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## VoRTEX: A VIRTUAL REALITY THUNDERSTORM EXPLORER

Kathryn Wheeler  
and  
Lucinda Caughey  
Texas Wesleyan University, Texas, U. S. A.

### ABSTRACT

This paper describes a project to create a virtual thunderstorm chamber to simulate and visualize the variables in an unstable atmosphere. The chamber will show how these affect their formation of clouds, their production of thunderstorms, and the intensity of the produced storm.

The virtual chamber consists of a three dimensional atmospheric space whose properties are governed by fundamental cloud formation and turbulent atmosphere equations. A C++ program was written to estimate discrete values for atmospheric conditions over time within our sample space based on user defined initial conditions. Visualization of the resultant atmospheric space was produced using VRML, a web-based three-dimensional modeling language.

**Keywords and phrases:** atmosphere, convective instability, conditionally unstable, cloud formation, cloud base, cloud height and visualization

### INTRODUCTION

Meteorologists have long used computers to assist in weather forecasts. Computers can keep track of the many atmospheric variables used in weather forecasting including vapor pressure, relative humidity, dew point, time, temperature, etc. which would be unfeasible for humans. The observation, collection, and interpretation of data, or simply put the “statistics of weather,” are becoming increasingly automated.

Weather forecasts are routinely made using integral calculus equations for the atmosphere. These atmospheric fluid dynamics equations are used in governing the behavior of the atmosphere in computer simulations.

#### **Background.**

Numerical Meteorology: Leonhard Euler formulated the first equations of fluid mechanics in 1755. He used the differential calculus invented by Isaac Newton in 1665, Gottfried Wilhelm Leibniz in 1675, and partial derivatives devised by Jean le Rond d’Alembert in 1746. Equations describing fluid motion, often called the Navier-Stokes equations (for Claude-Louis Navier in 1827 and George Stokes in 1845), added the terms for molecular viscosity, which was later refined by Herman von Helmholtz in 1888. About ten years later, Vilhelm Bjerknes suggested that these equations could be used for the atmosphere. He preferred to use physics rather than empirical rules to make weather forecasts [Stull 2000, pg.312].

The ability to make forecasts has gone through several changes. Many difficulties developed as atmospheric research proceeded including: having to do many calculations by hand using slide rules and mechanical calculators, changing the differential equations into discrete form, writing the code in machine language because FORTRAN and C++ had not yet been invented, and deciding how large the forecast domain must be. However, several years later, numerical forecasts had one of the highest verification rates in the world. Improvements

have been attributed to the growth in computer power, as well as the improvements in the parameterizations of physical processes such as cloud formations, precipitation, and turbulence [Stull 2000, pg. 313].

**Cloud Development:** Clouds form when air becomes saturated with water. Saturation may result from adding water vapor, cooling, or mixing. The buoyancy of the air and stability of the environment determines the vertical growth of the cloud. Clouds form by adiabatic cooling of rising air. The adiabatic process takes place without a transfer of heat between the air parcel and its surroundings. In this process, compression results in warming and expansion results in cooling.

Air rises due to 1) intense surface heating, 2) surface air masses “colliding” or converging, 3) air masses of unlike temperature coming into contact along warm and cold fronts, and 4) a topographic barrier such as a mountain range [Lutgens 1995, pg.85]. For the purpose of this simulation, the focus will be placed only on convective instability, which occurs when surface heating causes convection and results in the difference in adiabatic lapse rates and stability. This paper will use convective instability to develop cumuliform clouds that form in unstable air, and once triggered, lifting mechanisms will evolve independently.

Previous work (Whittaker and Ackerman) has been done regarding the visualization of cloud formation as seen in the Verner E. Suomi Virtual Museum. However, this work was done in a two-dimensional space with several assumptions including the following: a constant environmental lapse rate, uniform cloud base formation, and assumptions in regard to the height and density of the cloud. Our model calculates the cloud base height and uses the environmental and adiabatic lapse rates as they change throughout the atmosphere.

### **Project Goals.**

Though the computer could produce a forecast of all variables influencing the weather, this project will limit the number of variables and focus on those influencing cloud formation, which could lead to storm formation. The software designed can be used by students to visualize the atmosphere created by their input of initial variables, and the program will show the changes in the atmosphere over time. In addition, the student will see how the length of time affects the life cycle of clouds and storms. In the future, the goal of this project is to input real time data and successfully recreate the weather situation occurring locally on the computer.

Furthermore, studies have suggested that the terrain plays a leading role in the rate of development of the convective cloud field. The type of soil and vegetation coverage are considered to be equally important in the early stage of cloud formation and for this reason, it is supposed that the geometrical structure of the field, cloud size distribution, and cloud sky coverage are mostly determined by surface topography rather than the thermodynamics of the surface layer [Clark 1984, pg.502]. Future work will be done to account for these aspects of cloud development and to determine if they play a role in the region known as “Tornado Alley,” which repeatedly encounters severe storm development.

## **METHODOLOGY**

An object-oriented methodology was used to create a cloud based on user defined atmospheric conditions (ambient temperature, ambient dew point, and initial convective air mass size). The C++ program methods calculate the base of the cloud formation using Eq. (1). The program also calculates the pressure trend as altitude increases using Eq. (2), and generates a data file of these values. The height of the cloud is determined by the intersection of the air parcel temperature and the surrounding air temperature. That is, when the air parcel temperature equals the temperature of the environment surrounding it, the cloud ceases to grow vertically. Prior to the cloud base a dry adiabatic lapse rate is assumed. From the cloud base to the cloud top the moist adiabatic lapse rate is used.

This implies cloud formation is dependent on the change in temperature within a cloud. “The influence of updraft fluctuations is not as important as the fluctuation of temperature which depends upon the amplitude and frequency of the fluctuations, and the expansion rate of volume,” [Carstens, 1975, pg.145]. The height will then be determined by extrapolating the line of intersection, if necessary, on a graph of altitude versus temperature.

Visualization: Marching Cubes is an algorithm for rendering isosurfaces in volumetric data. The fundamental process is to define a voxel (volumetric pixel) by the pixel values at the eight corners of the cube. By calculating the vertex isovalues, we can get a measure of how much the voxel contributes to the component of the isosurface. A determination is made as to which edges of the cube are intersected by the isosurface, which results in creating triangular patches that divide the cube between regions within the isosurface and regions outside. By connecting the patches from all cubes on the isosurface boundary, we get a surface contour. Coloration based on cloud density is used during rendering to generate the final cloud image.

### FORMULAE

Equation (1):

The lower cloud level height (distance above the height where temp and dew\_temp are measured) for cumuliform clouds is approximated by:

$$z\_lcl = a*(temp-dew\_temp);$$

where a is the constant 0.125 km/deg. Celsius.

Equation (2):

The pressure at a given altitude can be estimated by the derivative in the hydrostatic equation as:

$$(pa,1-pa,0)/(z1-z0) = -densitya,0*g$$

where pa,1=pressure at altitude z1, and pa,0, and densitya,0=pressure and density at a lower altitude z0.

### RESULTS

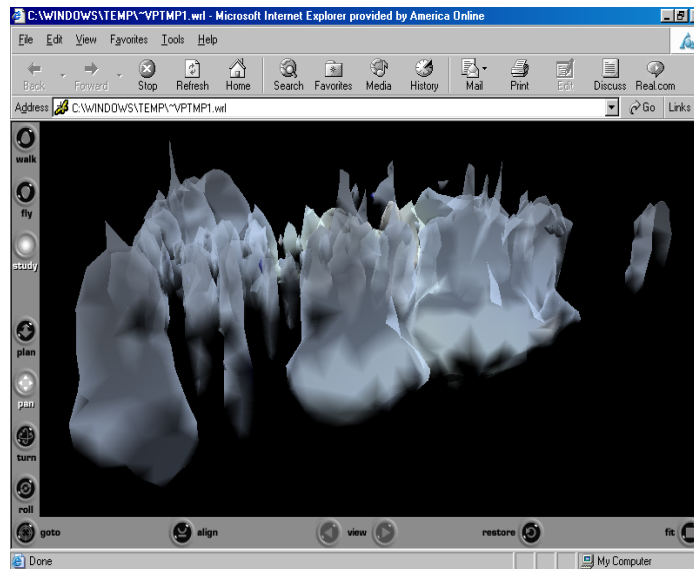


Figure 1: A single Cloud Isosurface at constant vapor pressure

### CONCLUSIONS

Recent advances in the capabilities of computer hardware and the theoretical understanding of the mechanisms which trigger cloud formations have made it possible to create a virtual atmosphere for study. This project

focused on cloud formation driven by convective instability; visualizing the resultant vapor pressure isosurfaces. However, the framework developed is extensible to any of the principle atmospheric variables that trigger cloud formation (topology, convergent air masses, etc.).

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