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Asteroid Generated Tsunami: Summary of NASA/NOAA Workshop

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Abstract

A two-day workshop on tsunami generated by asteroid impacts in the ocean resulted in a broad consensus that the asteroid impact tsunami threat is not as great as previously thought, that airburst events in particular are unlikely to produce significant damage by tsunami, and that the tsunami contribution to the global ensemble impact hazard is substantially less than the contribution from land impacts.

Workshop Organization

The 2016 Asteroid Generated Tsunami (AGT) Workshop was co-sponsored by the NASA Ames Asteroid Threat Assessment Project (ATAP) and the NOAA Pacific Marine Environmental Lab (PMEL). The two-day workshop, held on August 23-24 at the PMEL facility in Seattle, WA was attended by a multidisciplinary team of experts from NASA (Ames, JPL), NOAA, the DoE Tri-Labs (LLNL, SNL and LANL), DHS, FEMA, and academia to address the hazard of tsunami created by asteroid impacts. Program managers in attendance were Lindley Johnson, NASA Planetary Defense Coordination Office Executive, and Michael Angrove, NOAA Tsunami Program Manager.

The workshop, led by Ethiraj Venkatapathy and David Morrison of NASA Ames, was organized into three sessions: 1) Near-field wave generation by the impact; 2) Long distance wave propagation; 3) Damage from coastal run-up and inundation, and associated hazard. Workshop approaches were to compare simulations to understand differences in the results and gain confidence in the modeling for both formation and propagation of tsunami from asteroid impacts, and to use this information for preliminary global risk assessment. The workshop focus was on smaller asteroids (diameter less than 250m), which represent the most frequent impacts.

Near-field Wave Generation by the Impact

The charge to Session 1 was to model the tsunami-producing potential of airbursts and direct water impacts, and to evaluate the nature of the waves produced. The approach was to model specific airburst cases (energy 5MT, 100MT, and 250MT, corresponding to approximate diameters for stony asteroids of 50m, 125m, and 180m) and also cratering impacts in shallow and deep water. The session organizer was Mark Boslough (Sandia National Labs), and the discussion panel chair was Bob Weaver (Los Alamos National Lab). The speakers were Boslough, Galen Gisler (Los Alamos National Lab), Michael Aftosmis (NASA Ames), and Darrel Robertson (NASA Ames).

The results presented reflect a major improvement in computing capability and code complexity over the models used for the 2003 NASA SDT analysis. Simulations were compared using a variety of both 2D and 3D codes (xRAGE, CTH, ALE3D, and Cart3D). The most sophisticated hyrocodes required supercomputer runs of weeks to months. The Cart3D code was used to evaluate the effects of atmosphere energy deposition based on the NASA fragment-cloud model and angle-of-attack effect that result in non-circular surface damage footprints. The speakers agreed that for both airbursts over water and water impacts with energies of 5MT, 100MT, and 250MT, the resulting waves would not travel long distances. For a given energy, airbursts were less effective in generating waves, but in both cases, the waves formed are essentially circular (unlike a typical seismically generated tsunami) and dissipate rapidly due to the localized nature of the source and the turbulence of the wave. Local damage from impacts into the water may be similar to the cases of landslides into fjords, but these disturbances do not travel far. The potential for severe damage from asteroid generated tsunami over the energy range studied is therefore limited to impacts near the shore, and even in these cases the air blast, fireball, and possible ejection of sediment in shallow water areas may exceed the damage from the wave.

The airbursts modeled, most of which assumed an explosion altitude of 10 km, produced a wave from blast over-pressure. Most of the models did not explicitly consider other explosion altitudes or combined effects of airburst and solid impact on the water. Also not modeled were possible coupling mechanisms that might contribute to wave formation, such as steam explosions, plume ejection and collapse. It is not expected that these effects will substantially change the conclusions, but they deserve further consideration. While there may be conditions under which dangerous waves can be generated (e.g. airburst over very deep water or impact very near shore), the probability of such events is relatively small and therefore they do not significantly contribute to the ensemble hazard. There was a solid consensus among the workshop attendees that impact far from shore of asteroids <250m do not endanger coastal populations and infrastructure, and that the 2003 SDT Report (http://neo.jpl.nasa.gov/neo/report.html) substantially overestimated the hazard from ocean impacts.

Propagation of Waves from Asteroid Impacts

The charge to Session 2 was to determine the ability of near-field impact-produced waves (from Session 1) to propagate over large distances, in deep and shallow water. Since propagation depends on several variables, including size of tsunami, distance of travel, and specific bathymetry along the path, multiple examples are needed to allow some generalizations.

The session organizer was Marsha Berger (New York University), and the discussion panel chair was Robert Weiss (Virginia Polytechnic Institute and State University). The speakers were Berger, Souheil Ezzedine (Lawrence Livermore National Lab), and Vasily Titov (Pacific Marine Environmental Lab/NOAA). Robert Weiss also contributed some model computations. The sites chosen for comparison were the South China Sea, the city of Westport WA, and the Long Beach area in southern California.

The major uncertainty in the presentations in Session 2 concerned the applicability of different computer codes to the propagation of waves described by Session 1. Berger used a computationally efficient code called GeoClaw that solves the Nonlinear Shallow Water Equations, which gives somewhat different results from the more complex Boussinesq codes. Ezzedine and Weiss used different Boussinesq codes. Titov discussed shallow water codes and also results from the NOAA models for predicting the effects of seismically generated tsunami, but he did not present results for the shorter-wavelength waves from impacts. Due to differences in implementation, fidelity and boundary conditions, detailed code comparisons were not possible. Although there were differences in the models, the consensus was that the waves that reached the shore as a result of airburst cases were not significantly different from one another. Only Berger discussed results from the South China Sea, but all of the speakers presented results for the Westport and Long Beach locations.

These models showed that the shorter wavelength waves produced from asteroid airburst or surface impact do not travel for great distances and that they also produce less inundation and flooding when they reach the shore. For these waves, the wave height is not a good measure of the potential damage; we must consider how much water is actually moving. The panelists found it very difficult to produce major inundations even with large (250MT) airbursts near shore.

In the case of Westport, the modest 4m ridge between the city and the sea was not overtopped, although considerable damage was done to the boat harbor. Long Beach, with its very shallow slope, is more vulnerable, but even here a 250MT airburst 18 km from shore does not top the seawall and lead to major inland flooding. One uncertainty, however, concerned the inability of these codes to resolve in detail the interaction of waves with seawalls and other obstacles, including possible focusing effects.

Shore Inundation and Hazard from Asteroid Generated Waves

The charge to Session 3 was evaluation of the threat to humans posed by asteroid-generated tsunami. The presentations overlapped those of Session 2 in examining the inundation and damage from waves for specific locations, but with more detailed damage estimates. The ultimate product was a model for the AGT contribution to the ensemble impact hazard.

The session organizer was Donovan Mathias (NASA Ames), and the discussion panel chair was Steve Chesley (NASA JPL). The speakers were Vasily Titov (Pacific Marine Environmental Lab/NOAA), Randy LeVeque (University of Washington), Barbara Jennings (Sandia National Labs), Cynthia McCoy (FEMA), Lorien Wheeler (NASA Ames) and Mathias. Guest speaker Shunichi Koshimura (Tohoku University, Japan) provided perspective from the 2011 Tohoku earthquake tsunami.

Titov and LeVeque described inundation model results from AGT or seismic events, respectively. Titov showed that very large (250 MT) airburst events could, in some cases, lead to significant inundation at isolated locations even hundreds of km from the airburst due to wave focusing effects. Leveque demonstrated the effectiveness of GeoClaw for modeling inundation from seismic events, but did not explicitly model the kind of waves produced from asteroid impacts.

Jennings and McCoy discussed detailed analyses of the economic and human costs of two hypothetical tsunami events. Jennings focused on the economic effects of a 250 MT airburst over the ocean near Long Beach, using the Department of Homeland Security tool called FASTMap, which allows quick identification of key infrastructure elements. McCoy explored the possible effects of an AGT using HAZUS, a FEMA tool that is in development and used to estimate the effects of various natural disasters. She emphasized the need for properly reinforced construction techniques to mitigate the damage from a tsunami inundation, and the importance of evaluating evacuation times and routes.

Wheeler and Mathias presented perspectives on the ensemble risk based on NASA Ames "engineering models". Mathias concluded that the current assessment of the AGT hazard is substantially reduced relative to the best understanding from a decade ago. He noted that the modeling results presented earlier in the workshop consistently showed less efficient coupling of the impactor energy into wave production, and lower damage from short-wavelength waves. The ensemble hazard assessment concluded: (1) The impact tsunami hazard is negligible for asteroid diameters below 200m. (2) For asteroids larger than about 300m, the risk peaks at about an order of magnitude lower casualty rate than the land impacts. (3) Larger than about 500m the global risk (based on previous work) dominates over either land or ocean impact. (4) The average annual casualties from land and ocean impacts (not including global effects) are in the range of 1-10.

Workshop Summary Discussion

The workshop concluded with a general discussion moderated by Steve Chesley (NASA JPL). These summary comments are drawn from that and other discussions throughout the AGT workshop.

Individual vs. ensemble risk. There is an important difference between the treatment of risk from individual impacts with specified targets and the ensemble risk from the entire asteroid population. Individual cases require detailed knowledge (or assumptions) about the nature of the impactor and the target, taking into account ocean bathymetry, shore configuration, breakwaters, and distribution of infrastructure and population. Evaluation of the global ensemble hazard, in contrast, is based on weighted averages over a wide range of conditions, which can be estimated with less precise engineering models. One of the objectives of this workshop was to investigate what level of precision is needed to move from individual cases to the global ensemble risk.

People affected vs. casualties vs. damage. There is no uniform, accepted approach for how to estimate the cost associated with AGTs. In the 2003 SDT Report (http://neo.jpl.nasa.gov/neo/report.html), inundation was used to estimate the number of people affected, with no attempt to determine the number or cost of actual casualties. Some subsequent estimates of tsunami casualties have arbitrarily assumed, based on the likelihood of some warning, that 10 percent of the affected population would be killed, with the other 90 percent "wet and angry". More detailed FEMA and DHS tools discussed at the workshop can provide infrastructure damage estimates for specific scenarios, but cannot effectively be used to understand the ensemble risk. It is important when discussing impact hazards to state clearly what metrics are being used.

Actuarial approach vs. focus on catastrophic events. A recurring issue within the impact hazard community is the challenge of properly analyzing and communicating the impact threat. Traditionally, the metric used has been average annual fatalities, a metric that does not convey the rarity or severity of catastrophic events. As an illustration, asteroids may kill 100 people per year on average, but this derives mostly from events affecting a million people on 10,000- year intervals. That is clearly not the same thing as, e.g., commercial airline crashes, which may have a comparable annual fatality rate, which is actually realized year after year. The contour-style hazard plots presented by Mathias help to quantify the episodic, catastrophic threat posed by asteroid impacts and thus represent a new and useful tool for decisions makers.

Characterizing uncertainties. To get from an impact flux to a damage rate for either ocean or land impacts, there is a long chain of modeling challenges. Uncertainty estimates are more important for evaluating individual threats than for estimating the ensemble risk. In either case, estimates of uncertainty need to be communicated to stakeholders and decision makers.

Workshop Conclusions and Recommendations

The Workshop on Asteroid Generated Tsunami achieved its primary goals of re- evaluating the tsunami risk from impacts by small (<250m diameter) asteroids using modern codes and simulations, and providing a better estimate of the ensemble risk from water impacts.

Any evaluation of impact hazard requires knowledge of the population of impacting asteroids. Recent work on population has shown that the impact frequency once identified for asteroids a few hundred meters in diameter was too high, and that the overall impact frequency for asteroids in the range 30-300m is about a factor of three lower than once assumed. This is a contributing factor in the lowering of the tsunami threat relative to that estimated for the 2003 SDT report (http://neo.jpl.nasa.gov/neo/report.html).

Airbursts over water are not likely to generate substantial tsunami-like waves. The waves generated by water impacts are quite different from seismically generated tsunami, having shorter wavelength and higher turbulent dissipation. There was a broad consensus that the tsunami threat is not as great as previously thought (as stated by the 2003 NASA SDT Report), but there are variations in the degree of confidence among the participants because of the limited number of cases that were modeled and the possibility that we have missed something important.

In the case of airbursts and surface impacts from objects less than about 250m diameter, most damage to coastal populations is limited to impacts close to the shore, in which case the direct blast damage may be more important than the wave generated. Detailed evaluation of the inundation is highly dependent on the near-shore bathymetry and shore configuration; these effects generally require higher resolution models than those used in the workshop. The risk from near-shore impacts may be important for considering individual cases, but they do not contribute significantly to the ensemble hazard.

Mathias summarized the ensemble hazard as follows: (1) The impact tsunami hazard is negligible for asteroid diameters below 200m. (2) Larger than about 300m, the tsunami hazard peaks at about an order of magnitude lower casualty rates than the hazard from land impacts. (3) Larger than about 500m the global hazard (based on previous work) dominates. (4) The average annual casualties from land and ocean impacts (not including global effects) are in the range of 1- 10 persons per year.

Follow-on activities recommended by the participants included:

(1) Additional modeling of airbursts to better understand effects such as high wind speeds, potential for wind-wave generation, meteo-tsunami, and storm surge. One attendee stressed that study should be done to see if other important effects have been neglected such as steam explosions from the high temperatures of the shock heated air.

(2) Modeling of the combined effects of airburst and surface impact, which is a likely scenario for impact by stony asteroids.

(3) Consideration of the shortcomings of Nonlinear Shallow Water Equations for simulation of waves generated during an airburst or impact. Options to be considered include the use of Boussinesq or incompressible three-dimensional Euler or Navier-Stokes solvers. An important first step would be to bound the discrepancy shown at the workshop for a simple study of a radially symmetric model airburst problem with a Long Beach type barrier.

(4) Development of an interagency collaboration in the multidimensional analysis of ocean impacts by asteroids.

(5) Collaboration on the study of a 300m impactor striking in the mid-Pacific with a focus on predicting network signals and the proper interpretation of these data for tsunami warnings.

(6) Use of higher-level tsunami codes and hazard assessment tools to validate engineering models for a range of specific events.