Hurricane and Typhoon Visualization

Michael Swenson
u0585863@utah.edu

James Fantin
james.fantin@utah.edu

Woochul Jeong
u0749319@utah.edu

ACM Reference Format:
Michael Swenson, James Fantin, and Woochul Jeong. 2021. Hurricane and Typhoon Visualization. In *Proceedings of ACM Conference (Conference'17).* ACM, New York, NY, USA, 8 pages. https://doi.org/10.1145/nnnnnnn.nnnnnnn

1 OVERVIEW AND GOALS

For our scientific visualization project, our group is interested in visualizing the various types of data sets, especially multivariate time-series data. Tropical cyclone data has been selected for our purposes, because tropical cyclones are one of the most common natural disasters. We set out to visualize the key structures of a hurricane, how a cyclone changes in correlation to its categorical classification, the composition of precipitation and the correlation of cloud formation to wind speed.

The hurricane data we examined was modeled after hurricane Isabel, IEEE Visualization 2004 Contest[11], a complex data set allowing for interesting and insightful visualizations that make use of advanced analytic techniques. Isabel was a storm that hit North Carolina in September of 2003 causing 3.37 billion dollars worth of damage and 17 direct fatalities, illustrating the importance of understanding these deadly storms [4].

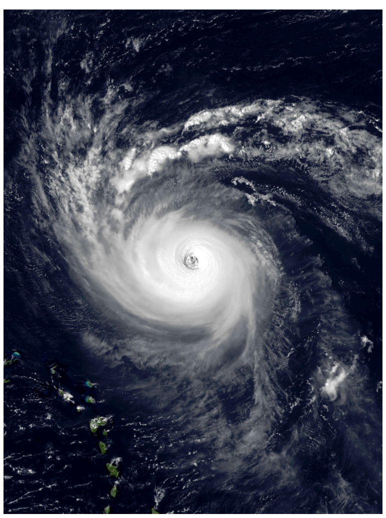


Figure 1: Isabel Peak Intensity
[3]

The other data set, provided by the China Meteorological Administration(CMA) [8], contains several decades worth of cyclones that mostly make landfall over the western North Pacific area. This is a simplified data set, from a data dimensionality perspective, that is useful for analyzing historical trends in data.

Finally, a composition of images taken from TRMM/3B42 satellite and stitched together using Google Earth Engine (GEE), that provides a good time-varying visual subset of the typhoon path data.

The goal of these visualisations is two fold. First, the exploration of complex data will increase the expertise of the student group revealing difficulties in visualizing cyclones and increase their ability to assist domain experts in their meteorological applications. As a group we were able to investigate many advanced software suites, data processing techniques and image visualization methods. For instance, using Paraview we are able to blend volume rendering, isosurface extraction, and slicing techniques to generate multivariate visualizations. These visualizations were then used to create animations of time stepping through the data. Second, the hope is that we can further the understanding of these natural phenomena to reduce casualties and property damage through better path prediction and informationally dense graphics for quicker analytical comprehension.

2 BACKGROUND AND RELATED WORK

Each data set presented its own unique challenges which required unique support materials. The Isabel Model was processed exclusively in Paraview. In order to load the data into Paraview it had to be converted into either BOV or XDMF format. The website SeedME[5] provided an XDMF header for this data that allowed it to be used. After that, we created new header files so that the data could be read by Paraview. Additionally, a Paraview wiki[10] provided insight into the supported data types. The visualization handbook was especially useful in the multivariate images and animations. Our goal and choice of data sets were also validated by the Visualization Handbook specifically, "In terms of visualization techniques, they are the traditional line graphs, contour diagrams, streamlines, velocity vectors, maps, and so forth." Also, we follow the analysis process for hurricane data, mentioned in Visualization Handbook "not just about 3D visualization, but about overall workflow: data ingest, processing, regridding, analysis, 2D visualization, and, ultimately, 3D exploration and analysis."

The historical data from CMA is composed of storm name, date of time, intensity, longitude, latitude, pressure, and wind speed. Since the original extension of data is txt, conversion to csv is done to work with our choice of programming tool. MatLab documentation[2] helped with understanding how to create a density graph of the typhoon paths for a clearer visualization that didn't have the occlusion a scatter plot did.

The initial work with the typhoon paths was done in Google Earth. It involved extracting the latitude and longitude, scaling, and

Conference'17, July 2017, Washington, DC, USA

ACM ISBN 978-x-xxxx-xxxx-x/YY/MM…$15.00
https://doi.org/10.1145/nnnnnnn.nnnnnnn

creating a csv file that could be imported as a path into Google Earth[1].

Google Earth Engine work drew on tutorials from Google and NASA's advanced webinar series[9]. The composites generated from different Google Earth image collections was done using GIMP and various color keying tutorials.

3 DESCRIPTION

Our project involved two main data sets, one a thorough simulation of hurricane Isabel from the 2004 IEEE Visualization Contest, the other data set contains years worth of basic wind speed and path data of South Eastern Asian typhoons provided by the China Meteorological Administration. The hurricane Isabel data set is a simulation of the 2003 hurricane with information over 48 time steps of the simulation, where each time step is one hour from the previous step. The data set contains total cloud amounts, total precipitation amounts, pressure, temperature and wind vectors. We set out to couple a highly qualitative event simulation with real long term data. By using several different software suites our project delivers a variety of visualizations that characterize different aspects of tropical cyclones.

The questions we sought to answer are: What are the relevant attributes of a tropical cyclone? How does a storm change over time? How are different attributes correlated? What visualizations will provide useful information to domain experts? How important is historical data and what is the best way to visualize large simple data sets? Which software can use the data provided by these different sources?

As we worked we had quite a few questions. The first questions regarded the formatting and content of the data and how that would affect the tools we could use. Was the data well formed? What exactly did the column headers mean? Eventually the questions became more about the visualizations approaches. What is the best angle/color/data to create the optimal visualization? How much data should be on the screen? We settled on different choices for each data set and goal.

4 IMPLEMENTATION

4.1 Typhoon

4.1.1 Typhoon Paths. The very first implementation of the typhoon paths was to create simple marker "tours" in Google Earth and do a fly by parallel to the plane of viewing of the different data points followed by a zoom out to the globe where the entire path could be seen. Eventually, this process was migrated to a Matlab program and displayed as a density plot of latitudes and longitudes on a 2D geographic map. This was done because the extraordinary length of the data caused visual confusion before a significant amount of the data could be displayed. Additionally, the density gradient provided very quick data comprehension.

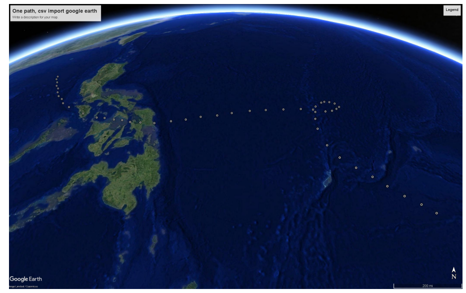
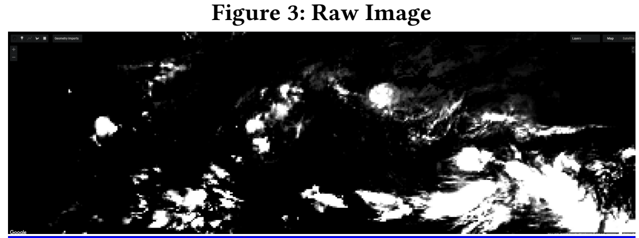


Figure 2: GE Typhoon Path

4.1.2 Satellite Precipitation. We also created a set of animations using the Google Earth Engine that measured the precipitation in an area where many of the typhoons occur. The data was taken from TRMM/3B42, specifically the IR precipitation band. This band is black and white so the values of precipitation are measures of gamma. A transfer function was used to map the values of gamma on a blue to red gradient.

Figure 3: Raw Image



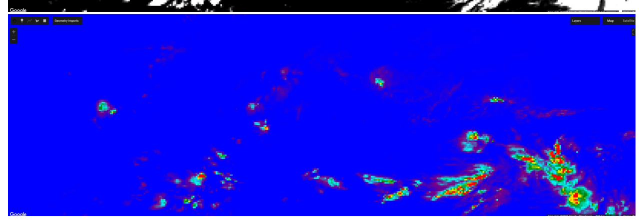


Figure 4: Mapped Image

Next, each month was sliced into 3, 10/11 day animations, and then compiled into one video that described the precipitation of the year 2002 centered at (138.679, 9.1802) with a resolution of 5Km/pixel.

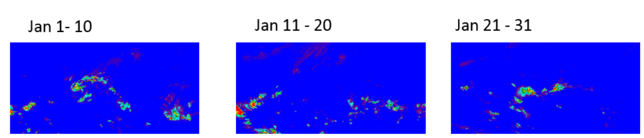


Figure 5: Small Grid of Precipitation Animations

The 10/11 animations were then superimposed onto a geographical map of the same region by removing the 0.0 value color(blue), adding a transparency channel, and adding the static landmass image as a background.

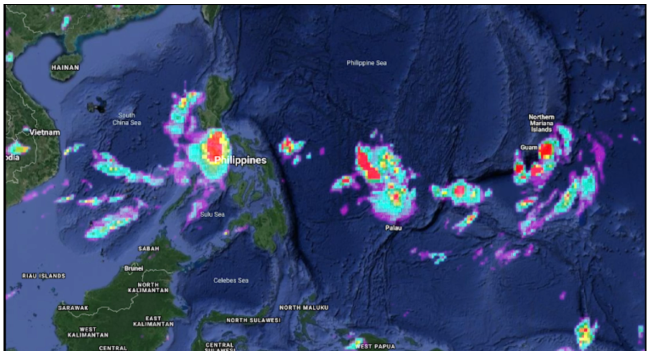


Figure 6: Superimposed Precipitation Values

4.2 Cyclone

4.2.1 Cyclone density plot. Data collected from CMA is from 1951 to 2019. Our group merged decades of data to figure out any historical changes. For this density plot the intensity of the cyclone is not considered, only latitude and longitude of the cyclone data are considered. There are not many changes over decades, so only two most recent decades, from 2001 to 2019, are plotted in figure 7 and 8. Based on the figures, there are more cyclones on the border area between the land and sea than just sea area. The Philippines and Taiwan, both countries are surrounded by sea, are most affected by cyclones.

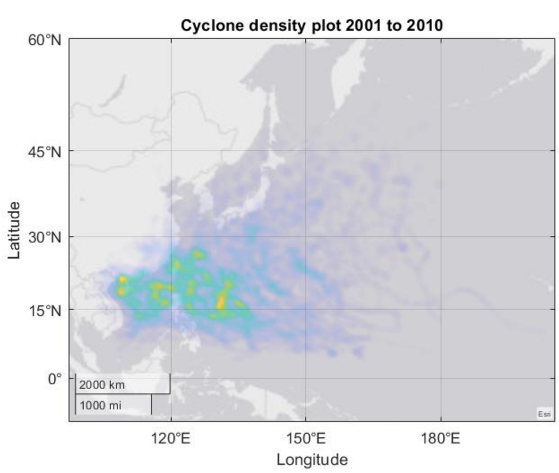


Figure 7: Cyclone density plot from 2001 to 2010

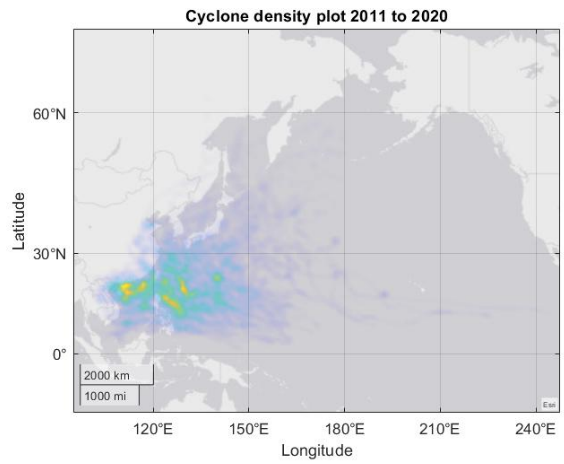


Figure 8: Cyclone density plot from 2011 to 2019

4.3 Hurricane Isabel

For nearly all of the hurricane Isabel data visualizations, we have provided animations over all 48 of the time steps in a zip file within our submission. For hurricane Isabel, we have three main areas of focus for the hurricane: cloud formation, precipitation and the flow of wind over the hurricane.

4.3.1 Cloud Formation. First, we focus on the cloud formations of the hurricane. We visualize the cloud formations by using an isosurface with an isovalue of 0.0001 which highlights the cumulus and cumulonimbus clouds of the hurricane.

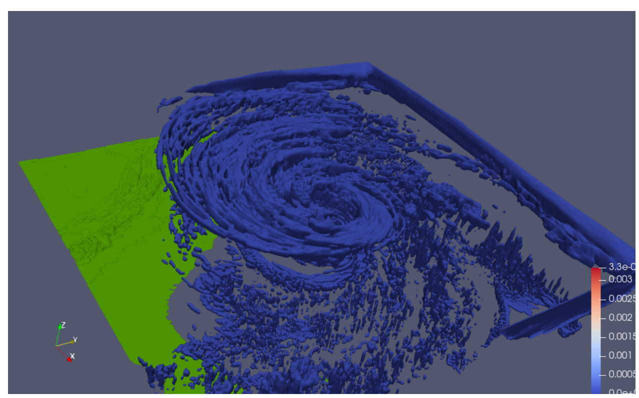


Figure 9: Isosurface of Cloud with Isovalue of 0.00001

Cloud formations of hurricanes occur due to the low pressure system in the eye of the hurricane which forces air and moisture to the top of the hurricane where clouds form. In figure 10 we combine the cloud formation and pressure by using a volume rendering of the clouds alongside a slice of the volume rendering of the pressure. This allows us to clearly see the low pressure system in the hurricane alongside the clouds of the hurricane.

To get a better idea of how dense the area of low pressure is, we use volume rendering of the pressure over the course of the

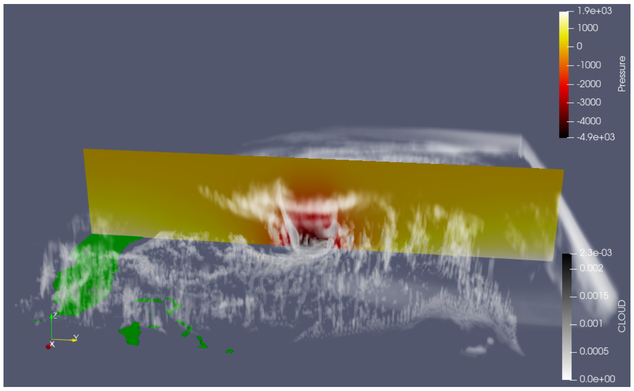


Figure 10: Volume Rendering of Cloud with Slice of Pressure

simulation in figure 11. It is easy to see that the low pressure system is a small ball where the eye of the hurricane is located. As the hurricane moves closer to the land, the area around the hurricane begins to drop in pressure, as seen by the lightly shaded area around the eye of the hurricane.

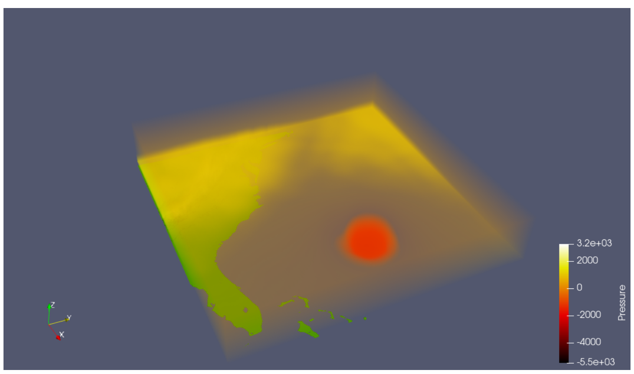


Figure 11: Volume Rendering of Pressure

In hurricane systems, the warm air from above the ocean moves upwards in the eye of the hurricane. To visualize the change of temperature in the hurricane, we use volume rendering for the clouds and then a slice from a volume rendering of the temperature. This behavior is clearly observed in figure 12 and figure 13 as the temperature inside the outline of the hurricane is higher compared to parts outside the hurricane, though not too significantly.

4.3.2 Precipitation. Next, we focus on the precipitation of the hurricane. Rain, snow and ice tracking is critical information in hurricane tracking and prediction. Once the hurricane makes landfall, areas can often see high areas of flooding and other damage. So visualizing and understanding precipitation patterns is critical. First, we use volume rendering of the precipitation data, which contains both precipitation from rain, snow and ice over the course of the simulation. Here we can also visualize an interesting feature of hurricanes which are rain bands.

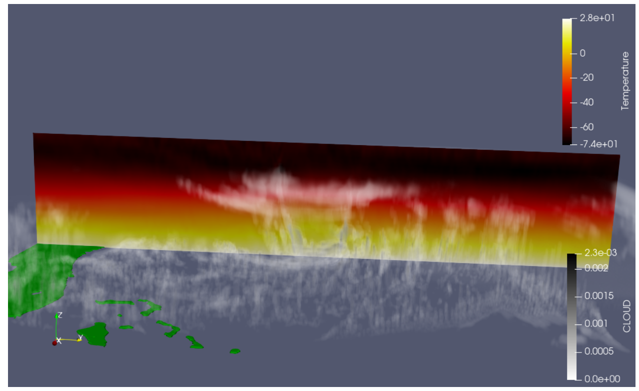


Figure 12: Volume Rendering of Cloud with Slice of Temperature

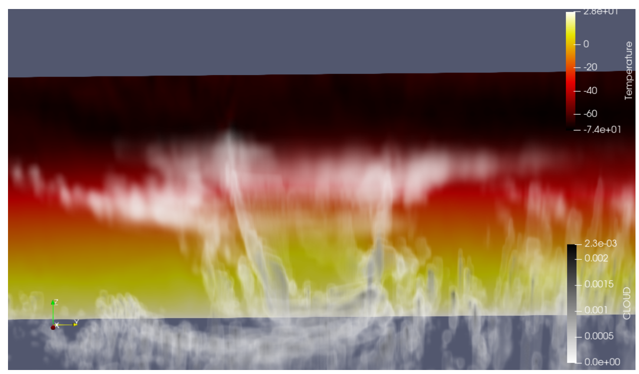


Figure 13: Volume Rendering of Cloud with Slice of Temperature Zoomed In

Rain bands are bands of very intense rain which spiral outward from the eye of the hurricane. In the figure 14 we can see three such rain bands on the right side of the eye.

In the animation view, we can see that the amount of precipitation reduces once the eye of the hurricane reaches land and the total region of precipitation begins to spread from the eye of the hurricane.

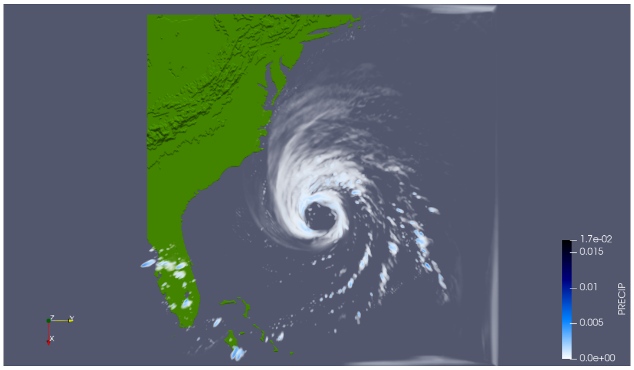


Figure 14: Precipitation in the Hurricane

To understand the total path and precipitation over the entire hurricane, we use a volume rendering and sum the precipitation over all time steps. This will bias areas in the center of the path of the hurricane, but it still provides a useful metric for understanding the impact of the hurricanes path. In figure 15 we can clearly see that more rain accumulates on the edges of the eye of the hurricane than anywhere else.

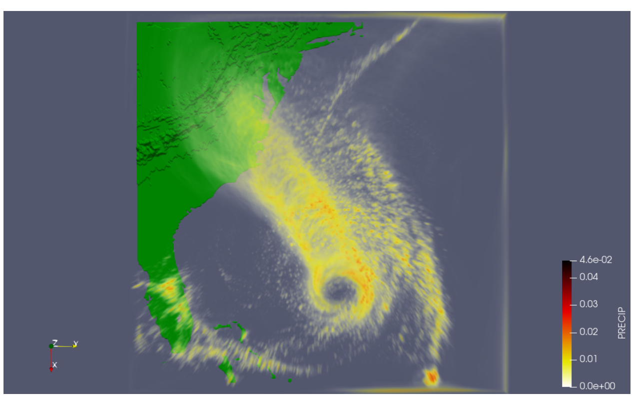


Figure 15: Total Precipitation Over Simulation

We also had a goal of visualizing the change in precipitation over each time step. To visualize the difference, we subtract the current rain from the previous time step. In figure 16 the red portion indicates areas which have more rain in the next time step and the blue areas are regions which have less rain in the next time step.

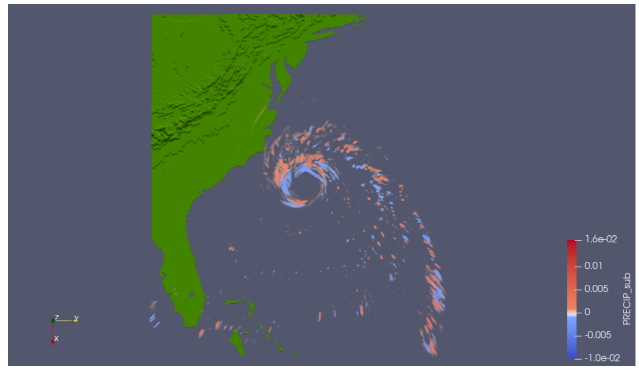


Figure 16: Difference in Precipitation over Time

4.3.3 Wind Flow. Finally, we focus on the wind flow of the hurricane. Information about wind speed and direction is critical information in hurricane tracking as it determines the magnitude of the hurricane and it the cause of most damage by hurricanes. First, we use a vector field visualization along with a volume rendering of the clouds to get an overall sense of the vector field. In figure 17, we can clearly observe most of the wind is moving away from the eye of the hurricane, with some wind in the upper portions of the hurricane swirling around the eye.

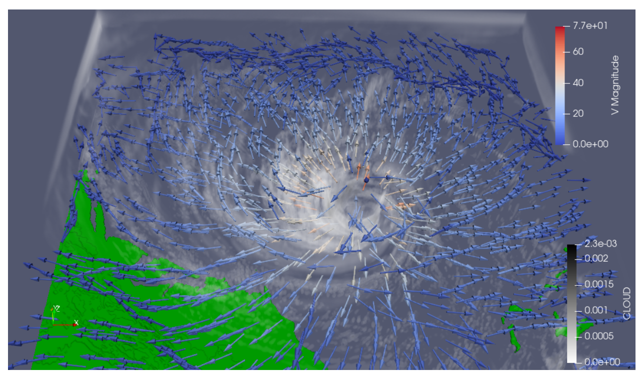


Figure 17: Cloud and Wind Flow

To see the airflow alongside the cloud and the low pressure system we use streamlines with a cloud source and sample glyphs along the streamlines to get a sense of the flow in figure 18. While we cannot see the airflow in the eye of the hurricane moving air upwards as expected, we can clearly see that near the eye of the hurricane the wind speed is quite fast and the air generally moves away from the eye of the hurricane. We also see that the wind curves around the hurricane which lines up with the cloud formations we see on the far side.

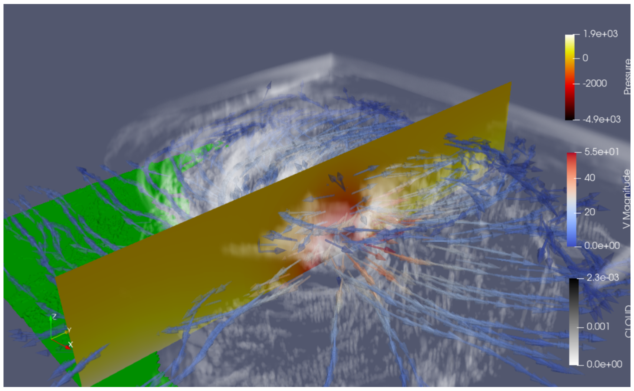


Figure 18: Cloud, Pressure and Wind Flow

An important part of hurricane tracking is classifying the hurricane. This is done using the Saffir-Simpson hurricane scale which ranks hurricanes in categories from 1 to 5. Category 1 hurricanes have moderately high wind speeds at 74-95 mph while category 5 hurricanes have major wind speeds of over 157 mph. The Saffir-Simpson scale uses the maximum sustained wind speed over a period of at least one minute and in a location at least 10 meters above the surface. One difficulty encountered with our data set is that we can only gather the instantaneous wind speed at 48 moments in time. We do not have access to the information about sustained wind speed, but still find this attempt useful as it gives a good indication of the category of the storm. We attempt to visualize the change in the hurricane classification by using volume rendering with a transfer function which uses 6 colors to represent a tropical storm and the 5 categories of hurricanes. We use volume rendering to attempt to get a larger understanding of wind speed at various heights of the hurricane, since the classification is based on any wind speed above 10 meters. In figure 19 we can see that the hurricane appears to be a category 3 or 4 storm, which it was at this time in its path based on historical data [6].

We can also clearly see how inside the center of the hurricane has very low wind speed and is actually a very calm region of the hurricane with the regions outside the center having the highest wind speed.

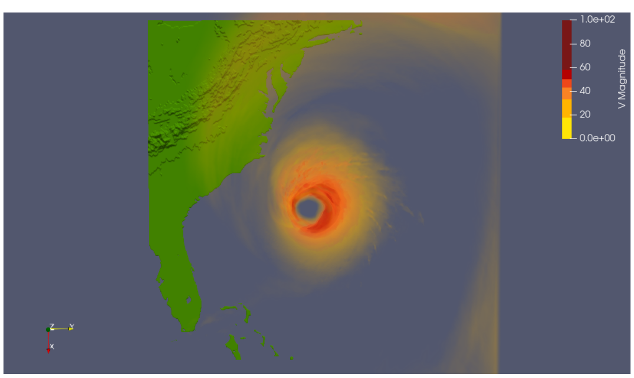


Figure 19: Magnitude of the Wind Speed for the Hurricane

A surface line convolution integral (LIC) can be used to find key features in the vector field. We select a slice of the hurricane and use a surface LIC to understand the wind flow. In figure 20 we have overlayed the plot with a color map of the wind speed as well to show both wind speed and the vector field. We can clearly observe the eye of the hurricane based on the focus critical point in the center of the figure. Near the eye of the hurricane is a saddle point where the air begins to start swirling around the hurricane. Near the right side we can observe many node critical points where the air swirling around the eye contacts air not a part of the hurricane.

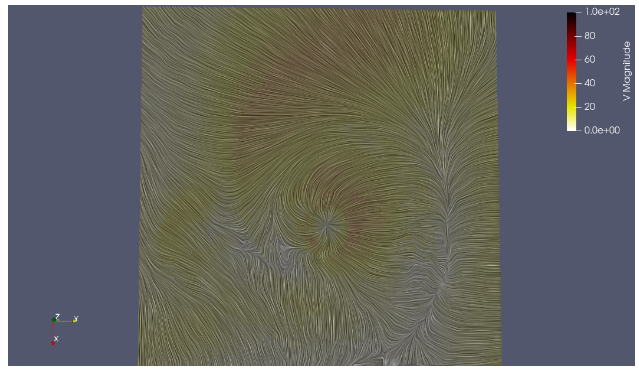


Figure 20: Surface Line Convolution Integral with Magnitude of Wind Speed

We now use vortex detection techniques to visualize the eye of the hurricane. The Q-Criterion is named after a method for vortex detection by Hunt et al [7]. The method uses the second invariant of the velocity gradient tensor to visualize eddies in the vector field. We can clearly see in figure 21 the vortex of the hurricane and the smaller eddies in the other regions of the hurricane.

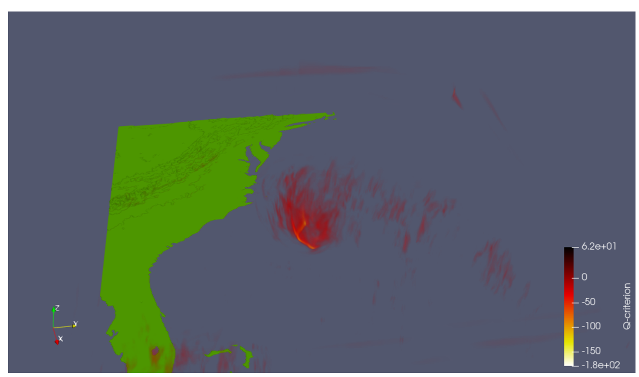


Figure 21: Q-Criterion

We now use the vorticity in the vector field to visualize the vector field. We can clearly see the regions of high turbulence around the eye of the hurricane and in the upper regions of the hurricane.

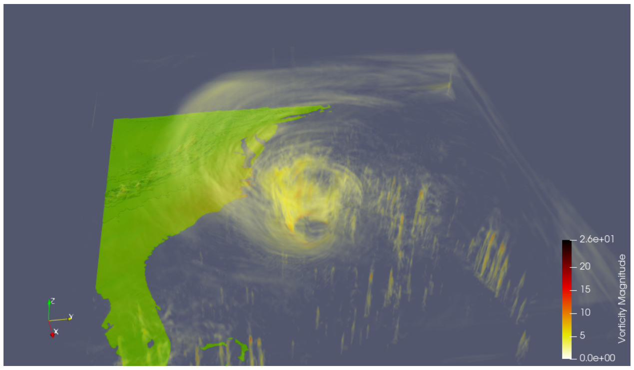


Figure 22: Vorticity

5 WHAT WE LEARNED

5.0.1 Isabel and Paraview. Each data set and each visualization presented obstacles that ultimately we overcame and learned from. The IEEE Model data was the most difficult initially because of the format of the data and the number of variables involved. This required learning about the data format "brick-of-floats" and the various readers that Paraview uses. After loading the data, deciding what variables would be interesting to view and which filters would give the best images were the next set of problems. No one in the group had any expertise in meteorological disasters so some brief research on the structure of cyclones was needed. The size of data also began to be problem for visualizations and logistics as the total size of the data exceeds 50 gigabytes. We chose a limited number of variables to visualize and import so it could be more easily used. Finally, class lectures helped us in understanding how to create multivariate images, such as volume rendering, isosurface extraction, and techniques as advanced as surface line convolution integrals.

5.0.2 Google Earth Engine. There was a great deal of learning incorporated in using the Google Earth Engine. Understanding how the engine generated, blended, and created images from different satellite bands was the first steps learned. We then had to research which satellites held relevant data and what benefits/drawbacks each image collection held. Lastly, figuring out the solutions to the animation/video export limitations such as animation length, image size, image resolution, data storage, automation, alpha channel implementation and data type restrictions.

6 CHANGES TO PROJECT

Visualizing the precipitation overlaid on a geographic map, that highlights topographical data, would be far more insightful than simply graphing markers over time steps of the center of the typhoon. Additionally, the satellite data is taken in 90 minute intervals where most of the typhoon steps were taken in 6 hour intervals giving a much higher resolution of data if we choose to look at it in that tight of a scope. This new skill set may also be applied to the Isabel using the precipitate data and pathing data that is only available for North American cyclones. This means cleaning the typhoon data will change also because data like the storm category number will not be relevant to our new goals, although this does not mean it will be ignored all together.

An additional change made was that we were unable to visualize the convective cells in the hurricane. Convective cells are regions of the hurricane which contain upward wind drafts along with high pressure regions which drive moisture back up into the hurricane. Unfortunately, the simulation data provided seemed somewhat limited and was not granular enough to be able to visualize this phenomena in the hurricane.

7 EVALUATION

Based on the our original project descriptions, our project is done successfully as expected. We visualized the various perspectives of the hurricane Isabel. Also, density plot of the historical cyclone data over the western north pacific area and typhoon path from satellites are visualized. We were able to gain valuable insight about the hurricane by using generated plots and figures. For future works, intensity of cyclone or weather data can be added and visualized together to understand the relationship between the cyclone and weather. Also, synchronizing satellite and historical data might give us different perspective of hurricanes.

One of the strengths our analysis and report show is the diversity of data and visualizations. The combination of long historical data in conjunction with very detailed animations from a single event gives a comprehensive scope of tropical cyclones. Additionally, the fact that none of us had any domain knowledge let us fully explore the data unbiased and look for what we believed to be interesting imagery. This could also be a short coming, in that some of our analysis may have been superfluous because it provides little insight to a meteorological expert. Another weakness is that due to the time constraints we weren't able to compare our data sets to any other comparable data sets. Finally, we also we were not able to investigate any other software packages to see if we could have created other interesting visualizations. Overall, we feel that our report and the media generated will be useful to amateur and expert atmospheric scientists.

REFERENCES

[1] [n.d.]. *Google Earth Tour Tutorial.* https://www.google.com/earth/outreach/learn/creating-a-narrated-tour-in-google-earth/
[2] [n.d.]. *Matlab Density Plot Documentation.* https://www.mathworks.com/help/matlab/ref/gradient.html
[3] [n.d.]. *The National Oceanic and Atmospheric Administration.* https://www.avl.class.noaa.gov/saa/products/welcome
[4] [n.d.]. Ten Years Later: Memories and Lessons Learned from Hurricane Isabel. *National Oceanic and Atmospheric Administration* ([n. d.]). https://buoybay.noaa.gov/news/ten-years-later-memories-and-lessons-learned-from-hurricane-isabel
[5] Chourasia Amit. [n.d.]. *XDMF header files for Hurricane Isabel data.* https://www.seedme.org/node/54202
[6] Jack Beven and Hugh Cobb. 2004. Tropical Cyclone Report: Hurricane Isabel. (2004).
[7] Hunt' JCR, A Wray, and P Moin. 1988. Eddies, stream, and convergence zones in turbulent flows. *Center for turbulence research report CTR-S88* (1988), 193–208.
[8] Ying M, Zhang W, Yu H, Lu X, Fend J, Fan F, Zhu Y, and Chen D. [n.d.]. *2014: An overview of the China Meteorological Administration tropical cyclone database. J. Atmos. Oceanic Technol.* http://tcdata.typhoon.org.cn/en/zjljsjj_sm.html
[9] NASA's Applied Remote Sensing Training Program. [n.d.]. *Nasa's Webinar Series on GEE.* https://www.youtube.com/watch?v=4Y2giuRPCuc
[10] Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. . [n.d.]. *ParaView/Data formats.* https://www.paraview.org/Wiki/ParaView/Data_formats

[11] Wei Wang, Cindy Bruyere, Bill Kuo, and Tim Scheitlin. [n.d.]. *IEEE Visualization 2004 Contest*. http://sciviscontest-staging.ieeevis.org/2004/data.html