2021 PDC Hypothetical Impact Exercise: Probabilistic Asteroid Impact Risk

Scenario Day 1

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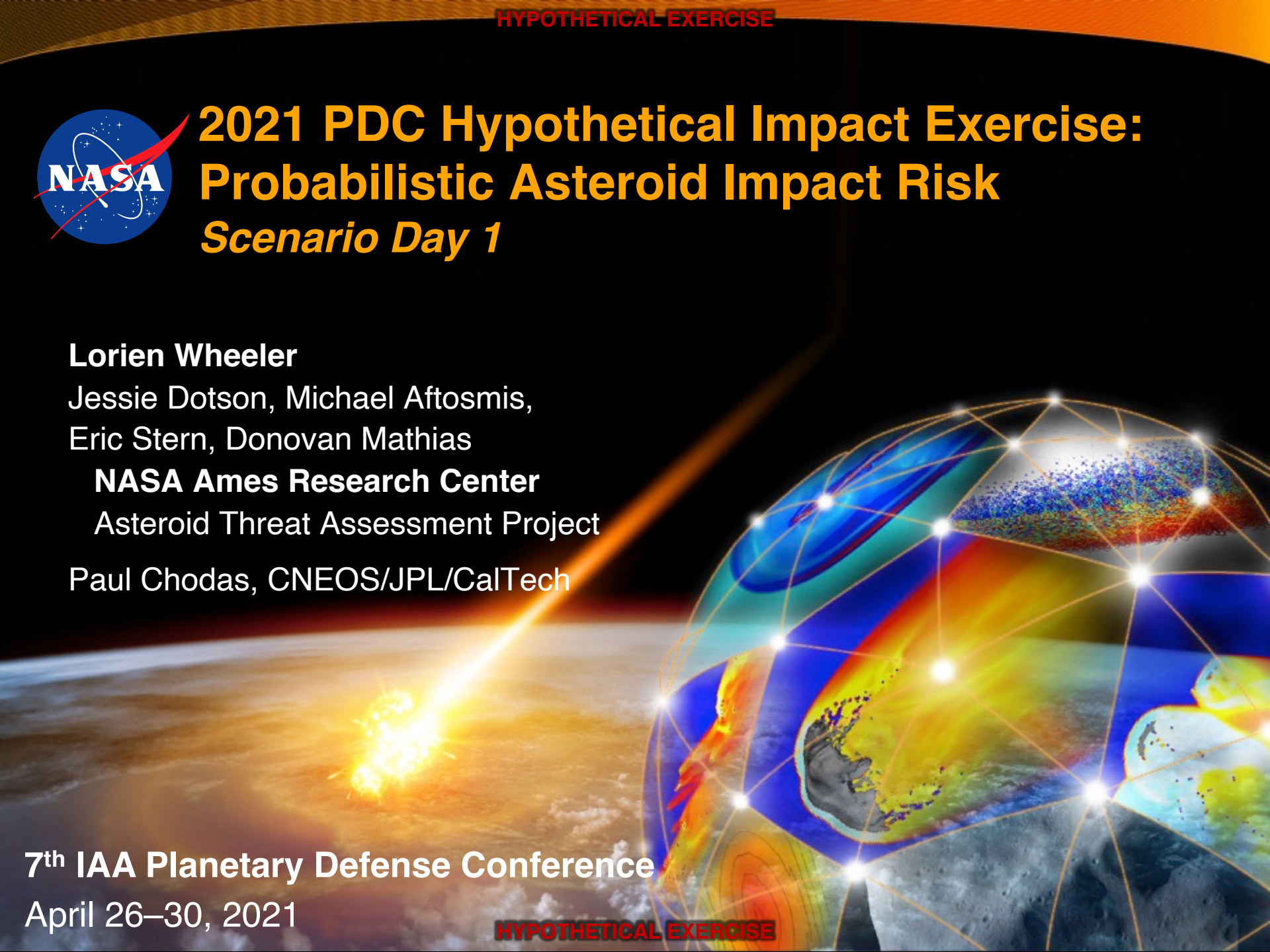


7th IAA Planetary Defense Conference
April 26–30, 2021

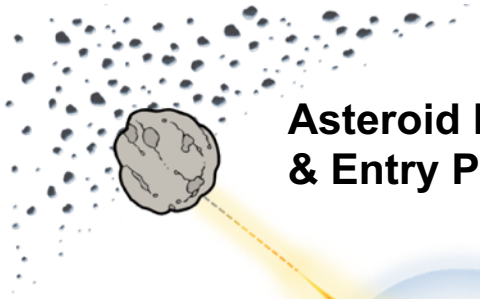
HYPOTHETICAL EXERCISE

Ames Research Center

Asteroid Impact Threat Assessment

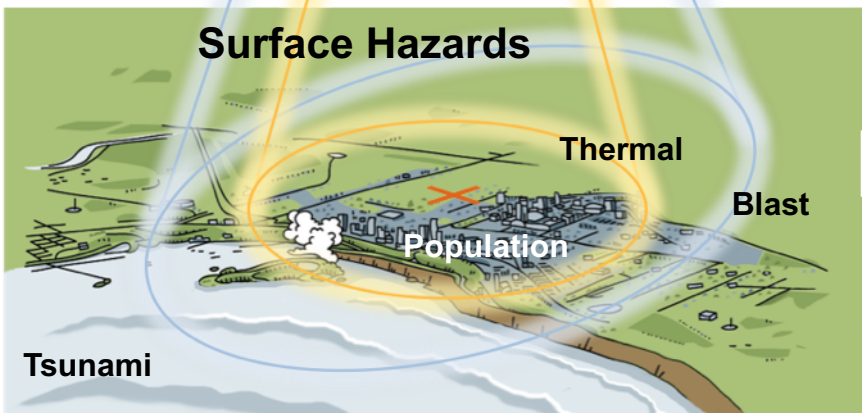
NASA

Probabilistic Asteroid Impact Risk (PAIR) Model



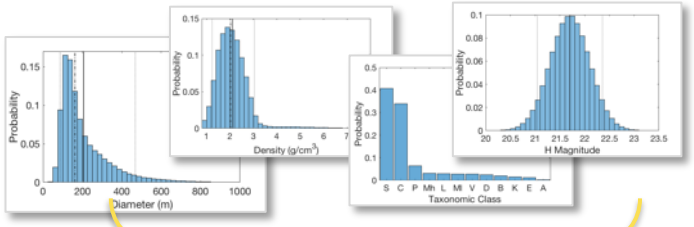
Asteroid Properties & Entry Parameters

Entry & Breakup Modeling

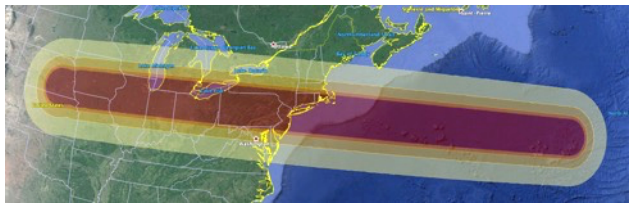


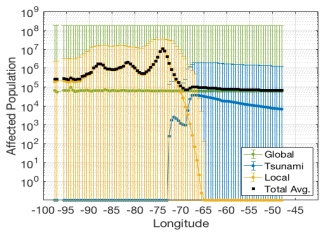
Impact Threat Scenario

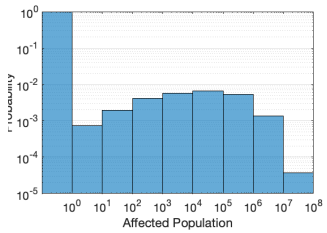
Asteroid Property Distributions



Probabilistic Risk and Damage





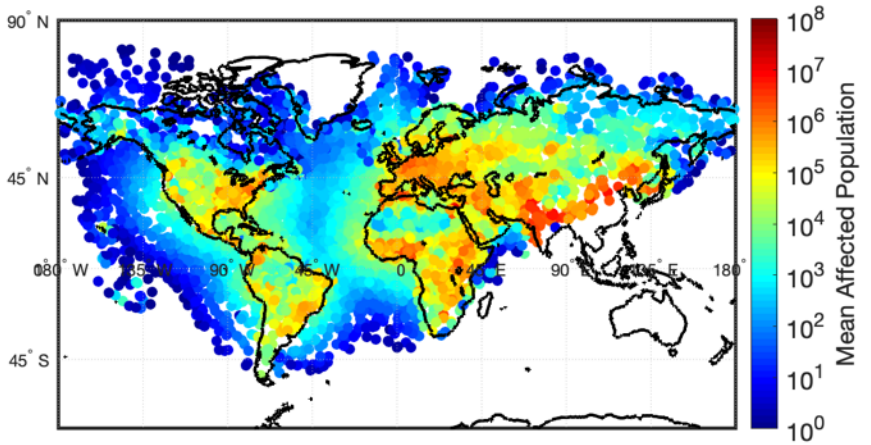


Impact Risk Summary

Characterization Summary & Updates

- Assessment date: 26 April 2021 (initial discovery)
- Potential impact date: 20 October 2021 (6 mo.)
- Earth impact probability: 5%
- Diameter: 35–700 m, ~150 m average
- Energy: 1 Mt – 13 Gt, 256 Mt average
- Properties: unknown type or physical properties

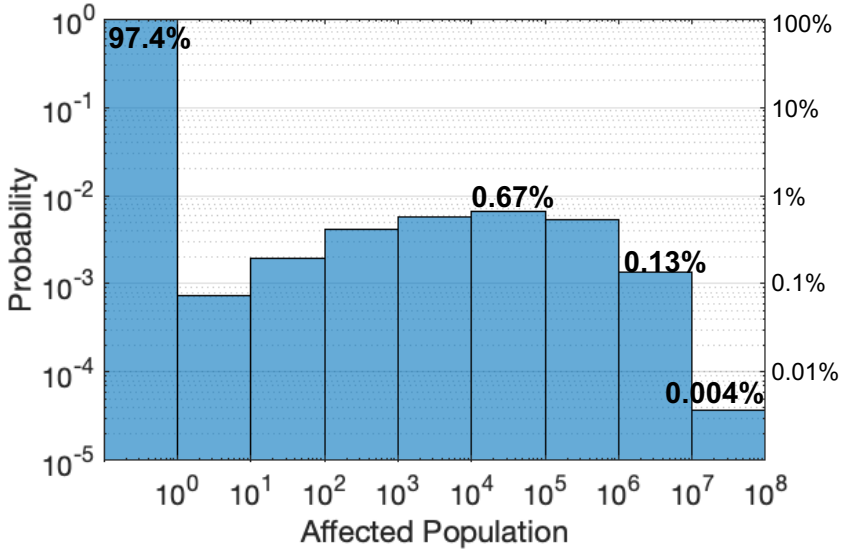
Impact Damage Map



Hazard Summary

- Potential damage sizes, severities, and locations remain very uncertain
- Primary hazard: airburst/impact causing blast overpressure, from minor structural damage to potentially unsurvivable levels
- Damage radii: 0–470 km, ~90 km average
- Affected Population: 0–86M, 6k average
- 97% chance of no damage, with small chances of affecting thousands to millions of people

Affected Population Risks

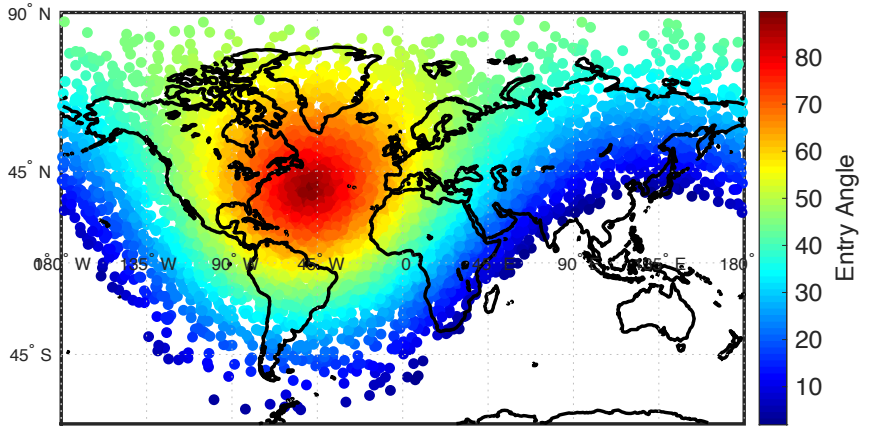


Entry Parameters & Locations

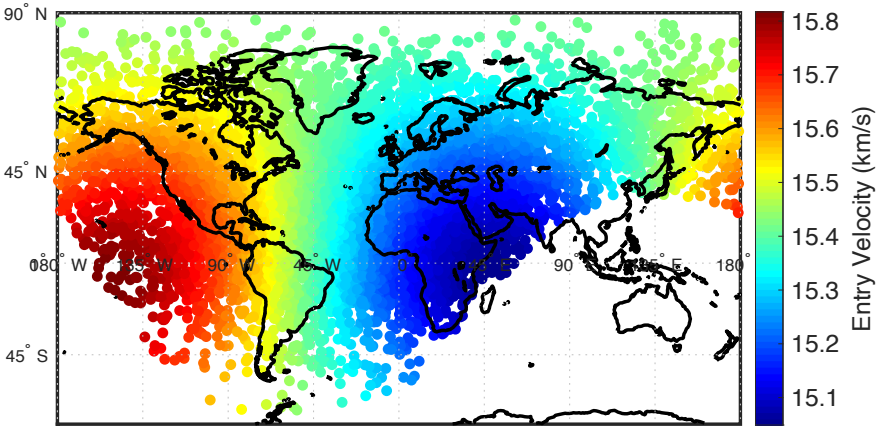
5% chance of Earth impact with potential impact regions spanning most of the globe, centered around mid-Atlantic

- Entry parameters vary across the globe, but are well-known for given impact points
- **Entry Angle:**
  - Vertical (90°) entries near mid-Atlantic
  - Shallow/skimming entries near edges
- **Entry Velocity:**
  - 15-16 km/s
  - Little variation across points
- Velocity determines impactor energy and entry angle affects burst altitude ranges for damage models

Entry Angle (from horizontal)



Entry Velocity



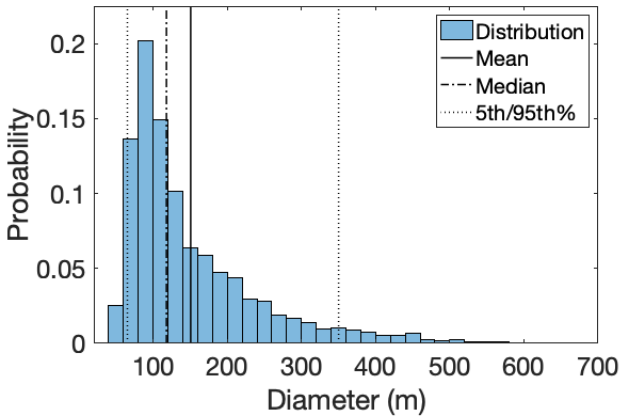
[Impact entry data: P. Chodas, CNEOS/JPL]
https://cneos.jpl.nasa.gov/pd/cs/pdc21/

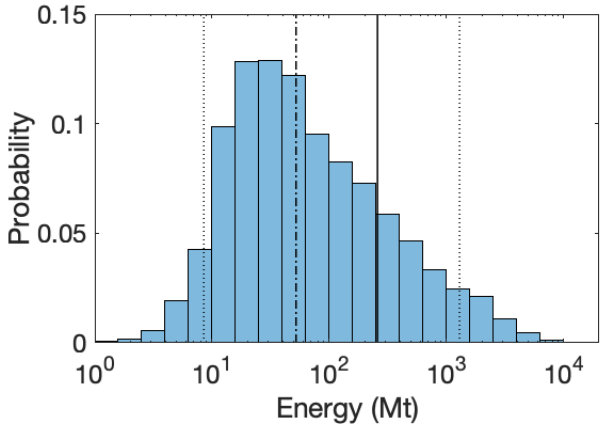
Asteroid Properties

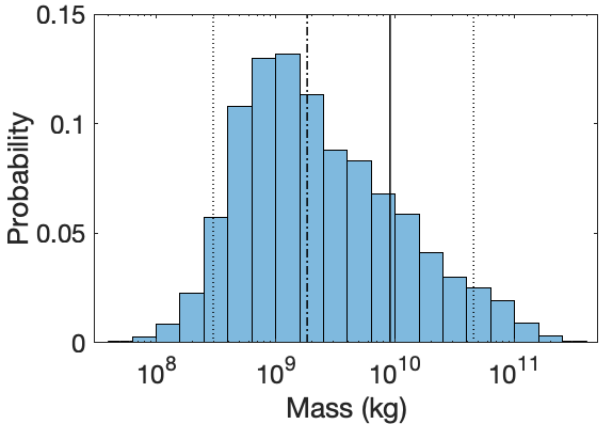
- **Asteroid sizes and properties are highly uncertain**, ranging from small objects that would pose little threat to objects hundreds of meters across with gigatons of impact energy
  - **Maximum sizes are very large, but also very unlikely**
  - Averages are ~150 m, 250 Mt
  - Likelier size ranges are smaller
  - Type and properties are unknown, ranging from more common stony types to rare iron types

Asteroid Size Ranges

	Diameter (m)	Energy (Mt)	Mass (kg)
Full range	35–700	1–13,000	4.4e7–4.4e11
Average	150	250	9.1e9
Median	118	52	1.8e9
Most likely	~65–125	~20–50	~1e9
5th–95th %	65–350	~8–1280	3e8–4.5e10







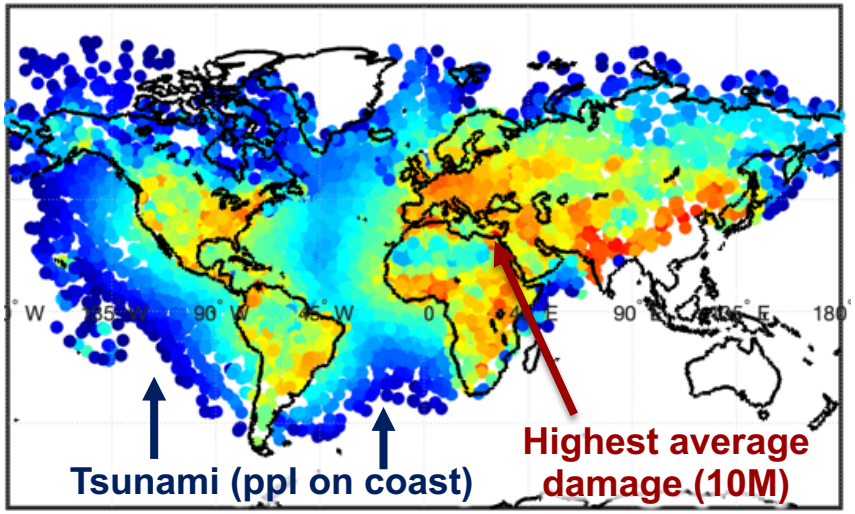
[Property inference model: J. Dotson PDC 2021]

Affected Population Ranges Across Globe
(among 5% Earth-impacting cases)

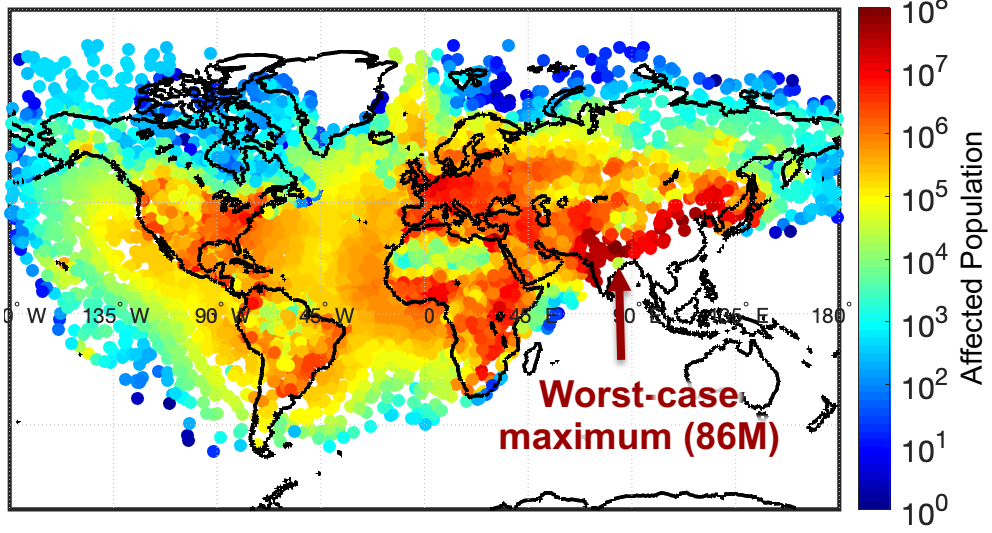
Affected population ranges from 0 to tens of millions across the globe, depending on population density and damage ranges

- Average affected population range: 0–10M across entry points (117k overall avg.)
- Max affected population range: 0–86M across entry points (1M avg. max among all points)
- Worst case maximum is at very edge of potential impact zone (unlikely skimming entry)

Average Affected Population



Max Affected Population

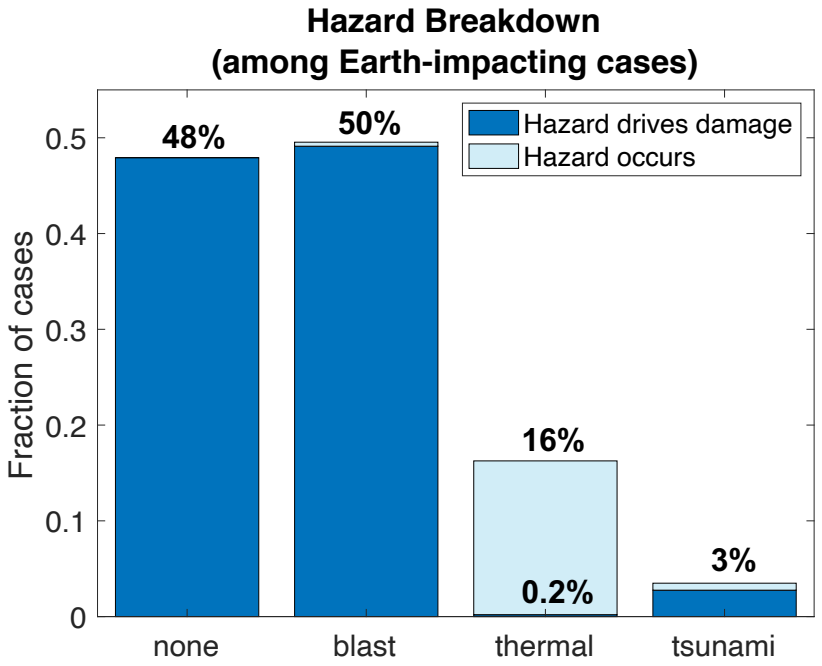


Maps of average and maximum affected population for each sampled impact entry point, given the potential range in asteroid properties and resulting damage
(ocean points represent tsunami damage to surrounding coastal regions)

Hazard Sources

(relative hazard risks among 5% Earth-impacting cases)

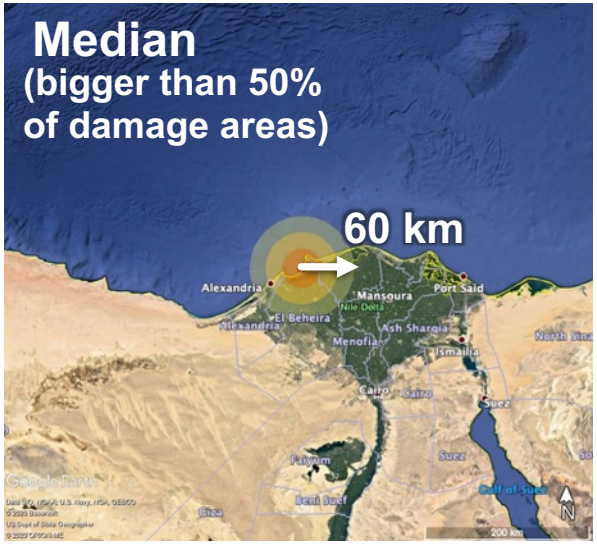
- Blast damage is the predominant hazard source in ~50% of impact cases
- Thermal damage also occurs in ~16% of cases, but is smaller and less severe than blast damage in nearly all cases
- Risk of tsunami is low, occurring in ~3% of impact cases, but the largest impacts could cause significant inundation
- No global effects are expected, but potential for regional environmental effects from larger impacts is unknown
- No damage occurs in 48% of cases

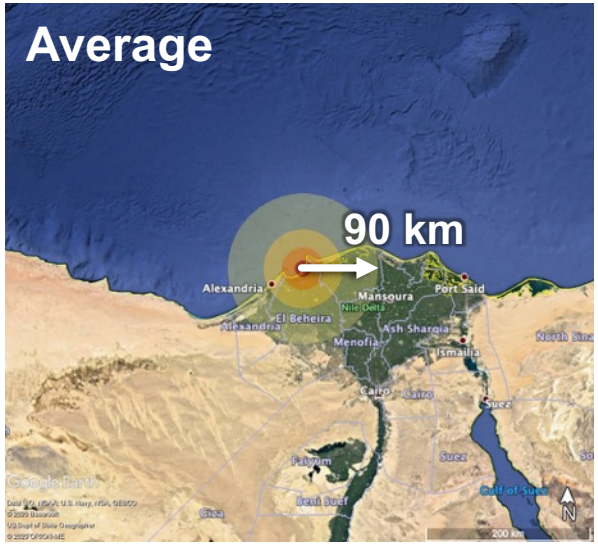


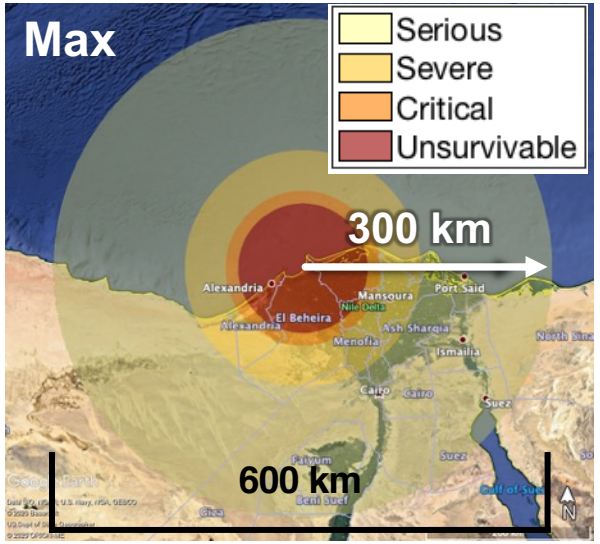
Hazard Source	% Cases Hazard Occurs	% Cases Hazard Drives Damage	Average Affected Population	Affected Population Range
Blast	50%	49%	117,000	0–86M
Thermal	16%	0.2%	8,000	0–48M
Tsunami	3.5%	2.8%	940	0–1.8M
No Damage	48%	48%	0	0

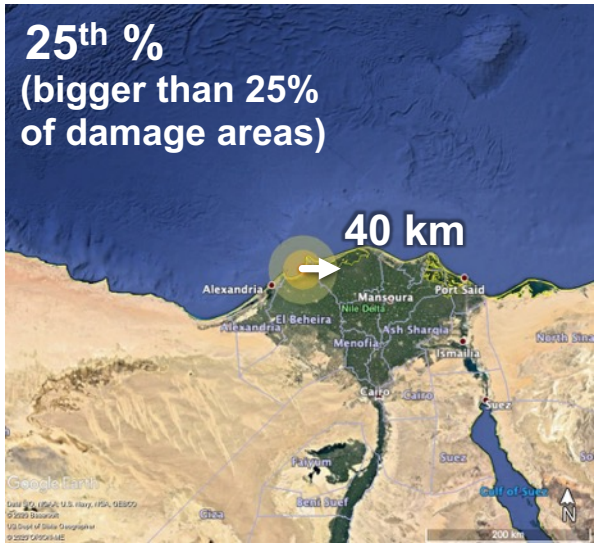
Sample Blast Damage Sizes

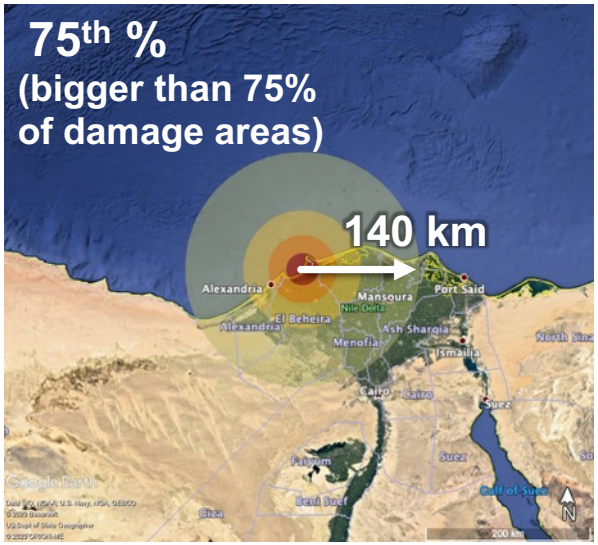
(regional sizes for an entry point near Alexandria, Egypt)

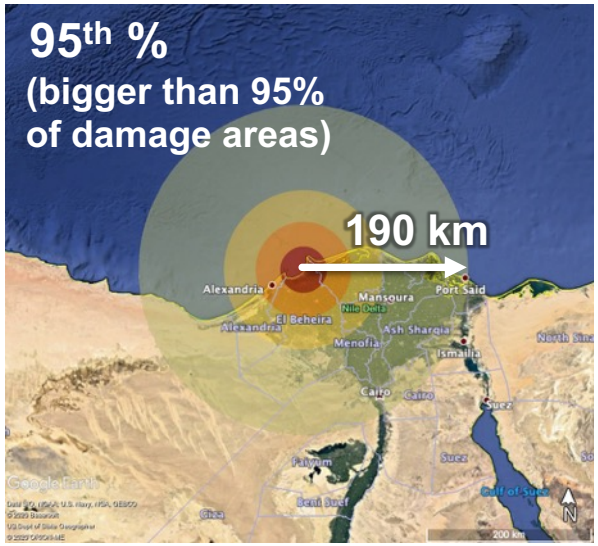






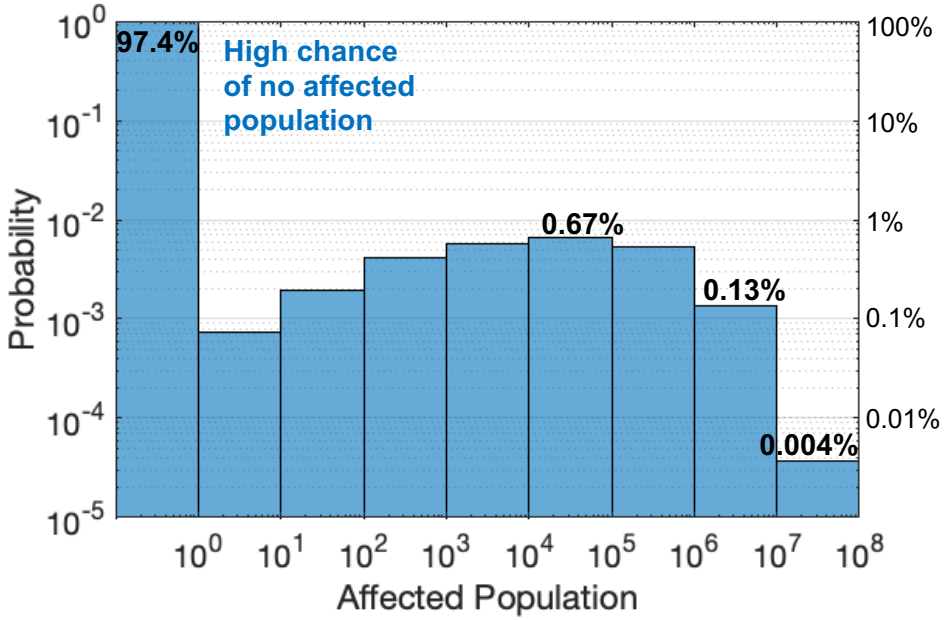




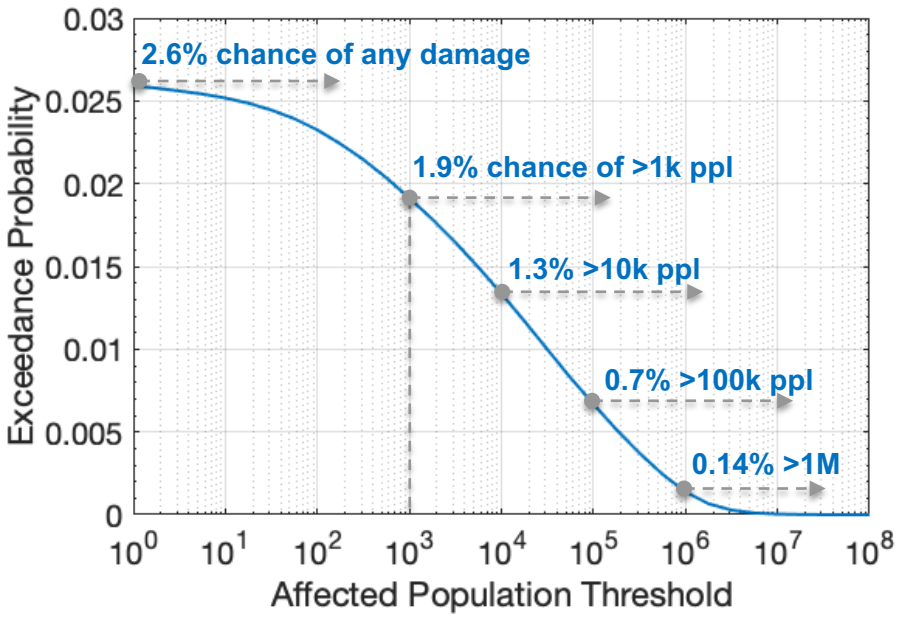


Total Affected Population Risks
(Total Risk with 5% Earth Impact Probability)

Population risk histogram:
Probabilities of affecting the number of people within each range



Population exceedance risk:
Probability of *at least* the number of people *or more* being affected



- **Average affected population:** ~6k total (with 5% impact probability), ~117k among Earth-impacting cases (~50% of which cause some population damage)
- **No damage most likely:** >97% chance of no people affected (with 5% impact probability)
- **Maximum affected population:** 86 million people (but very unlikely)
- Only 0.14% total chance of affecting over 1M people, 0.004% chance of >10M people

Impact Risk Summary

- Object size, potential impact location, and resulting damage all remain highly uncertain
  - Earth impact probability is still low (5%)
  - Maximum impactor sizes and damage consequences are very large, but also very unlikely
- Affected Population Risks:
  - Range 0–86M people, average total population risk of 6,000 people
  - No population damage is most likely (97% total chance, 48% chance among impacting cases).
  - ~2% chance of affecting >1000 people, 1.3% chance of >10,000 people, 0.14% of >1 million people
- Hazard Summary:
  - Blast damage is the predominant hazard source, with potential ground damage radii up to several hundred kilometers
  - Thermal and tsunami damage are also possible, but less likely and less severe
  - No large-scale global effects expected, but potential for regional environmental or economic effects remains unknown.

	Asteroid Diameter (m)	Impact Energy (Mt)	Damage Radius (km) (given impact)	Affected Population (given impact)	Affected Population (5% impact)
Full range	~35–700	~1–13,000	0–470	0–86M	0–86M
Average	150	250	90	117k	6k
Most likely	~65–125	~20–50	~20–60	0	0
5^{th}–95^{th} %	65–350	8–1280	25–190	0–550k	0–0

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Risk Assessment Next Steps

- Continuing Threat Assessment:
  - Updated risk assessments will be performed as additional information is gained about the object and potential impact
  - More detailed risk analysis and damage simulations can be performed for critical hazards as impact location and object size are refined
- Risk Information for Decisions and Response Support:
  - Probabilistic risks enable response decisions to consider both the severity and relative likelihood of potential impact consequences, given large uncertainties
  - Asteroid property distributions will be provided to mission designers to inform mitigation capability requirements
  - Risk assessments can be performed to evaluate the benefit of proposed mitigation or reconnaissance mission options
  - Damage area probabilities can support preliminary disaster response planning to prepare for potentially large damage within short warning time

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REFERENCES

Related PDC 2021 Presentations

Asteroid Property Inference

- **Dotson** et al., "Bayesian Inference of Asteroid Physical Properties: Application to Impact Scenarios" (Impact Effects Session 9b)
- **Kelley** et al., "IAWN Planetary Defense Exercise: Apophis Observing Campaign 2020-2021" (Apophis Session 13)

Impact Effects – Hazard Modeling & Simulation

- **Aftosmis** et al., "High-Fidelity Blast Modeling of Impact from Hypothetical Asteroid 2021 PDC," (Impact Effects e-lighting talks)
- **Wheeler** et al., "Probabilistic Blast Damage Modeling Uncertainties and Sensitivities" (Impact Effects e-lighting talks)
- **Mathias** et al., "Interaction of Meteoroid Fragments During Atmospheric Entry" (Impact Effects e-lighting talks)
- **Coates** et al., "Comparison of Thermal Radiation Damage Models and Parameters for Impact Risk Assessment" (Impact Effects e-lighting talks)
- **Berger** and LeVeque, "Towards Adaptive Simulation of Dispersive Tsunami Propagation from an Asteroid Impact" (Impact Effects Session 9b)
- **Titus** et al., "Asteroid Impacts – Downwind and Downstream Effects" (Impact Effects Session 9b)
- **Boslough**, "Airburst Consequence Modeling Using Artificial Ablation" (Impact Effects e-lighting talks)

Mitigation & Mission Design

- **Barbee** et al., "Risk-Informed Spacecraft Mission Design for the 2021 PDC Hypothetical Asteroid Impact Scenario" (Mission & Campaign Design Session 8b)

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- Register et al., 2020. Interactions between asteroid fragments during atmospheric entry. Icarus 337, 113468. https://doi.org/10.1016/j.icarus.2019.113468

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- Aftosmis, et al., 2019. Simulation-based height of burst map for asteroid airburst damage prediction. Acta Astronautica 156, 278-283. https://doi.org/10.1016/j.actaastro.2017.12.021
- Robertson & Mathias, 2019. Hydrocode simulations of asteroid airbursts and constraints for Tunguska. Icarus 327, 36–47. https://doi.org/10.1016/j.icarus.2018.10.017
- Aftosmis, et al., 2016. Numerical simulation of bolide entry with ground footprint prediction. 54th AIAA Aerospace Sciences Meeting. https://doi.org/10.2514/6.2016-0998

Tsunami Simulations

- Robertson & Gisler, 2019. Near and far-field hazards of asteroid impacts in oceans. Acta Astronautica 156, 262–277. https://doi.org/10.1016/j.actaastro.2018.09.018
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