

Shelter-In-Place as an Effective Means of Civil Protection

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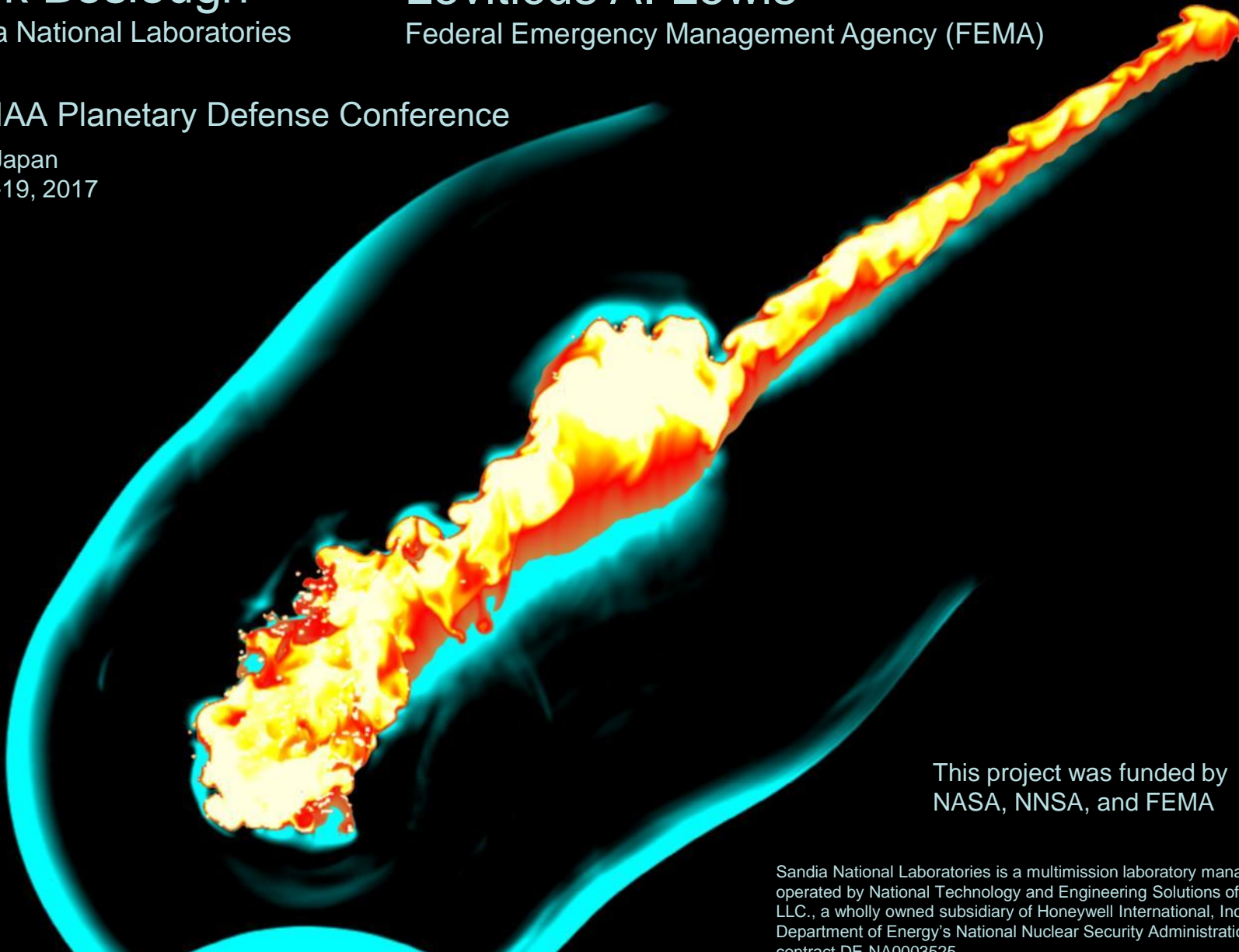
Leviticus A. Lewis

Federal Emergency Management Agency (FEMA)

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Tokyo, Japan

May 15-19, 2017



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Is shelter-in-place effective?

- Run ensemble impact/airburst simulations
- Plot wind fields, generate contour maps
- Convert to damage zones
- Compare hydrocode to simulator results
- Sum over probability-weighted areas
- Test sensitivity to assumptions

100 km

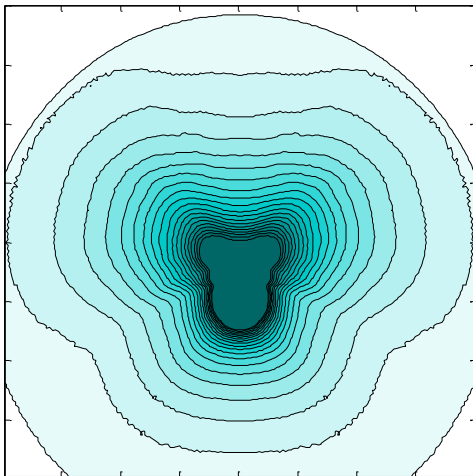
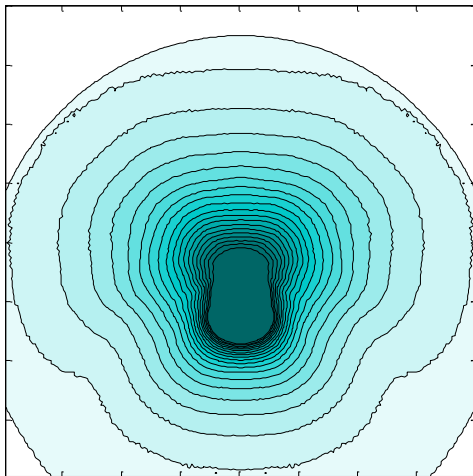
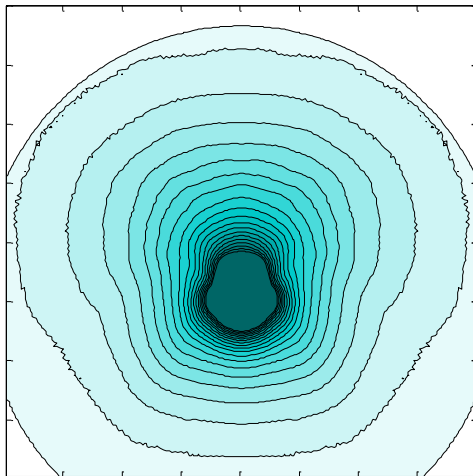
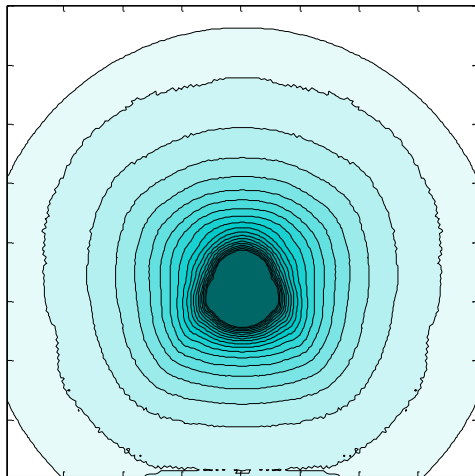
16 Mt (~63 m asteroid)

85°

75°

65°

55°

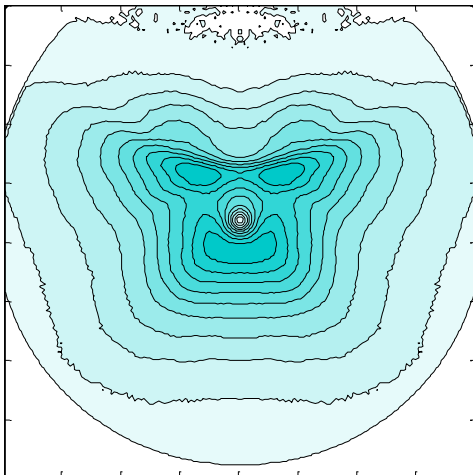
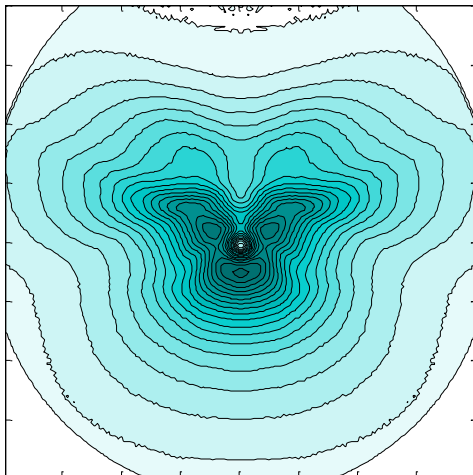
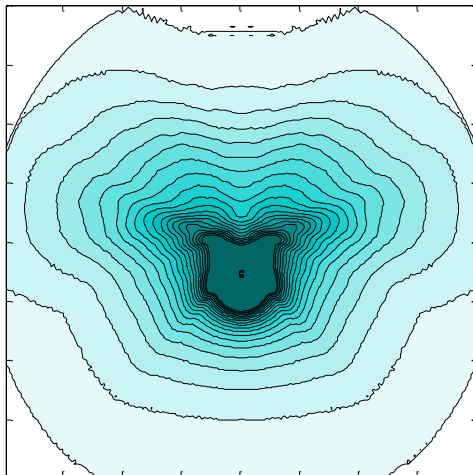
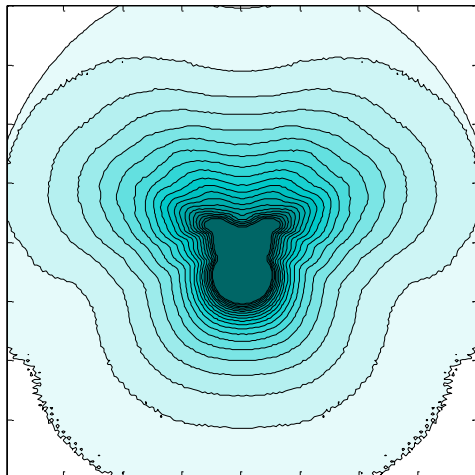


45°

35°

25°

15°

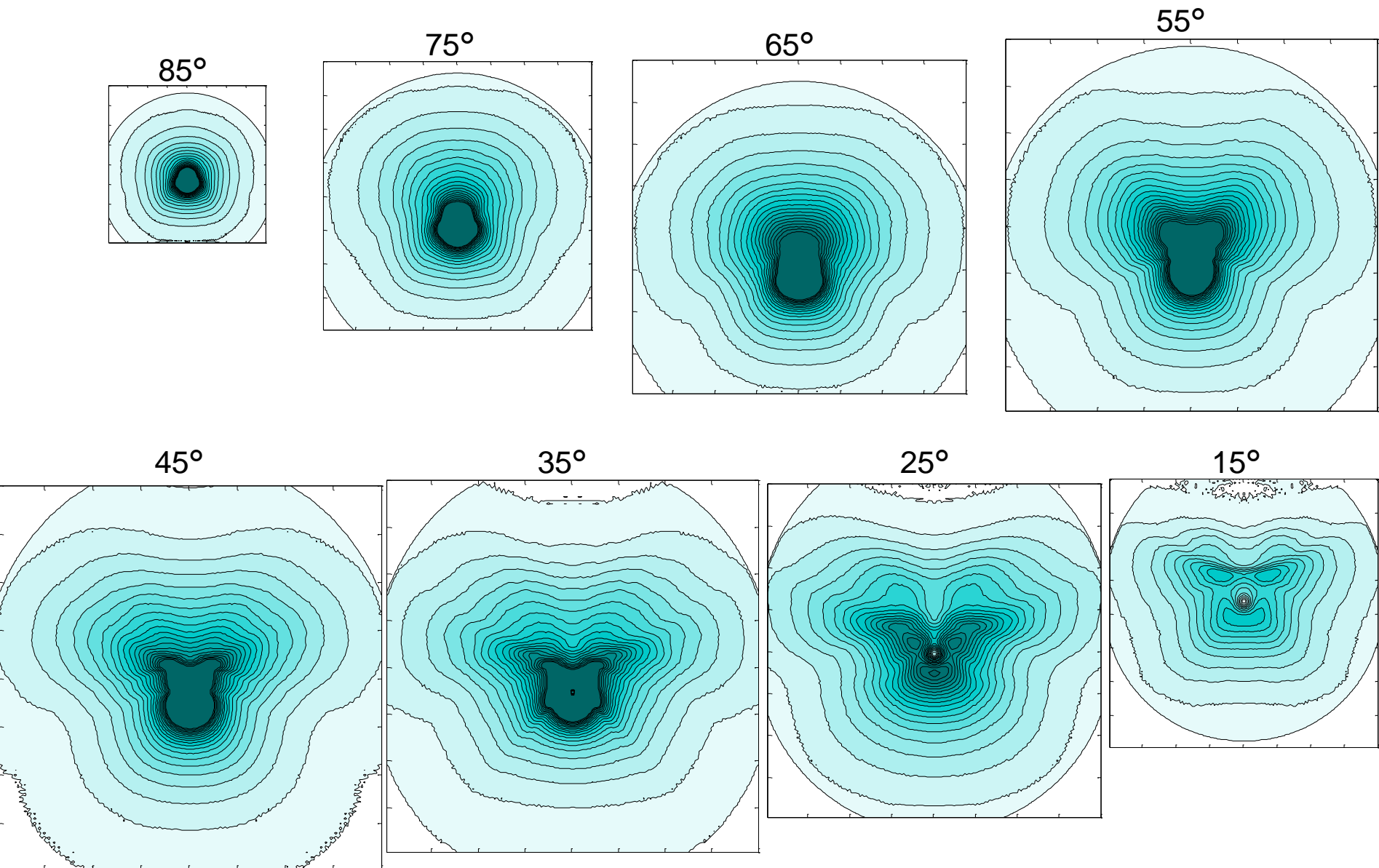


0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

Max wind speed (cm/s)



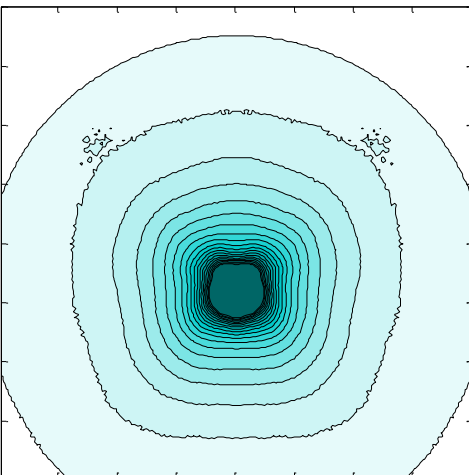
16 Mt (~63 m asteroid)



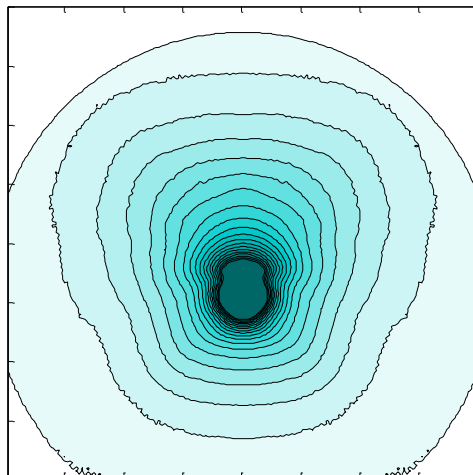
Area weighted by probability of given entry angle $P \sim \sin(2\theta)$

8 Mt (~50 m asteroid)

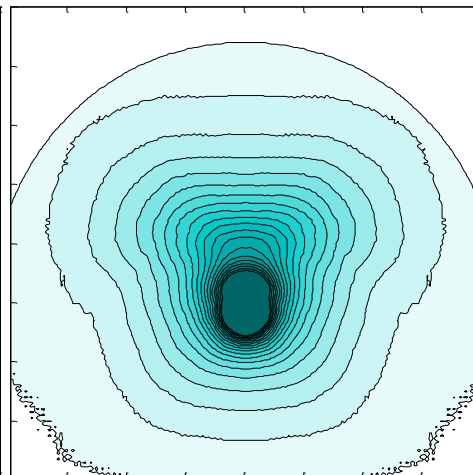
85°



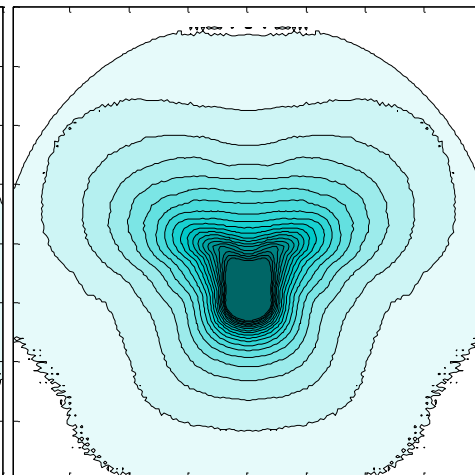
75°



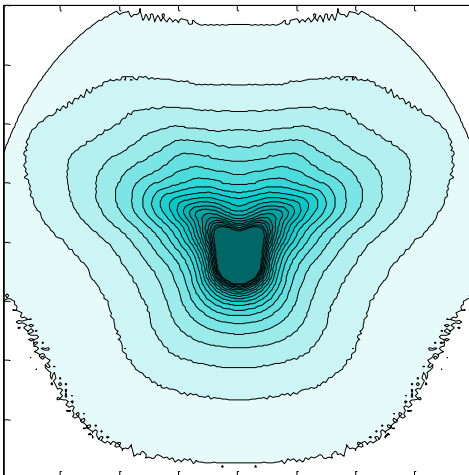
65°



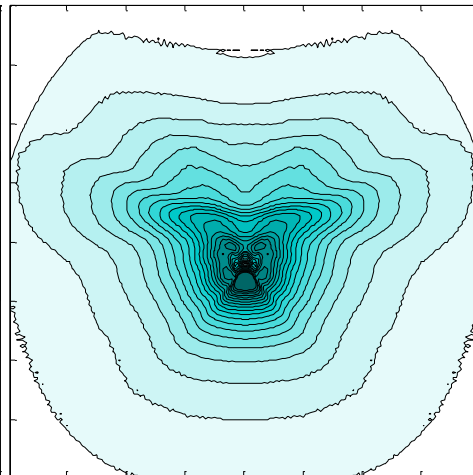
55°



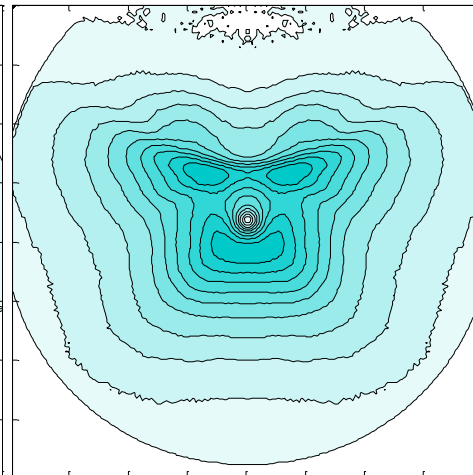
45°



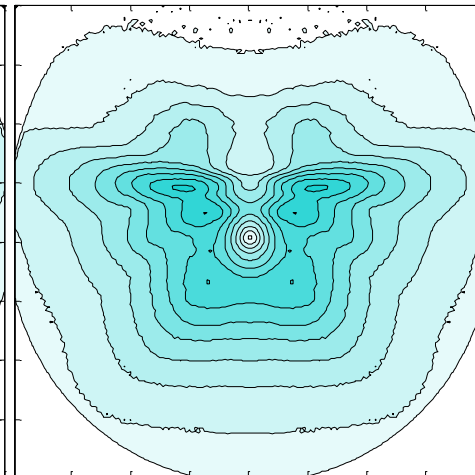
35°



25°



15°



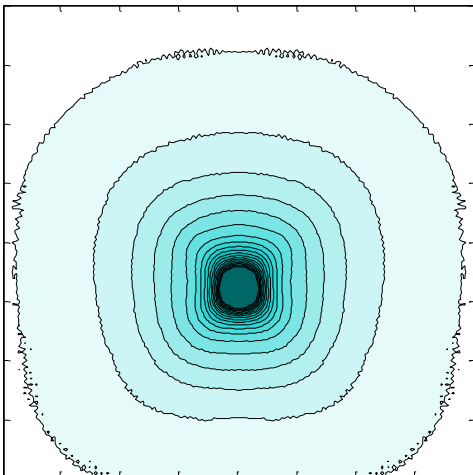
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Max wind speed (cm/s)

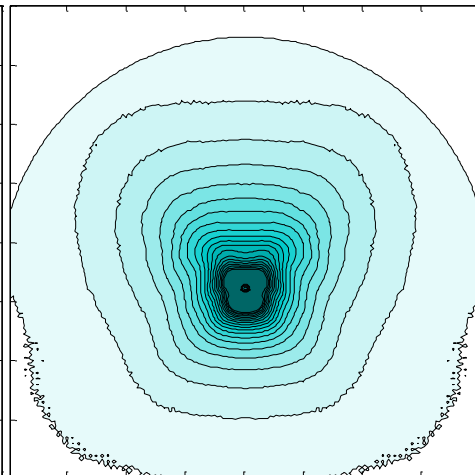


4 Mt (~40 m asteroid)

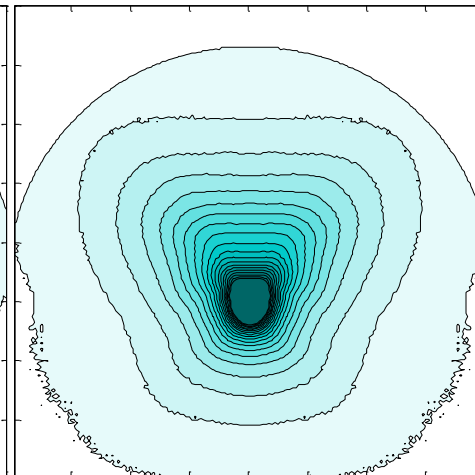
85°



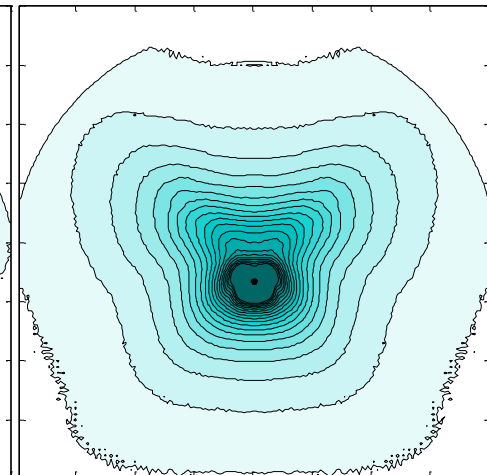
75°



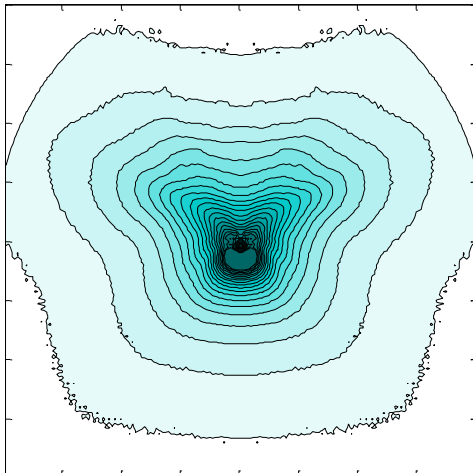
65°



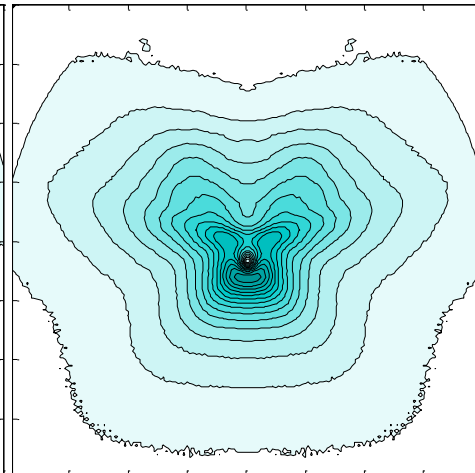
55°



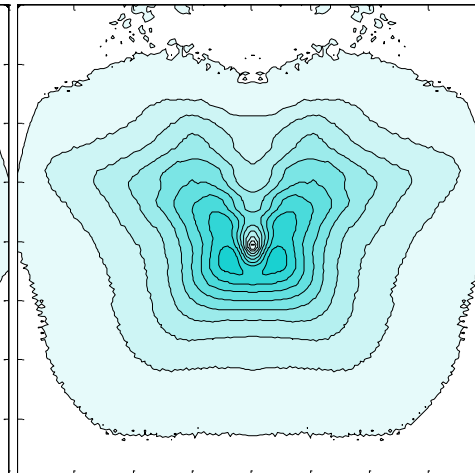
45°



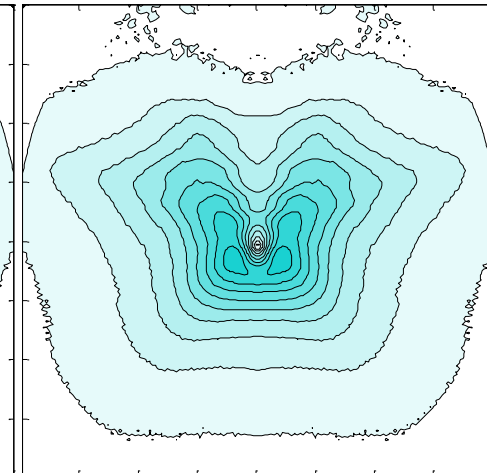
35°



25°



15°



0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

Max wind speed (cm/s)



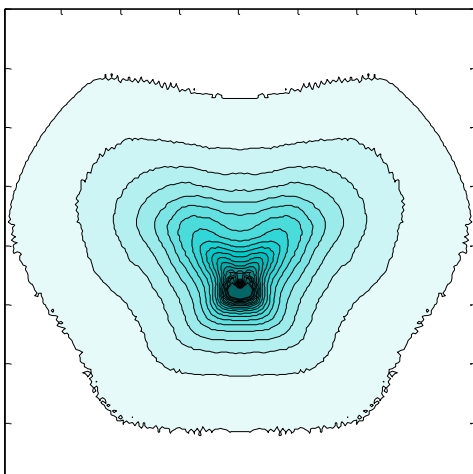
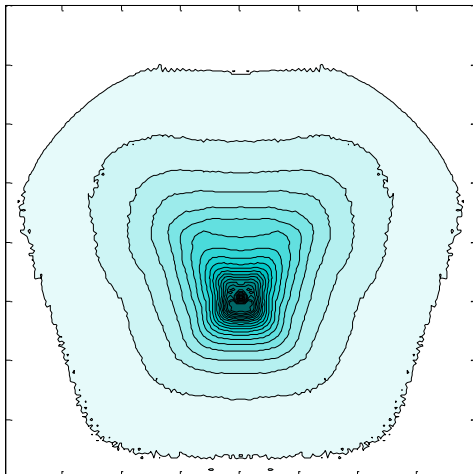
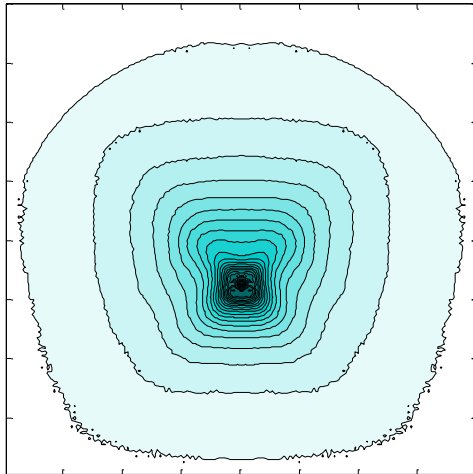
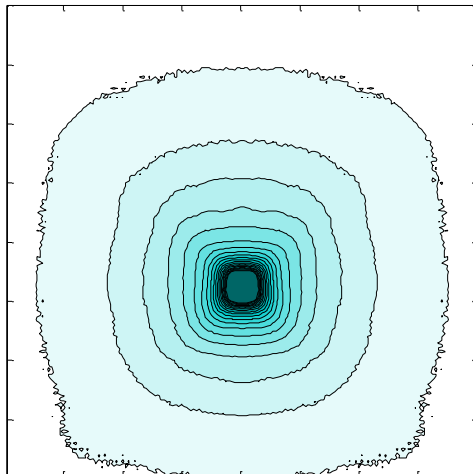
2 Mt (~32 m asteroid)

85°

75°

65°

55°

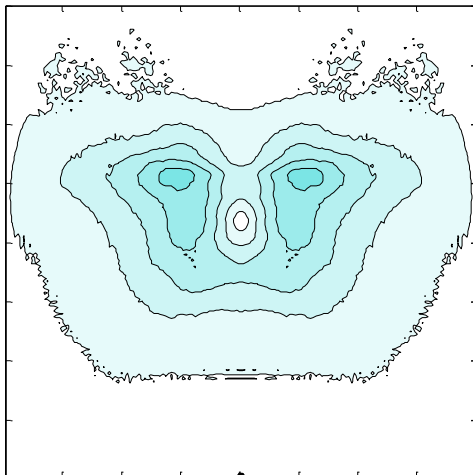
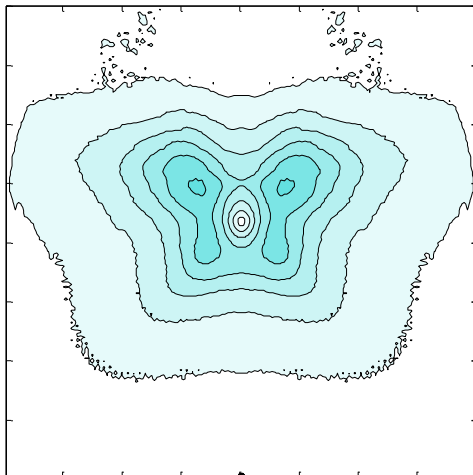
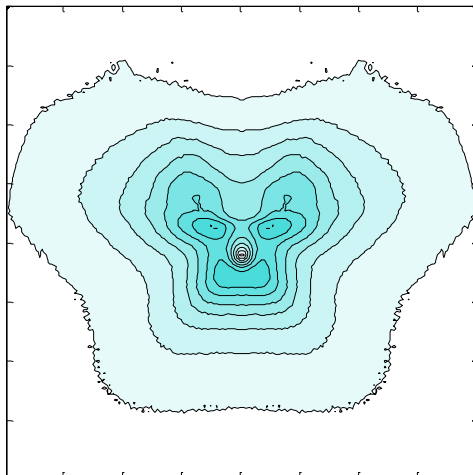
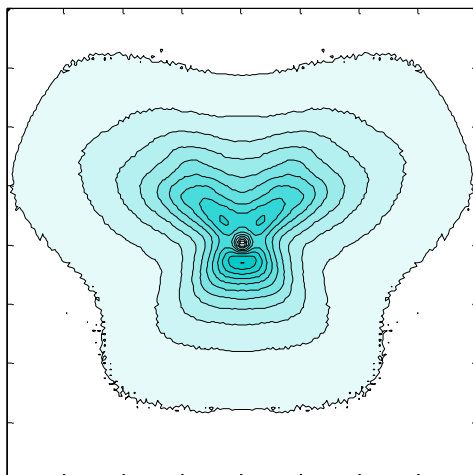


45°

35°

25°

15°



0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

Max wind speed (cm/s)



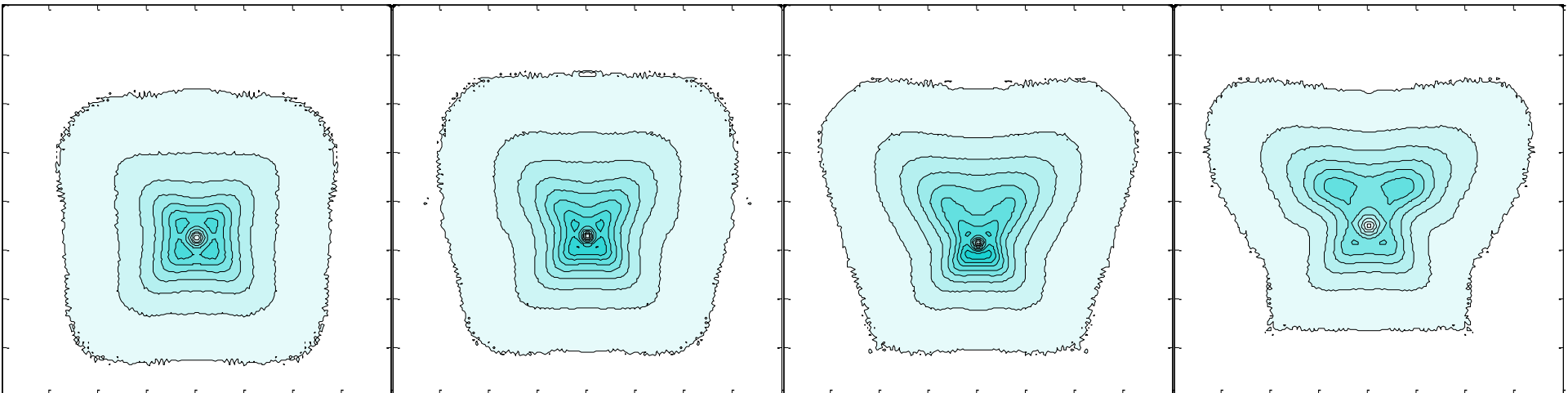
1 Mt (~25 m asteroid)

85°

75°

65°

55°

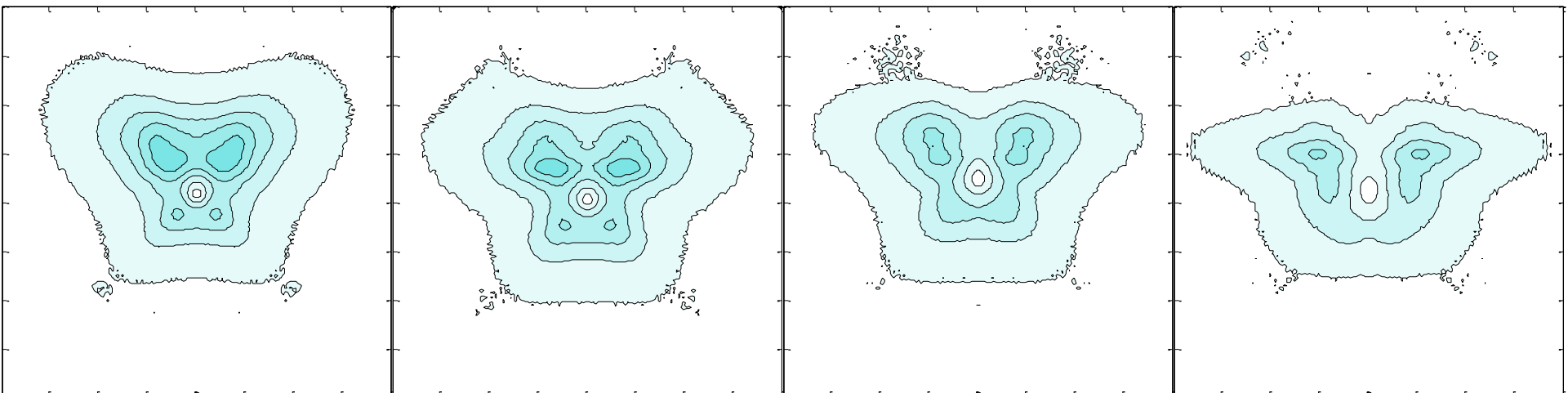


45°

35°

25°

15°



0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

Max wind speed (cm/s)



0.5 Mt (~20 m asteroid)

85°

75°

65°

55°

45°

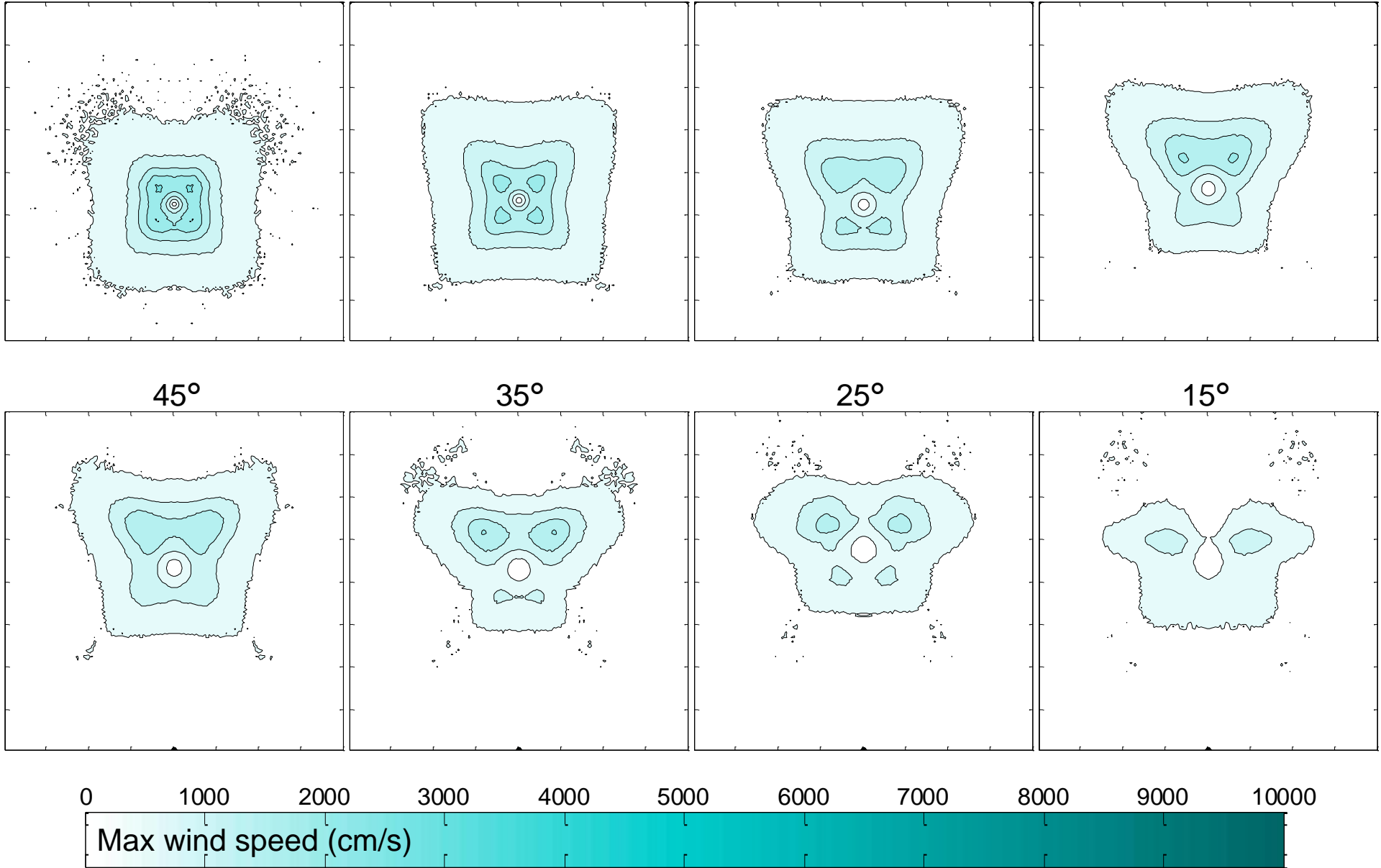
35°

25°

15°

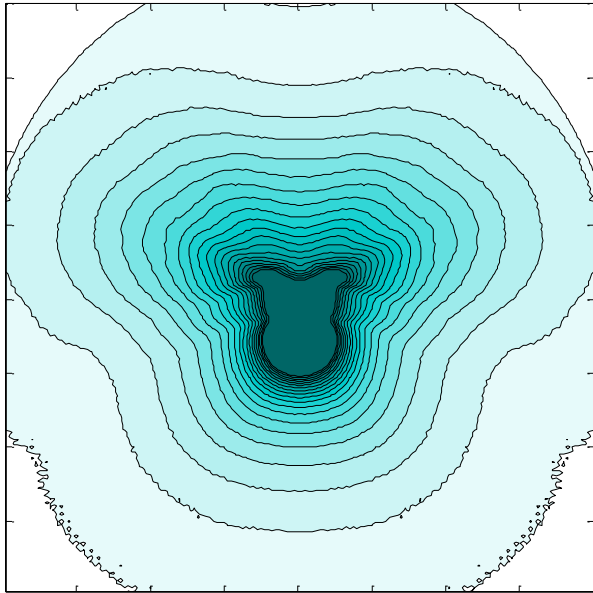
0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

Max wind speed (cm/s)

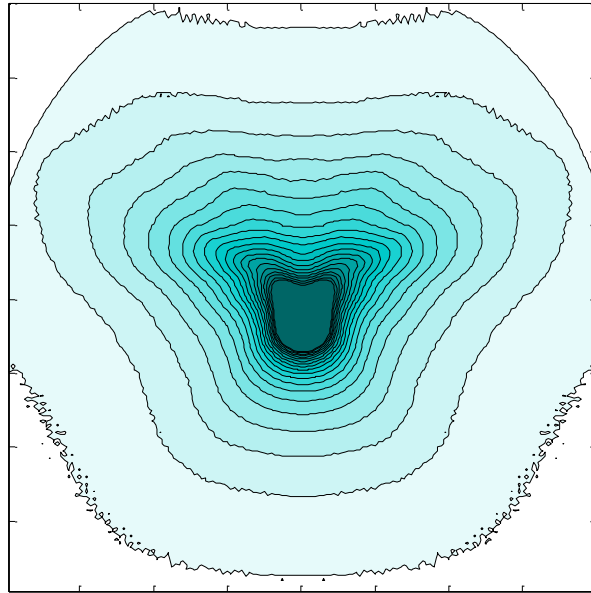


$\theta = 45^\circ$ for each size

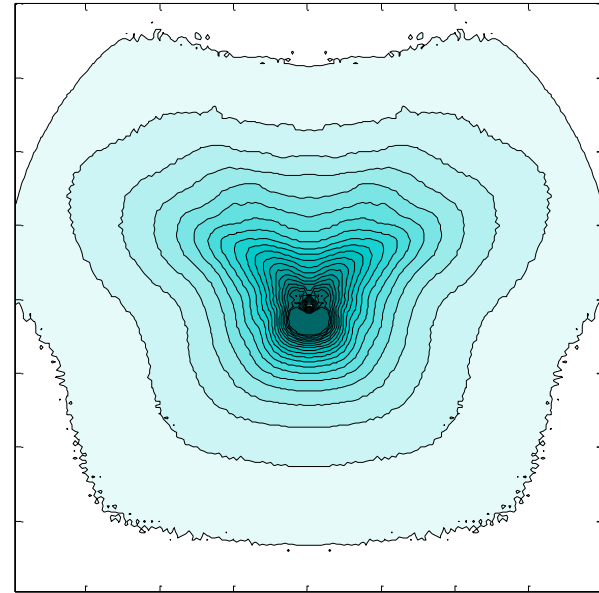
16 Mt



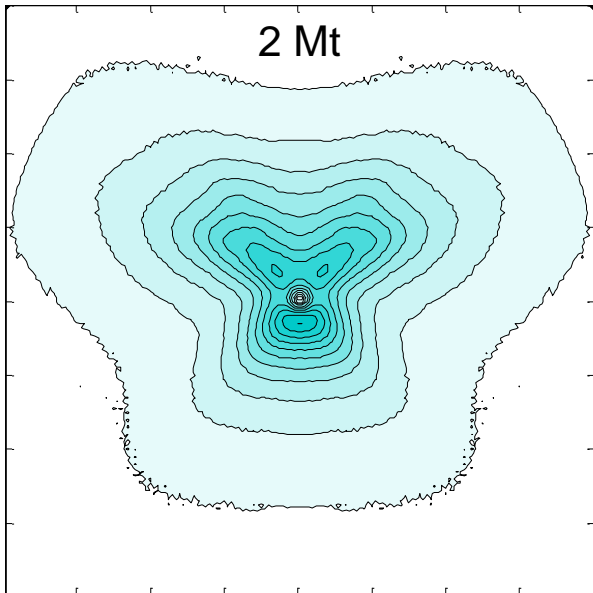
8 Mt



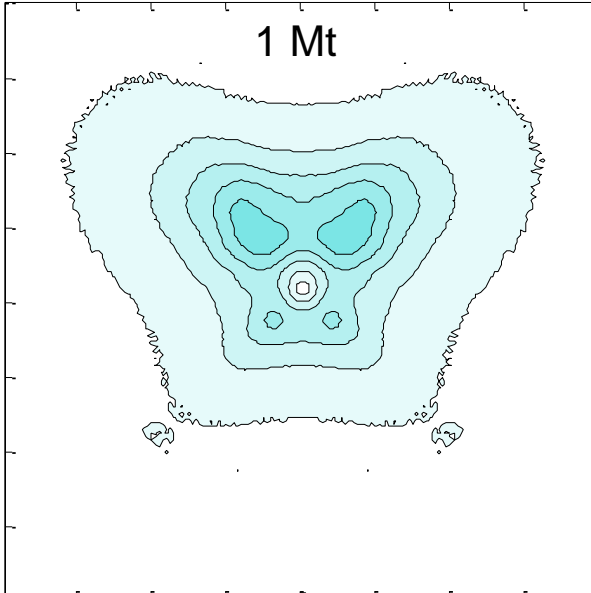
4 Mt



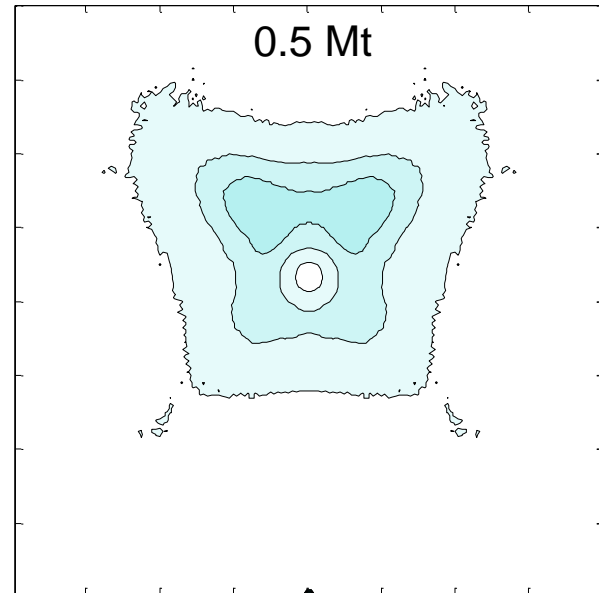
2 Mt



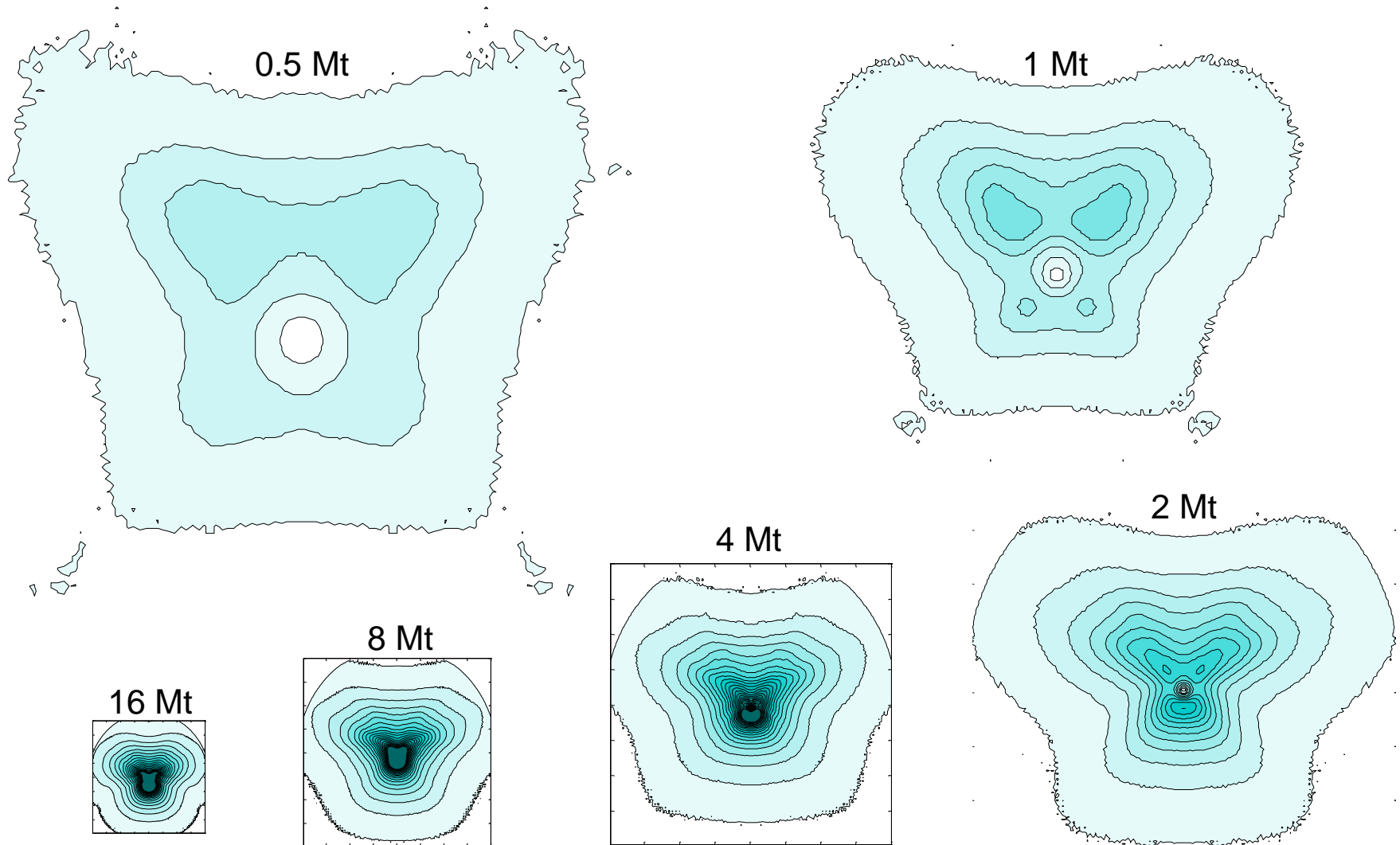
1 Mt



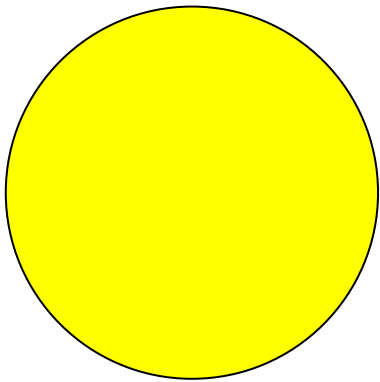
0.5 Mt



$\theta = 45^\circ$ for each size



Area weighted by probability of impact of given magnitude



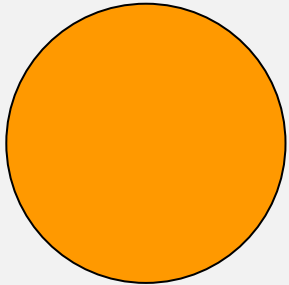
Air blast > 15 m/s

FROM:

- Glass windows will shatter.

UP TO:

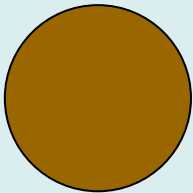
- Interior partitions of wood frame buildings will be blown down. Roof will be severely damaged.
- About 30 percent of trees blown down; remainder have some branches and leaves blown off.



Air blast > 60 m/s

UP TO:

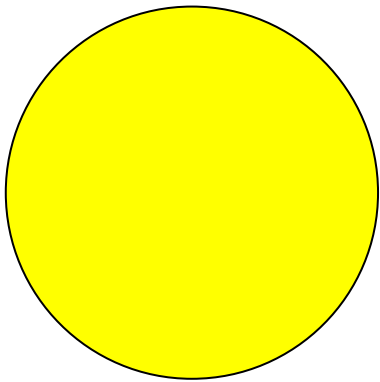
- Multistory wall-bearing buildings will collapse.
- Wood frame buildings will almost completely collapse.
- Highway truss bridges will suffer substantial distortion of bracing.
- Up to 90 percent of trees blown down; remainder stripped of branches and leaves



Air blast > 200 m/s

UP TO:

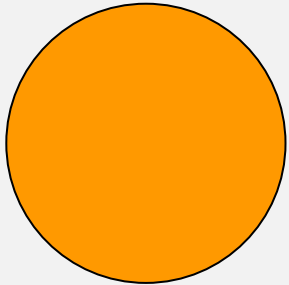
- Multistory steel-framed office-type buildings will suffer extreme frame distortion, incipient collapse.
- Highway truss bridges will collapse.
- Highway girder bridges will collapse.
- Cars and trucks will be largely displaced and grossly distorted and will require rebuilding before use.



Air blast > 15 m/s

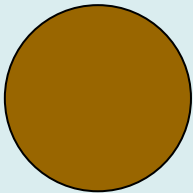
One possible set of assumptions to test

Shelter-in-place reduces fatalities from 10% to 1%



Air blast > 60 m/s

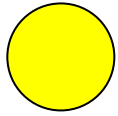
Shelter-in-place reduces fatalities from 90% to 10%



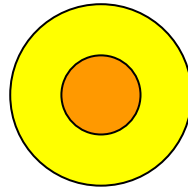
Air blast > 200 m/s

Shelter-in-place has no effect. 100% fatalities

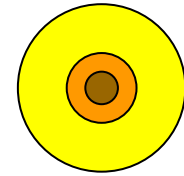
Purdue Impact Simulator results



2 Mt, ~32 m



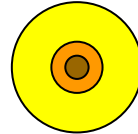
4 Mt, ~40 m



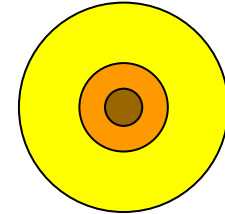
8 Mt, ~50 m



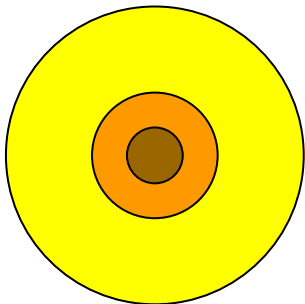
16 Mt, ~63 m



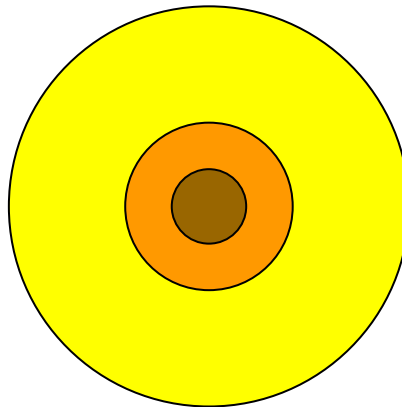
32 Mt, ~80 m



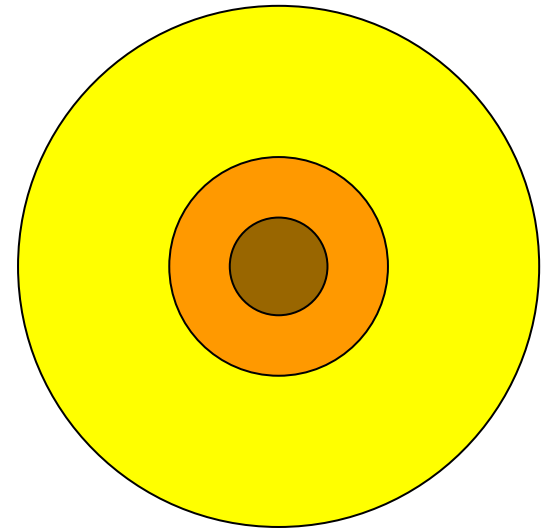
64 Mt, ~100 m



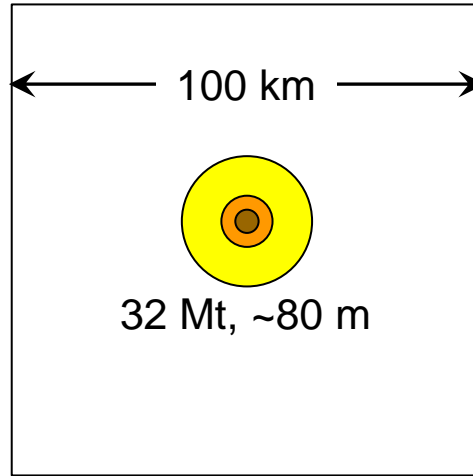
125 Mt, ~125 m



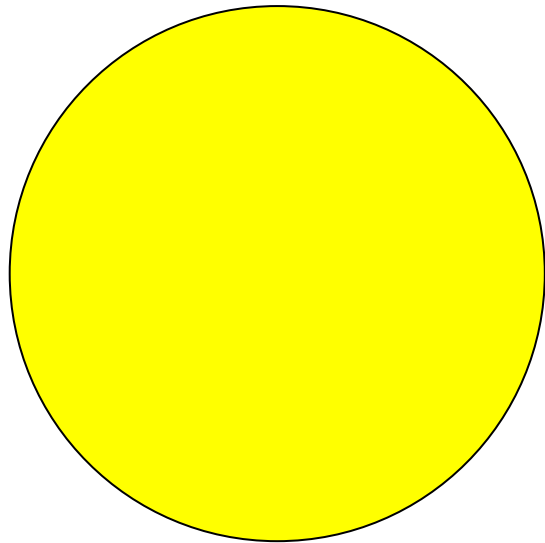
250 Mt, ~160 m



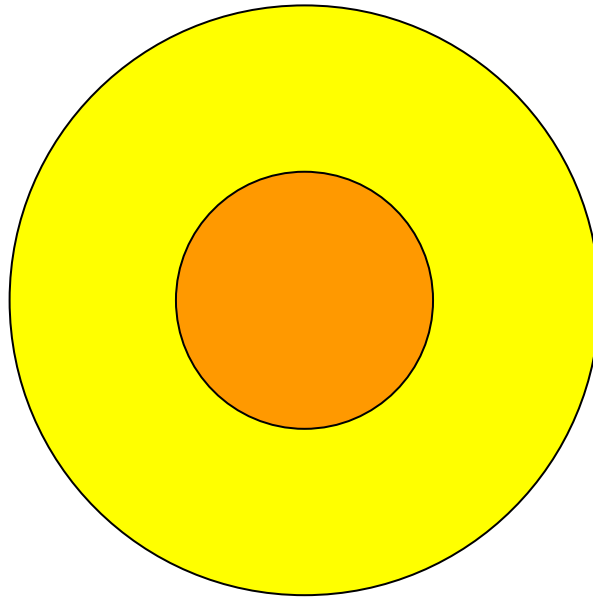
500 Mt, ~200 m



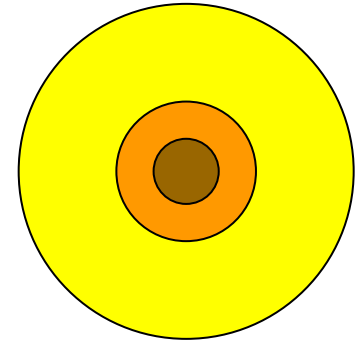
Purdue Impact Simulator results



2 Mt, ~32 m



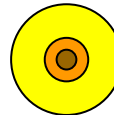
4 Mt, ~40 m



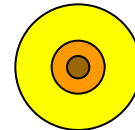
8 Mt, ~50 m



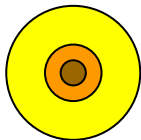
16 Mt, ~63 m



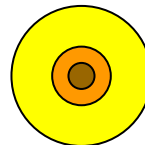
32 Mt, ~80 m



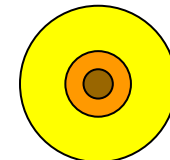
64 Mt, ~100 m



125 Mt, ~125 m



250 Mt, ~160 m



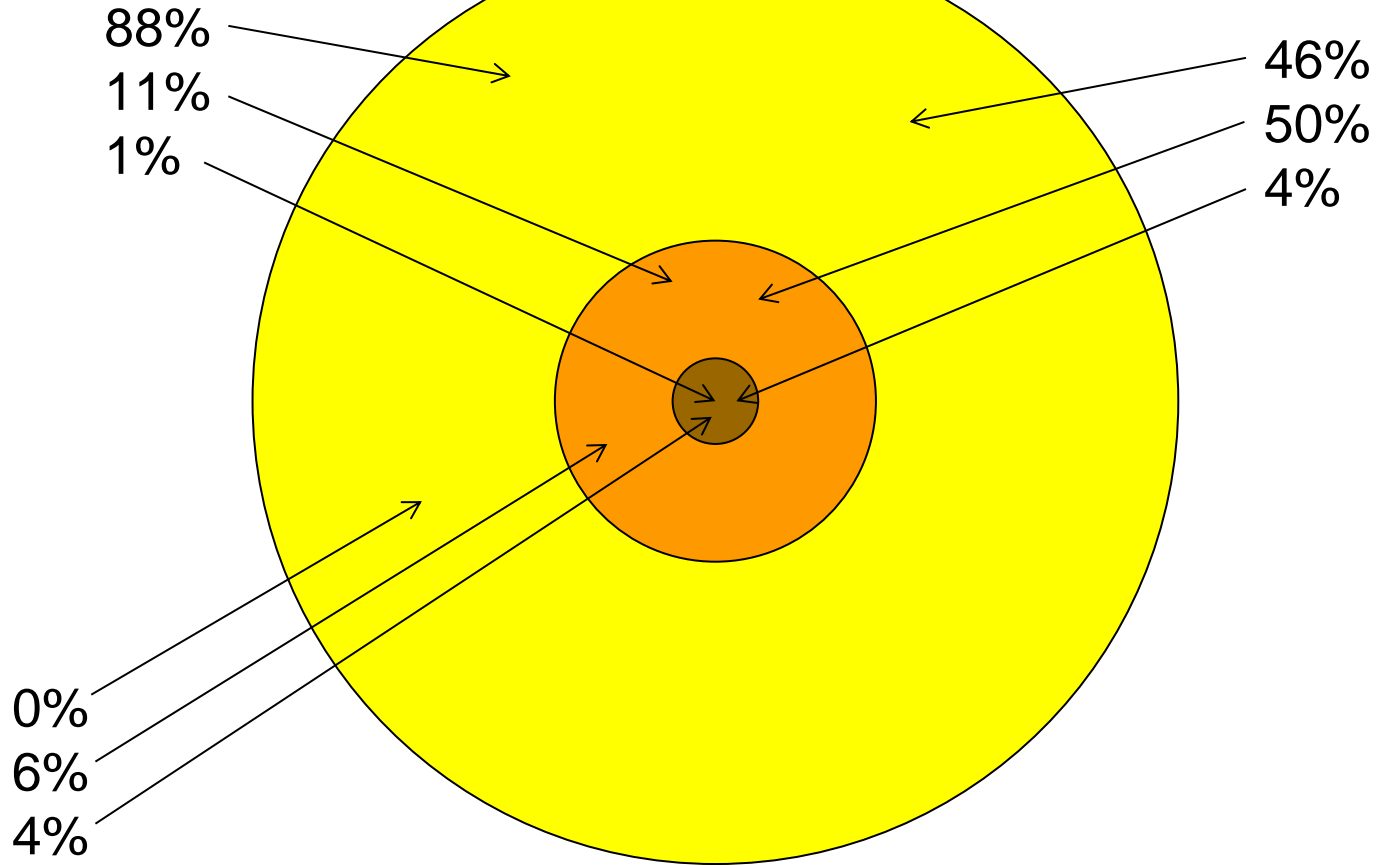
500 Mt, ~200 m

Area weighted by probability of impact of given magnitude

~90% reduction in fatalities for this case

Probability-normalized area

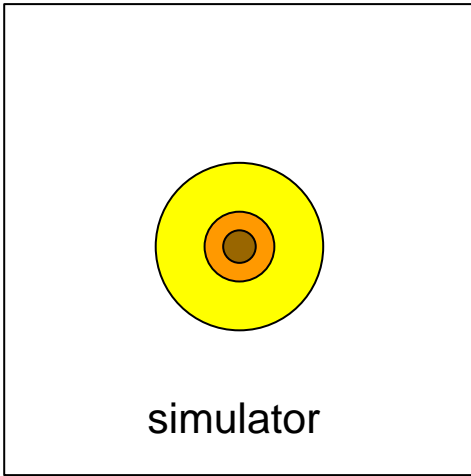
Unsheltered fatalities



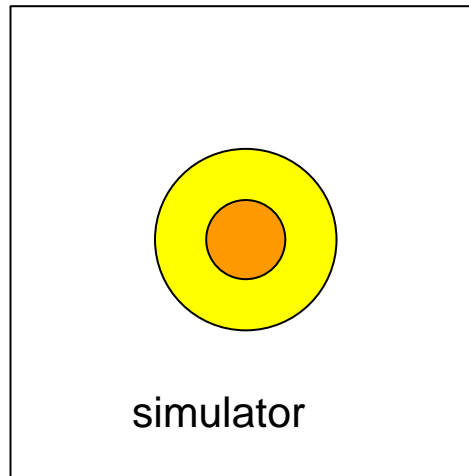
Sheltered fatalities
(percentage of unsheltered)

In this case, 90% of lives are saved by shelter in place

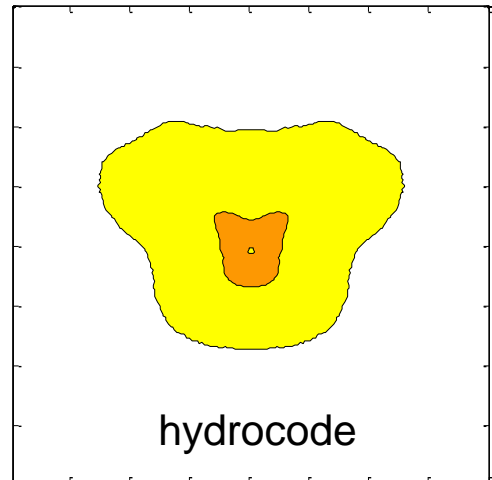
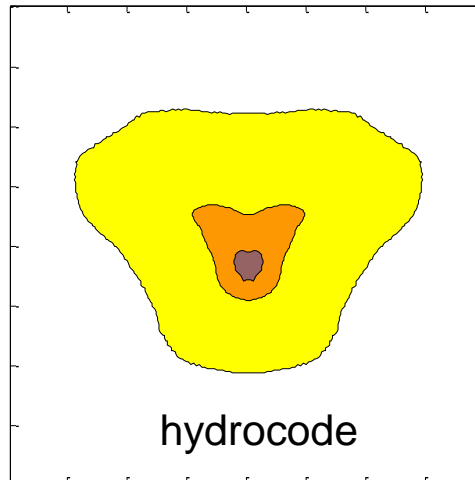
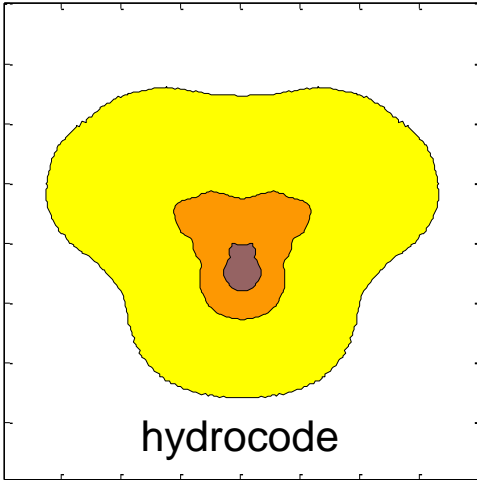
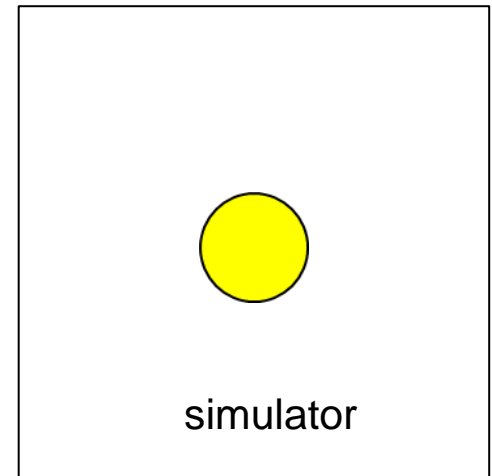
16 Mt



8 Mt

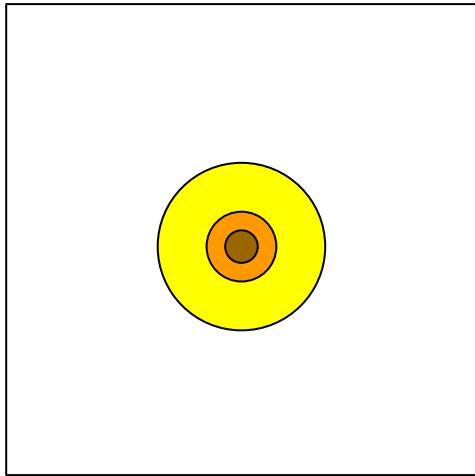


4 Mt

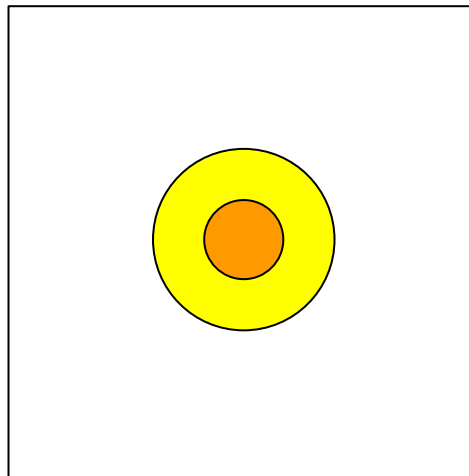


Comparison of simulator to hydrocode

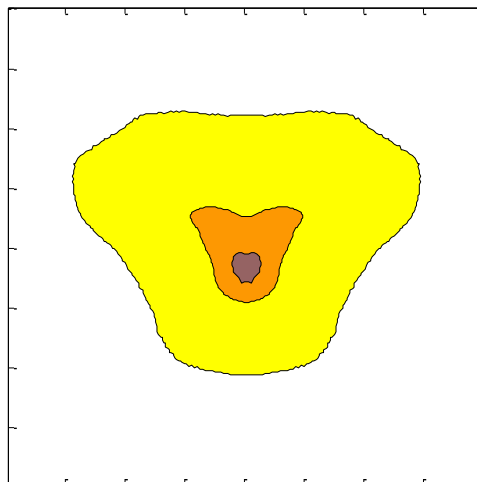
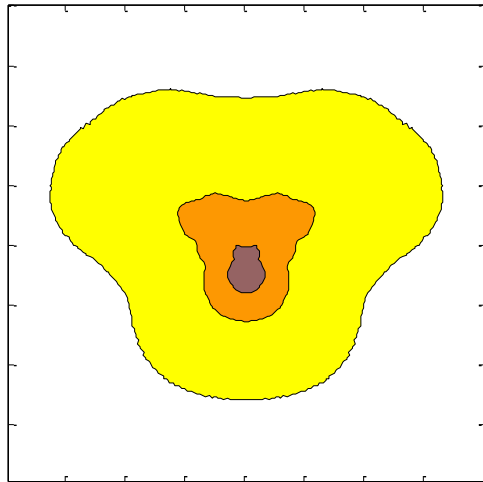
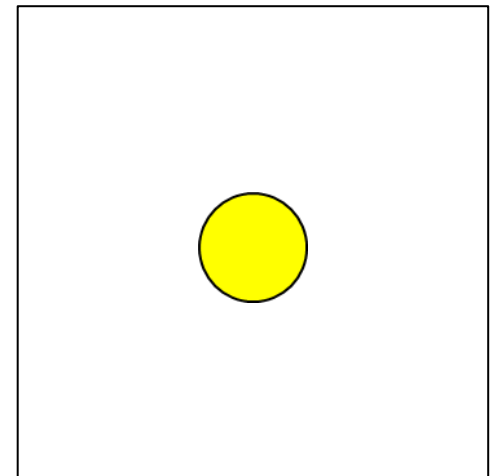
16 Mt



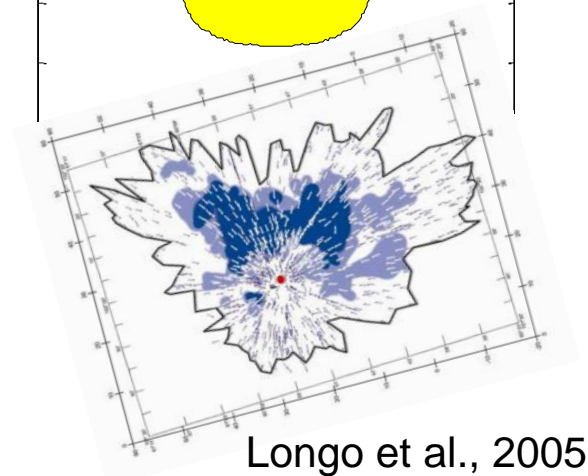
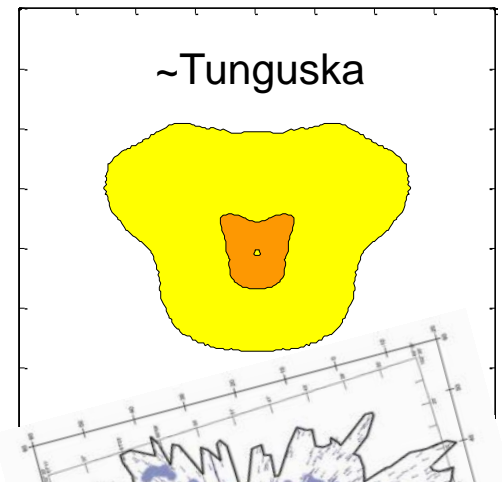
8 Mt



4 Mt

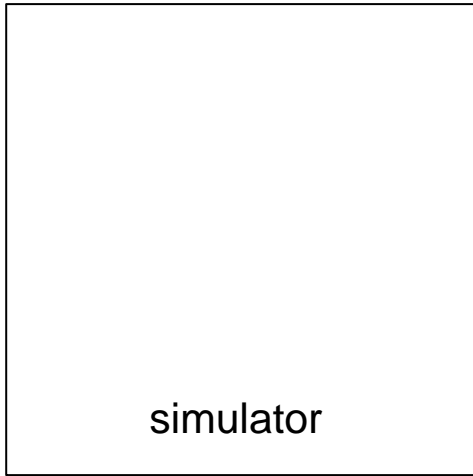


~Tunguska



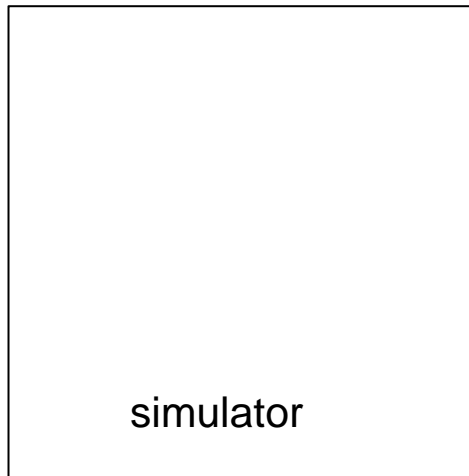
Longo et al., 2005

2 Mt



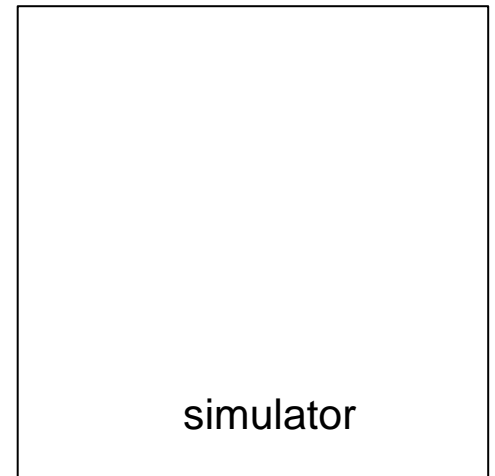
simulator

1 Mt

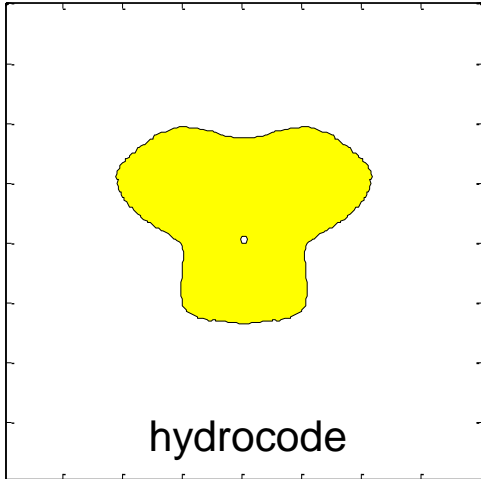


simulator

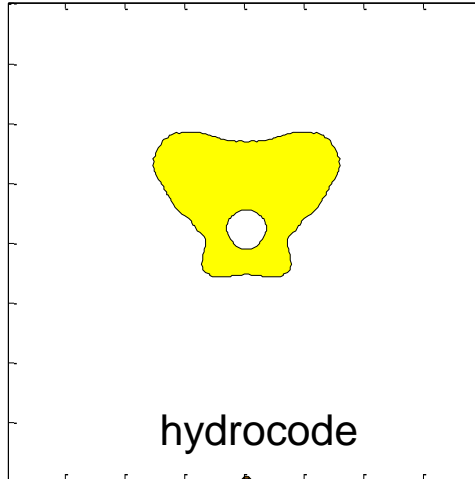
0.5 Mt



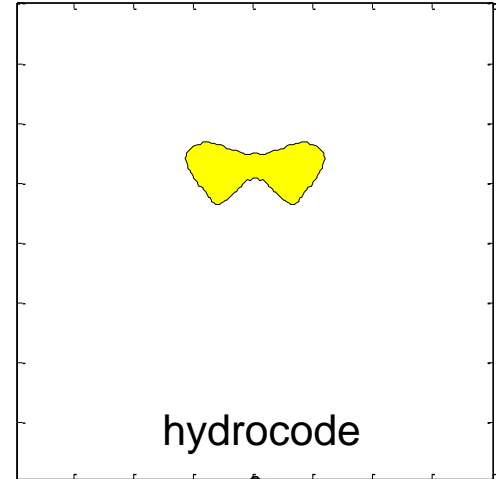
simulator



hydrocode



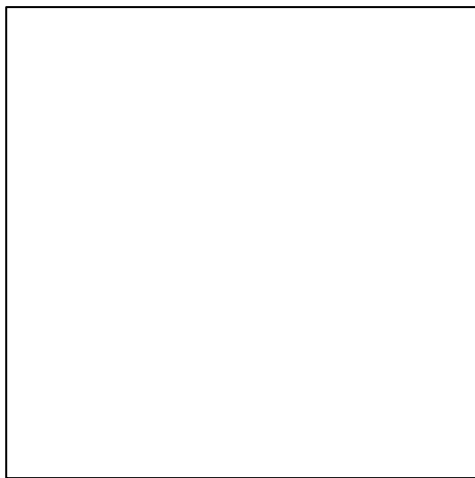
hydrocode



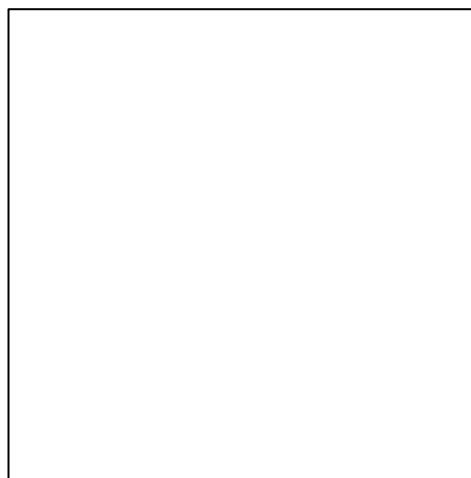
hydrocode

Comparison of simulator to hydrocode

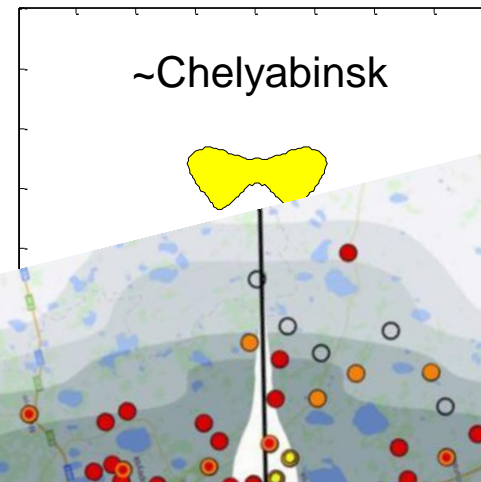
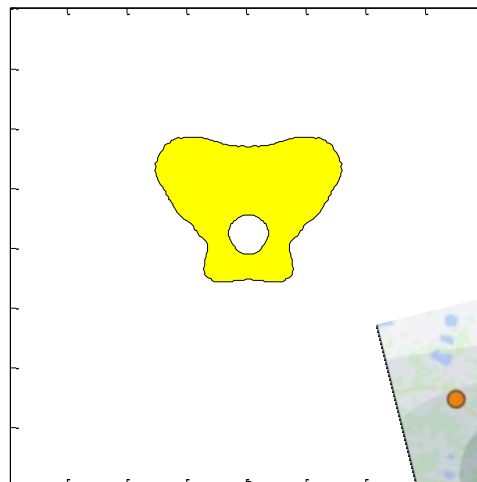
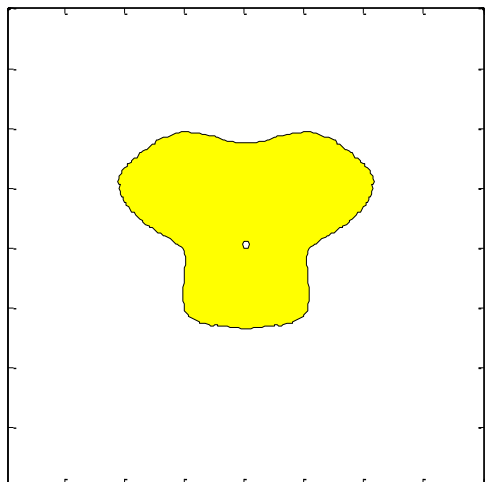
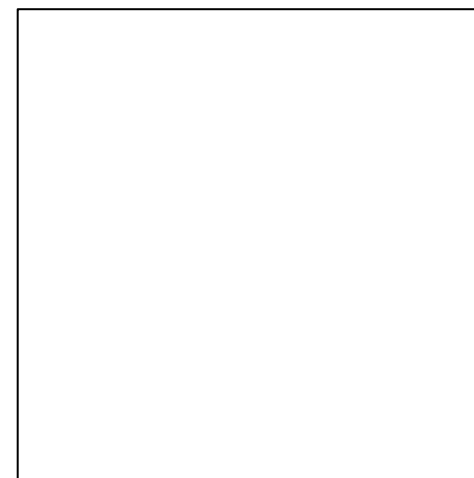
2 Mt



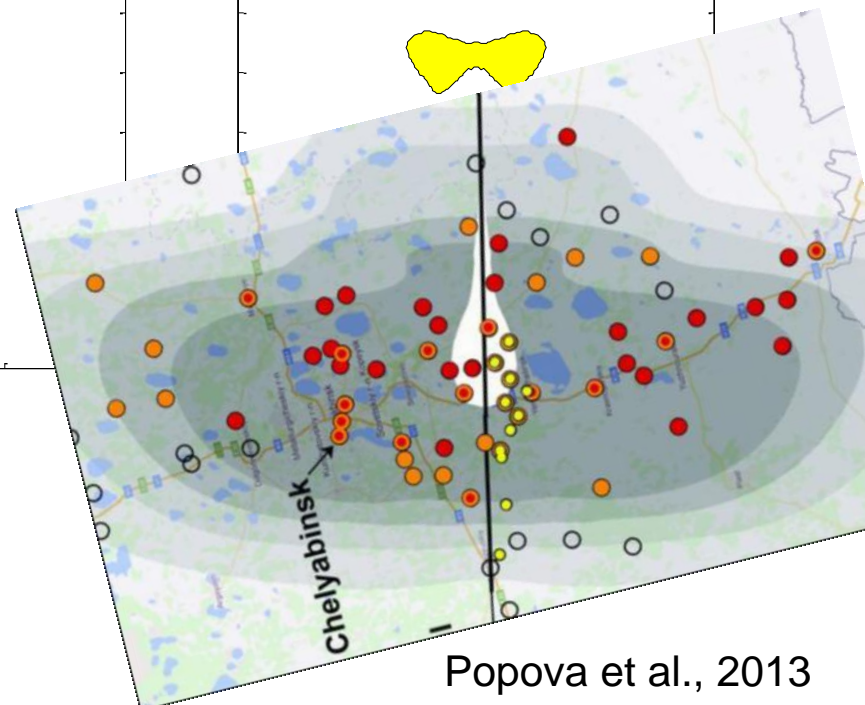
1 Mt



0.5 Mt

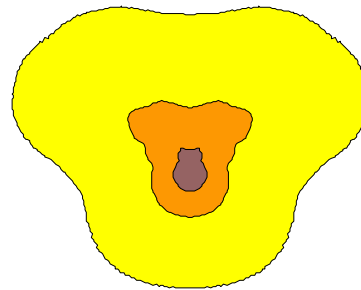


~Chelyabinsk



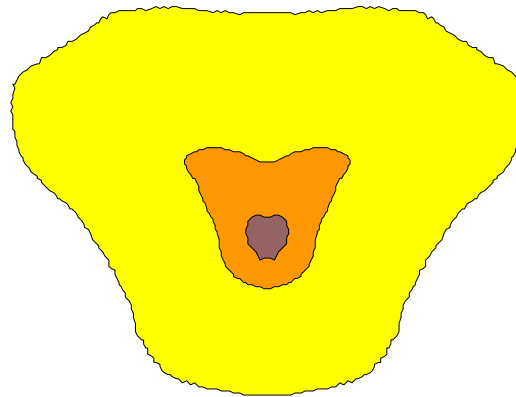
Popova et al., 2013

Probability-weighted area



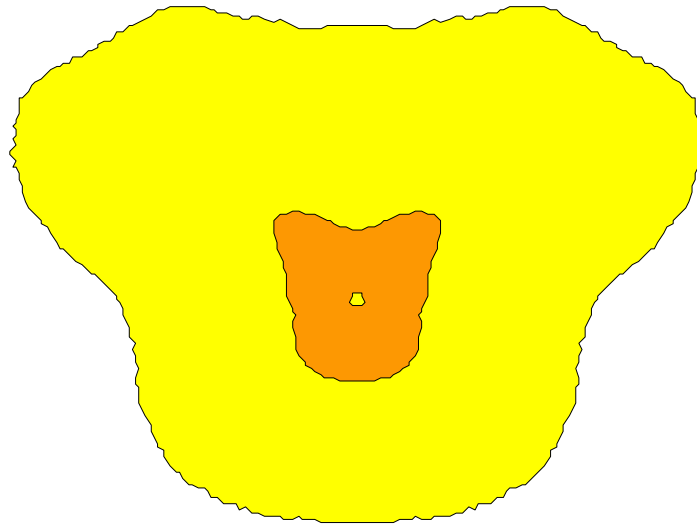
16 Mt

Probability-weighted area



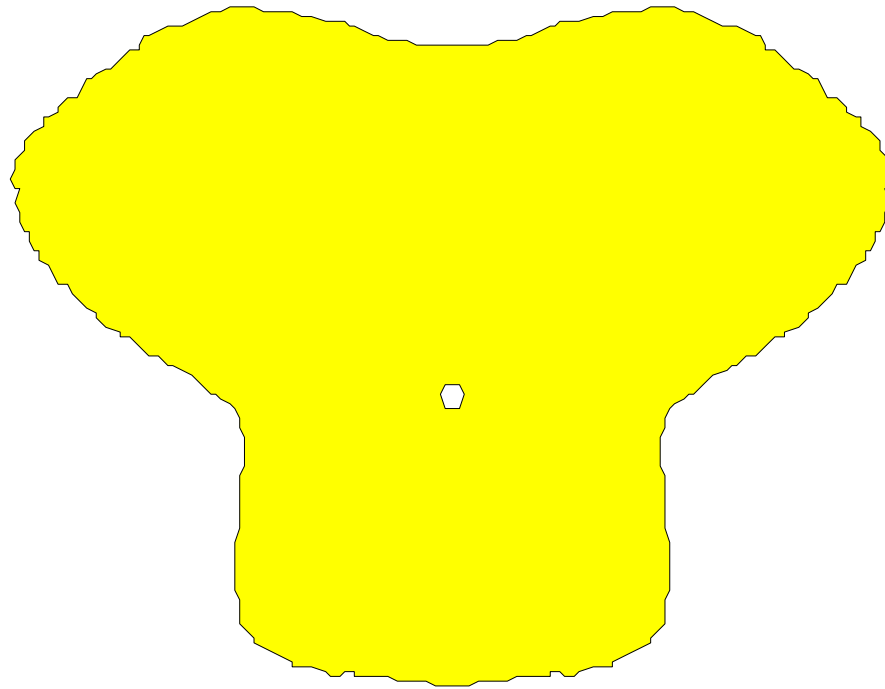
8 Mt

Probability-weighted area



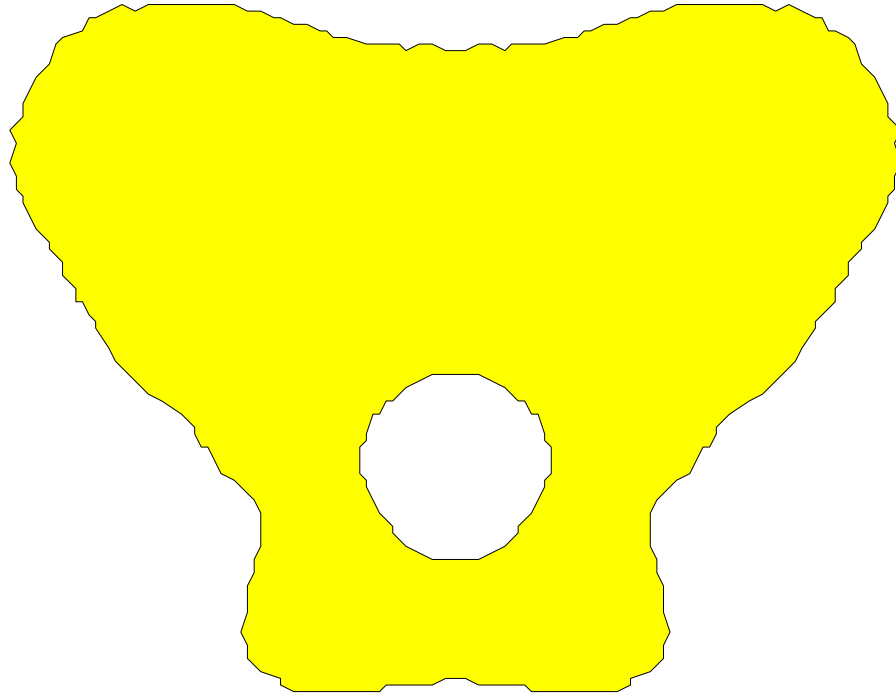
4 Mt

Probability-weighted area



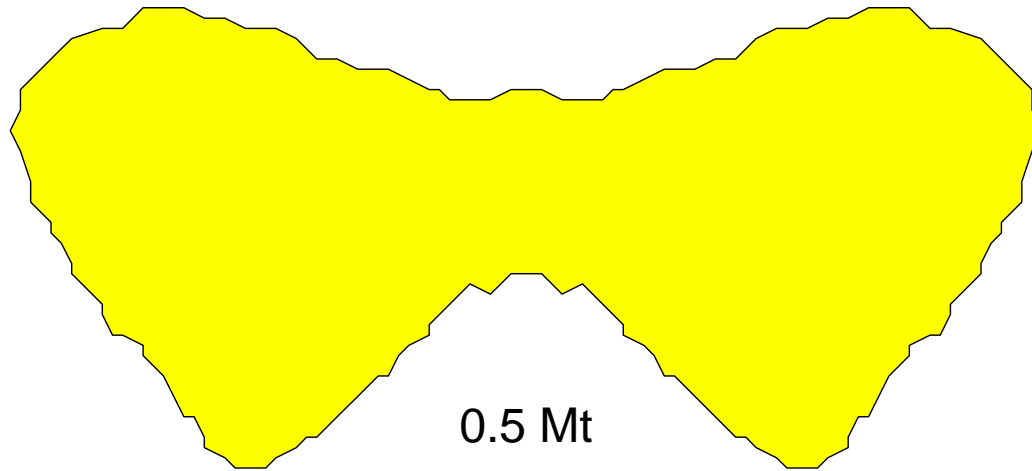
2 Mt

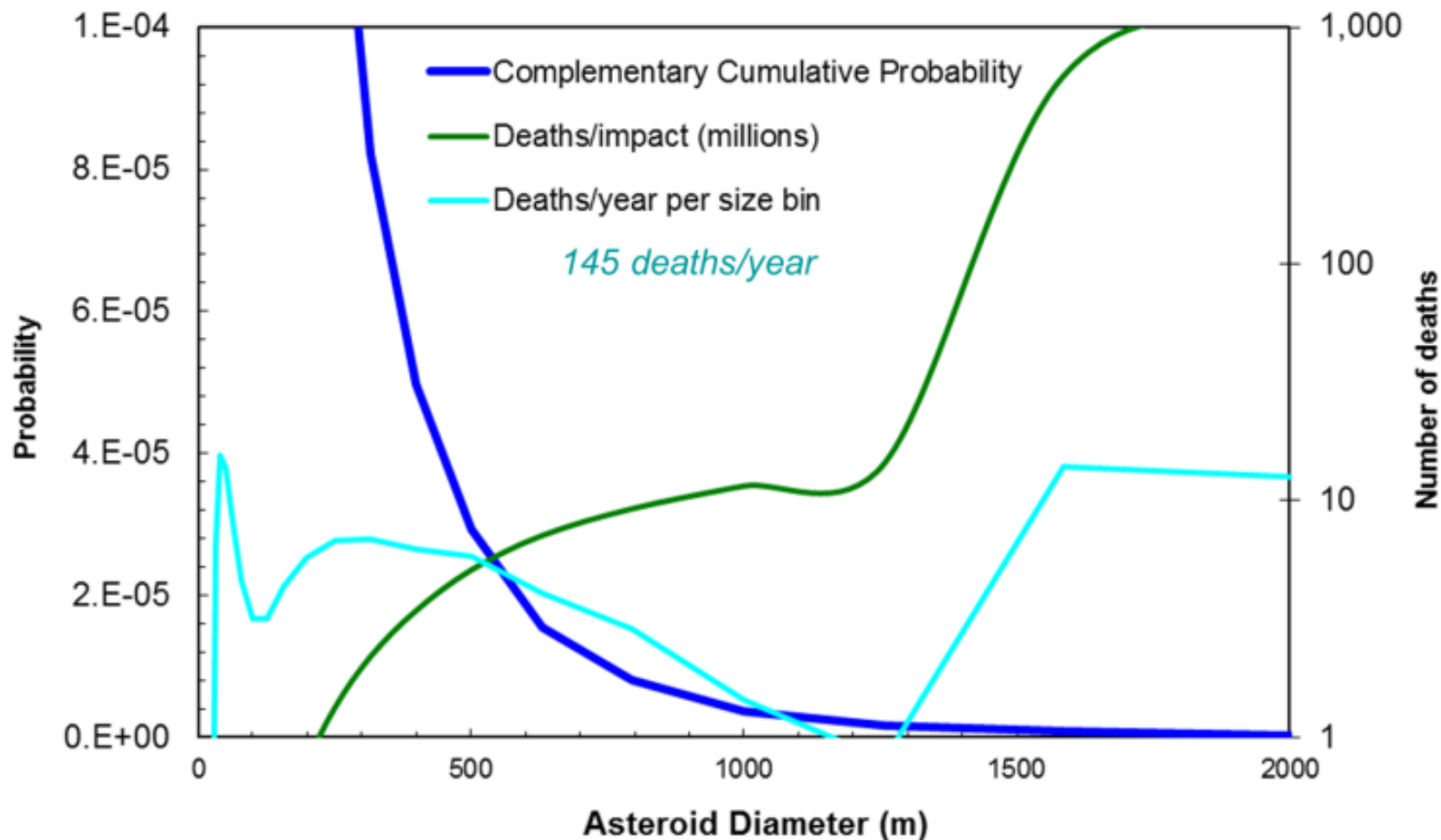
Probability-weighted area



1 Mt

Probability-weighted area





145 deaths/year from current undiscovered asteroids (Boslough et al., 2015)
85 deaths/year from asteroids smaller than 450 m
74 deaths/year avoided (given present assumptions) by shelter in place
~50% reduction in asteroid risk through awareness and education

Conclusions & future work

- Shelter-in-place saves lives
- Exact number depends on assumptions
- Online tool would be useful for policy