Darrel Robertson, NASA Ames

NEO Science Definition Team Study

Performed comprehensive impact risk assessment for the 2017 Near-Earth Object (NEO) Science Definition Team (SDT) study

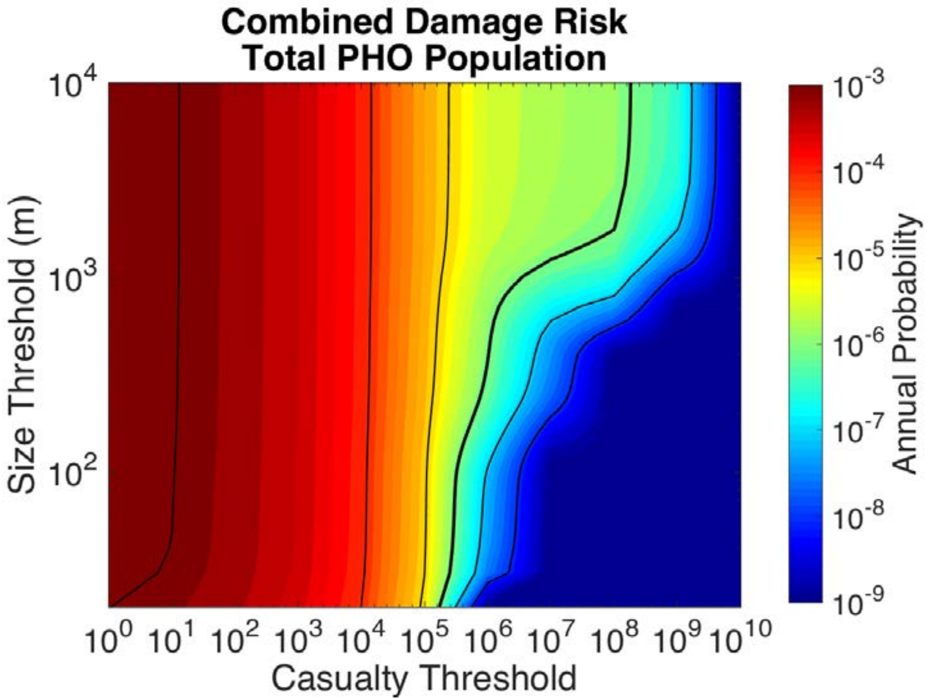
- SDT convened by NASA's Planetary Defense Coordination Office (PDCO) to reevaluate the level of threat posed by asteroids of various sizes
- Will guide survey systems and search criteria for future NEO surveys

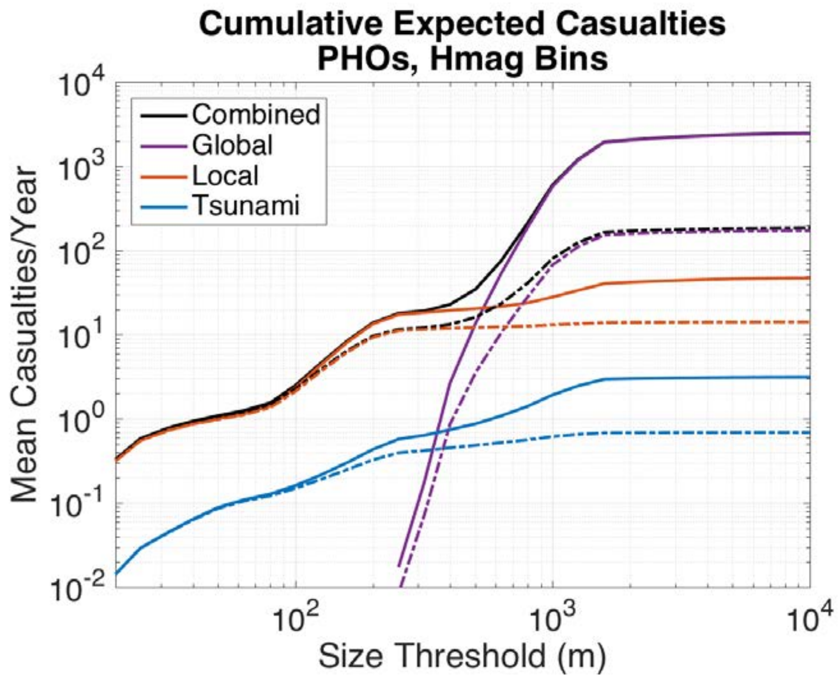
Risk modeling on Pleiades Supercomputer provided substantial advancements since the prior 2003 study



SDT Impact Risk Results

- 60 million impact cases analyzed on Pleiades Supercomputer
- Asteroid sizes 20m – 10km in diameter
- Assessed local damage from blast waves and thermal radiation, tsunami inundation from water impacts, and global effects from large-scale impacts.





Impact Response Exercises

- Have participated hypothetical impact exercises to vet and improve assessment tools, response protocols, and decision support.
- Risk model takes impact trajectory inputs from JPL orbital models and evaluates risk probabilities along a potential impact corridor.
- Pleiades Supercomputer enables rapid risk assessment for emergency response.

Probabilistic risk assessment for HYPOTHETICAL impact exercise performed at the 2017 Planetary Defense Conference in Tokyo