Deep Water Asteroid Impact

Final Project Report

SciVis (ENGR-E484/E584) – Fall 2022

Team - 3

Aastha Ketankumar Patel (ap61)
Bhanu Prakash Guntupalli (bguntup)
Aravind Ganta(aganta)

1. Topic Summary

It is critical to study asteroids cause the one that occurred at Chicxulub 65.5 million years ago changed the planet's ecosystem. It is likely the asteroid that killed the dinosaurs. Even though the asteroid that hit Chicxulub is rare and we still need to classify asteroids based on size and impact. Most of the earth's surface is covered with water so the probability of an asteroid hitting water is high usually they don't pose any threat but when these asteroids hit too close to the coastal areas, they can generate huge water waves (Tsunamis) that can interfere with human operations. We want to visualize the water displacement for asteroids of different diameters and air busts so we can analyze the threat and take measures to prevent loss of life and property.

2. Visualization Tasks

2a. Scientific Tasks

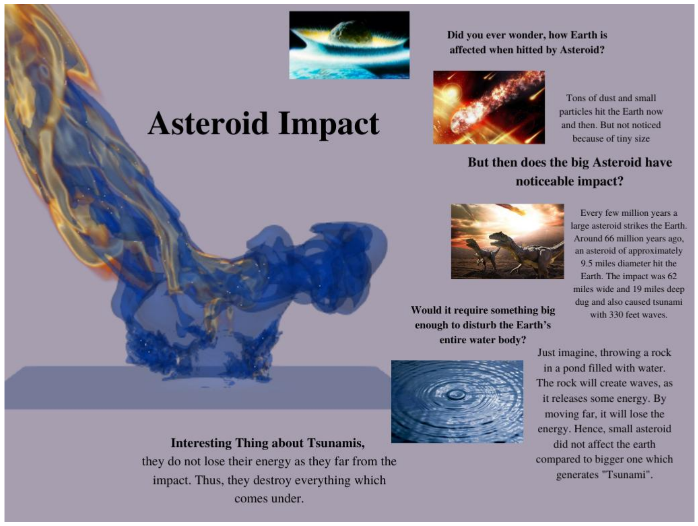
The data set consists of simulations of asteroid impact-generated tsunamis (AGTs). The goal of the contest is to explore the data set and identify any interesting patterns or features that may be present. This could include:

1. Identifying when tsunamis are generated
2. what are the near and far field effects of the impact are
3. major events that occur during the simulation

Additionally, it specifically addresses the question of whether an airburst affects the size of the tsunami waves, and how the angle of impact affects the crater size, AGT, and other near and far field effects.

2b. Outreach/Communication Tasks

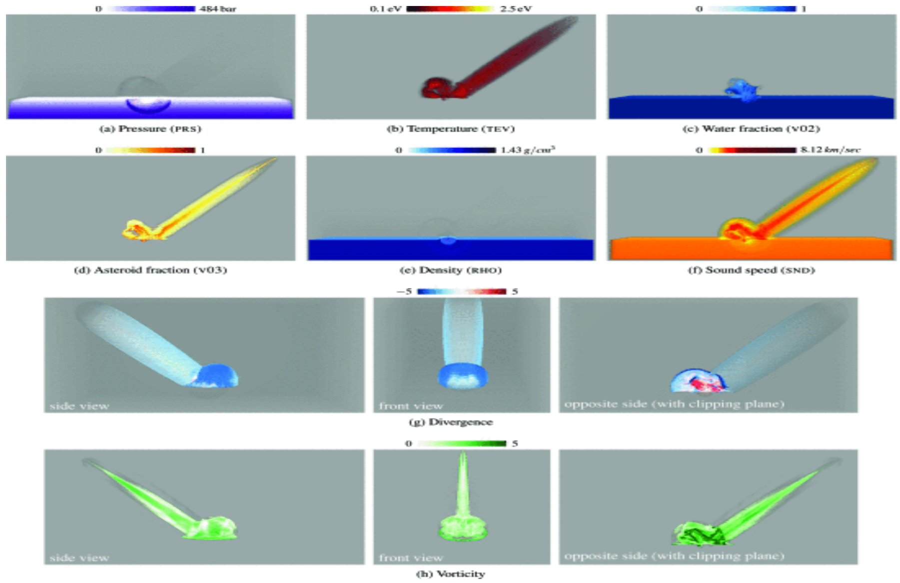
Starting with the fundamentals, we created an infographic to illustrate how an asteroid would affect the surface of the earth (that is, how throwing a rock into a pond will cause ripples, how the rock generates energy which leads to ripples and why the size of the asteroid matters). In addition, we provided general illustrations for each of the questions we raised above for non-technical people to understand, as well as a straightforward scientific impact visualization that demonstrates what occurs when an asteroid of significant size collides with the earth.



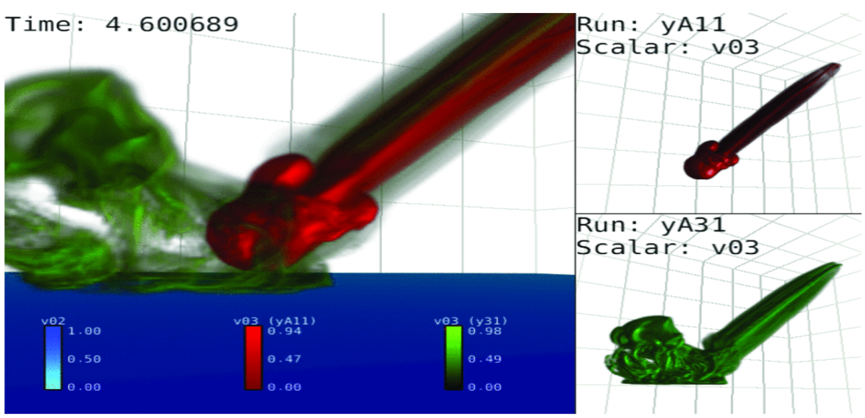
3. Prior Work

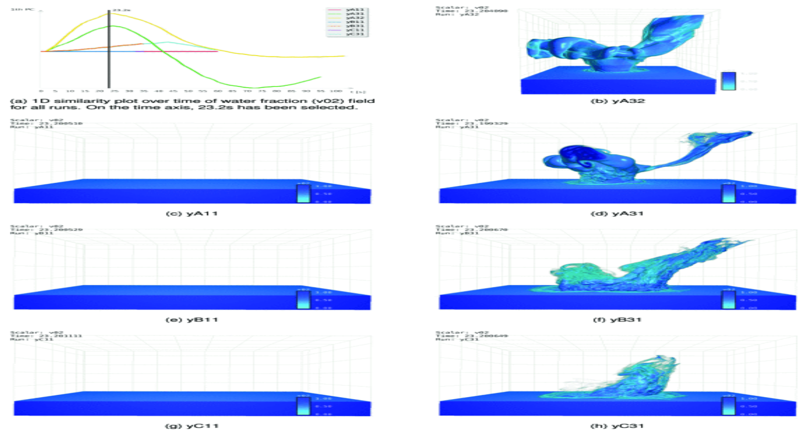
3a. Prior visualization submissions

1. Visualization and Analysis of Deep Water Asteroid Impacts by **Raphael Imahorn; Irene Baeza Rojo; Tobias Günther [1]**
    a. This paper describes the **wide range of state-of-the-art visualization techniques** to analyze the asteroid decay before impact, the generated waves for various ensemble members, the pressure waves, the material distribution, the attribute correlations and passageways of water vapor into the stratosphere.
    b. And the paper stated about using diverse **set of tools, including Monte Carlo** based integrators for Lagrangian transport analysis, linear optimization for interactive visibility adjustment of pathlines and streaklines, **derived Eulerian fields to study the vector fields**, **coordinated views with two-dimensional histograms for interactive linking and brushing. [1]**



2. Visualizing Deep Water Asteroid Impacts: Interactive Visual Analysis of Multi-run Spatio-temporal Simulations by **Simon Leistikow; Karim Huesmann; Alexey Fofonov; Lars Linsen. [2]**
    a. This paper presents an interactive visual analysis approach of **multiple spatio-temporal simulation runs that aggregates the information at multiple levels allowing for overview visualizations**, comparative visualizations, and detail visualizations and uses Coordinated views to interact with the different aggregation levels and different facets of the data in an intuitive manner, allowing for a top-down analytical workflow.
    b. It provides an **interactive visual analysis** approach that supports the visualization of the mentioned facets in coordinated views. We first present the methodology including a **top-down analytical work-flow**, various visual encodings of information extracted at multiple aggregation levels, and respective interaction mechanisms supporting the analysis. [2]

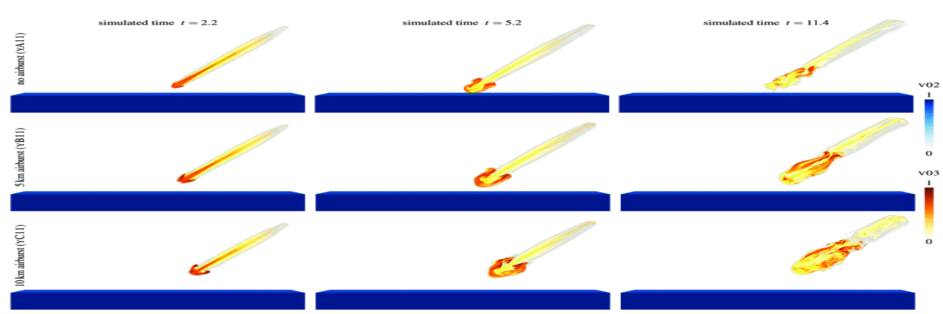




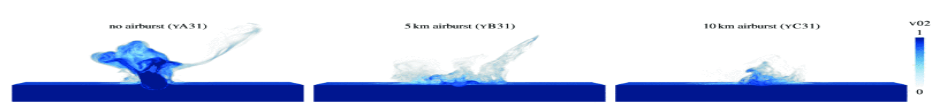
(a) 1D similarity plot over time of water fraction (v02) field for all runs. On the time axis, 23.2s has been selected. (b) yA32 (c) yA11 (d) yA31 (e) yB11 (f) yB31 (g) yC11 (h) yC31

3b. Visualization from related publications

1. Visualization and Analysis of Deep Water Asteroid Impacts by **Raphael Imahorn; Irene Baeza Rojo; Tobias Günther [1]**
    a. As stated in the paper, because the ensemble data is large, a general **overview** can be generated using in-situ at the highest available data resolution. For that, we first render animations of direct volume renderings for each attribute of the ensemble members.
    b. Rendering all the relevant animations leads us to few observations some of which are described below,
        i. **Asteroid Size :** Describes two scenarios where the asteroid diameter is only 100 m and the impact angle is 45°(the asteroid never impacts the water) and the asteroid diameter is 250 m and the impact angle is 45°(the asteroid impacts the water in every airburst configuration) which can be observed in the figure below,
            1. It also shows the water fraction (v02) for the three configurations, where we observe that without an airburst (yA31) the asteroid has a stronger impact, while the existence of an airburst dampens the impact the higher the airburst altitude. [1]

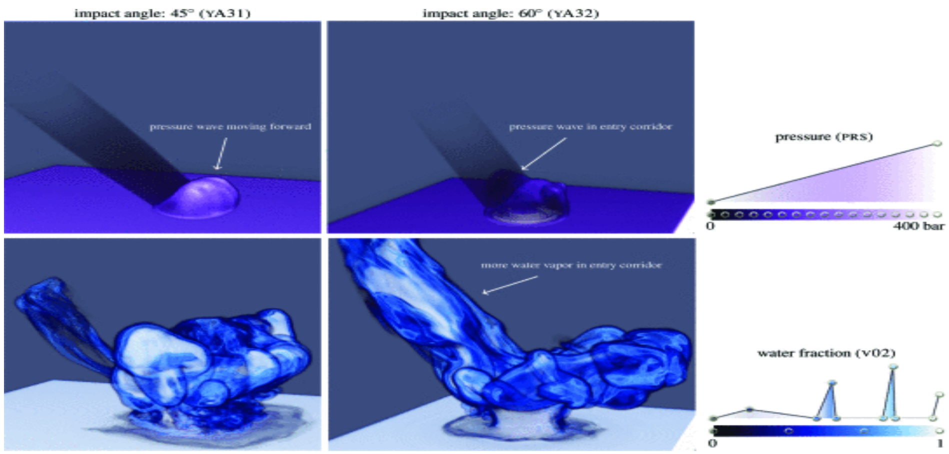


(a) Comparison of different airburst heights for the small asteroids (100 m size): no airburst (top), 5 km (middle) and 10 km (bottom). The volume renderings show the water fraction (v02) and the asteroid fraction (v03). In the columns, different time steps are shown, displaying the entry and decay of the asteroids. It becomes apparent that none of the 100 m asteroids impacts in the water, independent of the airburst height.

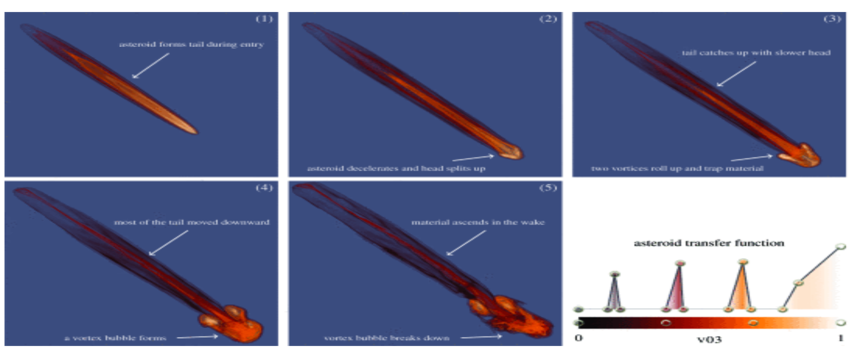


(b) The above volume renderings show the water fraction (v02) after 15 sec of the simulation for the different airburst scenario. Here, the large asteroids were chosen (250 m) with an impact angle of 45°, which resulted in a water impact for all cases. Without airburst (left), more kinetic energy is transferred into the water, creating a larger splash than in the two scenarios with airburst (middle and right).

ii. **Impact Angle:** It concentrates on two phenomena: the **shape of the pressure shock wave** and the **passageway of water vapor** into the stratosphere.
    1. And the figure attached below shows the behavior of the pressure (prs) wave of the 45° and 60° impact. [1]

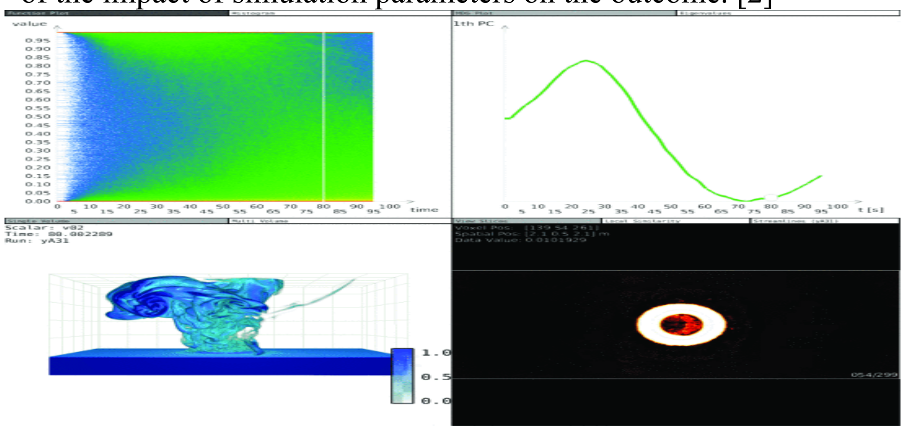


iii. **Pre-Impact Asteroid:** It showcases different observations about the entry and decay of the asteroid in the context of air friction. [1]

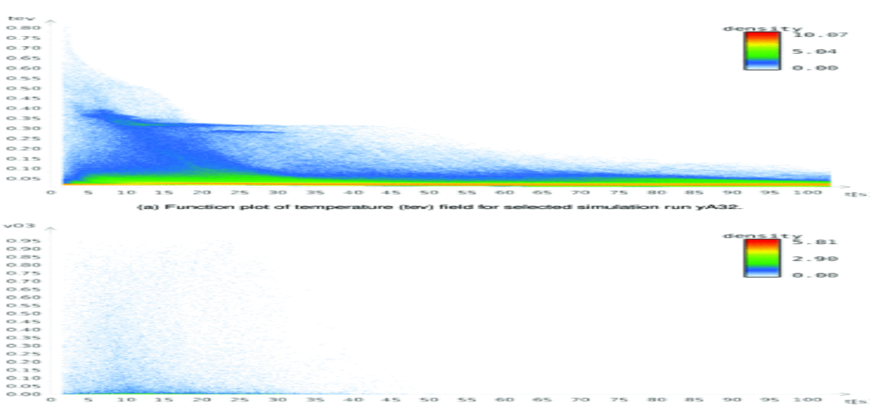


iv. **Flow visualizations :** It demonstrates the direct volume renderings of divergence and vorticity. And about using an unbiased **Monte Carlo-based rendering** approach where we can observe how the airburst of the asteroid affects the width of the entry corridor formed by the falling asteroid, the uplift paths of particles rising up into the stratosphere and the high degree of turbulence that followed the impact.

2. Visualizing Deep Water Asteroid Impacts: Interactive Visual Analysis of Multi-run Spatio-temporal Simulations by **Simon Leistikow; Karim Huesmann; Alexey Fofonov; Lars Linsen.**
   The methodology described in this paper is as follows,
   a. As mentioned in the paper, **top-down analysis** was used for overview visualization of the entire ensemble and the temporal evolution of the ensemble is performed first. Field/isosurface similarity and multidimensional scaling is used for a comparative visualization of multiple simulation runs over time and for the analysis of the impact of simulation parameters on the outcome. [2]



   b. **Function plots** are used to provide a first overview of the entire ensemble and its evolution over time. The function plot represents the function values of each spatial data sample of each simulation run as a piecewise linear graph of a time series. When observing multi-fields, we can produce one function plot per field and compare/correlate them with each other. We can also zoom to or select a specific region of interest for further analysis. [2]

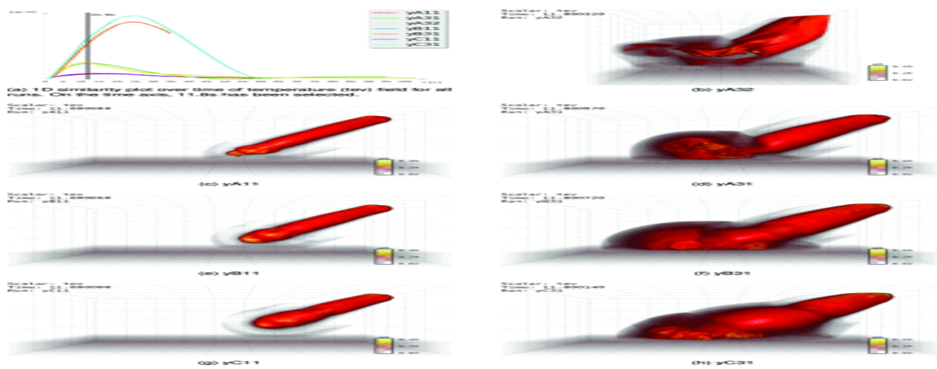


(a) Function plot of temperature (tev) field for selected simulation run yA32.

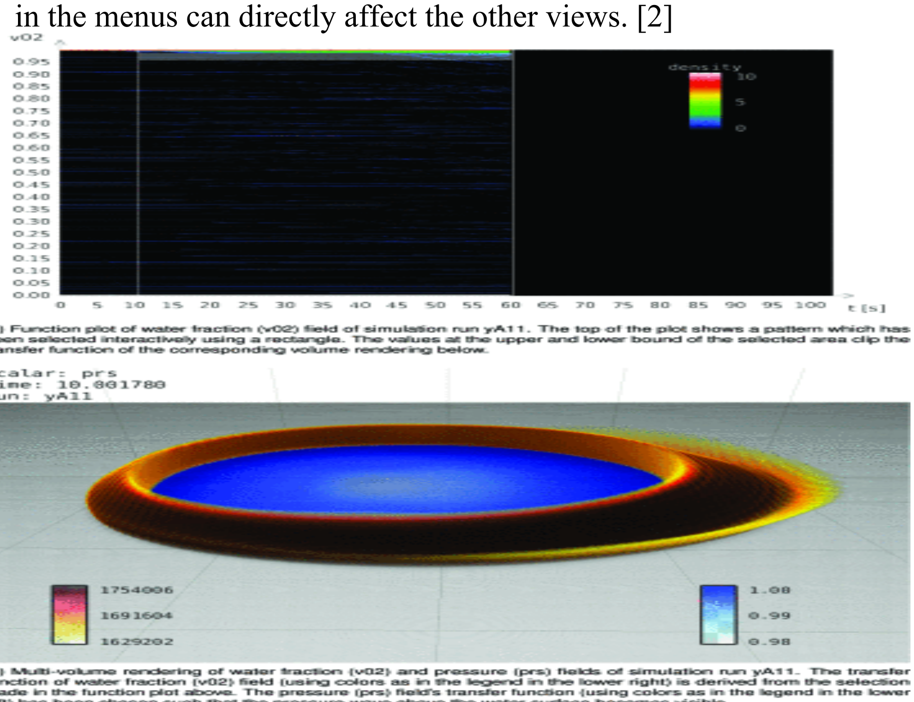
(b) Function plot asteroid fraction (v03) field for selected simulation run yA32.

   c. **Multi-run Similarity Plots** to compare the evolution of all simulation runs (or of a subset) and to analyze the impact of some simulation parameters. Multidimensional Scaling (MDS) approach is applied to the distance matrix to map each time point of each simulation run to a position in a projected space.

d. **Volume Visualizations** to analyze the spatial behavior of a feature within a single time step of a selected simulation run. For scalar fields, we use a direct volume renderer based on a GPU implementation of a ray-casting approach and for multiple scalar fields, the volume renderings of individual scalar fields can be combined within a multi-volume renderer. [2]



e. **Coordinated Interaction -** The different visualizations are embedded into a system of coordinated views supporting selecting and linking, i.e., selection in one view or in the menus can directly affect the other views. [2]



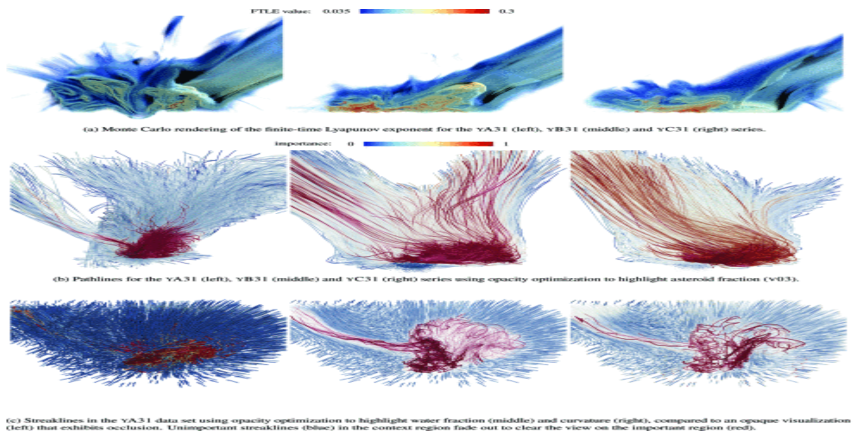
(a) Function plot of water fraction (v02) field of simulation run yA11. The top of the plot shows a pattern which has been selected interactively using a rectangle. The values at the upper and lower bound of the selected area clip the transfer function of the corresponding volume rendering below.

(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.

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

1. Visualization and Analysis of Deep Water Asteroid Impacts by **Raphael Imahorn; Irene Baeza Rojo; Tobias Günther**

a. The visualizations from the figure attached below take a **Lagrangian approach** to the visualization of the fluid flow. The top row displays transport barriers by employing a Monte Carlo rendering technique to show the finite-time Lyapunov exponent [3]. In the second and third row, we visualize integral curve geometry. For this, we use decoupled opacity optimization [5] to highlight selected pathlines (middle) and streaklines (bottom). [1]

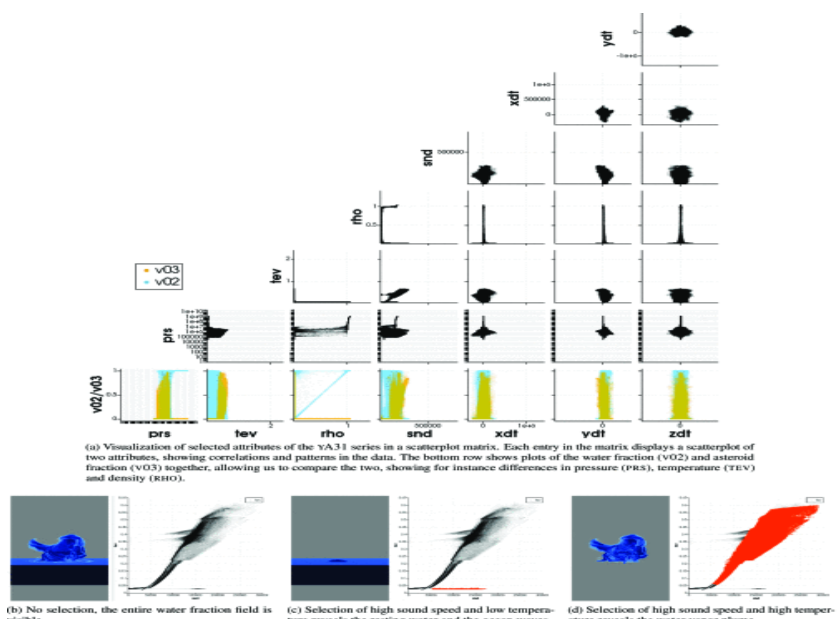


(a) Monte Carlo rendering of the finite-time Lyapunov exponent for the YA31 (left), YB31 (middle) and YC31 (right) series.

(b) Pathlines for the YA31 (left), YB31 (middle) and YC31 (right) series using opacity optimization to highlight asteroid fraction (v03).

(c) Streaklines in the YA31 data set using opacity optimization to highlight water fraction (middle) and curvature (right), compared to an opaque visualization (left) that exhibits occlusion. Unimportant streaklines (blue) in the context region fade out to clear the view on the important region (red).

b. The figure attached below provides **interactive exploration of the multivariate data to users using scatterplot matrix** to find correlations and patterns. Here, the user selects a scatterplot in (a) and performs interactive brushing in (b)–(d). Note that the 3D visualization of the water fraction is updated accordingly. Here, shown for the yA31 series (250 m asteroid diameter, no airburst, 45° impact angle). [1]



(a) Visualization of selected attributes of the YA31 series in a scatterplot matrix. Each entry in the matrix displays a scatterplot of two attributes, showing correlations and patterns in the data. The bottom row shows plots of the water fraction (V02) and asteroid fraction (V03) together, allowing us to compare the two, showing for instance differences in pressure (PRS), temperature (TEV) and density (RHO).

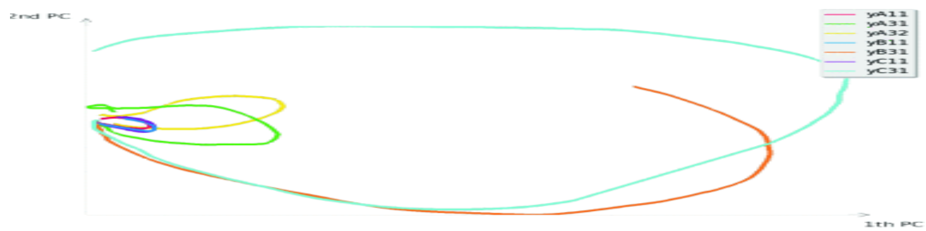
(b) No selection, the entire water fraction field is visible.

(c) Selection of high sound speed and low temperature reveals the resting water and the ocean waves.

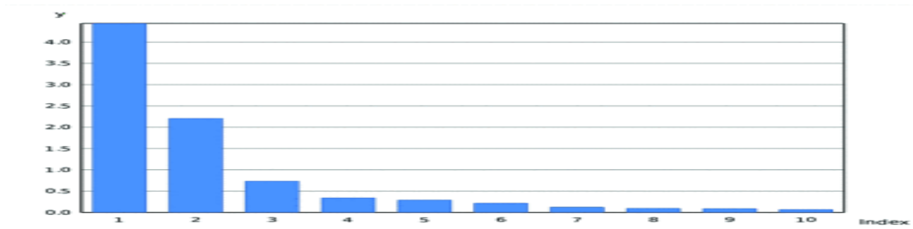
(d) Selection of high sound speed and high temperature reveals the water vapor plume.

2. Visualizing Deep Water Asteroid Impacts: Interactive Visual Analysis of Multi-run Spatio-temporal Simulations by **Simon Leistikow; Karim Huesmann; Alexey Fofonov; Lars Linsen.**

a. Figure attached below exhibits 2D similarity plot loops, which indicate that all runs return to their initial state towards the end of the simulation, where unclosed loops are caused by early terminations of respective simulations. [2]

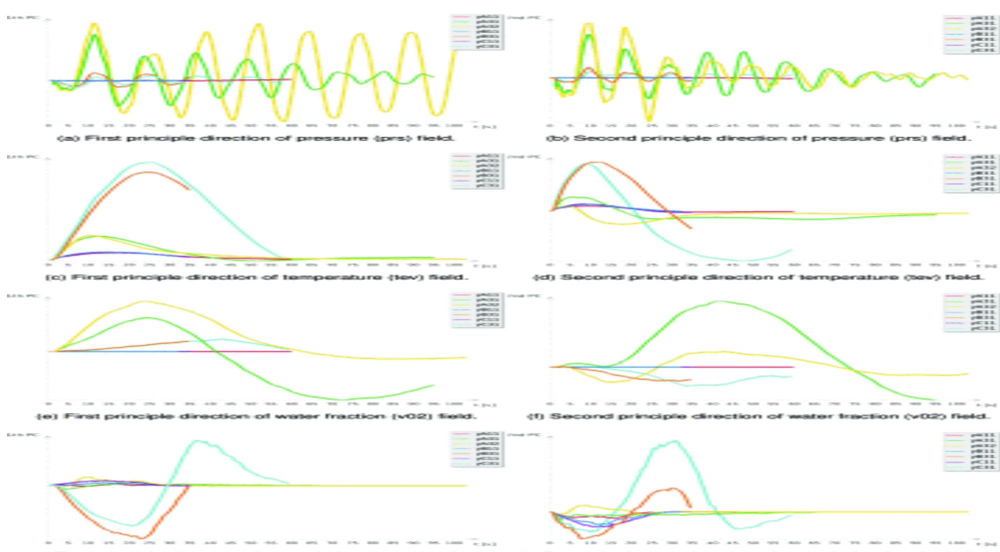


(a) 2D similarity plot of first two principle components of temperature (tev) field.



(b) Eigenvalue bar chart for the first ten principle components of temperature (tev) field. We observe that a projection using the first two principle components should capture the main features.

b. The figure attached below provides a 1D similarity plot over time of the entire ensemble for each of the four scalar fields considering first and second principle directions. Three groups of runs with similar behavior in all fields can be observed. [2]



(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.

4. Data Description

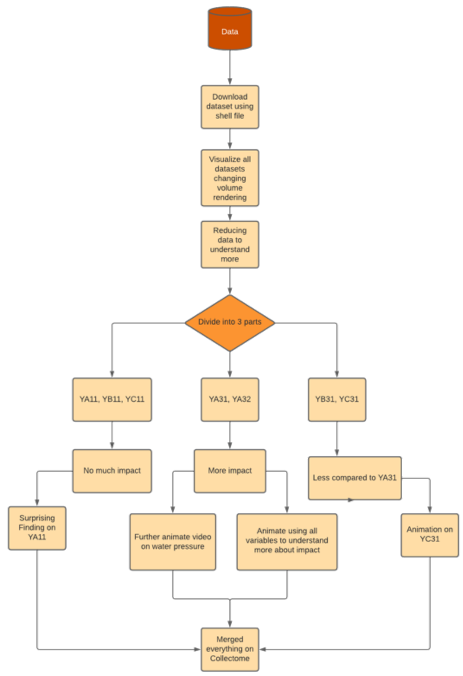
The data is generated by simulations and these simulations are initially used to study asteroid-generated tsunamis. We have a set of vti files (vti are used to store series of image data). The structure of data is Uniform Rectilinear Grid. All data variables in data files are listed below:

- rho density in grams per cubic centimetre. (g/cm3)
- prs pressure in microbars (μbar)
- tev temperature in electronvolt (eV)
- xdt x component vectors in centimetres per second (cm/sec)
- ydt y component vectors in centimetres per second (cm/sec)
- zdt z component vectors in centimetres per second (cm/sec)
- snd sound speed in centimetres per second (cm/sec)
- grd AMR grid refinement level
- mat material number id
- v02 volume fraction water
- v03 volume fraction of asteroid

Name	No. of time steps	Size (approx.) in Gb
yA11	216	20.01
yC11	178	12.46
yA31(300x300x300)	476	191.63
yA32	489	111.86
yB11	247	125.97
yB31(300x300x300)	269	55.86
yC31(300x300x300)	265	48.30

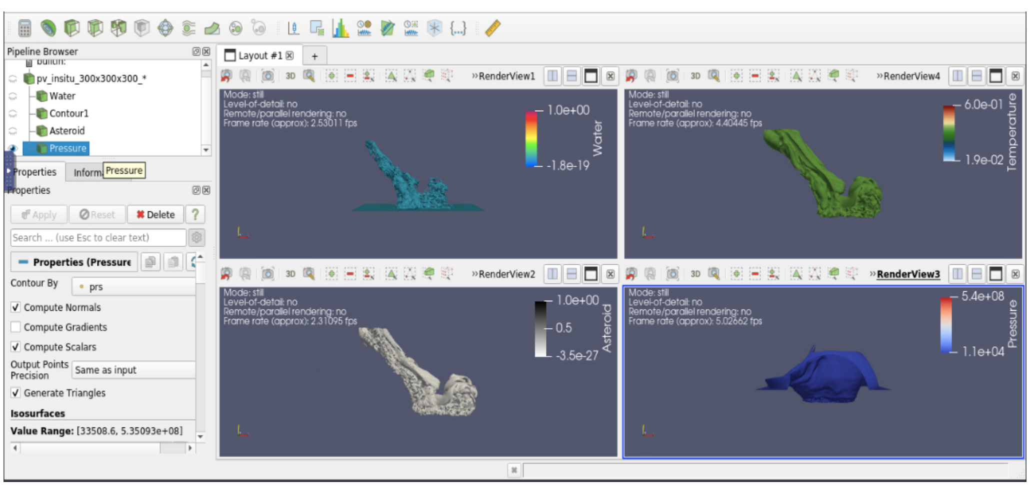
In the data file name, each position has some meaning such as the first letter is only used by the domain scientist to keep track of various simulation setup instantiations {x, y, z}. The second letter {A, B, C, D} depicts the four various airburst scenarios that the ensemble represents: Airbursts at distances of 0 km, 5 km, 10 km, and 15 km, respectively. The third letter {1, 3, 5} represents the size of an asteroid of 100m, 250m and 500m, respectively. The fourth character {0, 1, 2} represents the entry of the angle at 27.4 degrees, 45 degrees, and 60 degrees of momentum.

5. Final Visualization Workflow



Data Preprocessing:

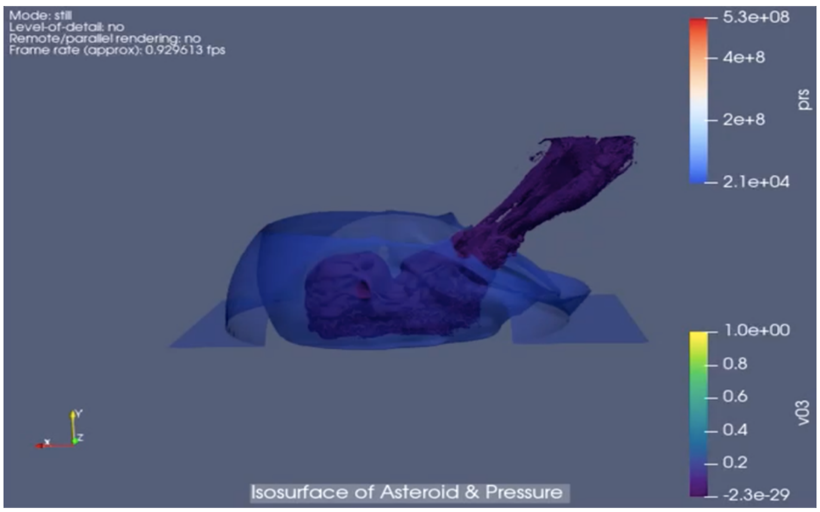
The datasets were huge in size, from 15 GB to 200 GB in each file. Downloading each file was a big task. So, by creating Shell scripts they were downloaded smoothly. These large datasets contain more time steps (200-500). We started visualizing them by changing it to volume rendering, adding different iso-surface values and changing the opacity on vo2 (water), vo3 (Asteroid), prs (Pressure) and tev(Temperature).



We considered three main variables: water, pressure, and asteroid. (Temperature was not affecting much)

Data Management:

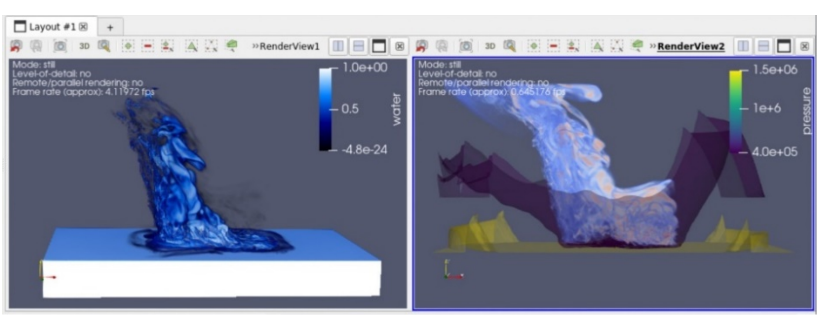
There were a lot of time steps, so we created a new folder and broke down the time steps into the range of 10s or 20s so that we can look more into the data and get more understanding of the data. This is how we break down the data size into small chunks and visualized it. We tried animating a video, on changing the iso-surface values of the asteroid and pressure, to know about the pressure when the asteroid hits it.



Visualization URL: [Isosurface of Asteroid & Pressure]

Experiments:

To know more about the pressure, we added another iso-surface value in it. This determines that, by adding more iso-surface value we got to know what kind of asteroid size or angle, or the characteristics of asteroid should be, that can generate more pressure as well as makes water splash.

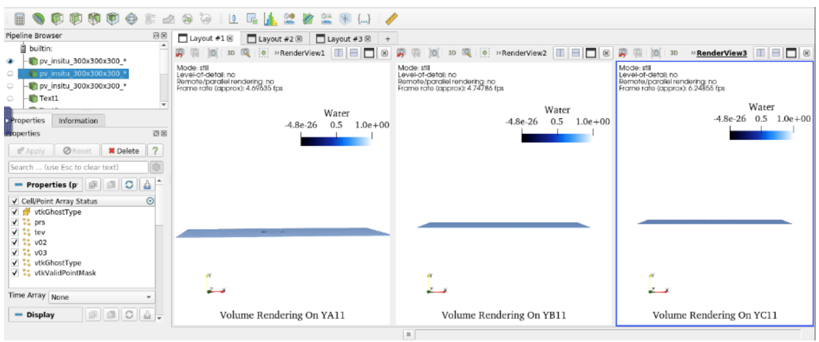


Visualization Process:

From this, we decided to visualize, what kind of characteristics and what angle of asteroid impacts more

We divided the data files into three parts. **The First part** consists of YA11, YB11 and YC11 data files, with the same asteroid diameter of 100m and angle of 45 degrees' momentum and different asteroid characteristics such as:

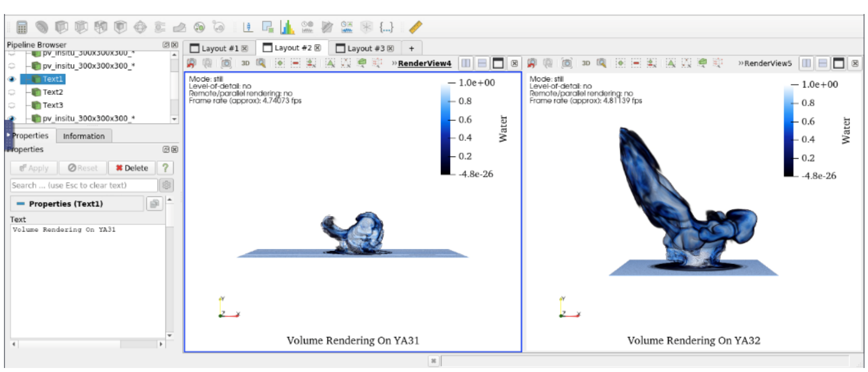
A: Direct impact (no airburst)
B: Airburst at elevation 5km above the sea level
C: Airburst at elevation 10km above the sea level



In each data file, by changing to volume rendering on water, we got to know there is no wave generated in either of them, as a small angle and small size would not impact enough to destroy.

The second part consists of YA31 and YA32 data files with the same diameter of 250m and the same characteristics of an asteroid with no airburst with a different angle such as:

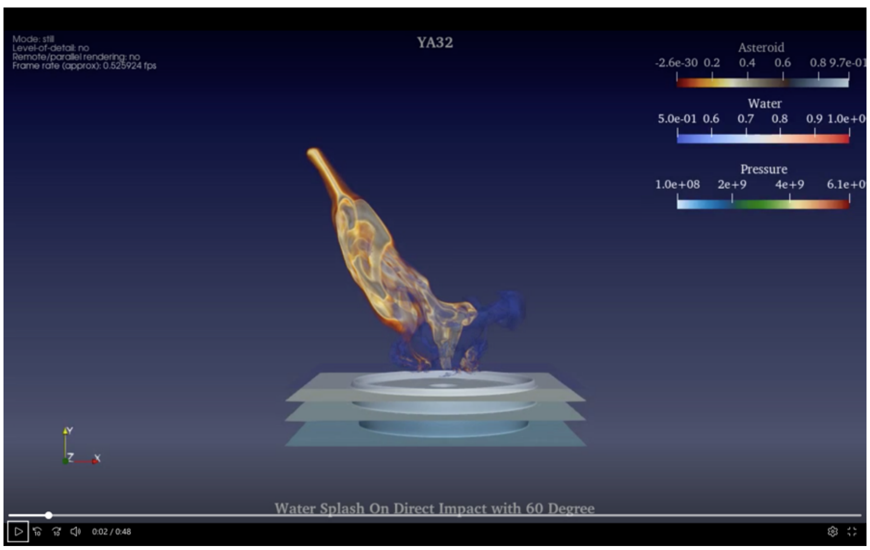
YA31: Asteroid initialized with 45-degrees momentum
YA32: Asteroid initialized with 60-degrees momentum



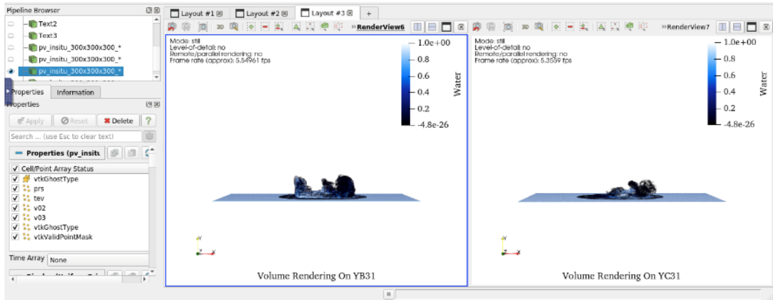
With the same timestep, we visualized YA31 and YA32 and got that there was more water splashed compared to YA11, YB11 and YC11. It has been visualized from a different angle and has more diameter.

YA31: Asteroid initialized with 45-degrees momentum

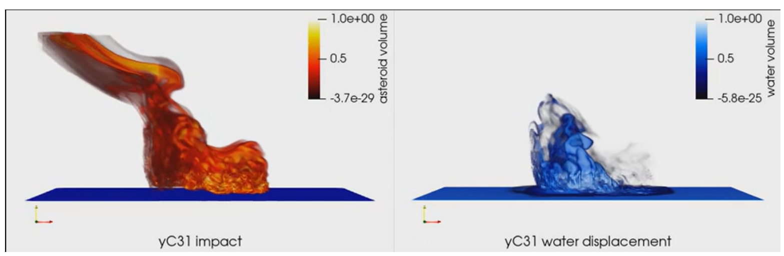
YA32: Asteroid initialized with 60-degrees momentum



The Third part consists of YB31 and YC31, with the same diameter of asteroid size of 250m, an angle of 45-degrees momentum, different characteristics of the asteroid and with airbursts such as:
B: Airburst at elevation 5km above the sea level
C: Airburst at elevation 10km above the sea level

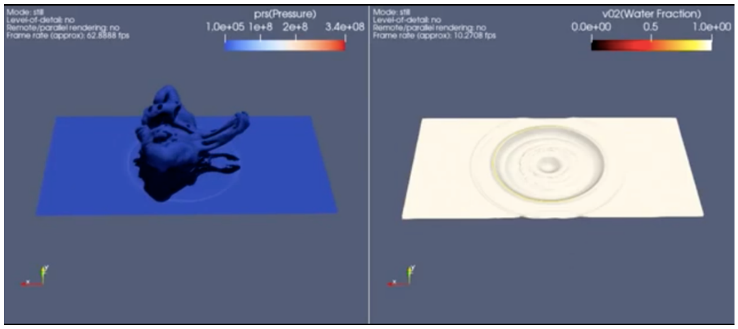


Visualization on YC31:
From the visualization, we can observe that the yC31 generated the highest amount of water displacement between yB31 and yC31. Animating asteroid volume and water side-by-side we found that pressure transfer was not instant. So even after many time-steps further from the first impact, we can see the water still rising. These longer impacts/transfers created pressure zones. The pressure from the trailing of the asteroid is now enough to create more water displacement. (The URL of visualization on yC31 is given below)

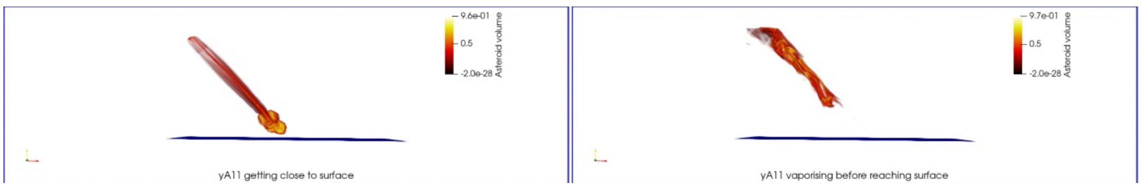


So, with the same timestep, there is less water splash on both data files compared to YA31 and YA32. There was an airburst in YB31 and YC31, so it vanished before reaching the surface. From this, we got to know that YA31 and YA32 have more impact than any other data file, as it has a direct impact, and the size of the diameter is more. YA32 impacts water more than YA31 because the angle of YA31 was slant and the angle of YA32 was straight. Therefore, animated a video by adding more pressure and changing the iso-surface value and opacity of water in YA31 and YA32. (The URL of YA31 and YA32 are given below)

Near-Field & Far-Field Effects
The pressure and water fraction of the yA31 dataset were visualized using contour. The impact's near-field and far-field effects can be seen in the pressure and water fraction contours, respectively. We can determine whether there is a chance of a tsunami based on the spatial dimensions, asteroid size, impact angle, and air bust. There would undoubtedly be a chance of a tsunami, for instance, if the spatial dimensions were 46*23 km and the asteroid impact occurred precisely at the midpoint. (The URL of Near-Field & Far-Field Effects is given below)



Surprising Findings on yA11
We have seen no water displacement for any of the 11 series asteroids this visualization shows us why. As we follow the asteroid's path, we can find that the asteroid didn't generate enough pressure and vanished before even reaching the surface. (The URL of yA11 is given below)

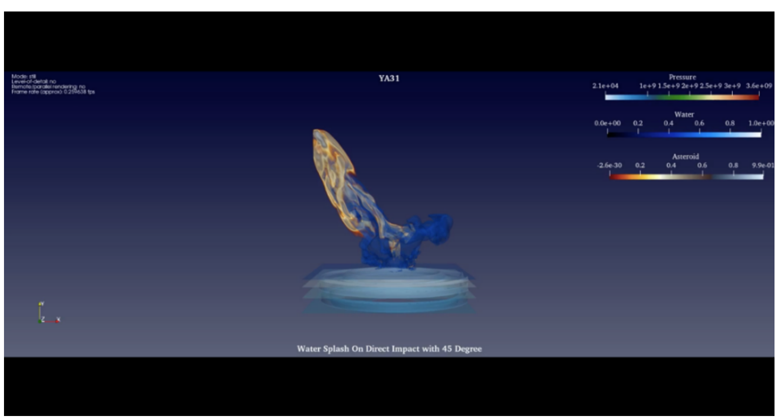


6. Final Visualization Results

Visualization On yA31:

By adding multiple iso-surface values to prs (pressure) and changing the opacity of vo2 (water), tried to animate a video to visualize the pressure effect and the water splash.

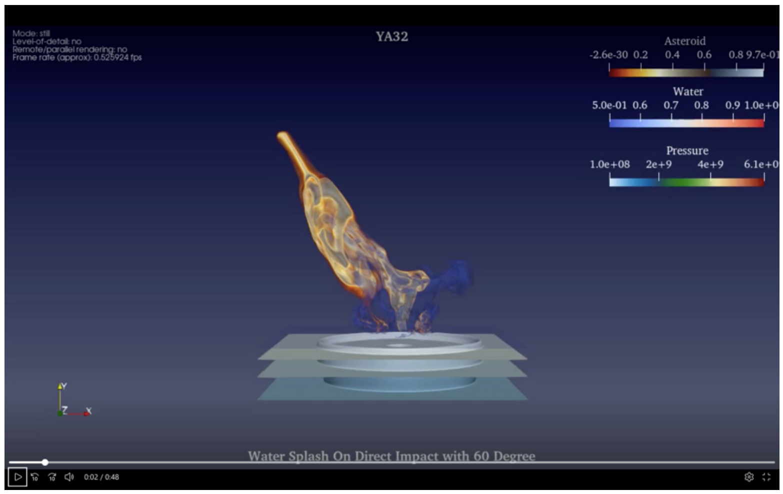
Visualization URL: [Visualization On yA31]()



Visualization On yA32:

By adding multiple iso-surface values to prs (pressure) and changing the opacity of vo2 (water), tried to animate a video to visualize the pressure effect and the water splash.

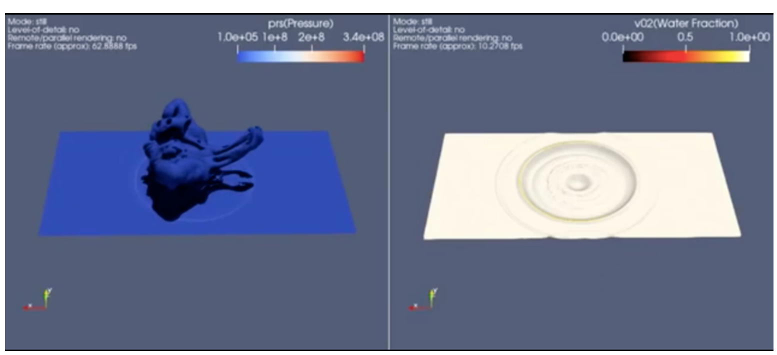
Visualization URL: Visualization On yA32



Near field - Far field effects:

The impacts near field and far field effects can be seen in the pressure and water fraction contours, respectively. We can determine whether there is a chance of a tsunami based on the spatial dimensions, asteroid size, impact angle, and air-bust.

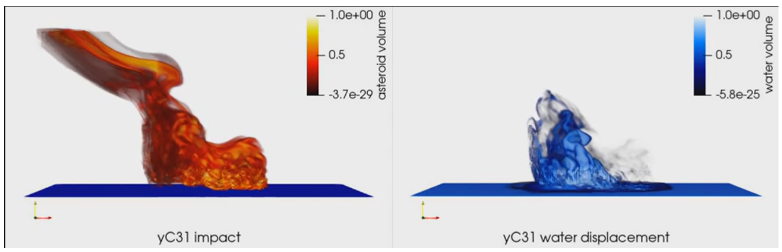
Visualization URL: Visualization of Pressure & Water On yA31



Visualization on yC31:

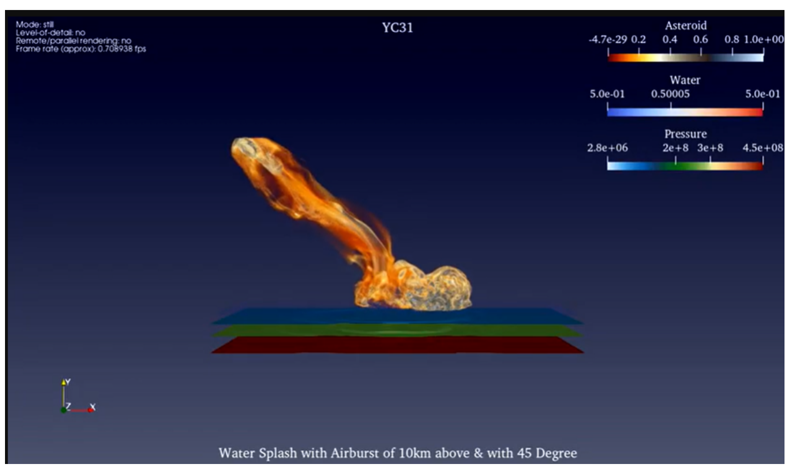
Animating asteroid volume and water side-by-side we found that pressure transfer was not instant. So even after many time-steps further from the first impact, we can see the water still rising. These longer impacts/transfers created pressure zones. The pressure from the trailing of the asteroid is now enough to create more water displacement

Visualization URL: [Visualization on yC31]



By adding multiple iso-surface values to prs (pressure) and changing the opacity of vo2 (water), tried to animate a video to visualize the pressure effect and the water splash.

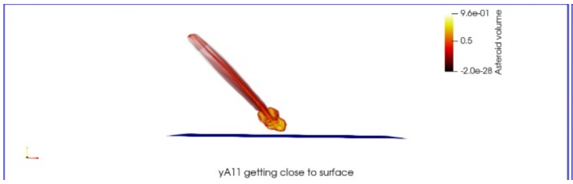
Visualization URL: [Another Vis on yC31]

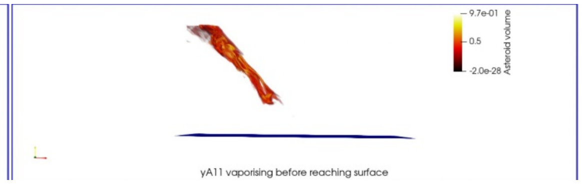


Surprising Findings on yA11:

We have seen no water displacement for any of the 11 series asteroids this visualization shows us why. As we follow the asteroid's path, we can find that the asteroid didn't generate enough pressure and vanished before even reaching the surface.

Visualization URL: [Visualization on YA11]





7. Group Reflection

a) What project features ended up being different from your team's initial vision to the final implementation? Why did they change?

- Implementation of an animation view of multiple attributes (vo2, tev and pressure) of different datasets under one view was not included in our initial vision of final implementation.

b) What tasks end up being easier than anticipated? Which were harder than anticipated?

- Animation view of all the attributes and animation view of individual attributes ended up easier but generating the contours and animating those into a single view was harder than thought as figuring out the iso values helped in visualizing the required impact in the case of each attribute.
- We would like to add the similarity plots as they would provide a different insight into how these asteroid simulations behave similarly for various attributes/fields and for which they behave differently and would have helped us to classify asteroids into different types (according to sizes, range of impact, etc.)

c) If your team had the project to do over again, and knowing what you do now, how would you change your technical approach?

- If we have to prioritize again, we would download the data with full resolution and scalars and do our visualizations on full resolution data and build the velocity vector from the scalar velocity components in x, y, z directions.
- When exploring full resolution and full scalar data we found RAM limitations for some data.
- Creating an iso-surface of water helped us to find the impact point and whether the impact happened or not.
- By animating the attributes in pairs, we were able to find some key relationships between the attributes.

d) If your team had the project to do over again, how would you change your task prioritization and time management?

- Now, we know data very well and we can prioritize accordingly. As we divided data into 3 parts. So, we can distribute our work. So, we can work plotting the graph to get more information. We can try to work on the high-resolution data for more visual representations.

8. References

1. Visualization and Analysis of Deep Water Asteroid Impacts

2. Visualizing Deep Water Asteroid Impacts: Interactive Visual Analysis of Multi-run Spatio-temporal Simulations

3. Aggregated Ensemble Views for Deep Water Asteroid Impact Simulations

4. Visualization of the Deep Water Impact Ensemble Data Set

5. Aggregated Ensemble Views for Deep Water Asteroid Impact Simulations- Youtube Video

6. Visualization and Analysis of Threats from Asteroid Ocean Impacts