LA-UR-17-21595

Title:	Deep Water Impact Ensemble Data Set
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Intended for:	Representative data set for Intel in their continued system development for Trinity. Report Web
Issued:	2017-02-24

Deep Water Impact Ensemble Data Set

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February 17, 2017

1 Introduction

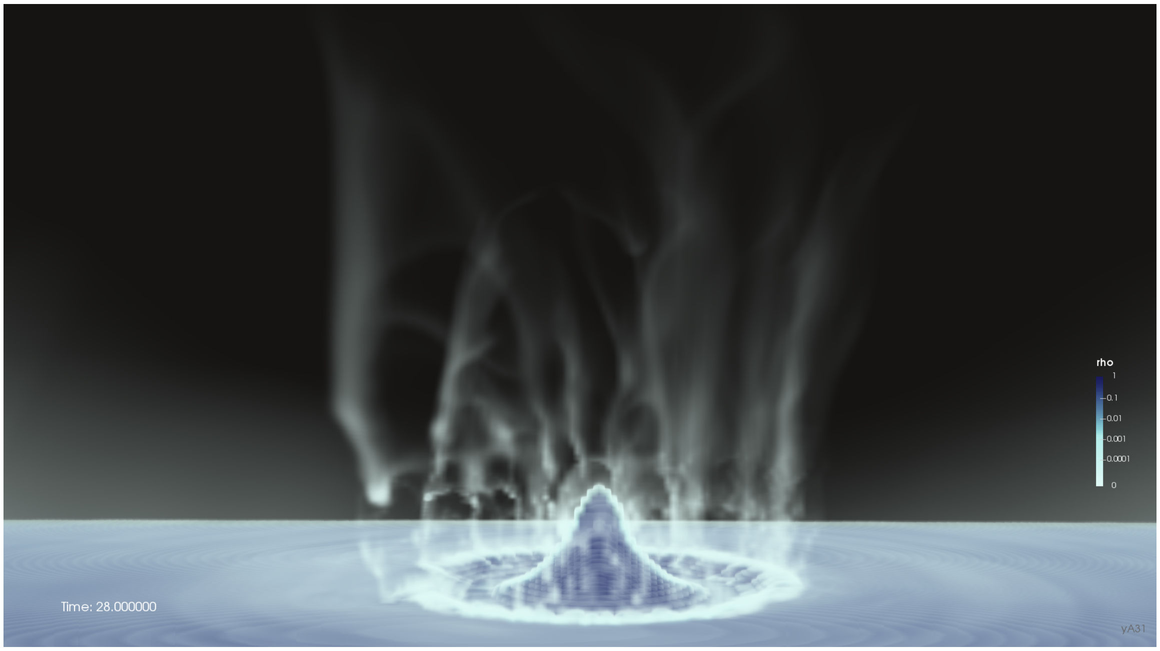

Figure 1: A representative image of the yA31 ensemble member after the asteroid impact.

This ensemble data set represents the study of asteroid impacts in deep ocean water. NASA's Planetary Defense Coordination Office [1] is keenly interested to know the lower size limit of dangerous asteroids, so as to focus resources on finding all larger objects that potentially threaten the earth. Since most of the planet's surface is water, that is where asteroids will most likely impact. This observation has generated a serious debate over the last two decades on just how dangerous impact-induced waves or tsunamis are to populated shorelines.

Galen Gisler, is a Los Alamos scientist who is interested in many aspects of asteroids, their interactions with the earth, their potential for harm and what we can do about it. To simulate the asteroids potential to generate tsunamis, Dr. Gisler used xRage [2], a parallel multi-physics Eulerian hydrodynamics code that is developed and maintained by the ASC program at LANL. xRage uses a continuous adaptive mesh refinement technique that allows smaller computational cells in areas of interest and larger, thus fewer, cells in other areas, which enables more efficient use of the supercomputer. All of the data in the ensemble, discussed here, was saved using the ParaView Catalyst [3] in situ capability integrated into the xRage simulation code during the 2013 CSSE L2 Milestone: Case Study of in Situ Data Analysis in ASC Integrated Codes [4].

An ensemble was produced by running a series of 3D simulations consisting of three materials: water, air, and asteroid. In all cases the simulation starts with an asteroid falling to earth from the upper atmosphere at a high velocity. The atmosphere and water start in a static state with no kinetic energy. The computational grid is made as small as sufficiently possible while allowing the asteroid to come in at an angle from the longest dimension, impact the center of water surface, and not make the crater in the water extend to the ocean floor. The ensemble data set represents the varying of three variables for asteroid impacts into deep ocean water. First, the elevation of an airburst. Airbursts happen when the asteroids interaction with the atmosphere causes it to explode before impacting the surface. This was notable in the 2013 Chelyabinsk meteor [5] whose explosion was captured on numerous video streams and was responsible for much damage. An airburst could possibly cause the transition of kinetic energy from the asteroid into the water to be more coherent and change the likelihood of tsunami generation. The second variable is size. We know that small asteroids on the order of 1 meter diameter enter the atmosphere biweekly, but the driving force that led to these simulations was searching for the smallest asteroid that would generate a tsunami that could reasonably travel dozens to hundreds of kilometers to reach distant shores, so the sizes ranged from too small to too big, but not planet killers. The third variable is the angle of entry which is important as we cannot forecast at what angle any given asteroid will impact our atmosphere

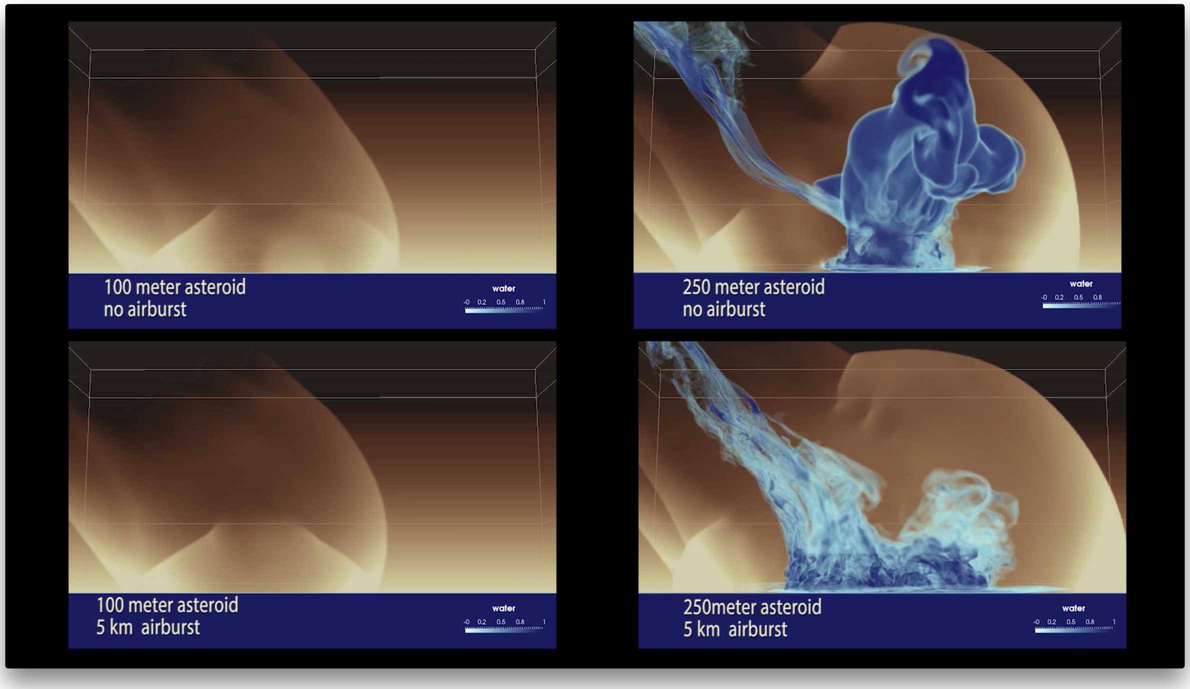

Figure 2: An image from the Supercomputing 2016 presentation showing aspects of the ensemble: asteroid size, airburst and angle.

and planet. For tsunami generation, a more oblique angle could possibly push the water in a more coherent direction increasing the likelihood of tsunami generation. A more oblique angle also increases the amount of time the asteroid spends in the atmosphere and therefore, increases the amount of ablation opportunity before the impact, possibly making a smaller impactor.

2 Data Set Details

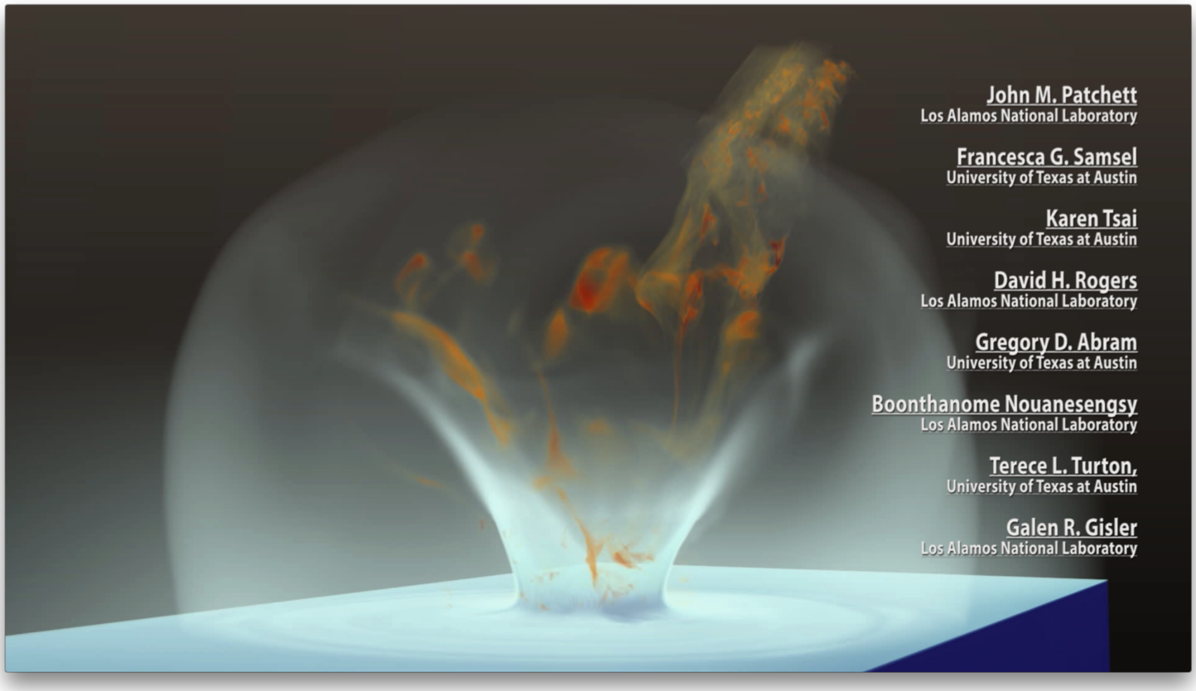

Figure 3: A frame from the Supercomputing 2016 video credits showing a volume rendering of the expanding shockwave after the impact.

2.1 Ensemble Member Naming Convention

Each ensemble member has a four character coded name to describe its combination of parameters: reserved, airburst, size and angle. Table 1 summarizes the positional meaning of each of the four characters and possible values that make up the ensemble member name. The first letter is reserved to track different instantiations of the simulation setup and is meaningful only to the domain scientist. It is a lowercase letter: {x,y,z}. The second letter in the name is a capital letter{A,B,C,D} and represents the four different airburst scenarios that are represented in the ensemble: None, 5 km, 10 km and 15 km elevation airburst, respectively. Figure 2 shows aspects of the ensemble from a presentation at Supercomputing 2016 discussed in section 3. The third position is a number {1,3,5} and represents the three different basalt asteroid diameters represented in the ensemble: 100, 250 and 500 meter, respectively. The fourth and final is a number {0,1,2} and

First Character	Second Character	Third Character	Fourth Character
reserved {x,y,z}	Airburst {A,B,C,D}	asteroid diameter {None, 1,3,5}	entry angle {0,1,2}

Table 1: The four characters and possible values in the ensemble member name.

Deep Water Impact Data Set Naming Convention
1st Character - No Intrinsic Meaning
2nd Character - Airburst [A] No airburst, full asteroid impacts water. [B] Airburst at elevation of 5 kilometer above sea level. [C] Airburst at elevation of 10 kilometers above sea level. [D] Airburst at elevation of 15 kilometers above sea level.
3rd Character - Asteroid Diameter [1] No Airburst, full asteroid impacts water. [3] Airburst at elevation of 5 kilometer above sea level. [5] Airburst at elevation of 10 kilometers above sea level.
4th Character - Angle Of Entry [0] Asteroid initialized with 27.4 degree momentum. [1] Asteroid initialized with 45 degree momentum. [2] Asteroid initialized with 60 degree momentum.

Table 2: Summary of the four character ensemble member naming convention.

it represents the three angles of entry: 27.4, 45 and 60 degrees off of the horizontal. Table 2 summarizes the details of the ensemble member naming convention.

2.2 File Formats and Naming

Each member of the ensemble data set is stored in a series of XML Visualization Toolkit (VTK) multiblock data set (vtm) files that combine VTK unstructured grid (vtu) files. Each vtm file contains pointers to vtu files in a subdirectory of the same name. Each vtm file represents a specific time step of a specific ensemble member. The top level directory will contain an ensemble member name and within that directory will be a series of vtm files named pv_insitu_*cycleNumber*.vtm and associated directories pv_insitu_*cycleNumber* containing the vtu files, where *cycleNumber* is a place holder for the actual cycle number, or time step index, of the simulation.

2.3 Scalar Fields

Eleven scalar field variables in the form of cell data are contained in the data set. They are density, pressure, temperature, velocity in x, velocity in y, velocity in z, sound speed, AMR grid refinement level, material ID, volume fraction of water and volume fraction of asteroid. They are labeled: 'rho', 'prs', 'tev', 'xdt', 'ydt', 'zdt', 'snd', 'grd', 'mat', 'v02', 'v03' , respectively. Three of these, temperature, volume fraction of water and asteroid, can be seen simultaneously in the visualization in Figure 4. Following is a list with a short description and units, where appropriate for each variable:

rho density in grams per cubic centimeter. (g/cm^3)

prs pressure in microbars (μbar)

tev temperature in electronvolt (eV)

xdt x component vectors in centimeters per second (cm/sec)

ydt y component vectors in centimeters per second (cm/sec)

zdt z component vectors in centimeters per second (cm/sec)

snd sound speed in centimeters per second (cm/sec)

grd AMR grid refinement level

mat material number id

v02 volume fraction water

v03 volume fraction of asteroid

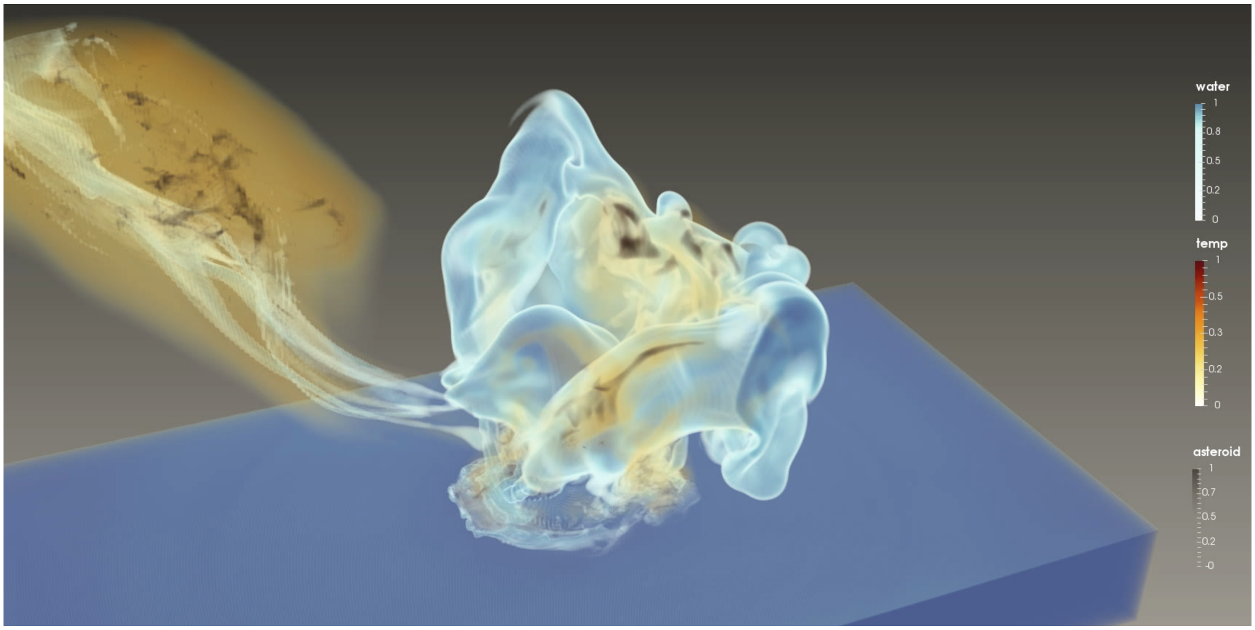

Figure 4: From the 2017 CHI submission, a volume rendering of the water, asteroid and temperature. Note the transparency of the temperature enables you to see the structure of the asteroid fragments, shown in dark brown within the ochre of the temperature. The trail to the left of water plume is a combination of water and asteroid particles exiting up the asteroid entry path via the vacuum created by its entry.

(a) Approach (b) Impact (c) Aftermath

Figure 5: From Supercomputing 2016 Visualization Showcase submission. A 250 meter wide asteroid impacting deep water at 45 degrees with no airburst. High concentrations of asteroid are shown in reddish tones while water is indicated in blue and temperature in yellow. In the simulation, ocean depth is 5 km with 23 km of atmosphere. Total simulation spatial dimensions span 28 km vertically with an area of 46 km by 24 km.

3 Ensemble Data Set in Use

The Deep Water Impact Ensemble Data Set has been presented in meetings and conferences. Results from the ensemble runs were presented at the Second International Workshop on Asteroid Threat Assessment: Asteroid-Generated Tsunami (AGT) and Associated Risk Assessment [6]. Galen Gisler used the simulation results to argue that smaller asteroids less than 130 meters in diameter do not pose a serious threat of generating tsunami. His talk can be found on the workshop's website.

A video submission was made to the Supercomputing 2016 Scientific Visualization Showcase which won the Best Scientific Visualization & Data Analytics Showcase Award [7]. Accompanying the video was short paper [8]. Figures 5 and 6 are from that supercomputing short paper submission. The goals of the submission were to showcase high performance computing and why it matters, how visualization can support scientific discovery, relevance of visualization to the HPC community and highlight the current state of practice.

With the above presentations and awards coupled with Dr. Gisler's presentation of the ensemble results at an AGU FALL Meeting [9] press conference focused on defending our home planet, we received a lot of media coverage. This included online articles, blogs and usage of the visualizations at space.com, gizmodo, Interesting Engineering, Discover Magazine and Smithsonian. Most of the media coverage occurred in December of 2016 and January of 2017.

Another work based on the deep water impact ensemble data set was accept at CHI 2017 [10]. This work describes hands on work flow issues specific to exploring ensembles of large scientific data, innovations in exploring such data ensembles with color and examples of multidisciplinary collaboration. Figure 4 shows a figure from this CHI paper with simultaneous volume renderings of 3 different scalar fields.

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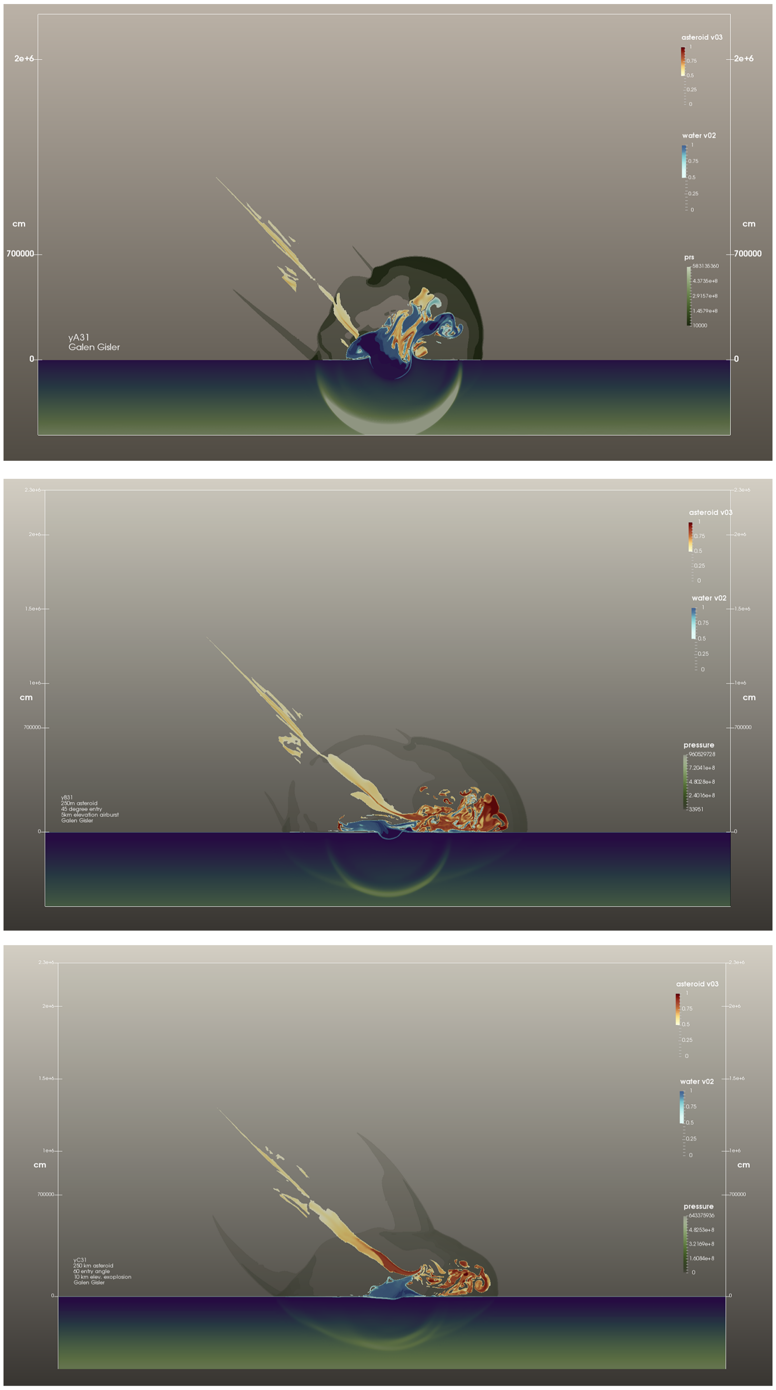

Galen Gisler 250m asteroids, Airburst elevation A- 0, B- 5km, C- 10km

Figure 6: From Supercomputing 2016 Visualization Showcase submission. Visualization showing asteroid material (reddish), water (blue and green), and pressure wave (transparent circle) for three different simulations in which the height of the airburst was varied. The images are from the same time step (20) in each simulation. In the top image, the airburst was at 0 km (impacting the surface), in the middle the airburst was at 5 km, and at the bottom the airburst was at 10 km. Note the profiles of the pressure waves, showing the difference in how the kinetic energy was transferred to the water.