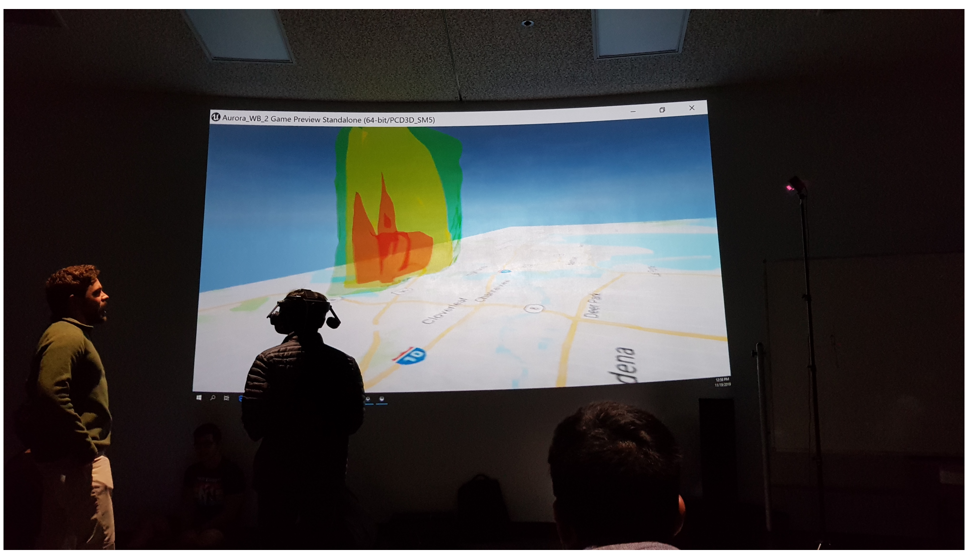
Presenting Weather and Radar Data in an Educational Virtual Environment

William Young, Amber Wilgnaowski, Jedidiah Ullrich, Hernaldo Jesus Henriquez



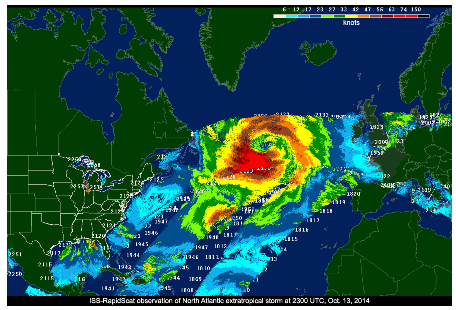
December 6, 2019

1 Abstract

Understanding multidimensional weather and radar data can be very challenging for meteorology students because they are not intuitive. When this data is presented in a 2D map that doesn't help much and it is a waste of the advantage of having three dimensions. In this paper we present a virtual reality application that displays weather data, and we evaluate if it is easier for students to understand it being immersed in a virtual environment where they can intuitively interact with the clouds. We implemented this with Unreal Engine 4, using real weather data from NOAA. The data can be seen in a miniature object, in a 2D map, in perspective screen or it can be seen in a map where the user is free to fly around. Our results show a positive feedback and many ideas to improve this first prototype of weather data visualization. We conclude that this approach is very promising and that meteorology students can greatly benefit from such applications.

2 Introduction

The purpose of this research is to see how a virtual environment can be used to facilitate a better learning technique for students in understanding meteorological sciences. Weather radar data for years has been represented in 2D formats across the globe. Virtual reality is a groundbreaking technology that has significantly helped with exploring new boundaries, as well as the way students and society can visualize and create a whole new world of possibilities. VR has not only opened the door to new and creative ways to do things, but has the ability to immerse the user with mind blowing interaction that takes the user to a whole new spectrum of intelligence.



This is an example of traditional weather radar data

3 Related Work

Weather radar data has been collected and visualized over the span of years in the past. In previous research for the visual representation of 3D scalar data they tested slices of iso surfaces and iso volumes from data sets obtained from research. The advantages of using slices as representation is that there is no need to define a range of values [6]. Touched on in this paper is how using big data sets comes with its own trials and tribulations. Though using a set of range values were found to be necessary to visualize the different data's isosurfaces when dealing with a large amount of data. A limit to the amount of isosurfaces was needed to assure that within the virtual environment visualizing this data would not become over stimulating, or hard to interpret. Afterall, the educational value is the overall expectations this research is involved with so having a confusing scenario for the users to view would be counterproductive. Pulling from a paper over research that was based on the 1960's Sensorama which is a hefty motorbike simulator that was a multisensory VE system. The paper uses the sensories of the human body to take people through virtual tourism where multiple users enter a virtual scene where, the humidity, lighting, and ambient scents change accordingly [3].

A future goal of our research would be beneficial to have some of these features to where students or users alike who use the application and feel the humidity or pressure will ultimately immerse them in the education virtual environment more efficiently. Other previous research involves a more in depth use for using weather simulation data in a 3D models city to accurate size. The Development and Application of the Stereo Vision Tracking System with virtual reality paper uses these aspects in their study. Their system used a detailed 3D model of their city where various scenes and scenarios were introduced of vehicle accidents by using various be it climate "weather" or visual distractors to gauge stereo vision [8]. Although in the method they used is not used in this research, the knowledge of the impact of various environmental variables on driver behavior and the impact of visual angle of driver from different environmental variables are analyzed, to improve data analysis of vehicle driver behavior in order for increased development benefit and cost was impressive. It also proves how weather can have an impact in different fields of research and shows different ways to visualize weather data.

4 Methods

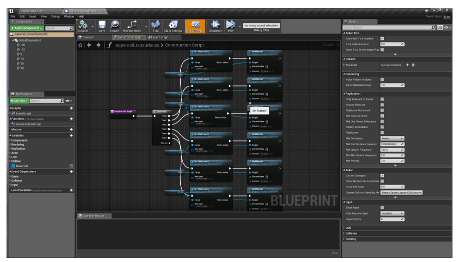
Visualizing data from large sets is not a trivial task when presenting information. [7] Large chunks of data with numerous dimensions and variables is something that's difficult to interpret even with basic techniques, such as using a coding software such as Matlab or Python. In most cases the task of taking raw sensor values, post processing them, and then presenting the results takes offers many areas where mistakes can be made and each step is more complicated than the last. Interaction with said data is another problem in the same vein. The information has to be presented in such a way that the user can interpret it as intended. Adding the capability to view the data in multiple ways adds complexity to this, but can greatly improve the user's experience.

For the application built in this project, the data being in a very visual and accessible format was a necessity. Weather radar is something almost everyone is familiar with. Almost all of the general public understands how to read and interpret a radar map to the degree where they can manage their entire schedules around what they see. However looking outside gives a much different perspective of the weather situation than looking at a radar does. Clouds in real life occupy three dimensions, whereas the radar only occupies two. This gives way to a disconnect for users that is between what the forecast is and what will actually happen in reality.[5] Bridging that disconnect is one of the goals of this application.

Weather data typically comes from radars, which operate by sending out radio signals that can bounce back to the radar and then be measured by sensors to derive different variables for any type of weather system. [2] The specifics of how the data is acquired is not covered in this study, but the transformation of the data into a usable format is a notion that is relevant. The goal of the visualization portion of this study is to take certain values of different weather variables and display them as isosurfaces to be viewed in a 3D space instead of 2D surfaces in a 2D space. The first issue when dealing with the data arises when choosing a method to translate radar data into 3D coordinates.

One of the best resources for weather data is the NOAA Weather and Climate Toolkit (WCT). This program uses Amazon Web Services to catalogue data at various times at various radar stations. This same data can then be saved in different formats depending on user preference. For this application, Net CDF (.nc) files are preferred. The data then needs to be interpreted by a software that can take the values and translate them into something more recognizable as an isosurface, such as a stereolithography (.stl), filbox (.fbx), or object (.obj) file. Paraview is an open source visualisation software that was used to create such surfaces. However, there was a disconnect that was not bridged in the work of this project. Getting .nc files from the WCT put them in a format using a kind of radial nomenclature that Paraview could not properly import. Future work must be done in this area to get real time data.

To overcome this issue, model data for storm cells was provided. This data was also in the .nc file format, but had cartesian nomenclature which allowed Paraview to read the data. Once the data is loaded in this software, the program allowed for many different ways to visualize the data. Different surfaces of different variable values can be created. Using this functionality allowed to create surfaces for reflectivity, cloud water, and cloud ice values. Both cloud ice and water surface were made using a value of 0.0001 g/kg, while the reflectivity surfaces were created at values of 10, 30 and 50 dBz. While simple, these examples made the difference to show how different values could mean different things and help users better understand what is happening inside a cloud.



An example of the UE4 blueprint coding structure used to generate the animations of the weather radar data

While Paraview has given surfaces to be displayed, there still is a need for a platform on which to display them. For this application the platform also had the requirements of being VR-capable and have a simple function for development. For these requirements, the Unreal Engine 4 was chosen. UE4 is a software most generally used for developing video games, but because of its graphical applications, can be used for other practical applications such as simulation or data presentation. The Unity engine is another example with similar advantages, but UE4 was chosen for this application mainly because of the researcher's prior experience with the program.

This report will document the main procedure and motivations for the development of this application, but will not include a step-by-step guide because most of that information can be found in the Github wiki of the project at the page in the footnote . To cover most of the concepts used, a Blueprint Actor was created for each time-step of the data. In this Actor, a Construction Script was created that assembled the Static Meshes that were imported .fbx or .obj files. One note about these different formats is that scaling was different by a factor of about 100. Inside the Construction Script, a material that was translucent and colored based on conventional radar map coloring is assigned. These were then mapped to another Blueprint in an array of Actors. Using Blueprints, every single frame was hidden, and then used a script to unhide an actor once per second. This is a workaround for how computationally intensive it can be to spawn and despawn an actor continuously.

These actors were also mapped to different control panels. Three control panels are used in the application, one to control the variables being shown, one to control the frame being shown, and one to control which scenario was being displayed. To briefly describe how the algorithms for the controls worked, the frame control must be considered first. The specific controls were a play and pause button, a skip frame button, and a previous frame button. The reason for this is because the algorithm for all of these used the index of the actor being hidden/unhidden to manipulate the display. This notion is central to the entire animation, so implementing this first better allowed for control development afterwards. The play and pause button triggered a boolean that told the animation to stop and effectively stop iterating the index or frame being shown. The frame control buttons were set to only work when paused, and triggered another boolean that would either subtract or add an index based on which button was pressed, and then hold that frame again.

The scenario controls were relatively simple compared to this. The algorithm here is dictated by booleans again based on which button was pressed, one for each scenario that was available. Once a button was pressed, the boolean associated with that scenario was set to true and immediately set all others to false. This boolean dictated whether any of the frames were shown at all. The counter for unselected scenarios still ran, in order to be consistent with the scenario being displayed at that time. The variable controls proved to be another challenge, but utilized more or less the same algorithms. Essentially more booleans are used for each variable, but this time they don't trigger the other booleans to turn off when set to true. The issue arises when trying to couple the indexing for each different variable when one is shown and another isn't. The way that was used in this application had all three variables be spawned in the same actor.

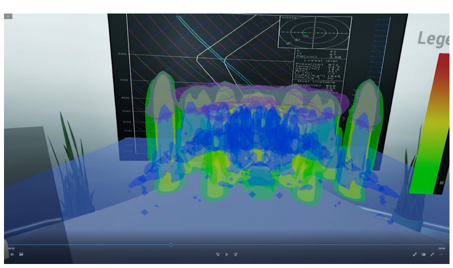
Experimental methods for data gathering were kept relatively simple for ease of data interpretation. The main element of the study was having subjects experience the application, and then gauging the knowledge they gained. Subject selection had a preference of meteorology students, because they were the demographic to most benefit from the application and would be most able to give objective feedback. The application should be first tailored to those that should reasonably be able to understand it, and once they do, then can be applied to a more general subject pool. The objective was specifically to gauge whether or not students subjectively felt like they learned about the subject material, and objectively learned about it. This data was gathered using a post-study questionnaire, which gave data based on prior VR experience of the user, questions related to the data being displayed, and other subjective measures. The hardware used was an HTC Vive head mounted display as well as the accompanying controllers. The application is not very intensive in its current state, but increasing the amount of surfaces loaded into the simulation will increase the GPU load on the computer.

5 Results and Discussion

During our trials, results and feedback were positive. We had a total of three subjects to run trials on, all of which were meteorology students with an extensive knowledge in their fields. Only one of the three subjects had any sort of previous experience with VR. Navigation in the environment was less fluid than desired while the user interface was put as being slightly stiff. Additional controls and accessibility of input should be implemented. Primarily additional wrist controls for added control in the environment view beyond switching environments and adding a time slider in both the hub and the environment view. Continued development of the application can benefit from the implementation of scale manipulation. Users mentioned that they wished there was something similar to that of a graphic ruler on or in the HUD or UI. Along with this wish to see the user's scale while in the application, an idea was considered to possibly allow different scalings for the user while in the environment to change how small or large the user is relative to the storm system and possibly having them to scale.

Ultimately, our application is to be used for education. Our subjects really appreciated that they can see the development among the variables which is a critical aspect for education and among those in the field observing data. One aspect that is not conveyed well enough is the difference in radar. What difference in radar that could be seen was mainly in the supercell system. Even then, our users knew to look for it because of their knowledge of it. This is something critical in the education of radar data. Many of our subjects believed that this would bring newcomers in the field to a massive disadvantage.

There is plenty of work to be done into integrating this application into a fully functional educational platform. Primarily with the user interface so that it may be streamlined for those with little VR experience. One possible way to do this is to include overlay buttons, perhaps that of a "where am I" button, that follow the user. As stated earlier, these could be added to the wrist buttons. Some cosmetic changes that were worked on, but never polished or implemented were a more traditional cloud look via particles on the storm system. This would have been done via sprite sheets and a particle emitter. This was never completed as a method to attach the emitters to the models was not developed well enough. Along with cosmetics is the addition of actual terrain in the environment with the map. This proved to be somewhat challenging as one of our locales is exactly at sea-level and would possibly be nothing more than a plane with a satellite image on it, but something to explore as well as the ability to switch locales. Another feature that was suggested to be added to the wrist is the addition of a 2D radar map, but this one would be on the user's right hand whereas the buttons were on the user's left hand. This application can also go on to possibly include live radar data much like when one views a radar map online or on television. In order to do this, new data must be added via an object-oriented, hierarchical structure [1]. An elaborate algorithm can hopefully be used to constantly update the radar data for a close-to live feed. Perhaps one day it can be a meteorologist in an HMD broadcasting the application instead of being in front of a radar map, and if not that, the application can at least help a great deal with explaining the evening weather.



A screenshot from within the application showing one way in which the weather radar surfaces are displayed to the user

Weather data in a virtual environment was heavily researched in Springer-Verlag's Concept and workflow for 3D visualization of atmospheric data in which a large amount of data and variables were put into their application. Our application is primarily for education and might be overwhelming for those who are unaware of certain datasets. In the future, inclusion of such a variety of variables and data could be included for those trying to analyze every aspect of the storm system. A possible inclusion of micrometer areas could be a great addition to the application as not even Springer-Verlag could quite add the aspect to their research.

6 Conclusion

In this paper we have presented a Virtual Reality application prototype to visualize weather data. Specifically the application shows Ordinary, Multicell and Supercell thunderstorms in their reflectivity, cloud ice and cloud water variables using 3D models that change in time (fourth variable). Those variables are colored similar to how it's done in regular 2D maps depending on the range of values they are. The main purpose of this application is to be used in Meteorology classes to help students to better understand multidimensional weather data. There were many challenges to make this application, starting with how to get the data into Unreal Engine, then how to display it in a way that is useful for the user and how to make intuitive navigation and interaction controls for users that may not be experienced in a Virtual Environment (VE).

We are happy with the outcome of our prototype, getting positive feedback from the users and many ideas on how to improve this. We are completely confident that presenting multidimensional weather and radar data inside a Virtual Reality application is promising and can improve meteorology teaching. Many of the improvements that can be done in future work are on navigation and user interaction for example to be able to scale the clouds, the possibility of moving faster, to see were the user is located or to show a ruler to figure out the scale of the clouds.

This type of application can also be used in other cases besides education. For example, it could be used for detecting possible damages of hurricanes or floods. Weather authorities could enter inside a Virtual Control Room and make informed decisions and communicate with stakeholders or in field agents, similar to what was done by [4] but instead of surveillance with weather information. To do that it would be useful to have live information inside the application, which should be very difficult to implement but not impossible.

References

[1] I. Brown. Developing a virtual reality user interface (vrui) for geographic information retrieval on the internet. *Transactions in GIS*, 3:207–220., 1999.

[2] Cloupas Mahopo Gagandeep Kang Margaret Kosek-Francisco de Sousa Junior Prakash Sunder Shrestha Erling Svensen Ali Turab Benjamin Zaitchik. Josh M. Colston, Tahmeed Ahmed. Evaluating meteorological data from weather stations, and from satellites and global models for a multi-site epidemiological study. *Environmental Research.*, 165:91–109, 2018.

[3] Michele; Gattullo Michele; Boccaccio Antonio; Bevilacqua Vitoantonio; Cascella Giuseppe L.; Dassisti Michele; Uva Antonio Manghisi, Vito M.; Fiorentino. Experiencing the sights, smells, sounds and climate of southern italy in vr. *IEEE Computer Graphics Applications.*, 37(6):19–25, 2017.

[4] Gutiérrez M. Thalmann D. Vexo F. Ott, R. Advanced virtual reality technologies for surveillance and security applications. *Proceedings of the 2006 ACM international conference on Virtual reality continuum and its applications*, pages 163–170.

[5] Ibrahim. Sermet, Yusuf Demir. Flood action vr: A virtual reality framework for disaster awareness and emergency response training. 2018.

[6] Springer-Verlag. Concept and workflow for 3d visualization of atmospheric data in a virtual reality environment for analytical approaches. *Environmental Earth Sciences*, 72(10):3767–3780, 2014.

[7] Shriram. Teräs, Marko Raghunathan. Big data visualisation in immersive virtual reality environments: Embodied phenomenological perspectives to interaction. *International Journal of Soft Computing*, 05:1009–1015, 2015.

[8] Ko-Chun; Lee Tsung Han; Hsu Kuei-Shu. Wang, Chia-Sui; Chen. Development and application of the stereo vision tracking system with virtual reality. *Mathematical Problems in Engineering.*, 2015:1–5, 2015.