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Evacuation and Shelter Plans for Asteroid Impacts

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2013, Moore, Oklahoma, EF5 tornado aftermath. Credit: G. Armstrong, FEMA

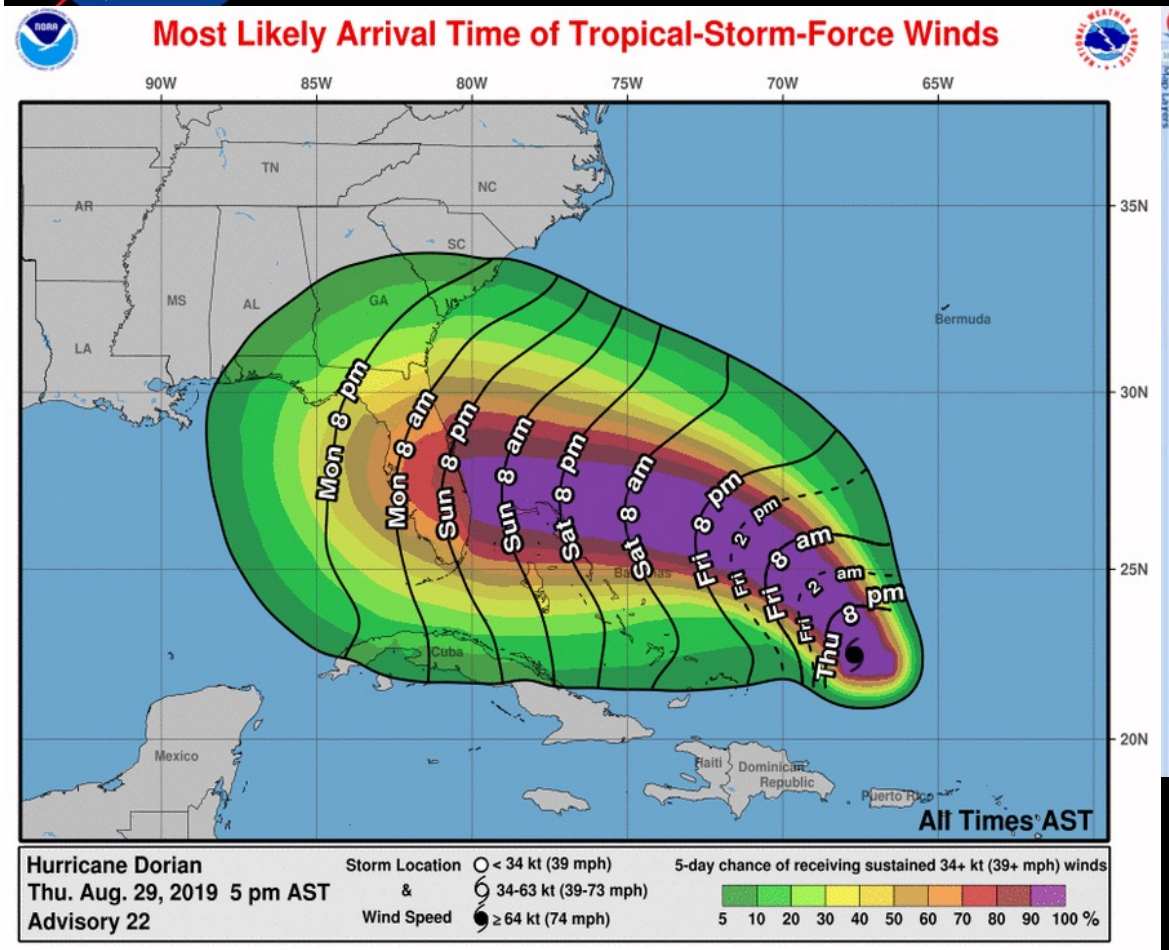
Lessons from Analogs

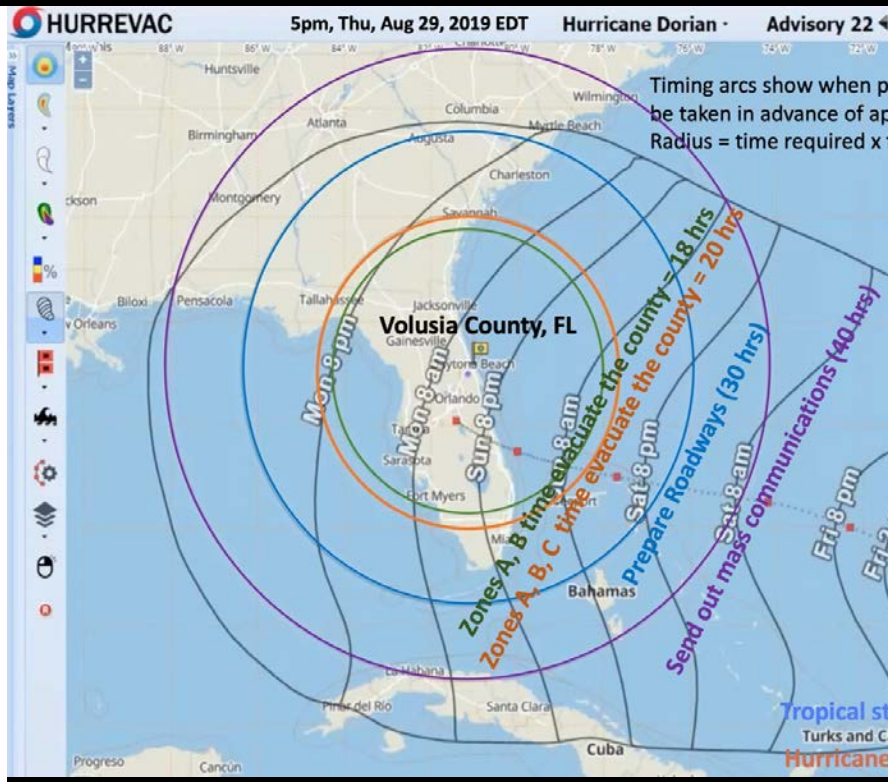
- Hurricanes
  - Forecasting in time to take action
  - Large scale evacuations
  - Risk tolerance
- Nuclear Explosions
  - Effects of large blast waves
  - Shelters
  - Fatality rates

Application to Asteroid Impacts

- PDC 2021: small, little warning, poorly constrained
- PDC 2023: large, well characterized

Hurricane Forecasting & Planning

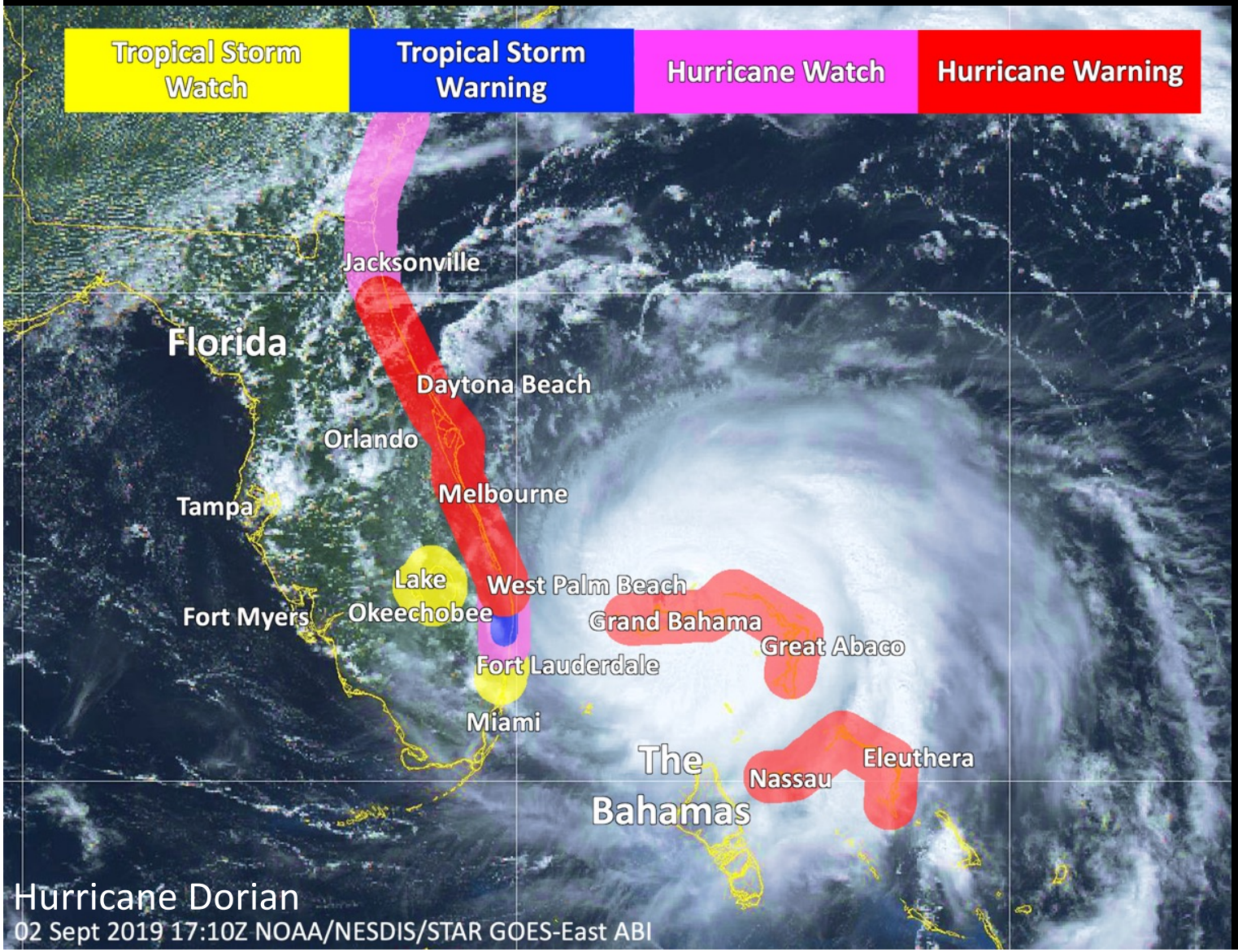




- Forecasters run 1000 simulations every day to predict track and strength.
- Create maps of probability of wind strength exceeding tropical storm force
- Notoriously unpredictable: Average error 100 miles for 24 hour forecast

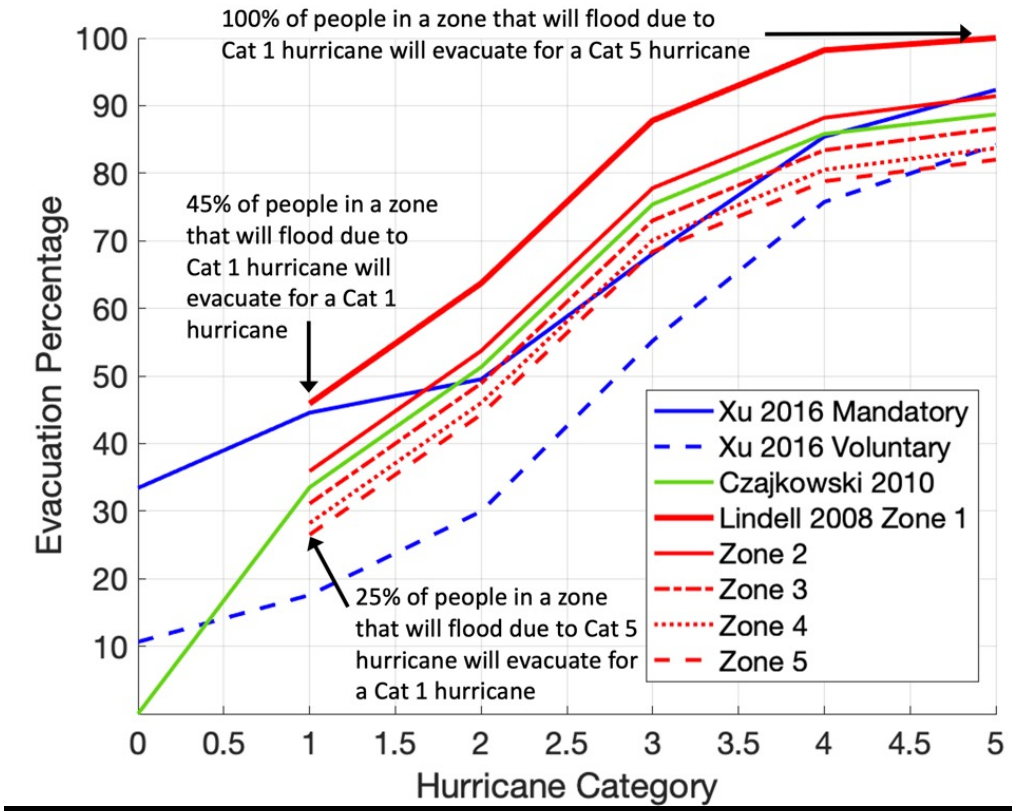
- For each county overlay timing arcs for when to take action
- Update as forecasts change
- Watches and warnings issued ~40 hours before landfall
- Roadways cleared 30 hours ahead
- Evacuation order based on time to clear area of evacuees before hurricane arrives

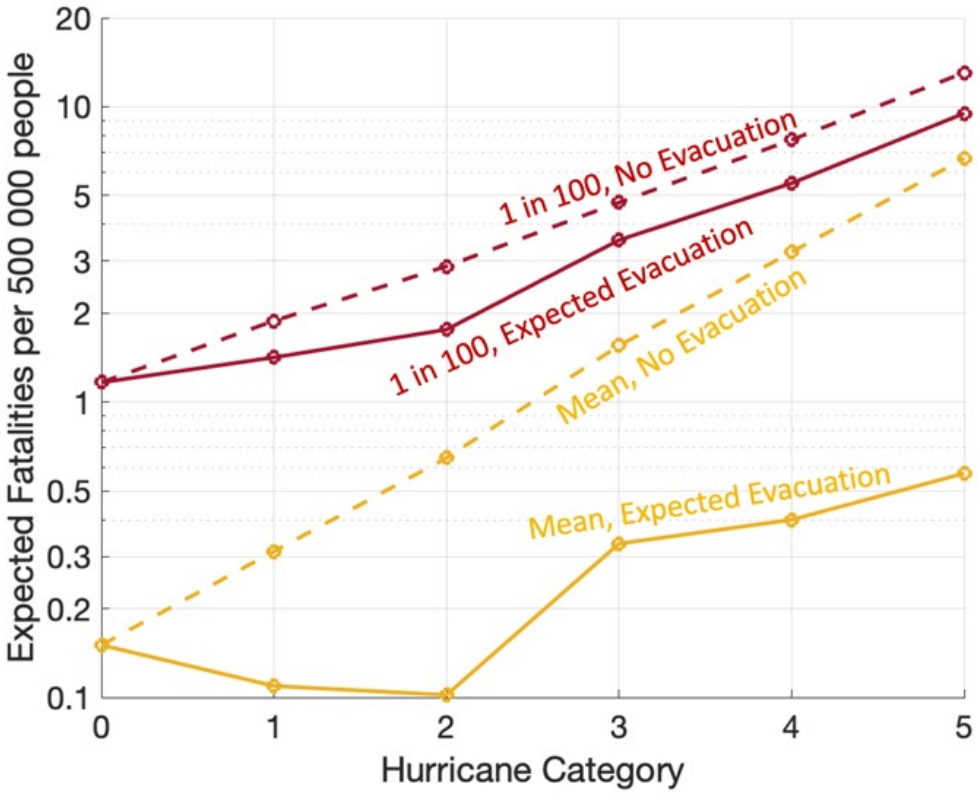
Hurricane Warnings



- Public message focuses on what to do.
- Warning = storm force winds *expected*
- Watch = storm winds *possible*
- Action = prepare to evacuate
- Followed by evacuation order
- Building codes mean most houses can withstand most winds expected over 50 year period.
- Typically only need to evacuate 10 – 20 miles inland to a building designed to withstand high winds.

Hurricane Evacuation





- Almost everyone evacuates Cat 5 storm as most houses not built to withstand it.
- Almost no-one evacuates tropical storm
- Most people self-evacuate
- Help given to those who need it
- No-one enforces evacuation orders

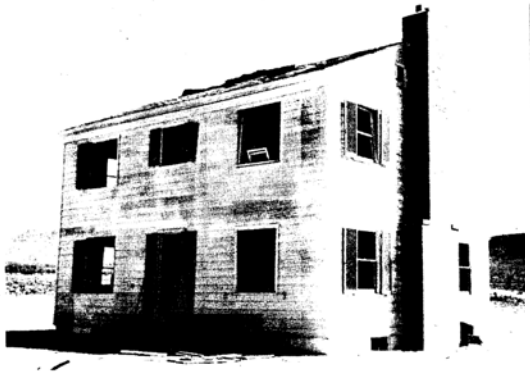
- Fatalities follow a zero-inflated Poisson distribution
- People evacuate to a fatality rate of about 1 in a million of the pre-evacuation population regardless of storm strength

Nuclear Blasts vs Buildings

5 psi vs Wood frame house.
House levelled but limited breakthrough to basement.
Reasonable survival chance in basement.

5 psi vs Brick house.
House levelled and partially collapsed into basement.

27 psi vs Reinforced concrete building.
Partially collapsed. Gutted by fire.

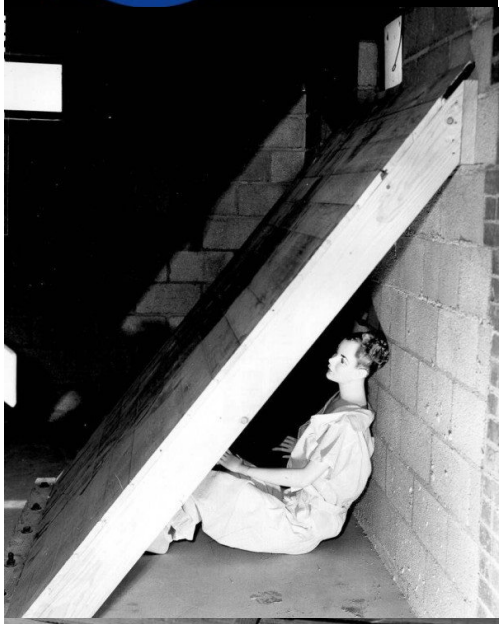


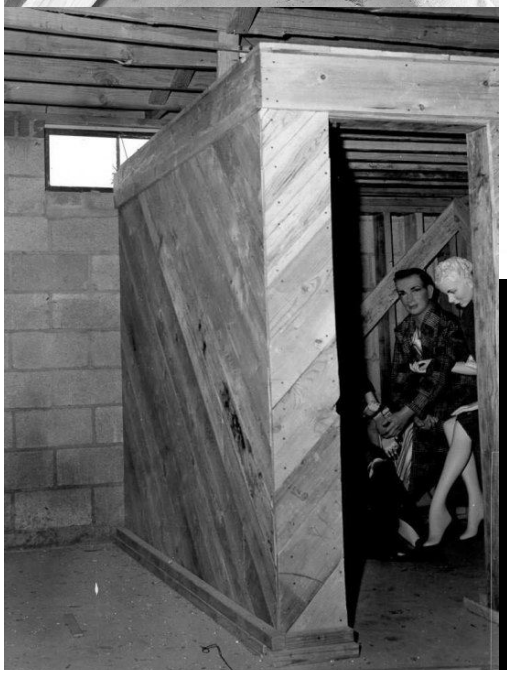
1.7 psi vs Wood frame house.
Badly damaged but still standing.
Flying debris likely fatal, but basement safe.

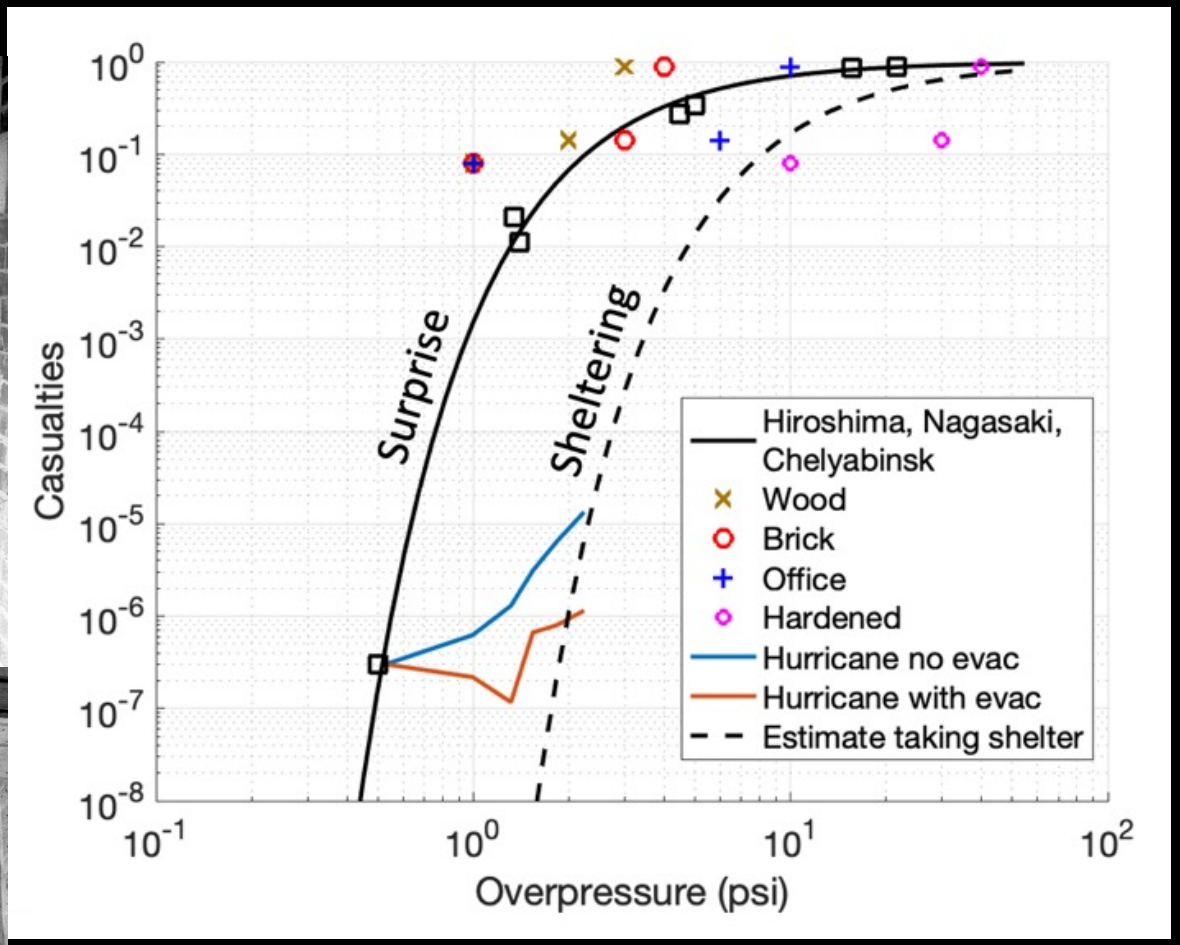
1.7 psi vs Brick house.
Badly damaged but still standing.
Flying debris likely fatal, but basement safe.

17 psi vs Steel + Reinforced concrete building.
First story collapsed dropping second story to ground.

Risks from Blast Waves

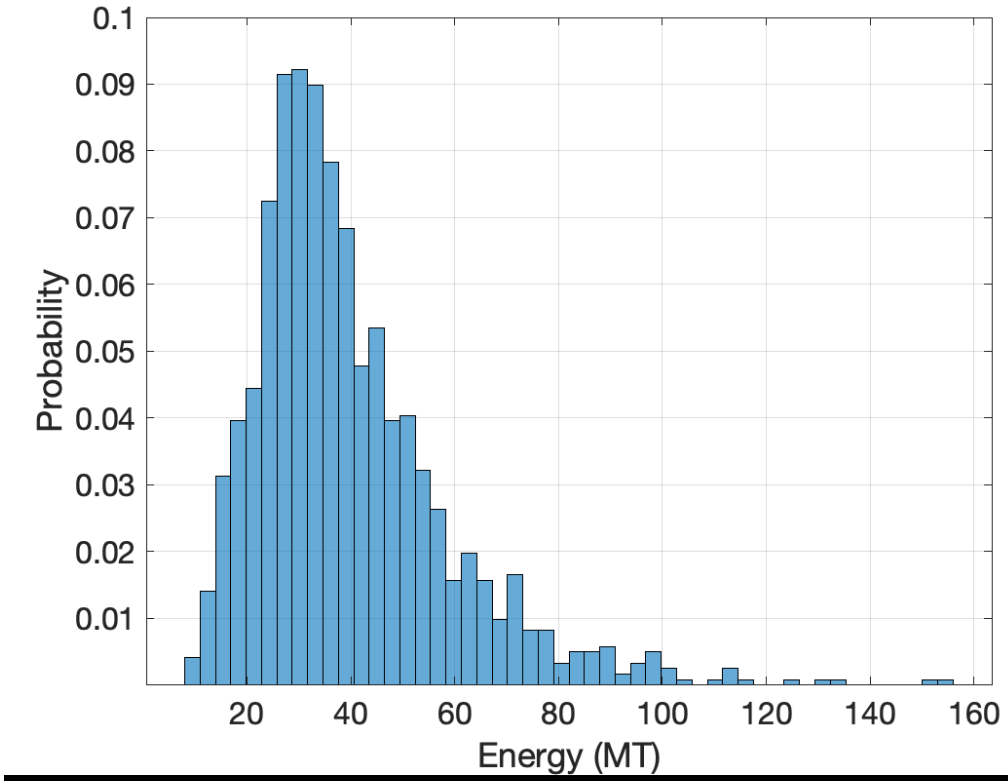


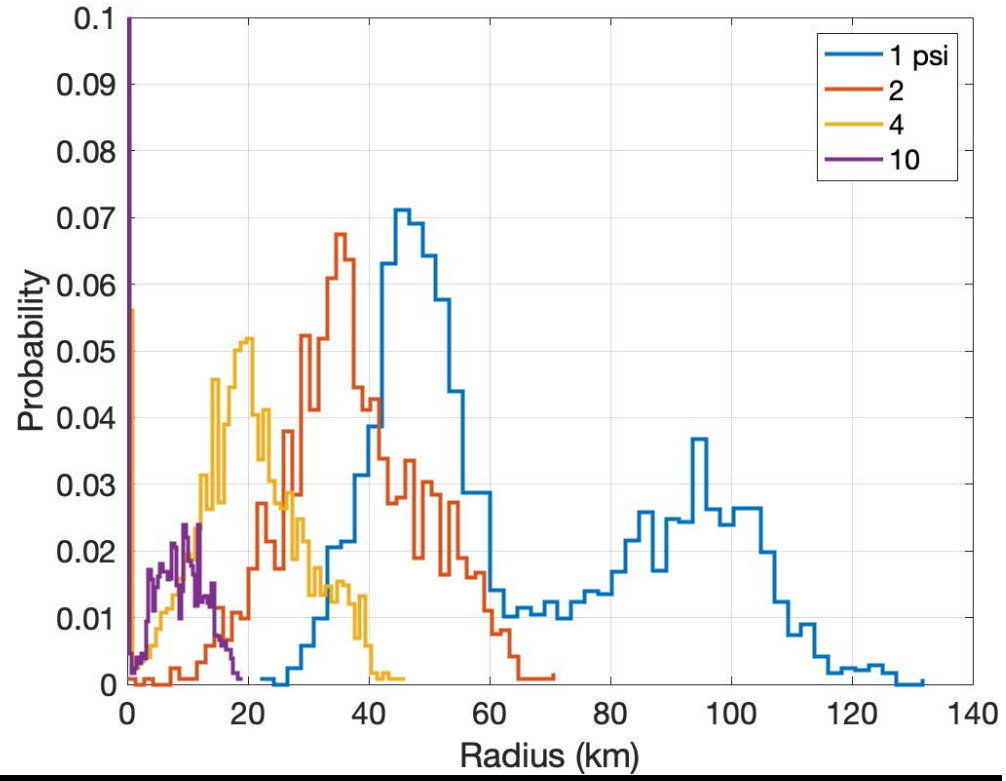




- In 1950's US tested many structures against nuclear blasts including a variety of shelters (e.g. improvised basement shelters and underground concrete bunkers).
- Outdoors especially hazardous due to flying debris
- By analogy to hurricanes estimate casualty rate when people find appropriate shelter

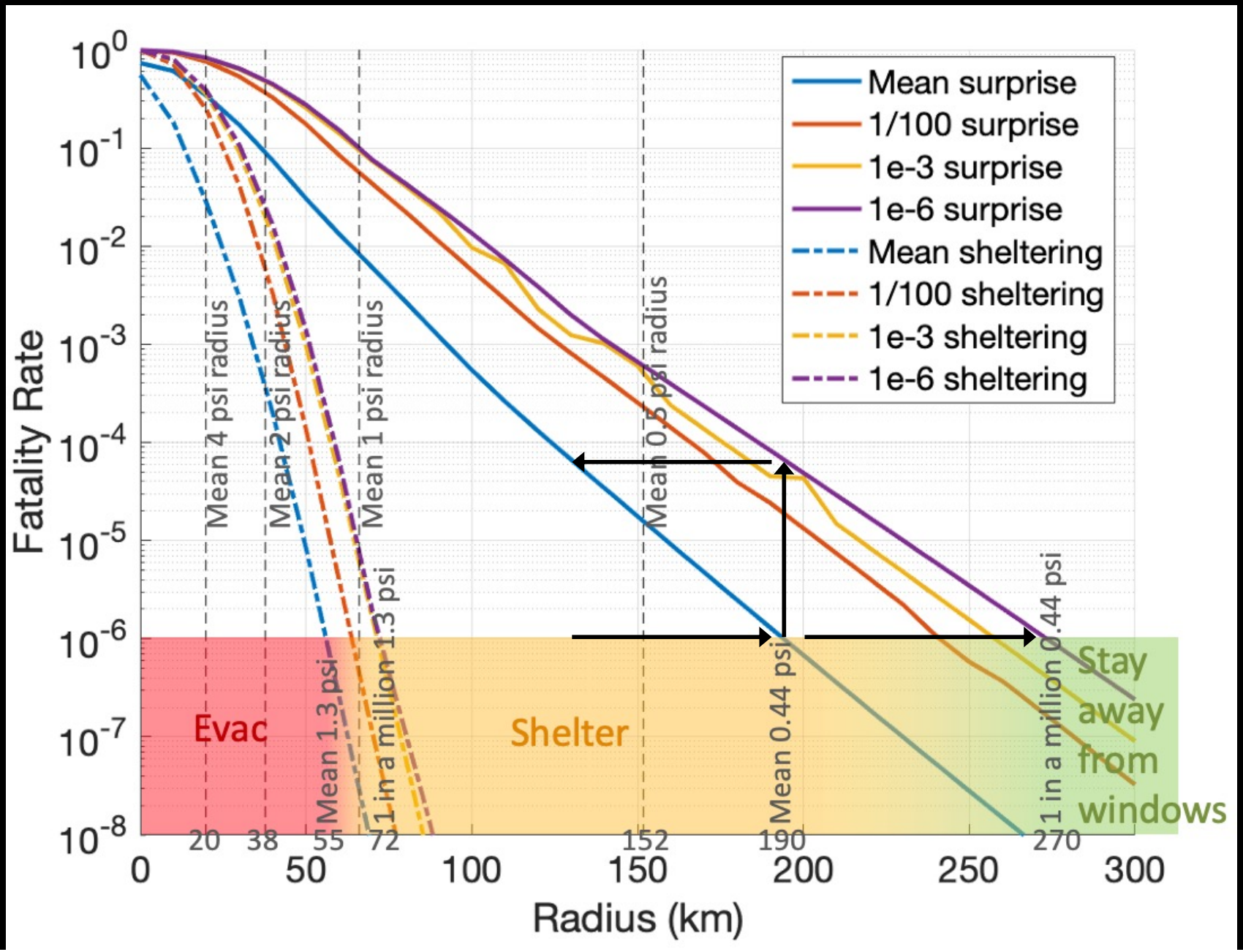
2021 PDC Exercise



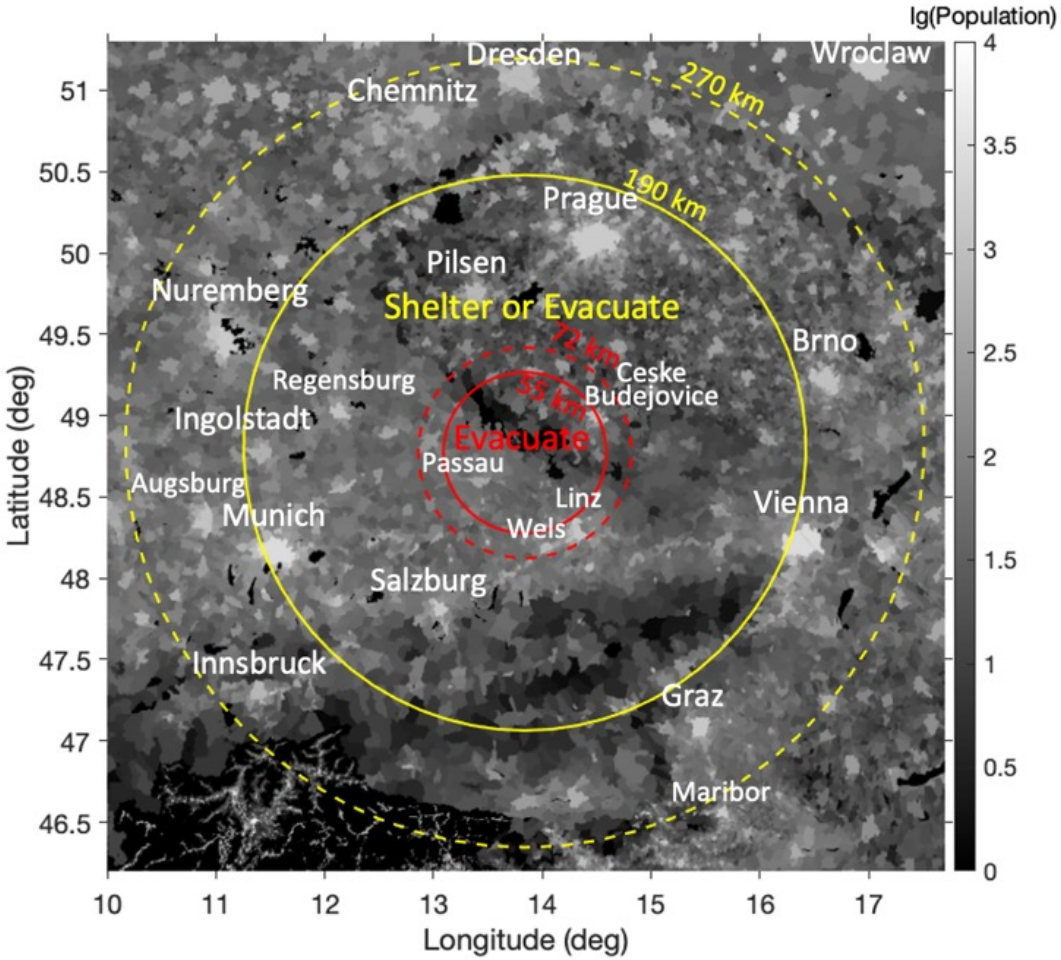


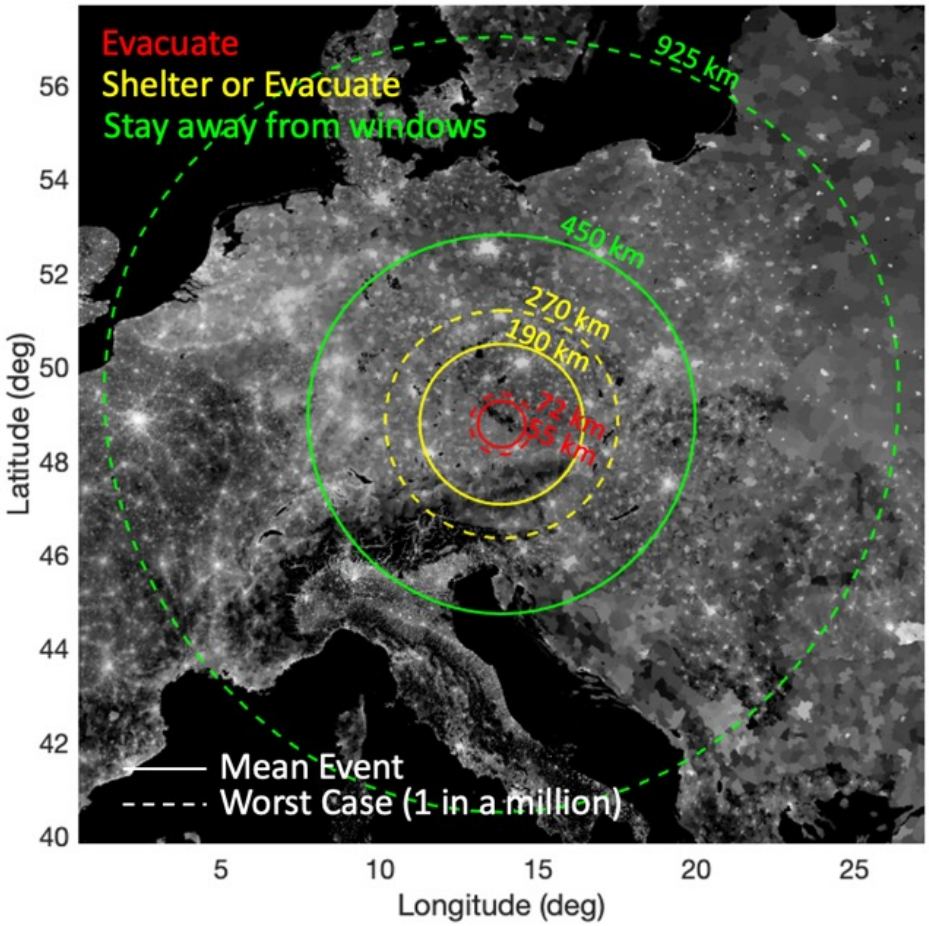
- Relatively small asteroid impacts forested area near border of Austria, Germany, Czechia
- 1 week before impact, radar refines size estimate to Ø105±11m
- Most likely energy ~35 Mt, but 1 in 1000 chance of exceeding 100 Mt
- Significant probability of 1 psi blast overpressure out to 130 km radius

2021 PDC Fatality Rate



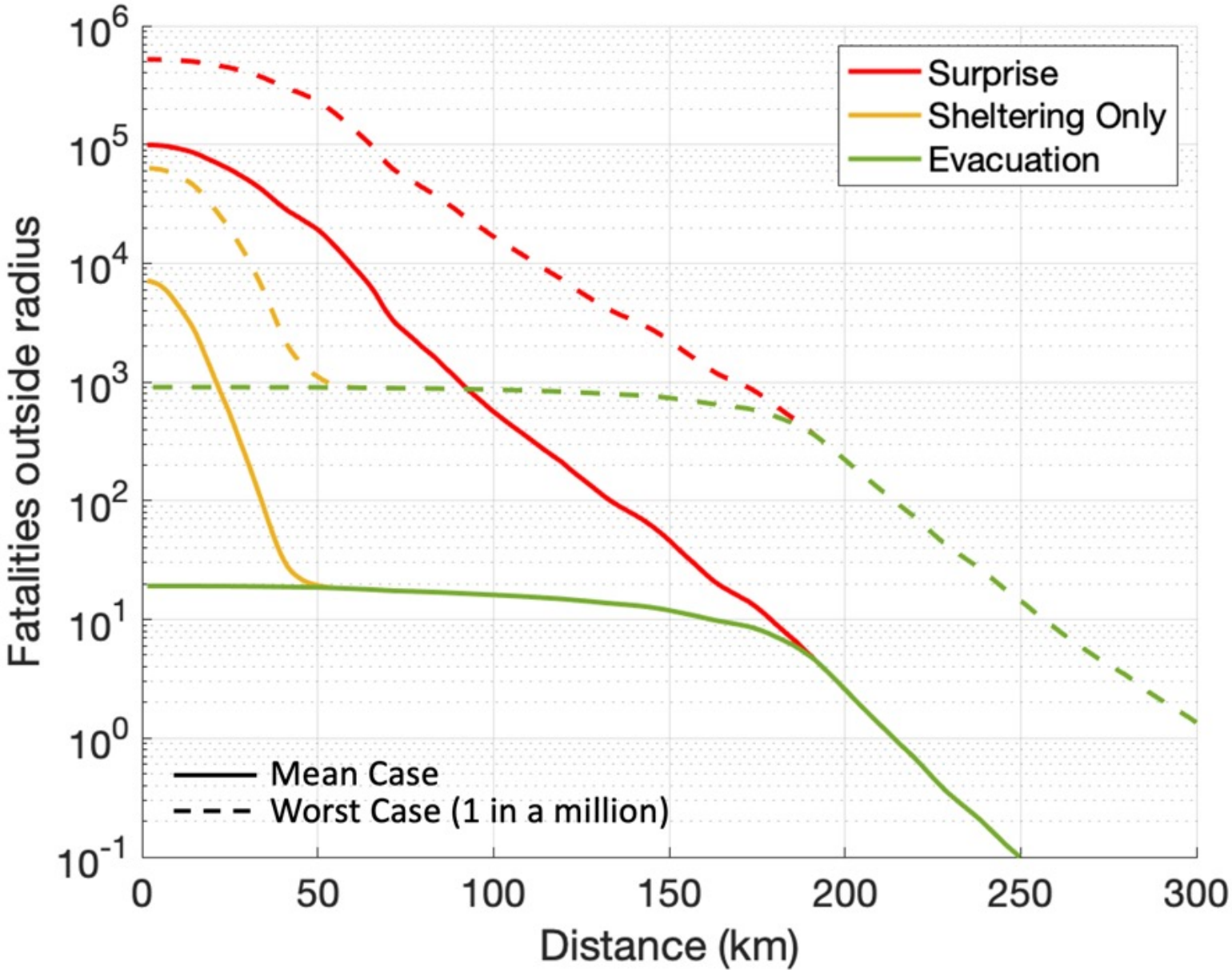
2021 PDC Evacuation





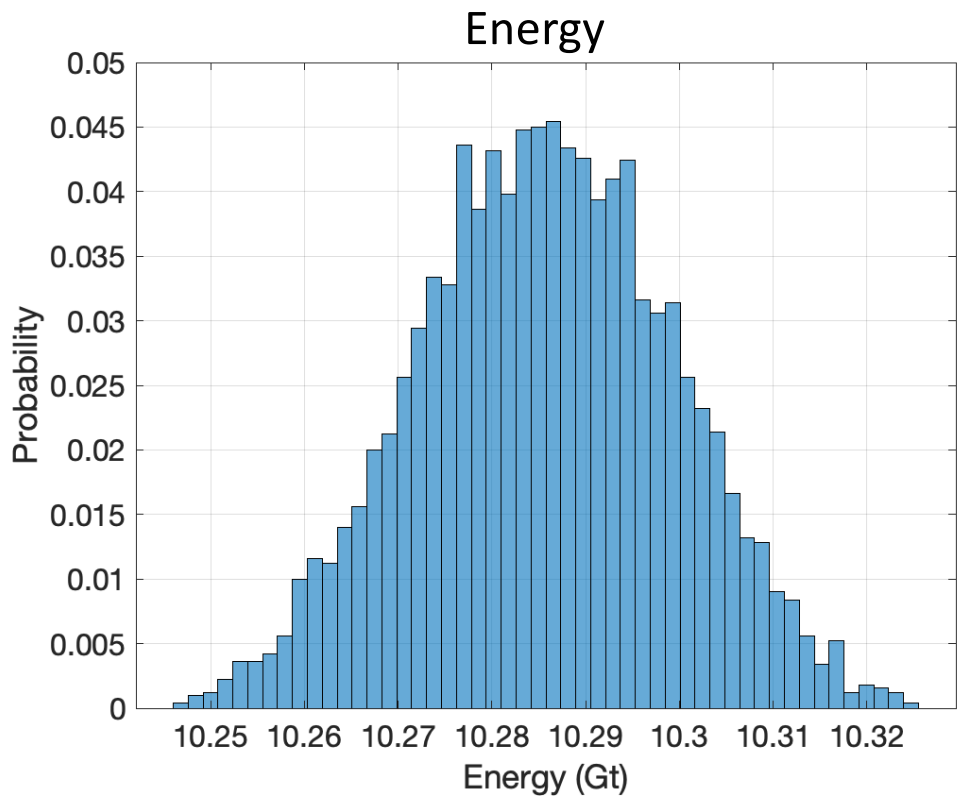
- To meet 1 in a million fatality rate everyone within 55 km needs to evacuate = 770 000 people
- Everyone within 190 km needs to either evacuate or find an appropriate shelter or build one = 14.4 million people
- Out to 450 – 925 km many windows still breaking

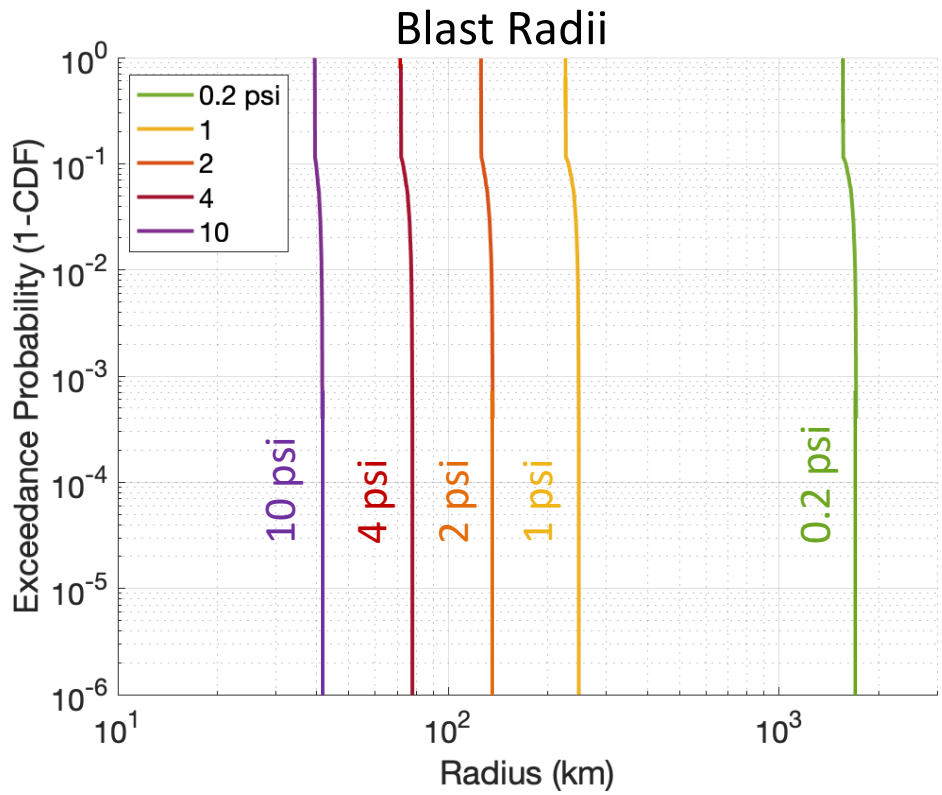
2021 PDC Fatalities



- If impact occurred without warning expected casualties 100 000. Worst case 500 000.
- Short warning time for sheltering but no evacuation, expected casualties 7000, worst case 60 000
- Sufficient time for evacuation, expected 17, worst case 900.

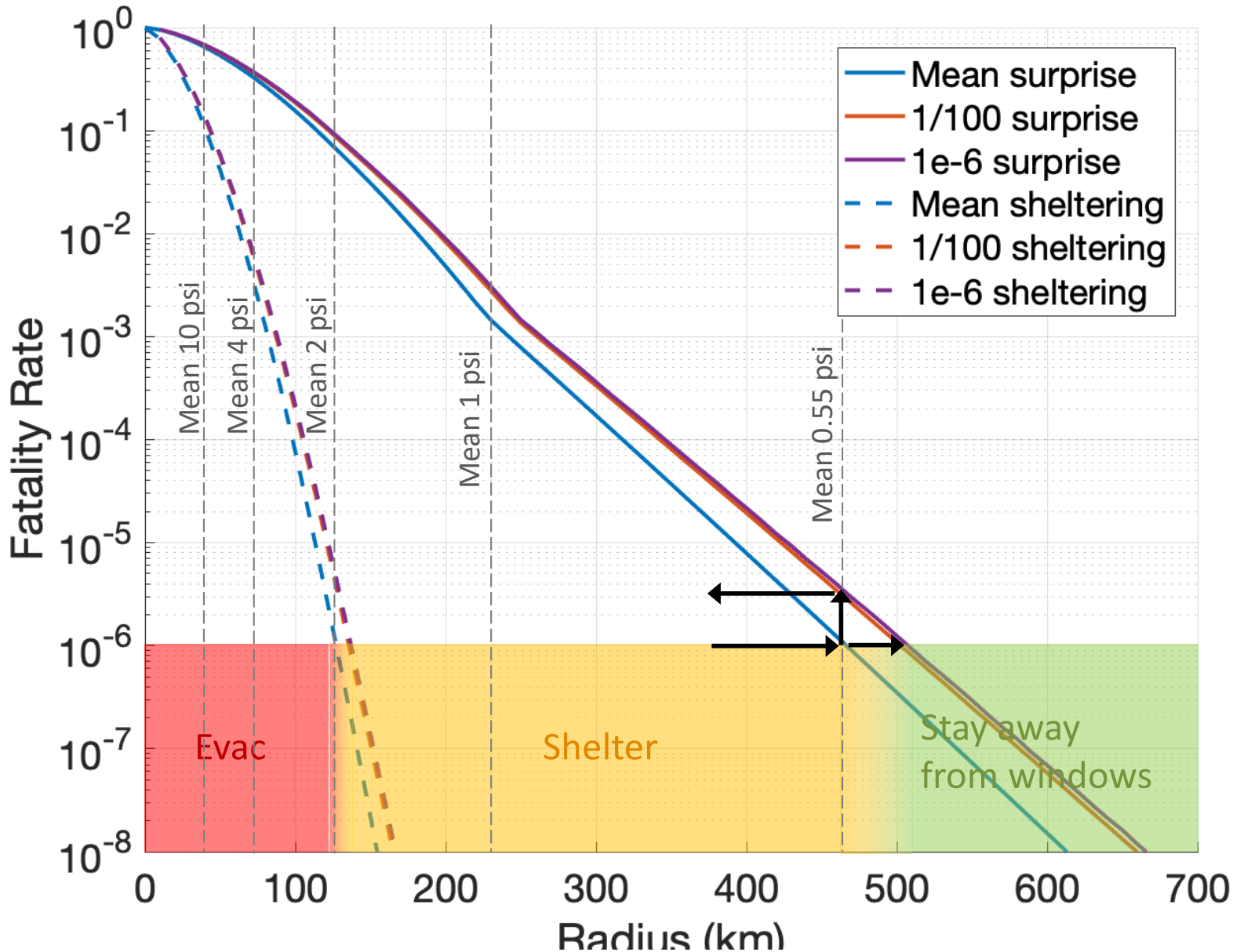
2023 PDC Scenario



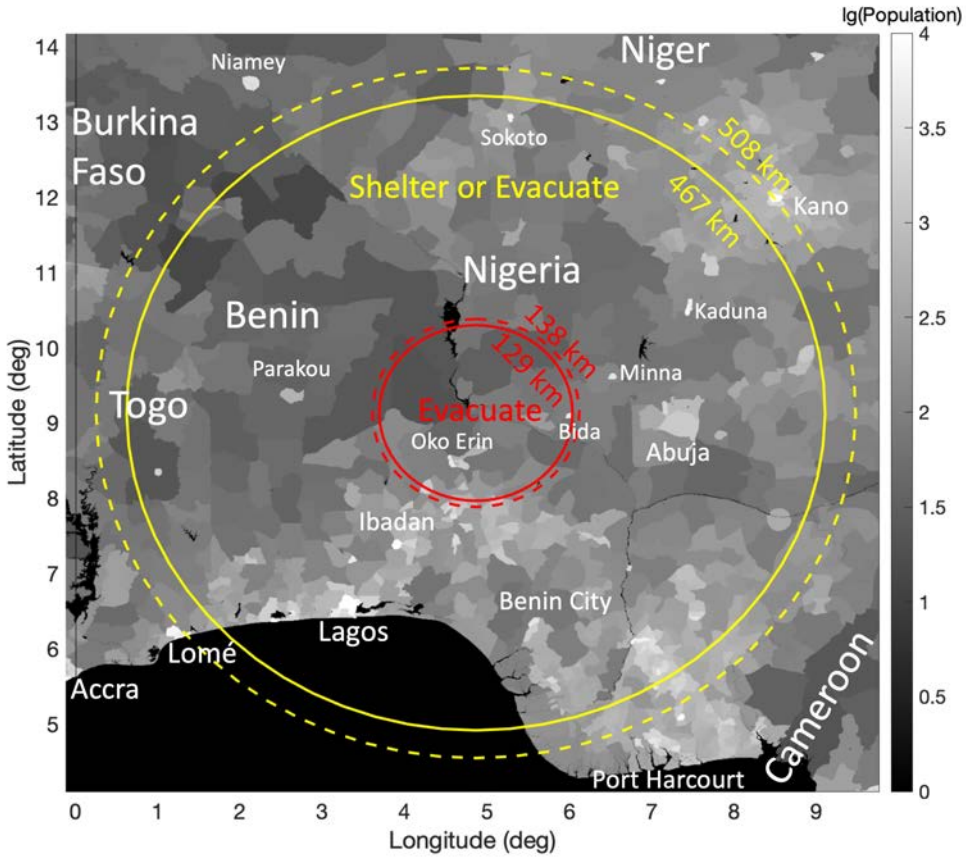


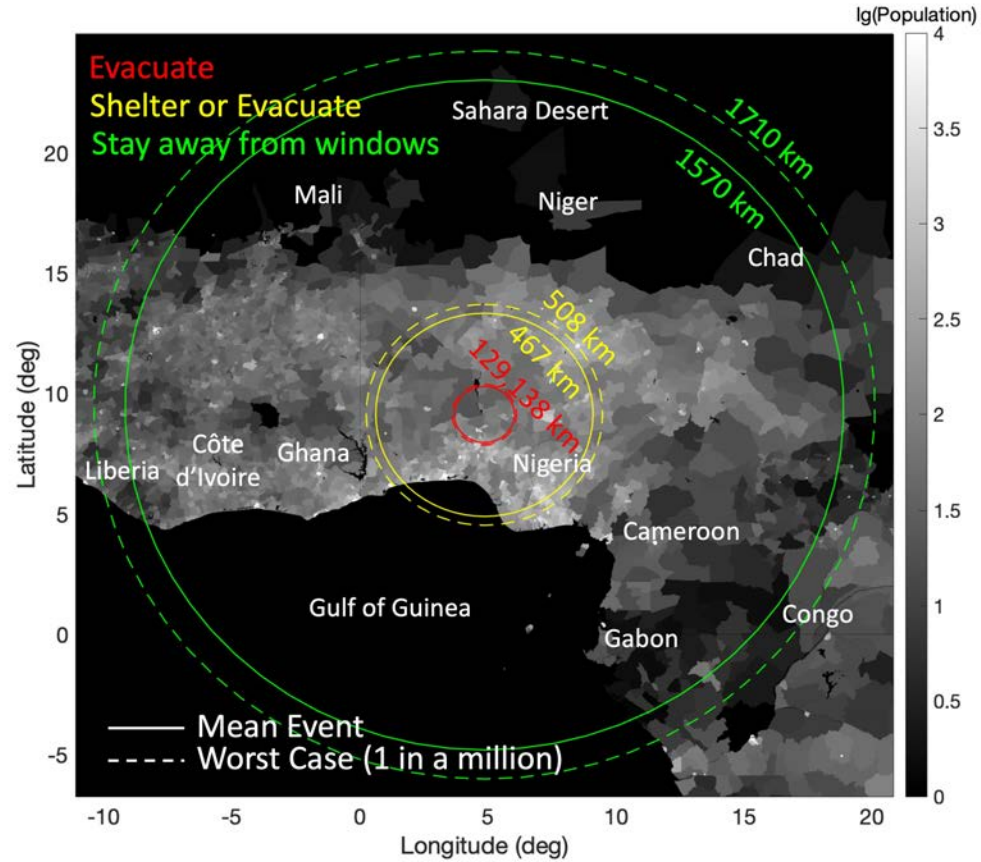
- Relatively large asteroid impacts Niger River, 333 km NNE from Lagos, Nigeria
- Rendezvous mission precisely determines size, mass, energy Ø800±0.5m, 10.29±0.02 Gt
- Hits the ground regardless of material properties
- Thermal radiation damage not modelled here but exceeds blast damage in 17% of cases at "severe" level (2 psi, 3rd deg. burns), 2.5% of cases at "serious" level (1 psi, 2nd deg. burns).
- Predicted blast radii very precise. Model uncertainty (not accounted for here) greater than uncertainty in the asteroid.

2023 PDC Fatality Rate



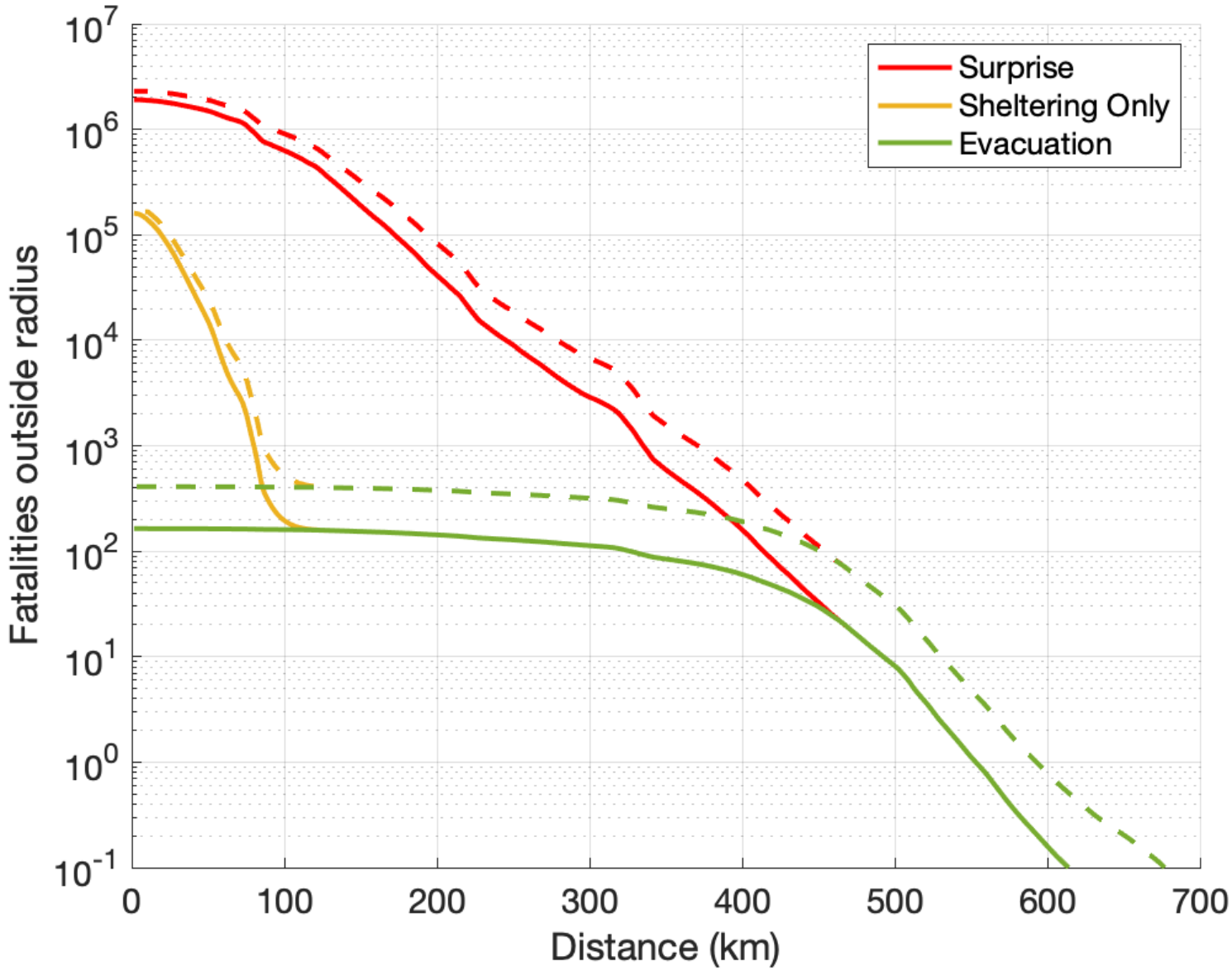
2023 PDC Evacuation





- To meet 1 in a million fatality rate everyone within 130 km needs to evacuate = 7 million people
- Everyone within 470 km needs to either evacuate or find an appropriate shelter or build one = 150 million people
- Out to 1700 km many windows still breaking
- Significant model uncertainty on explosions this large (e.g. potential channelling in atmosphere could make overpressures significantly worse, thermal radiation from plume collapse)

2023 PDC Fatalities



- If impact occurred without warning expected casualties 1.9M. Worst case 2.3M.
- Short warning time for sheltering but no evacuation, expected casualties 160 000, worst case 165 000
- Sufficient time for evacuation, expected 145, worst case 165.

Conclusions

- Currently asteroid risk mostly quantified by estimates of casualties if impact occurred without warning
- Becoming more likely impacting asteroids will be detected sufficiently in advance to evacuate if not mitigate in space
- Reasonable evacuation and shelter distances can be calculated
- Useful metrics may include number of evacuees and cost of damage to infrastructure that cannot be moved.
- Number of evacuees >> surprise impact casualties
- Costs can be compared to cost of in-space mitigation
- Significant model uncertainty for explosions this large, needs further investigation