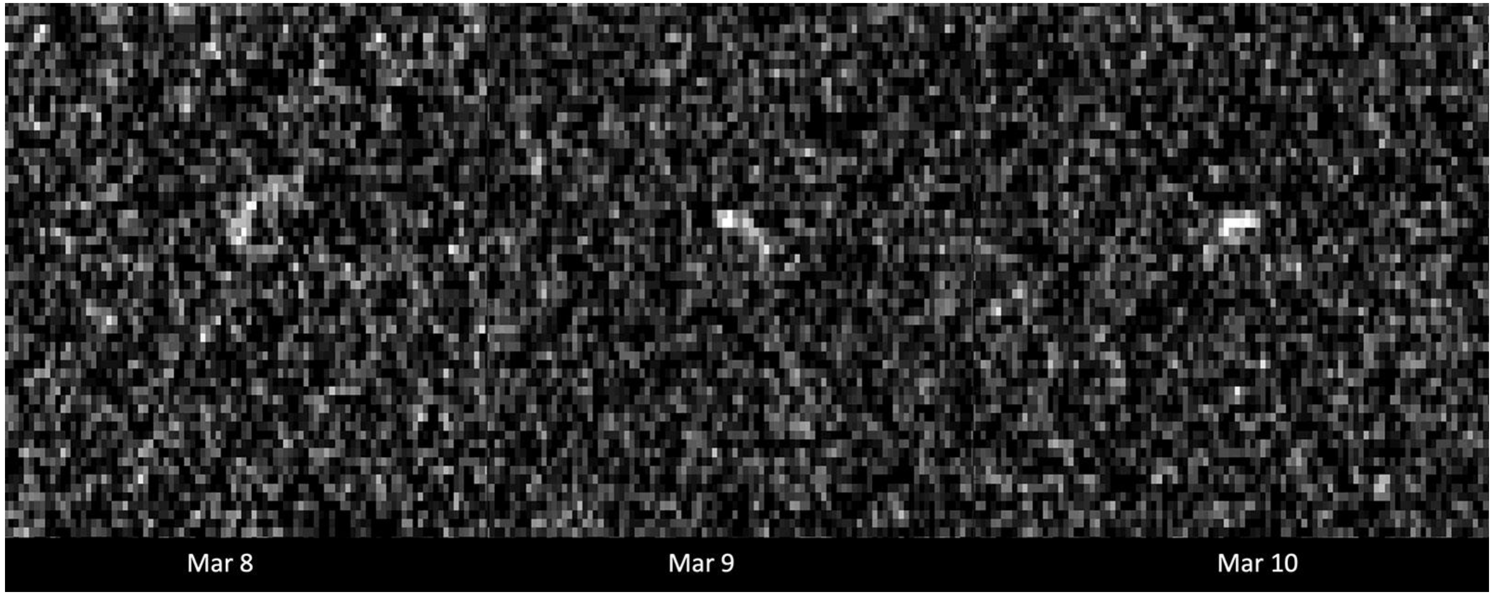
International Asteroid Warning Network (IAWN) Apophis Campaign



Credits: NASA/JPL-Caltech and NSF/AUI/GBO

NASA PDCO Lead: Mike Kelley, NASA HQ
IAWN Coordinator: Prof. Vishnu Reddy (University of Arizona)
Group Leads: Davide Farnocchia (JPL), Jessie Dotson (NASA ARC), Nicolas Erasmus (SAAO), David Polishook (WIS), Lance Benner (JPL), Joe Masiero (IPAC, CalTech), James (Gerbs) Bauer (UMD)

Hypothetical exercise

Planetary Defense Campaigns

- NASA PDCO has been conducting planetary defense tabletop exercises for several years in coordination with other federal agencies
- Planetary defense community also engaged in such activities through the Planetary Defense Conference Hypothetical Asteroid Impact Scenarios
- Those theoretical exercises do not include real world observational component with actual NEOs
- Proposal was made during the 2017 NEOO program review to use the October 2017 flyby of a small NEO, 2012 TC4, to exercise the entire global planetary defense system from observations to modeling to communication
- Since then, we have conducted two additional campaigns

Hypothetical exercise

Campaign Structure

- Participation is voluntary ("Coalition of the Willing")
- Participants organize themselves into working groups with a lead
- Working Groups: Astrometry, Photometry, Spectroscopy, Radar, Direct Imaging, Spacecraft Missions, Impact Risk Modeling
- Bimonthly telecons with updates from working groups
- Impact risk model is run at different epochs as information about the target is gathered by the observers
- Data quality/reduction timelines are set by operational rather than scientific needs

Hypothetical exercise

Probabilistic Asteroid Impact Risk (PAIR) in Apophis Exercise

Astrometry:
Davide Farnocchia
CNEOS-JPL, USA

Photometry:
Nic Erasmus
SAAO, South Africa

Spectroscopy:
David Polishook
Weizmann Inst., Israel

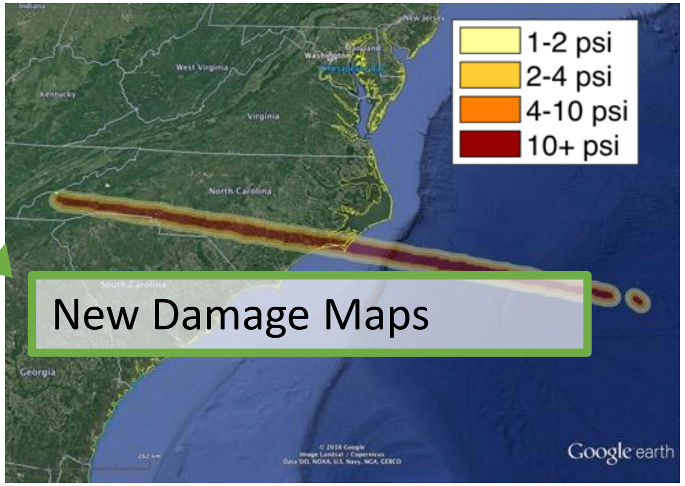
Spacecraft Missions:
Joe Masiero
IPAC-Caltech, USA

Radar:
Lance Benner
JPL, USA

Hypothetical exercise

Hypothetical Entry points

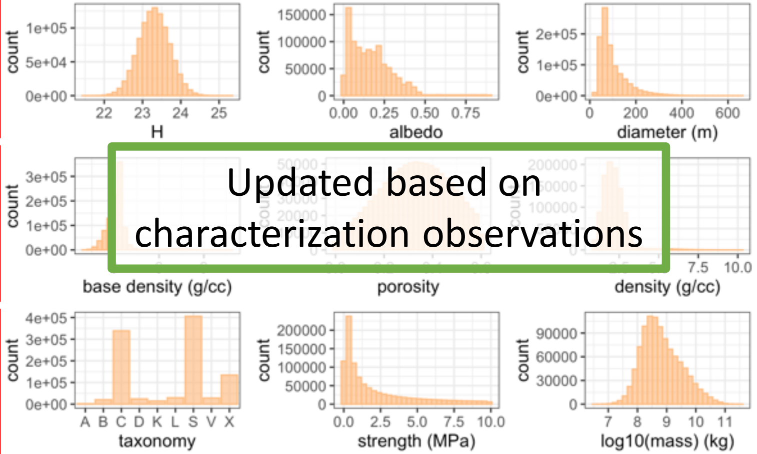
Damage Map



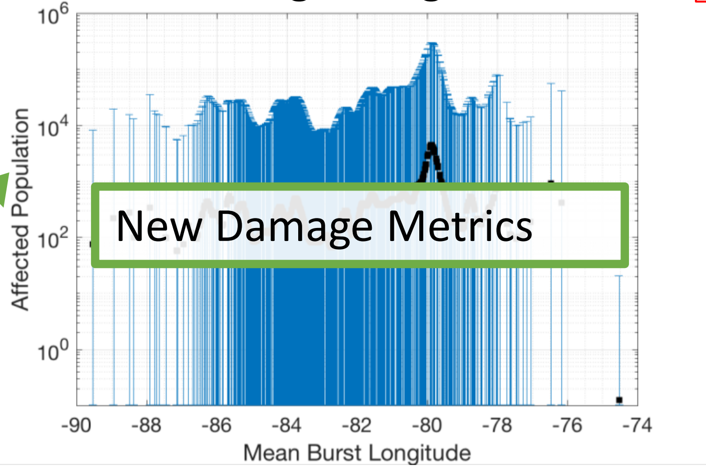
PAIR

Hazard Modeling:
Jessie Dotson
NASA Ames, USA

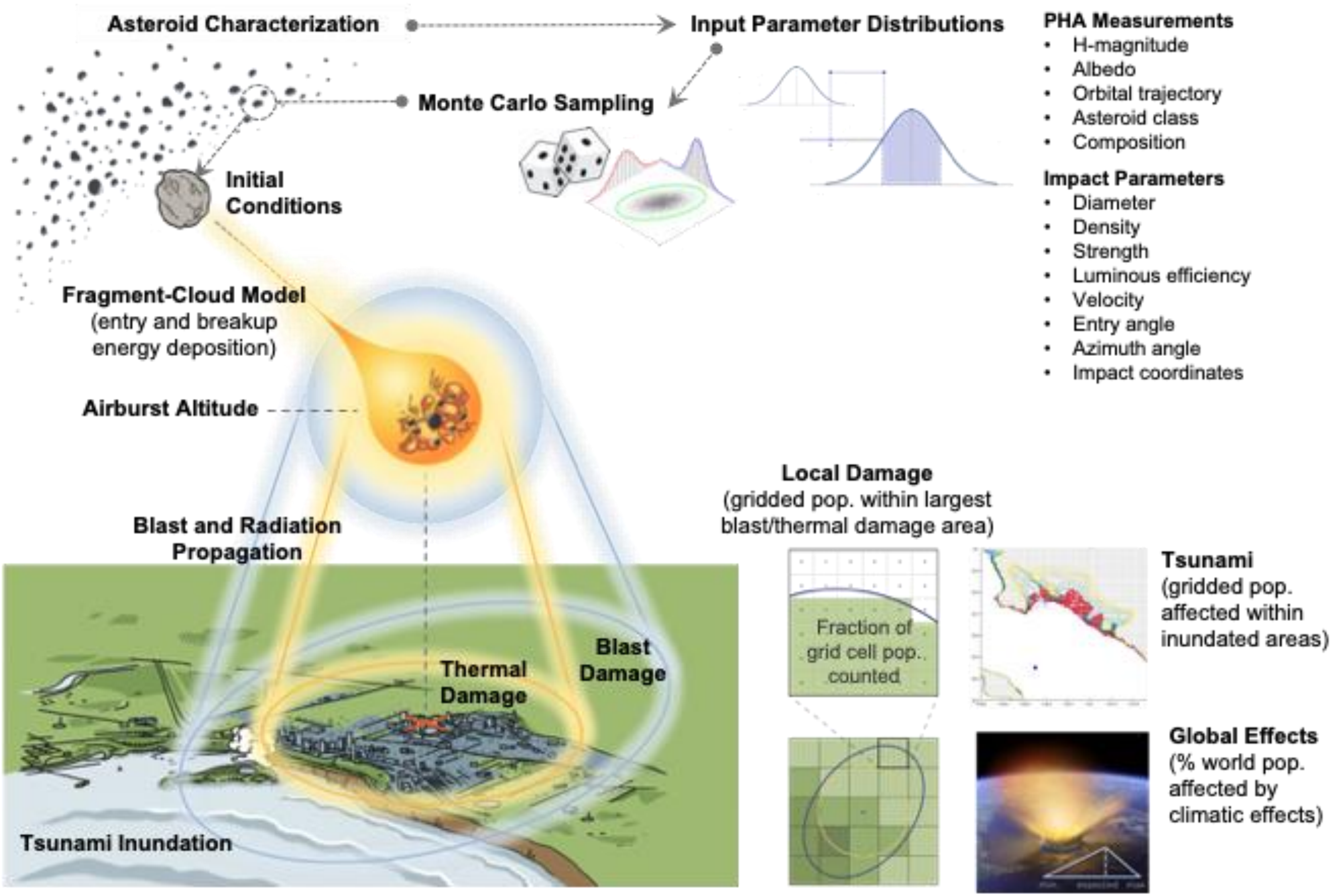
Physical Property Distributions



Damage Range



Probabilistic Asteroid Impact Risk (PAIR) Model



Hypothetical exercise

Apophis Campaign (Oct. 2020-April 2021)

- Goal: *Near-Earth asteroid Apophis will make a flyby on the Earth on March 06, 2021 at a distance of 10 million miles. The goal of Apophis Observing Campaign is to discover, track, and characterize Apophis as a potential impactor in order to exercise the Planetary Defense system from observations to impact modeling and prediction, and communication. This campaign is open for participation by amateur astronomers from around the world.*

- Participants: 40 observers/modelers from 14 different countries

- Working Groups: Astrometry (Davide Farnocchia); Hazard Modeling (Jessie Dotson); Photometry (Nic Erasmus); Spectroscopy (David Polishook); Radar (Lance Benner); Spacecraft (Joe Masiero)

Hypothetical exercise

Timeline

- Apophis was ‘discovered’ by CSS Schmidt after NEOWISE triggered the discovery process in Dec. 2020 when it was put on NEOCP.
- Impact probability was calculated with the real Apophis as follow up observations were made. As uncertainties and impact probability decreased, we switched to hypothetical impactor for the reminder of the exercise.
- Epoch 1: Using diameter and albedo from NEOWISE observations we ran the impact risk model on Dec. 23, 2020
- NASA IRTF spectral observations helped constrain the taxonomy and identify the meteorite analog (L chondrite). This helped constrain the density for a range of assumed porosities. Photometric observations helped refine the H magnitude.
- Epoch 2: Included NASA IRTF observations for taxonomy and meteorite analog and ran the model on Jan. 22, 2021.
- Epoch 3: Included radar observations for diameter and ran the model in late March 2021.

Hypothetical exercise

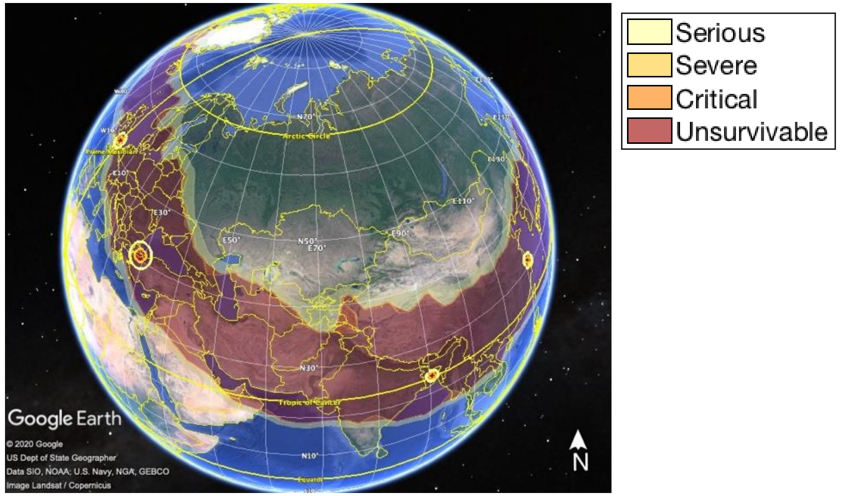
Impact Risk Summary

(Epoch 1: Initial Observations with NEOWISE, 0.6% Impact Prob)

Characterization Summary & Updates

- Assessment date: 23 Dec. 2020
- Earth impact probability: 0.6%
- Size refinement from NEOWISE data
- Diameter 300m ± 75m
- Albedo: 0.44 ± 0.19
- Energy: mean 678 Mt, full range 2 – 8220 Mt
- Entry: 12.2-12.8 km/s, at entry angles up to 54°

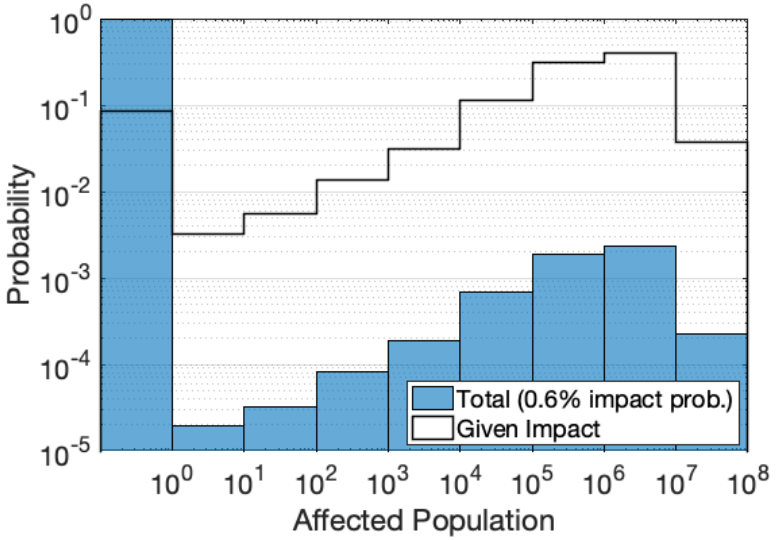
Potential Risk Regions



Hazard Summary

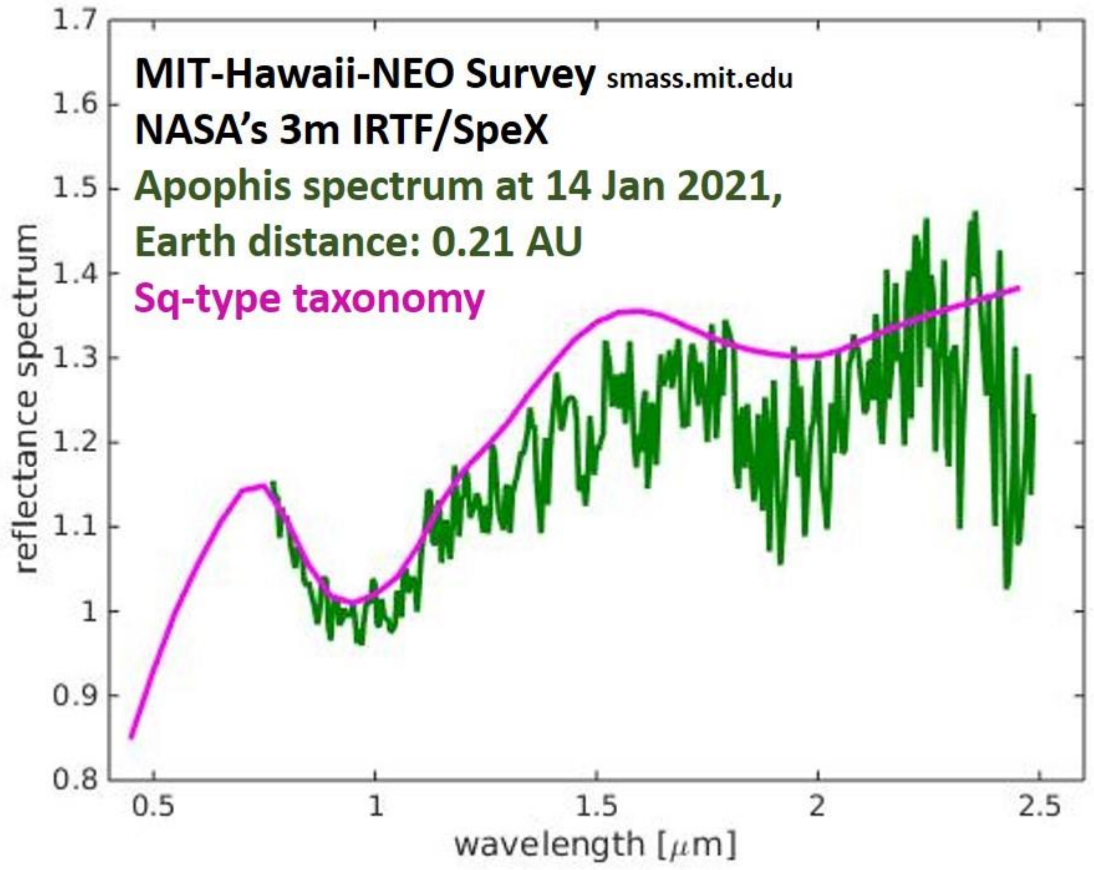
- Affected population: 0-61M, 12k average total risk with 0.6% impact prob., 2M average among impacting cases.
- No population damage for ~9% of impact cases.
- Blast overpressure is primary hazard for ~90% of impact cases.
- Local blast damage radii: 0-370 km, 150 km avg.
- Potential tsunami damage for ~4% of impact cases (primary hazard for <2%)
- No major global effects expected

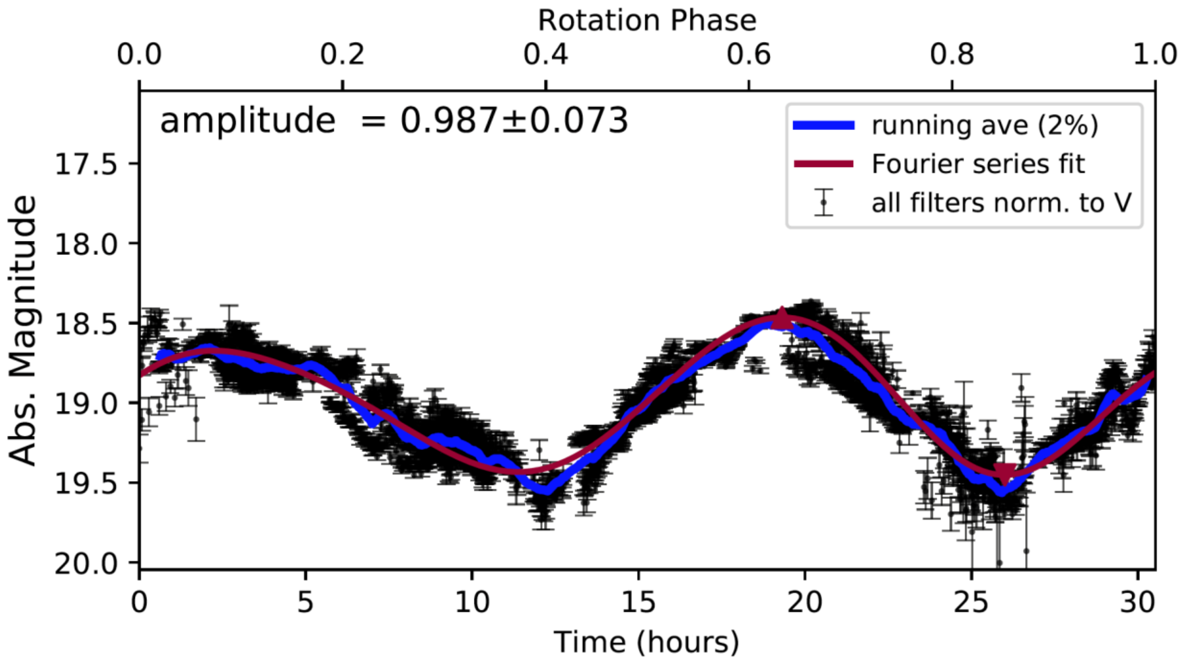
Affected Population Risk Probabilities



Hypothetical exercise

NASA IRTF and Photometric Observations





Hypothetical exercise

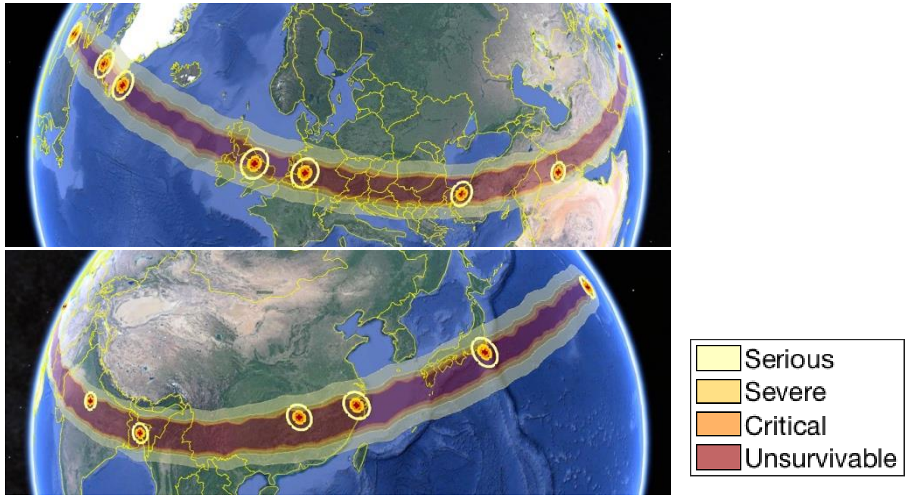
Impact Risk Summary

(Epoch 2: NEOWISE & taxonomy, 6% impact probability)

Characterization Summary & Updates

- Assessment date: 22 Jan. 2021
- Earth impact probability: 6%
- Taxonomy: Sq determination from IRTF
- Size: NEOWISE size refinement from Dec. 23
- Diameter 300 m ± 75 m, full range 44 – 550 m
- Energy: mean 670 Mt, full range 2 – 3770 Mt
- Entry: 12.2-12.8 km/s, at entry angles up to 50°

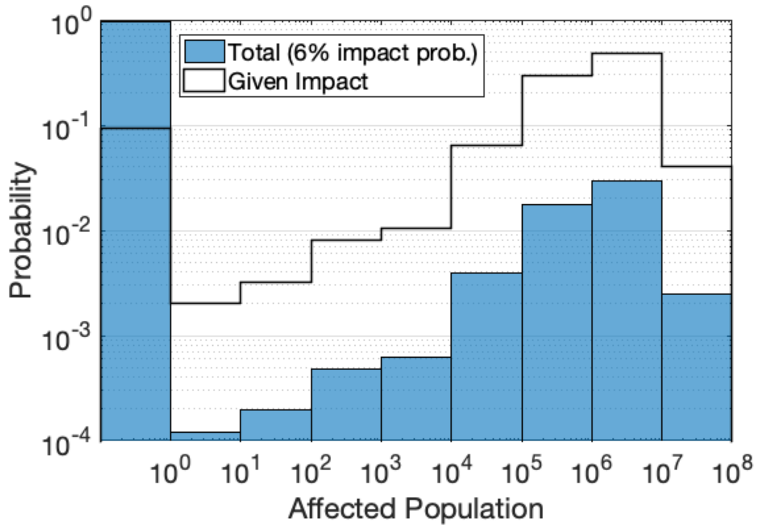
Potential Risk Regions



Hazard Summary

- Affected population: 0-54M, 138k average total risk with 6% impact prob., 2.3M average among impacting cases.
- No population damage for ~9% of impact cases.
- Blast overpressure is primary hazard for ~90% of impact cases.
- Local blast damage radii: 0-370 km, 150 km avg.
- Potential tsunami damage for ~2% of impact cases (primary hazard for <0.4%)
- No major global effects expected

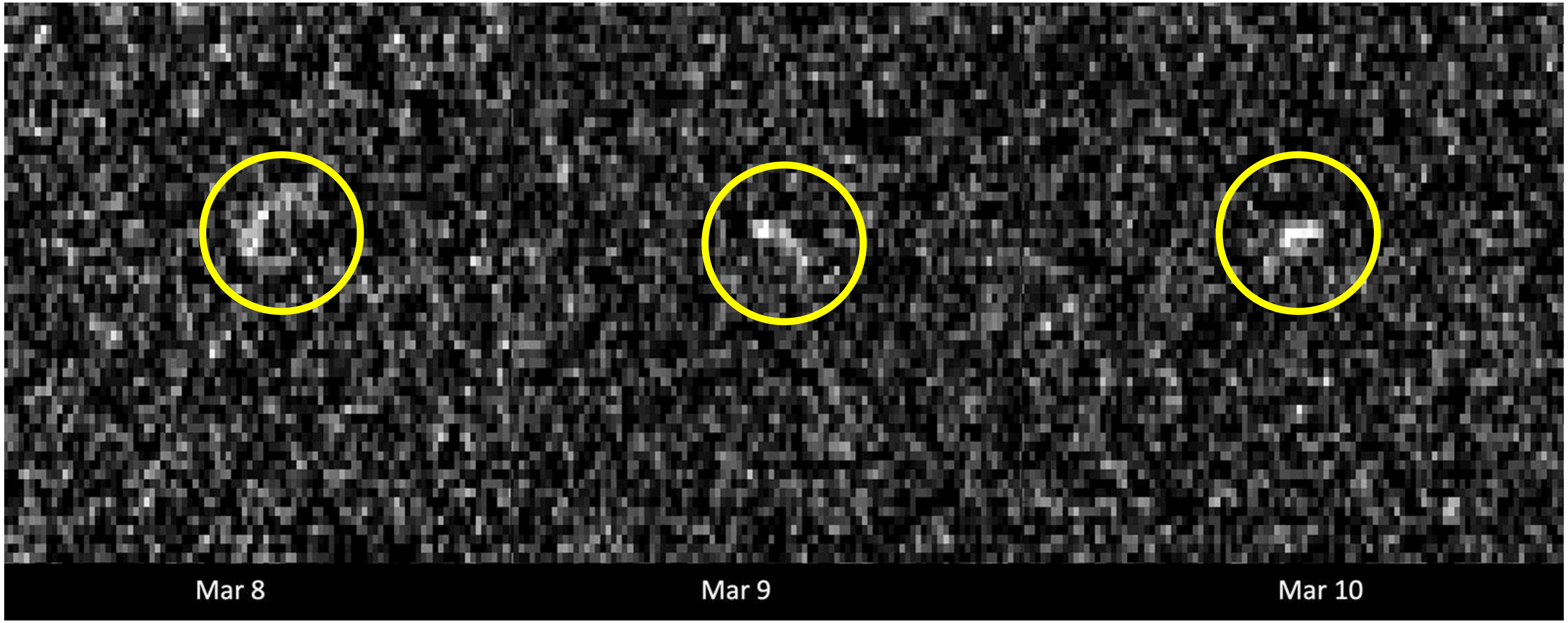
Affected Population Risk Probabilities



Hypothetical exercise

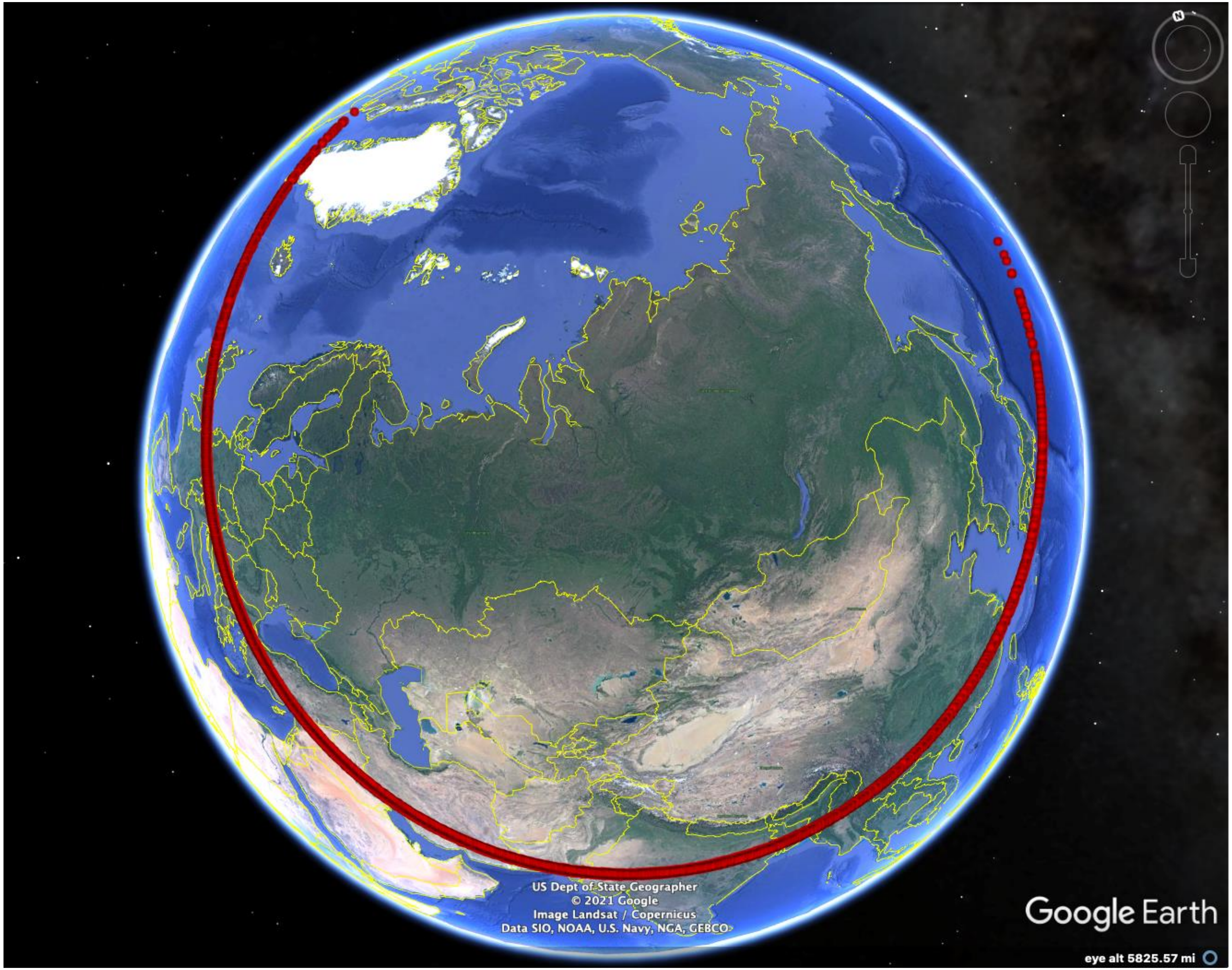
Goldstone Apophis Radar Observations in 2021

Quick Overview:
12 tracks: March 3 - 14.
Track durations: 1.25 – 8.5 hours
Some tracks will use Green Bank to receive (doubles the SNRs).
Goldstone > Green Bank SNRs comparable to those at Goldstone in 2013.



Hypothetical exercise

Impacting clone
Data cutoff Mar 1
Pre-Radar



Hypothetical exercise

Impacting clone
Data cutoff Mar. 15
With Radar data

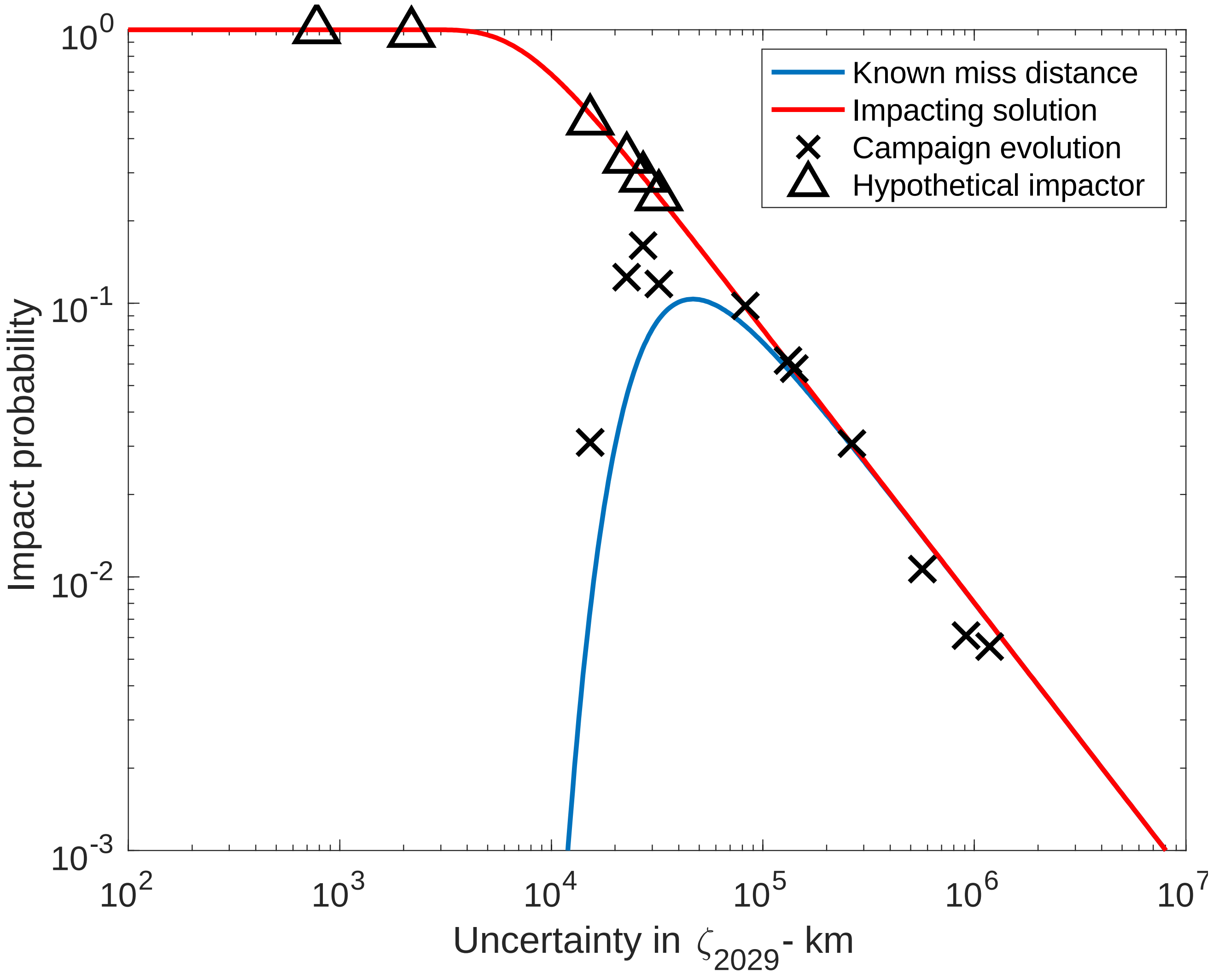
Hypothetical exercise

Impact probability for April 2029

As of March 15, 2021:

Real Apophis: 0%

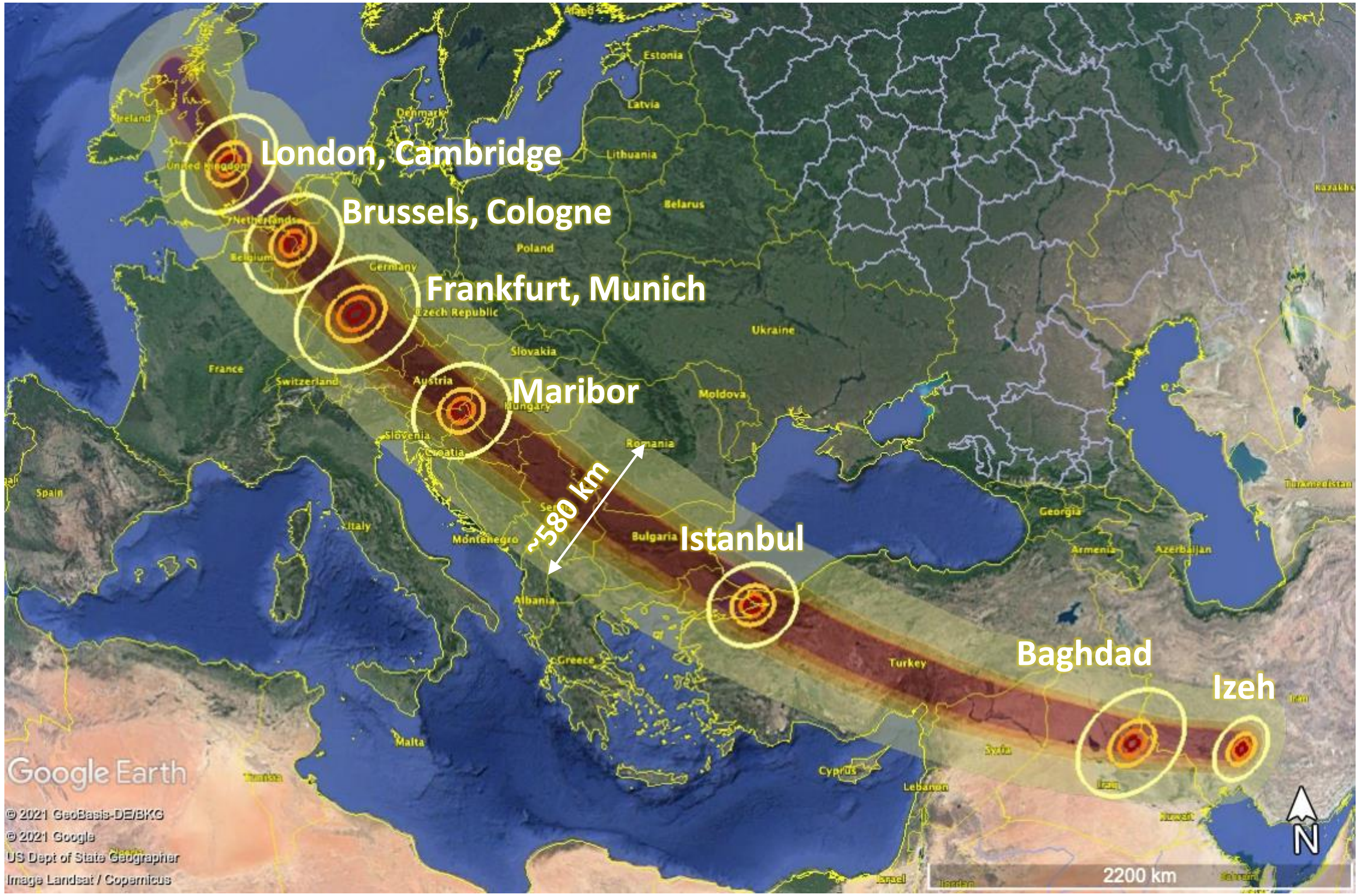
Impacting clone: 100%



Hypothetical exercise

Local Damage Swath

(Epoch 3: Radar size data, 100% virtual impact probability)



Map image/data credit: Google Earth, © 2020 Google. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image Landsat / Copernicus. © 2020 GeoBasis-DE/BKG.

Swath extent: ~5800 km long, from UK to Iran, ~650–470 km wide (~650 W. end, 580 km middle, ~470 km E. end)

Serious
Severe
Critical
Unsurvivable

Damage swath: Full range of regions potentially at risk to local ground damage, from all modeled cases (including unlikely worst-case objects and all sampled impact locations).

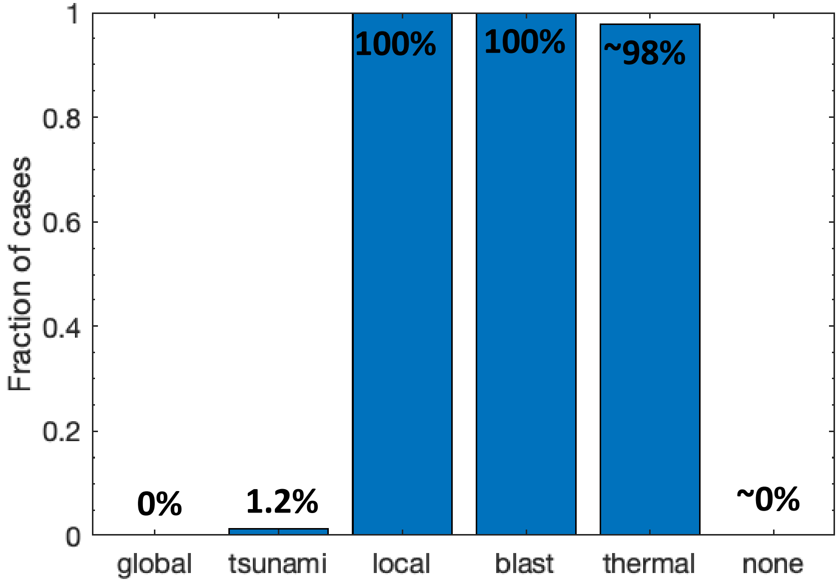
Sample average damage areas: Average blast damage areas at several high-population locations across the swath.

Hypothetical exercise

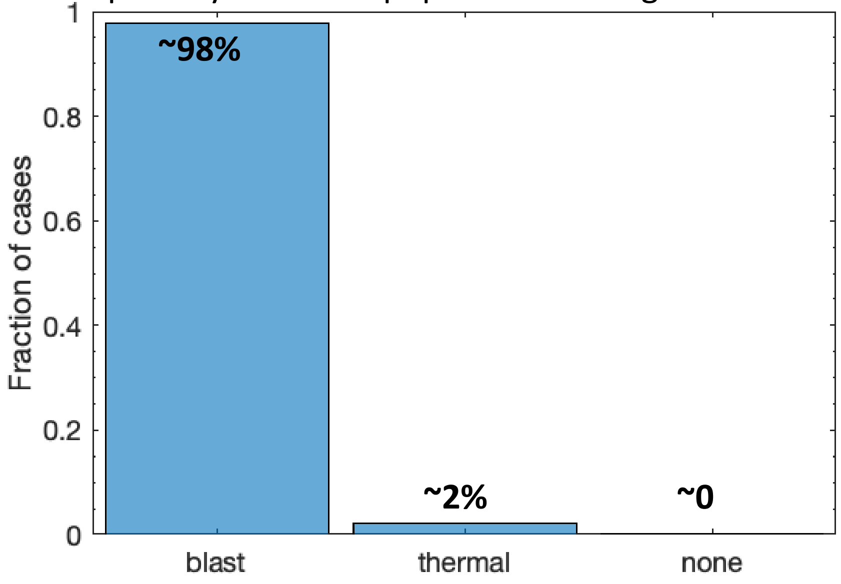
Hazard Sources

(Epoch 3: Radar size data, 100% virtual impact probability)

Occurrence of hazard sources
Fraction of Earth-impacting cases for which damage from each hazard occurs



Risk-driving hazard sources
Fraction of cases for which each hazard is the primary source of population damage

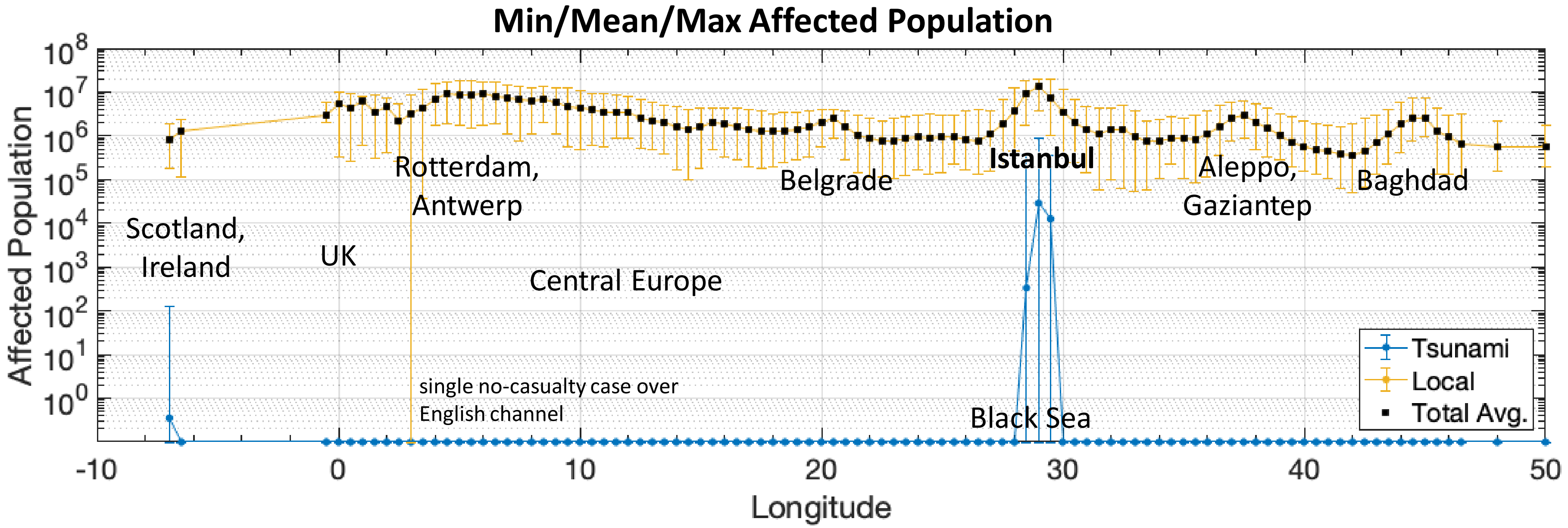


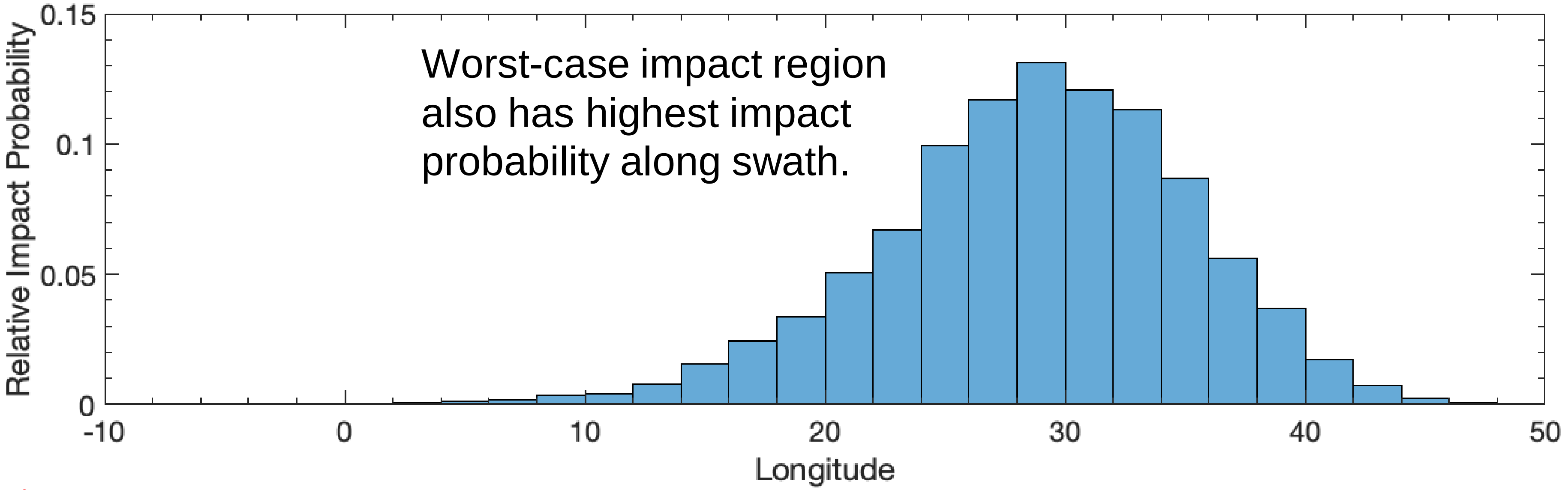
- Total affected population risk is driven primarily by local blast overpressure damage
- Blast damage occurs for all cases and is primary hazard source for ~98% of cases
- Thermal damage also occurs in 98% of cases but is smaller or less severe than the blast damage in nearly all cases (primary hazard source for only 2% of cases).
- Tsunami inundation potentially occurs for ~1% of cases, but is not primary hazard source in any cases (tsunami minor enough and blast always close enough to coast to cause more damage)
- No major global climatic effects are expected
- Only one out of 25M cases caused no population damage

Hypothetical exercise

Affected Population Ranges Along Swath

(Epoch 3: Radar size data, 100% virtual impact probability)





Hypothetical exercise

Summary

- Apophis no longer on the risk list as 2068 impact has been ruled out. No threats from Apophis in the next 100 years.
- IAWN campaigns have been very effective in identifying strengths and stress points of global planetary defense coordination efforts.
- Participants from this and previous campaigns are pleased with the process and results and express enthusiasm for participating again in future campaigns.

Hypothetical exercise