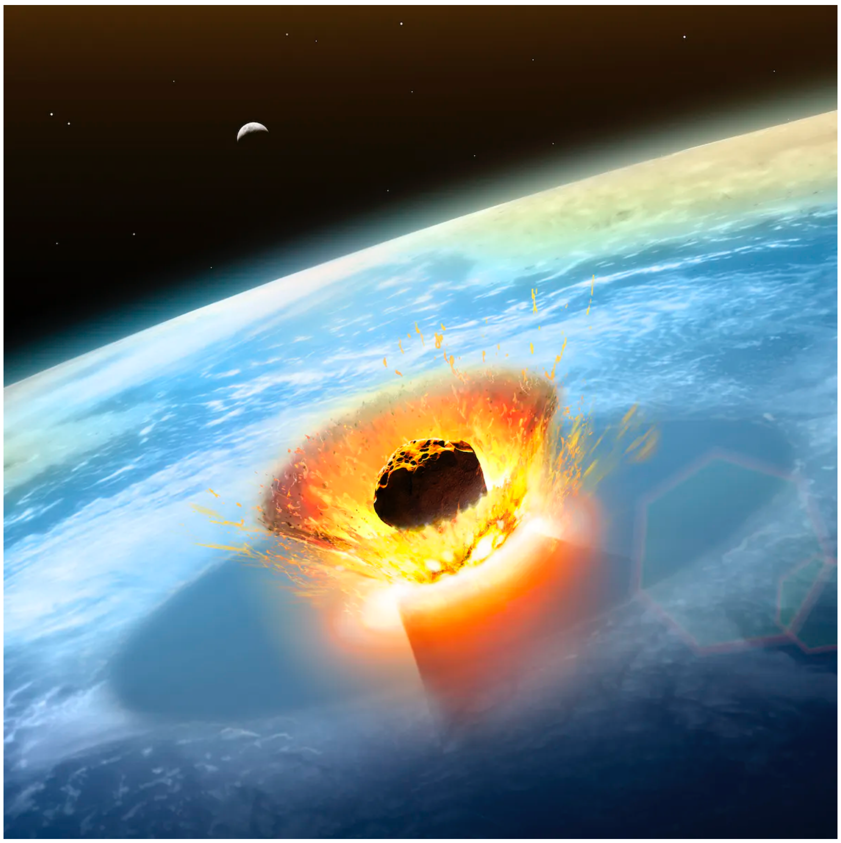
Deep Water Impact Asteroid Simulation



Semester Project Proposal

SciVis (ENGR-E484/E584) – Fall 2022

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Your semester project will be based on one of the past or current IEEE Scientific Visualization Contests. You will be assigned to a group of three students based on your expressed interest in the contest topics. By following these contest topics and data, we will dramatically simplify the process of finding, formatting, and cleaning data. It will also clarify the tasks that scientists want performed with the data and provide examples of potential solutions submitted by prior contestants. You will be asked to expand the set of tasks to include a communication/outreach/education plan with a complementary set of visualization products. The majority of your visualization work is expected to be carried out in ParaView.

1. Topic Summary (0.5 pt)

On February 15, 2013, a small asteroid entered Earth's atmosphere. As it entered the atmosphere, the asteroid exploded at a height of around 29.7 km over Chelyabinsk in Russia. Three years after this incident, NASA founded the Planetary Defense Coordination Office to track and document Near Earth Objects which are potentially hazardous. This field of science is important since it could prepare us to deal with the catastrophic consequences of an asteroid's impact. 71% of the Earth's surface is covered by water, and any asteroid entering the Earth's atmosphere is likely to impact a water body, resulting in a Tsunami Additionally, the majority of the population lives near the coast, so it is important to model how large an impact must be to produce a hazardous tsunami. If impacts can create tsunami waves that can propagate efficiently over long distances, they could pose a significant risk.

2. Visualization Tasks (1 pt)

2a. Scientific Tasks

The goal of this contest is to develop visualizations to communicate new insights of an asteroid ocean impact. The specific scientific tasks the contest requires to address for research/technical audience are:

1. Describe/summarize the dataset (could be done at the level of individual simulations, or discrete time steps). As part of this task, graphic representations of information (such as images, videos, narratives, charts, maps, and numerical values) could be included to enhance the summary.
2. To examine and respond to the following inquiries resulting from the study of asteroid-generated tsunamis:
    a. Are tsunamis generated by an asteroid impact?
    b. If generated, what are the near and far field effects of the impact
    c. The major events of simulation, their time of occurrence and how can we decide about the events
    d. The effect of the size of the airburst on waves generated
    e. The effect of angle of impact on the crater, tsunamis, near and far fields
    f. Any unexpected things and discontinuities about the data

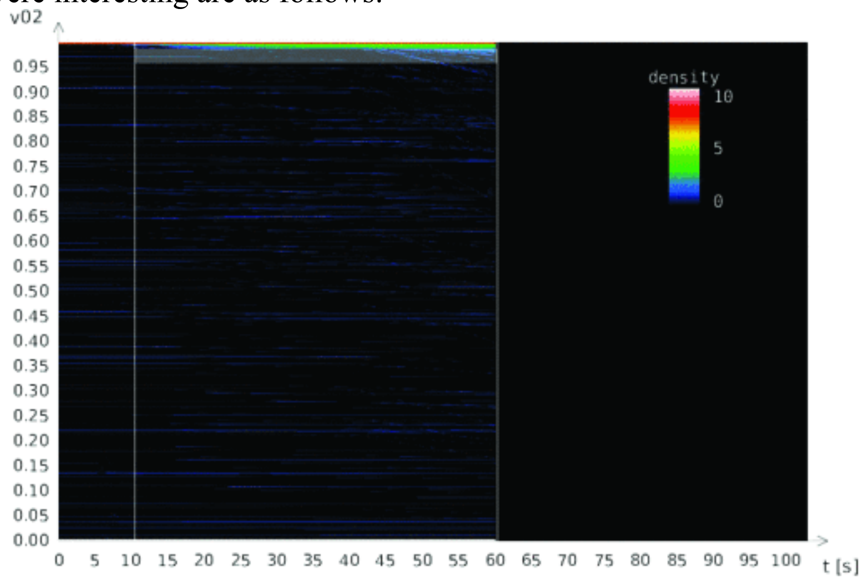
2b. Outreach/Communication Tasks

Our plan is to create an infographic containing sample visualizations and short write-ups of the background, aim, motivation, and importance of visualizing deep water asteroid impacts.

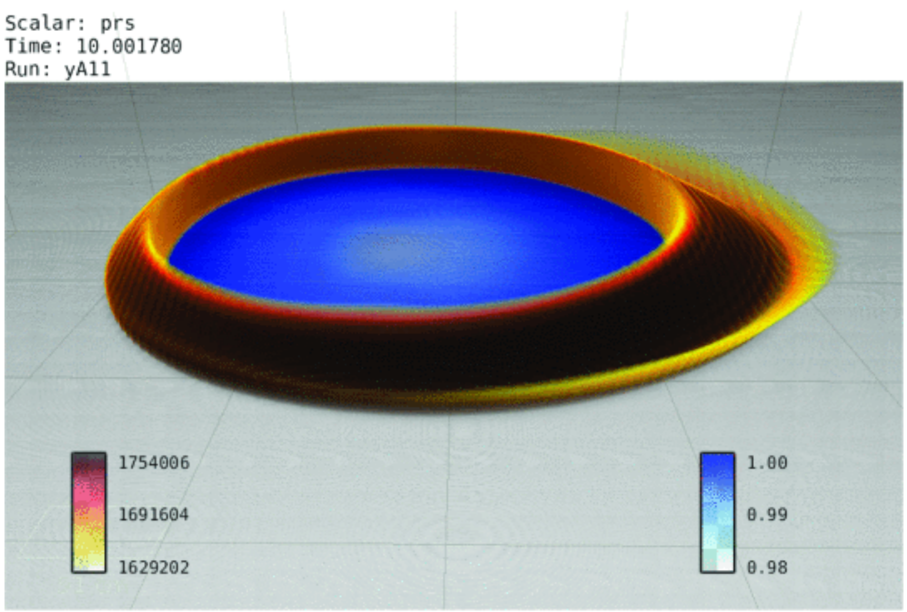
3. Prior Work (1 pt)

3a. Prior visualization submissions

There are many research publications based on this study, but the handful that we thought were interesting are as follows:

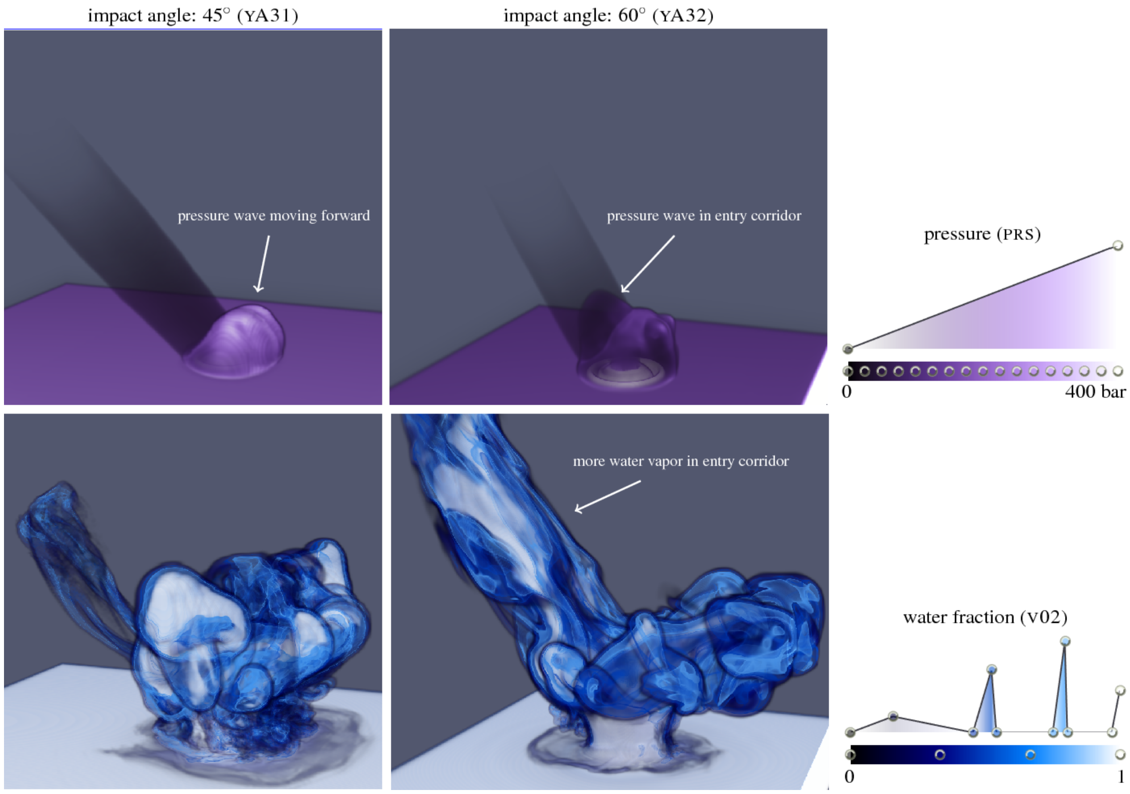


(a) Function plot of water fraction (v02) field of simulation run yA11. The top of the plot shows a pattern which has been selected interactively using a rectangle. The values at the upper and lower bound of the selected area clip the transfer function of the corresponding volume rendering below.



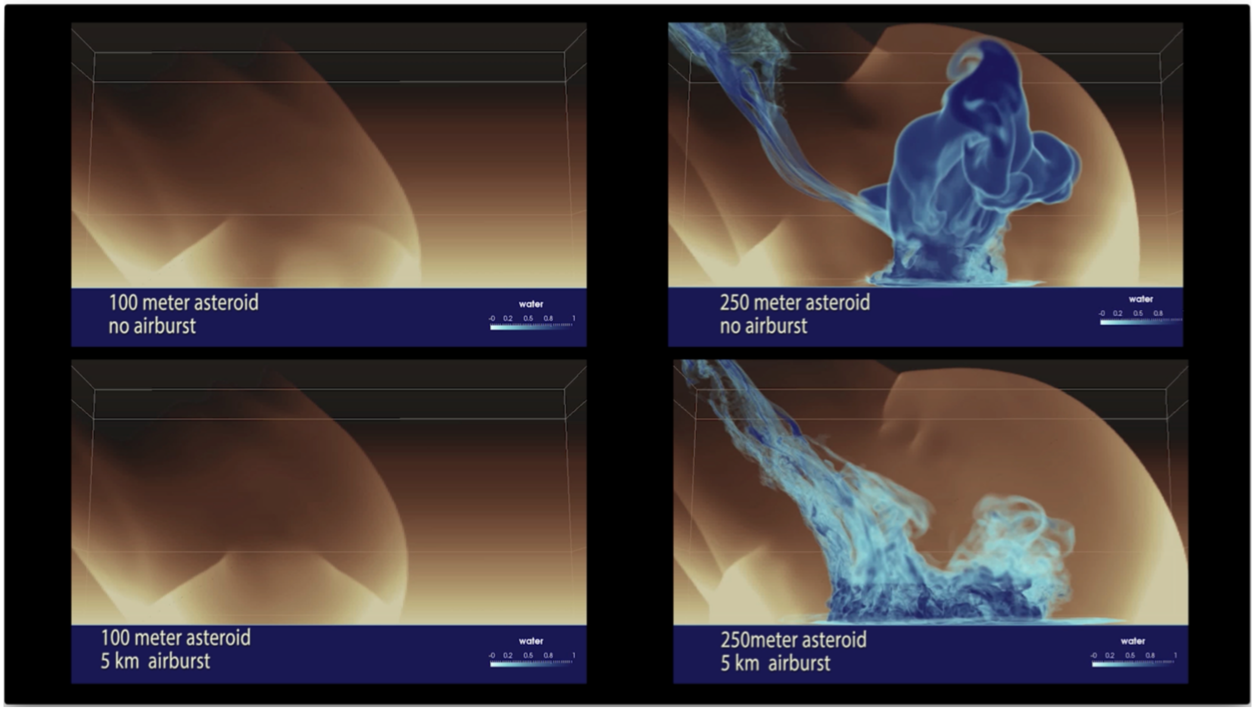
(b) Multi-volume rendering of water fraction (v02) and pressure (prs) fields of simulation run yA11. The transfer function of water fraction (v02) field (using colors as in the legend in the lower right) is derived from the selection made in the function plot above. The pressure (prs) field's transfer function (using colors as in the legend in the lower left) has been chosen such that the pressure wave above the water surface becomes visible.

The visualization above shows that there is a connection between the pattern that is seen on the water's surface and the pressure wave. Around the center of the impact, the patterns of both fields are very similar to one another. Therefore, we will be able to deduce the pattern of the water jet and the impact it has just by seeing the pressure wave. [1]

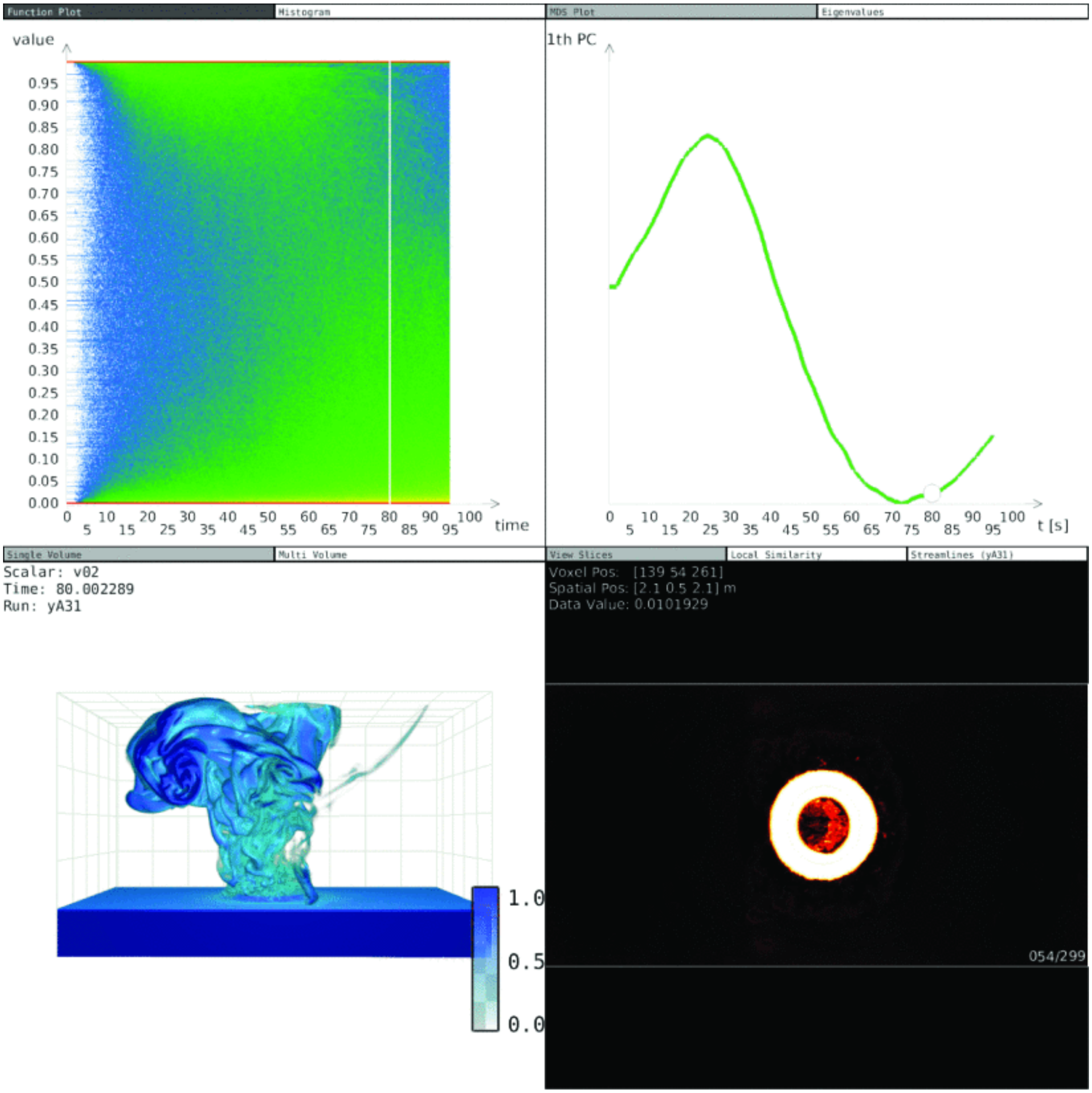


The figure above shows a comparison of impact angles for an asteroid with a diameter of 250 meters and no airburst shows changes in the pressure wave (top) and the entry of water into the atmosphere (bottom). Top: The pressure wave is larger and more symmetrical at the 45° angle. During the 60° angle impact, the pressure wave encounters bumps, one of which ascends the asteroid entrance corridor. Bottom: As the water vapor plume of the 60° impact travels higher upwards along the asteroid entrance corridor, which was denoted by the pressure wave above, more debris is pushed into the stratosphere. We conclude that a steeper impact angle may have a stronger influence on the climate because more greenhouse gasses (water vapor) will enter the stratosphere. [3]

3b. Visualization from related publications



Without an airburst, a 250-meter-wide asteroidal object strikes deep water at a 45-degree angle. Asteroid concentrations are shown in reddish tones, while water and temperature are shown in blue and yellow, respectively. The simulation makes use of 5 km of ocean depth and 23 km of the atmosphere. The simulation is 46 km by 24 km in size, with a total vertical dimension of 28 km. This is a straightforward depiction that provides a basic understanding of the investigation into asteroids' collisions. The fact that this visualization broke down the entire process into 3 easy steps makes it clear for both researchers and the general public, which is what we enjoyed most about it. [2]

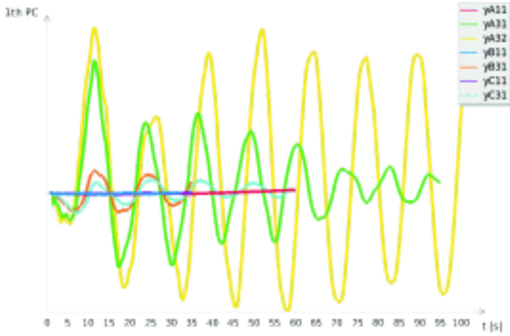


Because all views are linked, the user can select from function plots (upper left), multi-run similarity plots (upper right), and corresponding eigenvalue bar charts, as well as volume visualizations such as single and multi-volume rendering (lower left), slice or slab view (lower right), local similarity visualizations, and/or streamlines.

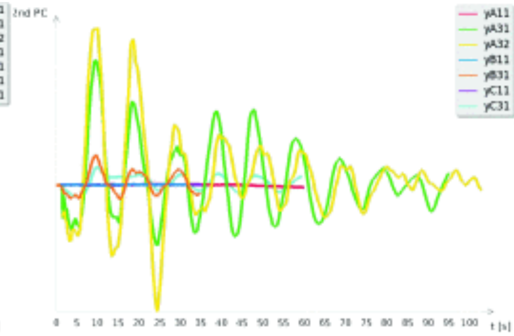
This graphic, provides detailed 1-D, 2-D, and 3-D renderings of the components that contribute to the outcome of the asteroid impact, piqued our interest.
This graphic can be used to identify time periods or functional intervals of interest, which can then be investigated further. The interplay of several fields can also be investigated. Individual runs must then be contrasted with one another in order to compare several simulation runs over time and understand how simulation settings affect the outcome. We present a method that is based on multidimensional scaling and field/isosurface similarity. Specific time steps of various simulation runs can be selected in these charts. To investigate the spatial distributions

of patterns inside a single time step, employ volumetric visualizations with animation over time steps. We can compare spatial distributions between different runs or time steps using a different encoding. To properly employ all sights, it is necessary to combine queries from several perspectives, and interaction mechanisms in coordinated views facilitate this process. A researcher or student can easily engage with one point of view and get in-depth knowledge about the elements that are critical in determining the likelihood of an asteroid striking the water. [1]

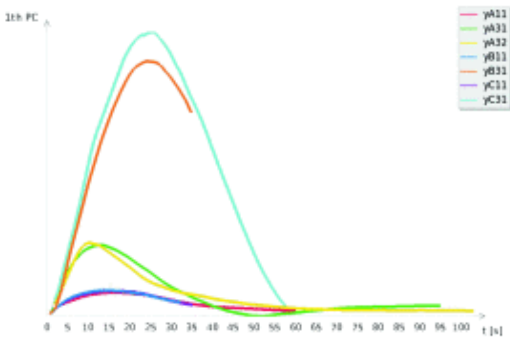
3c. Charts, graphs, statistical analyses, etc.



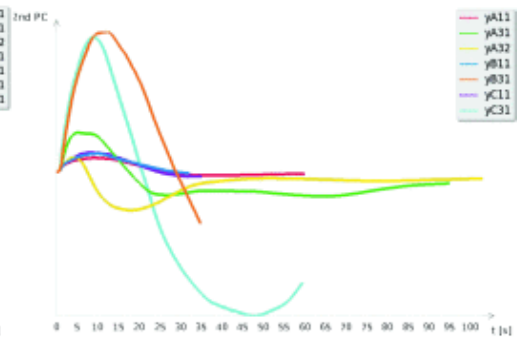
(a) First principle direction of pressure (prs) field.



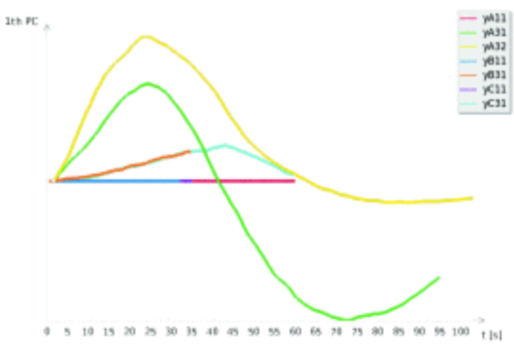
(b) Second principle direction of pressure (prs) field.



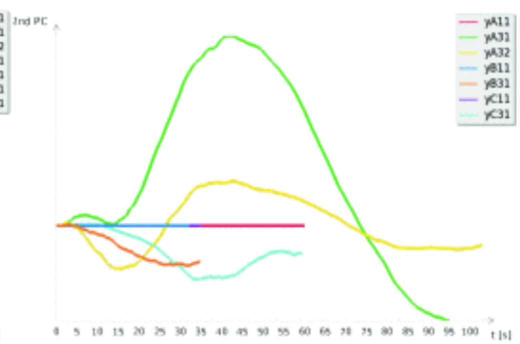
(c) First principle direction of temperature (tev) field.



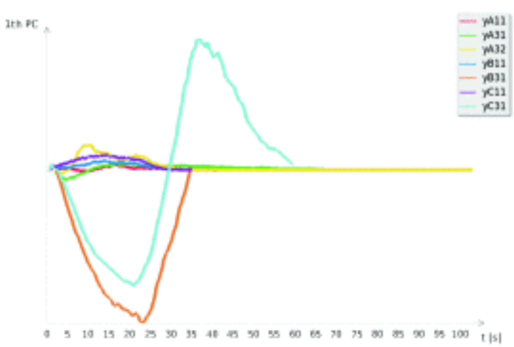
(d) Second principle direction of temperature (tev) field.



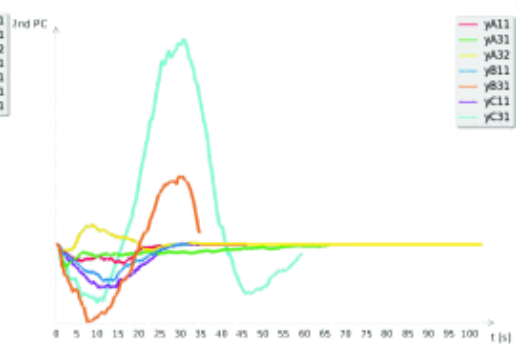
(e) First principle direction of water fraction (v02) field.



(f) Second principle direction of water fraction (v02) field.



(g) First principle direction of asteroid fraction (v03) field.



(h) Second principle direction of asteroid fraction (v03) field.

For each of the four scalar fields (pressure, temperature, water fraction, and asteroid fraction) the ensemble's 1D similarity plot over time for the first and second principle directions is shown. There are three distinct groupings of runs that behave similarly across all fields. Through this, we can see the change in behavior of the end result based on these factors taken into consideration. Asteroids' relative sizes appear to have the biggest impact on simulation outcomes, and the presence or absence of an airburst in scenarios involving large asteroids appears to be significant. Since the asteroid's oncoming angle was constant in all but one simulation run, this situation calls for additional study.[1]

4. Data Description (1 pt)

Describe the data provided for the problem. Be sure to touch on the previous areas:

- What is the source of the data? (i.e., computational simulation, scientific instrument, etc.)
  - Computational simulation
- What is the specific file format of the data? (.vts, .vti, etc.)
  - Collection of .vti files, each representing a frame of the simulation.
- What is the underlying structure of the data? (e.g. regular uniform grid, structured grid, point cloud, polygonal mesh, adaptive mesh, etc.)
  - Uniform Rectilinear grid with adaptive mesh refinement technique.
- List the variables that are encoded in the data's structure.
  - (rho) density in grams per cubic centimeter. (g/cm3)
  - (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
- Does the data have a temporal component? If so, how many timesteps?
  - Yes, the data consists of a temporal component. The number of time steps depends on the combination of parameters and the dataset. Values range from 177-time steps (yC11) to 488-time steps (yA32)
- Is the data made up of multiple simulation runs or scans? If so, how many separate data sets are there, and how do they differ from each other?
  - Yes, the data comprises multiple runs with different parameters resulting in 7 datasets (with some containing different resolution options)
- What is the size of each timestep/simulation run? What is the aggregate size of all data?
  - Size of timesteps ranges from 0.01 GB to 0.29 GB. Simulation run average around 70 GB
- What transformations/conversions will need to be made on the data?
  - To highlight important aspects of the dataset, we will need to use various filters available within Paraview. We are also looking at ways to reduce the size of the dataset while

preserving the details since we are facing issues with running the simulations in the IU Red instance and locally.

5. Proposed Solutions (1.5 pts)

Describe your intended solution to the scientific task(s) and the communications/outreach task(s). For each, be sure to include:

- Describe the prior work you will model your solution on. State why you made this choice.
  Ans.) We have chosen yA11 and yC11 as of now. We selected these two simulations, due to the difference in properties of the models (one with and one without an airburst, keeping all other parameters the same). This will enable us to compare and contrast the outcomes in the two scenarios.

- Will you make any changes or create a "mash-up" that combines the best components from several submissions?
  Ans.) Our main goal is to study the existing simulations created by other contestants of the competition and come up with a visualization that either is a mashup or an improvement to their solutions. We are still exploring the dataset and will make a decision as we progress.

- Describe your target visualization representation(s) (e.g., an isosurface with streamlines, etc.)
  Ans.) Combination of isosurfaces and various filters, utilizing Paraview to highlight important aspects of the ensembles and trying to create easy-to-understand visualizations; specifics to be determined as we explore further.

- Describe any supplementary representations you will use (e.g., charts, graphs, statistical summaries)
  Ans.) Charts and Statistical summaries, infographics.

- What is the intended output format(s)? (e.g., an image, movie, Sketchfab model)
  Ans.) Image (jpg or png) and animation (.avi)

- What is the target display platform? (e.g., desktop, Web page, ultra-resolution wall (Crystal Display Wall), stereoscopic display, VR/AR, 3D print, etc.)
  Ans.) Ultra-resolution wall and desktop

- What is the software toolchain you intend to use? (e.g., CSV to ParaView, then output as a 3D model for sharing in Sketchfab.)
  Ans.) Importing sample simulations (.vti files) to Paraview in order to generate Images and animations (.avi files) of the visualization.

5a. Solution for Scientific Tasks

1. Describe/summarize the dataset (could be done at the level of individual simulations, or discrete time steps). As part of this task, graphic representations of information (such as images, videos, narratives, charts, maps, and numerical values) could be included to enhance the summary.

Simulation	Grid (Extents)	Airburst	Size	Angle	No.of timesteps	Total size of dataset (approx)
yC11	300 ^ 3	10 km	100 m	45 degree	178	13.34 GB
yA11	300 ^ 3	no airburst	100 m	45 degree	216	21.09 GB

Ans) To get the summary of the data, we loaded the simulations in Paraview. We compared the information(coordinate structures, grids used, VTK data attributes and values) across different simulations. Through this process we observed that the first few (approximately 30) time steps are similar in structure and properties after which they differ based on the kind of parameters involved in the simulation. In the next phase of the project, we plan to explore other simulations and focus on creating simulations that differentiate the effects of asteroid impact with and without airburst.

2. To analyze and answer the questions from the analysis of the Asteroid Generated Tsunami which may be as follows:

From our preliminary research, we could answer some of the questions from the contest. The answers were not derived entirely from simulations, but rather from studies of asteroid impacts in general.

   a. Are tsunamis generated by an asteroid impact?

      Not Always! The generation of the tsunami by asteroid impact depends on the size of the asteroid. If the size of the asteroid is 100m, irrespective of the airburst it does not impact the water.

   b. If generated, what are the near and far field effects of the impact

      For large-sized asteroids, depending on different events like airburst, angle of impact, and size of the asteroid the near and far field effects of the asteroid on water and water on land can be analyzed. It is observed from the pre-work simulations that the airburst causes fewer field effects, and the low angle of impact makes the pressure distribution uniform thus having fewer effects. The greater the size of the asteroid, the greater the near and far field effects.

c. The major events of simulation, their time of occurrence and how can we decide about the events

For large-sized asteroids, depending on different events like airburst, angle of impact, and size of the asteroid the near and far field effects of the asteroid on water and water on land can be analyzed. It is observed from the pre-work simulations that the airburst causes fewer field effects and the low angle of impact makes the pressure distribution uniform thus having fewer effects. The greater the size of the asteroid, the greater the near and far field effects.

The major events of the simulation are Impact/Airburst, Relaxation, and Wave generation.

Impact/Airburst: From the pre-work plots we observe, noticeable patterns are present in the temperature field. Before the impact or airburst, the temperature was small and not quite varying, the simulation shows that this is when the asteroid was not moving. After a point, the temperature starts to increase slowly and continuously after which a sudden change in temperature was seen, it is where the impact or airburst was observed. For all the simulations this was observed and significant changes in temperature were observed, therefore this is one of the main events.

Relaxation: The phase after impact or airburst where the drastic reduction in temperature was observed. This is the relaxation phase where the simulation comes to its initial state. This is the other main event where the asteroid explosion is completed.

Wave Generation: When the asteroid hits the water, circular waves are formed which travel to the simulation boundaries. New waves are generated after initial waves have disappeared. This makes the waves travel and cause near and far field effects. When an airburst happens, the waves do not form but rather the particles are scattered over a larger area which prevents the formation of waves and thus reduces the effect of the tsunami. For smaller size asteroids, the wave generation was very small which is just observed on the water surface but no significant waves or craters were generated. Since this phase determines the effect of tsunami this is too one of the main events.

d. The effect of airburst on the size of waves generated

Airburst is a process in which an asteroid causes an explosion in the air when it enters the earth before hitting the water and thus decreasing the impact and reducing the tsunami effect on the shores. Therefore, it is expected that the airburst causes less size of waves and deeper craters and thus less tsunami effect on the shores.

e. The effect of angle of impact on the crater, tsunamis, near and far fields

The angle of impact mainly affects the distribution of pressure waves. The pressure distribution along the wave influences the near and far field effects, the crater and the pressure waves decide the tsunami to the shores. The simulations show that if the angle of impact increases, the pressure distribution is not uniform and thus increasing tsunami effects. Also, it was observed that the larger the impact angle, the larger the amount of water traveling into the entry corridor of the asteroid with high speed, which causes a lot of water vapor to escape into the atmosphere which causes significant impact even on the climate.

f. Any unexpected things and discontinuities about the data

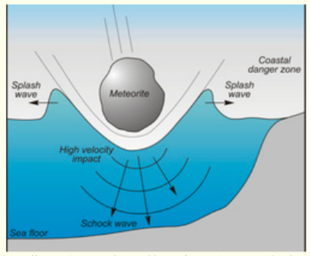
Discontinuities and any unexpected things in the data are not observed as of now.

The above solutions are from pre-works and from our analysis till now. These are all yet to be explored from our visualization to be created.

5b. Solutions for Communications/Outreach Tasks

Deep Water Asteroid Impact Simulation

https://www.independent.co.uk/space/asteroid-dinosaur-killer-nadir-new-b2147531.html



https://tsunamimargareth17.weebly.com/meteorite-tsunami.htmlour

Background

70 % of our planet is covered by water and majority of the population lives near the coast. Severe asteroid impacts pose a significant threat and it is likely that an asteroid entering the earths atmosphere will impact a water body.

NASA founded the Planetary Defense Coordination Office to track potentially harmful near Earth objects.

To improve our understanding of the threats imposed by asteroid impacts, scientists at Los Alamos National Laboratory conducted an ensemble simulation for varying impact scenarios into deep water oceans.

PLANETARY DEFENSE COORDINATION OFFICE
HIC SERVARE DIEM

Aim

Can destructive waves created by an impact travel long distances to populated shorelines?

https://sciviscontest2018.org/

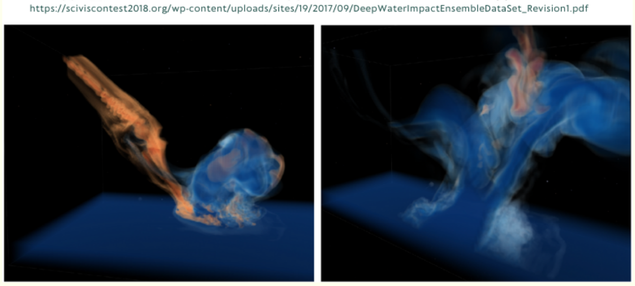
Los Alamos NATIONAL LABORATORY EST. 1943

Through emerging Data Science and Scientific visualization techniques, we can model, simulate and visualize various asteroid impact scenarios. This field of science is important since it could prepare us to deal with the catastrophic consequences of an asteroid impact.

Sample visualizations

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

https://sciviscontest2018.org/wp-content/uploads/sites/19/2017/09/DeepWaterImpactEnsembleDataSet_Revision1.pdf



https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8823609

6. Schedule and Division of Effort (1 pt)

Complete the following table for your project. This may include tasks needed to complete this proposal. Potential tasks might include:

- Download data to the Research Desktop directory and share with team members
- Analyze prior solution A / B / C (assign to different team members).
- Recreate prior scientific vis solutions A / B / C
- Create example communication vis
- Create a preliminary movie for YouTube or model for Sketchfab
- Prepare progress presentation
- Refine visualizations for final presentation
- Create final visualization deliverables: images, movies, models
- Prepare final presentation

Task	Due Date	Person(s) Responsible
Download data to Research Desktop directory and share with team members	5th November	Rohan (yC11,yA11) Rishika(yA31,yA32) Adheesh(yB11, yB31)
Analyze prior solution	7th November	Rohan, Rishika
Proposal Document Completion. Communication/ Outreach vis	8th November	Adheesh
Recreate prior scientific vis solutions	18th November	Rohan, Adheesh
Creating new visualizations leveraging existing models.	28th November	Rishika, Adheesh
Progress Presentation	1st December	Rohan, Rishika, Adheesh
Refine visualizations for final presentation	5th December	Rohan, Rishika
Prepare final presentation	7th December	Rohan, Rishika, Adheesh
Final presentation	8th December	Rohan, Rishika, Adheesh
Create final visualization deliverables: images, movies, models	14th December	Rohan, Rishika, Adheesh

References

[1] Visualizing Deep Water Asteroid Impacts: Interactive Visual Analysis of Multi-run Spatio-temporal Simulations

[2] Supercomputing 2016 Visualization Showcase submission

[3] Visualization and Analysis of Deep Water Asteroid Impacts

What to submit

Upload this document to Canvas. You only need to submit this once per group.