A Ray of Hope

New Mexico
Supercomputing Challenge
Final Report
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Executive Summary:

My project is a study of global warming from the viewpoint of light transport. This will be a two-step process. For the first step, I started off by creating a program that simulates the bouncing of light through a scene in a realistic manner. I used a method of a light simulation called backward path tracing (a version of path tracing that starts at the viewpoint instead of the light-emitting objects). Path tracing works by taking a photon (represented by a ray) and tracing its path through a scene as it bounces off surfaces. Based on the collisions and material properties of the objects the ray hit, a final color is designated to that simulated pixel. Due to the random nature of light, if you just simulate one photon, then the image will turn out very noisy. Because of this, you have to simulate many photons per pixel and take the average of them. This takes a very long time, although it gives highly accurate results. The next step, which will be the center of a future project, will be to simulate the actual heating by applying what I found in the first step. Path tracing can be used to find out the effects of gasses and clouds on global warming by finding what percentage of light gets trapped and for how long. The longer light is trapped, the hotter the earth; the quicker the light bounces out to space the less the earth warms. Some more simple approximations can be used to speed up the code at a slight loss of accuracy (likely not noticeable).

Problem Definition:

This project will explore the impact of various gasses and clouds on global warming. I will write a program that traces rays of light through clouds, the atmosphere, and gasses. This is to see how different gasses and varying amounts of cloud cover will affect the warming of the earth over time. Figure 1 graphically illustrates the physical process of how clouds influence the movement of light, and therefore energy.

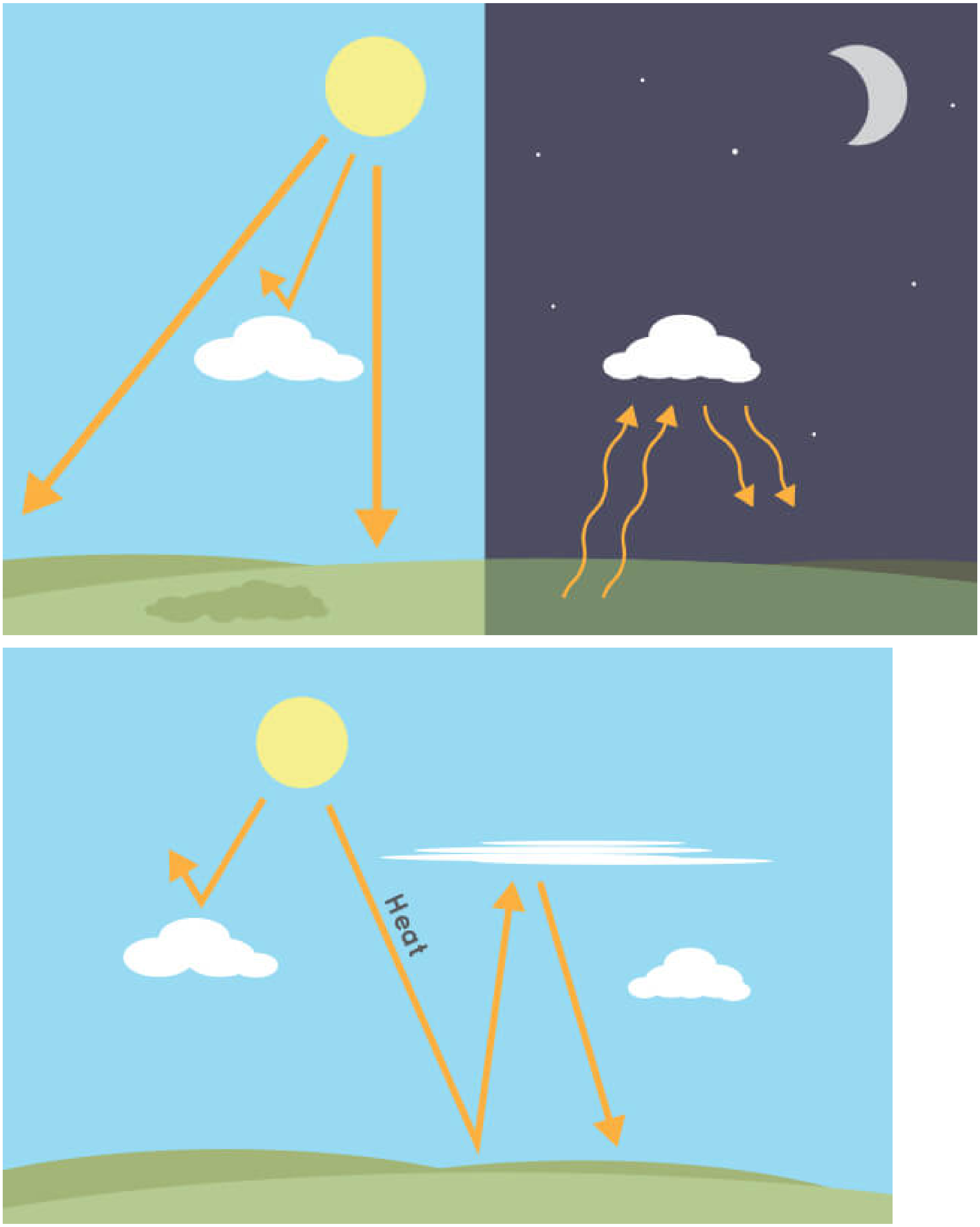


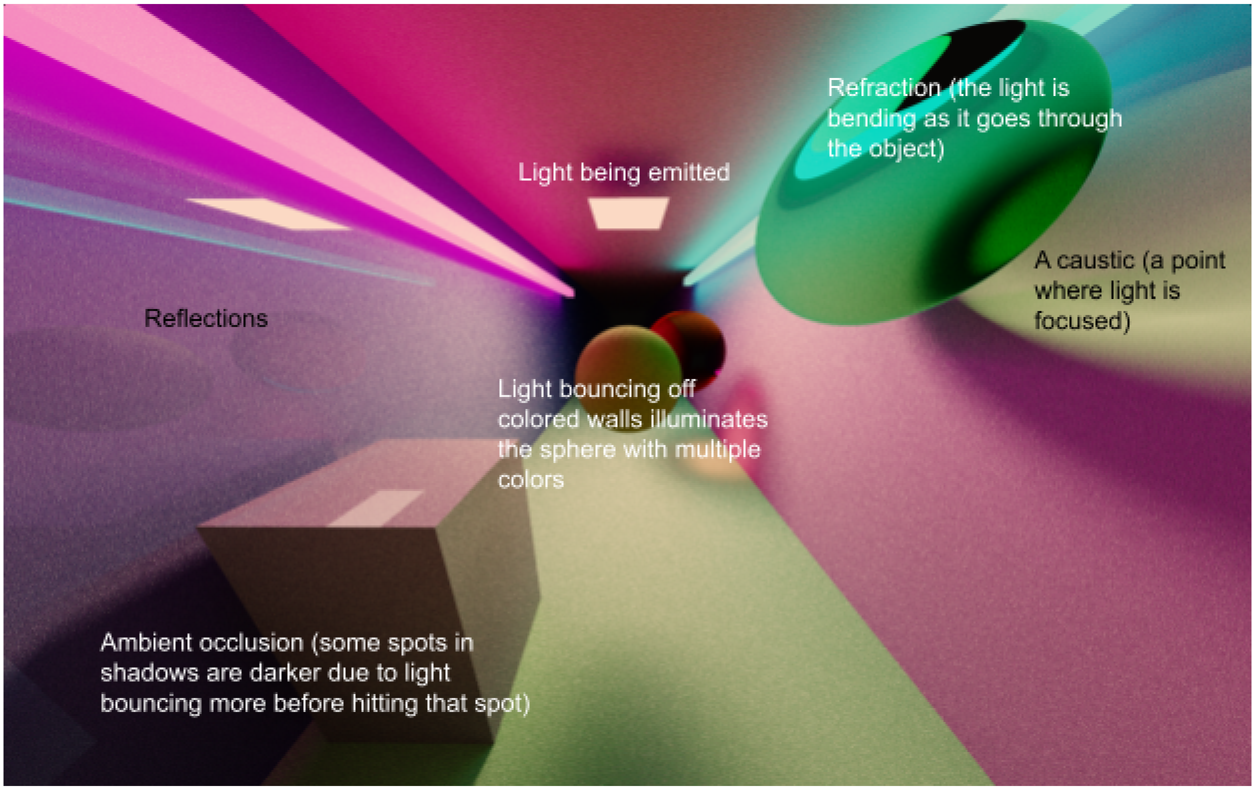
Fig. 1: This figure illustrates how the path of light can change when clouds are accounted for. Images taken from https://climatekids.nasa.gov/cloud-climate/

Method Description:

To simulate light bouncing through the earth's atmosphere, I will use multiple methods and combine them. The first method which will speed up the simulation immensely is using beers law (e to the power of negative total density represents how much light makes it through a volume of stuff). Instead of directly simulating the bouncing of light through clouds and the atmosphere, with varying levels of different gasses. This does mean that the distribution of scattered light, which changes based on the gas, will not be accounted for. Another thing that I will not be accounting for is how different wavelengths of light scatter through a volume of gas. I will find what percentage of light makes it into the atmosphere, and what percentage stays in the atmosphere, and this will represent the heating effects of varying amounts of gas and clouds.

Verification and Validation:

The methods used in this project were verified and validated by using path tracing and showing the resulting render on screen. The images produced properly matched real world situations similar to the one created in the program. The result of the path tracing can be seen in figure 2.



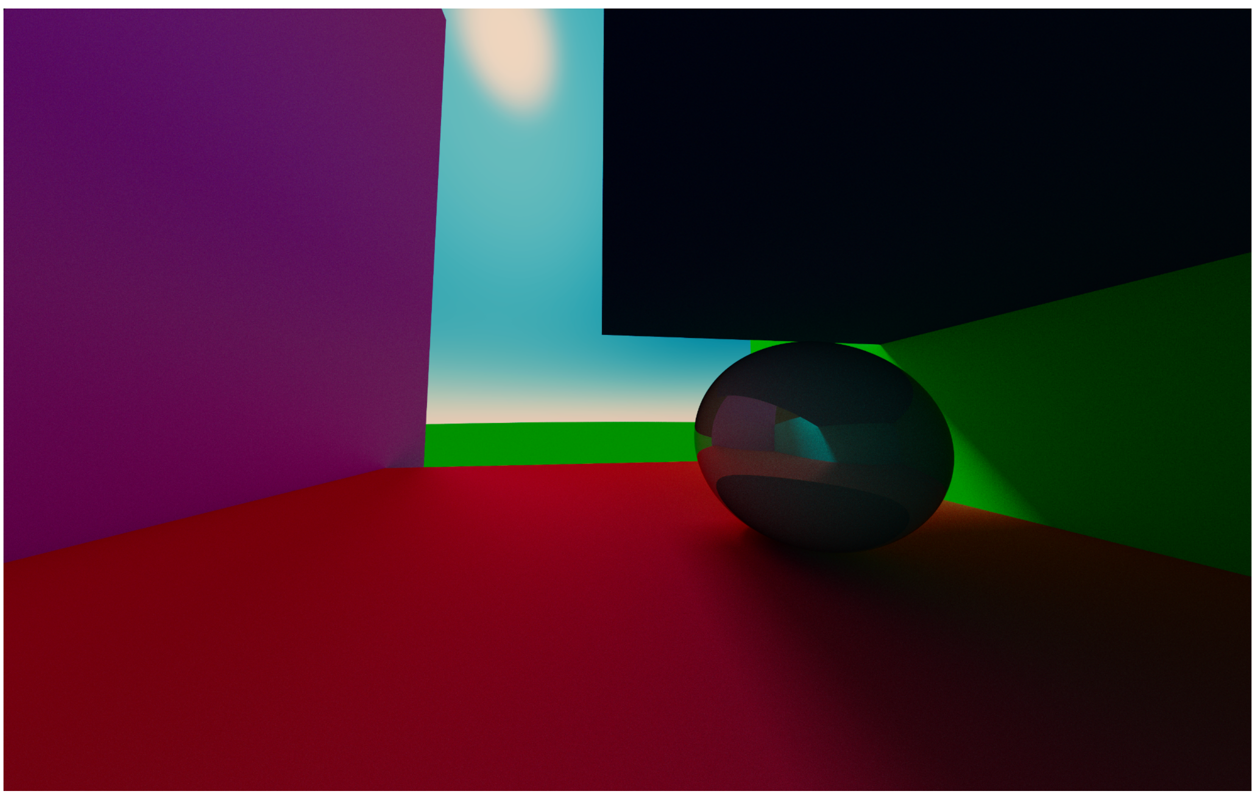


Fig. 2: These images from the code show the same path tracing in an indoor (top) and an outdoor scene (bottom). These scenes include diffuse objects, refractive/translucent sphere, and in the outdoor scene, the atmosphere which uses rayleigh scattering.

Results

When the sunlight strikes the atmosphere, like shown in figure 3, the rays of light scatter depending on the wavelength of the light. This means that at a far distance all of the blue light and a lot of the green light have been scattered off. An example where this happens is at sunset when the sun has to make it farther through the atmosphere before hitting the viewer's eye. During the day the sun doesn't have as far to go through the atmosphere, so very little green and red light are scattered, so the light appears mostly blue. At sea level the sunlight has to go farther compared to at higher altitudes, so in the day the sky is whiter due to more green and red light scatter. Inversely high up in the mountains, the sunlight has less distance to travel to your eye so it's a deeper darker blue.

When sunlight hits a cloud, like shown in figure 4, much of it is bounced back into space. Although if the cloud is thin and facing the direction of the sun, a lot of the sunlight makes it through the cloud, producing super bright highlights on the surface of the cloud. This likely can cause a change in the heating of the earth. The code correctly shows how the clouds can darken light, as well as have the bright highlights in thinner sections that are facing the sun.

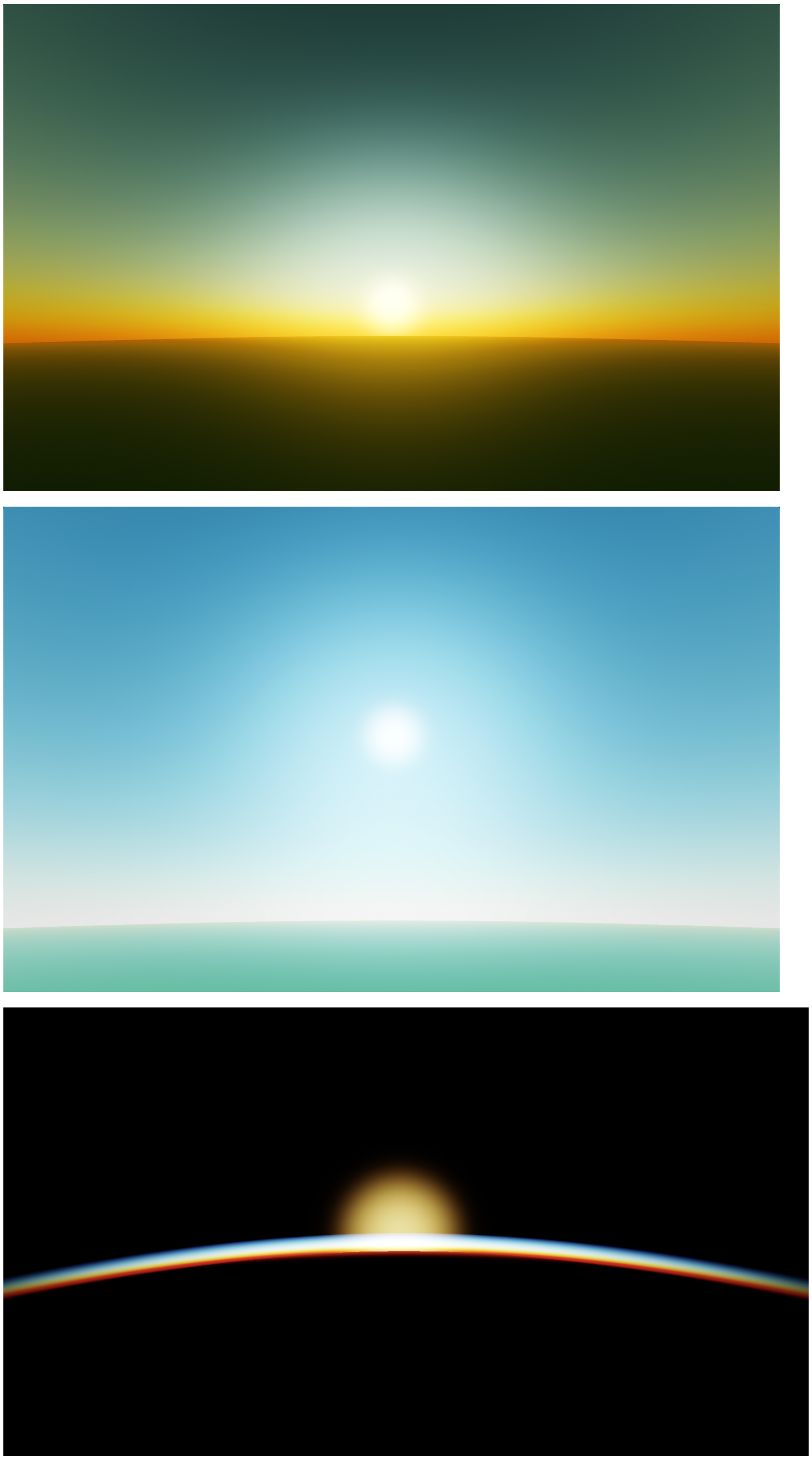


Fig. 3: The images from the code show the atmosphere correctly scattering light based on the angle of the sun in the sky respective to where the camera is viewing it from. The first two images show the sunrise and morning from an altitude of 7,500 feet above sea level and the third image shows the sunset from about the height of the international space station.

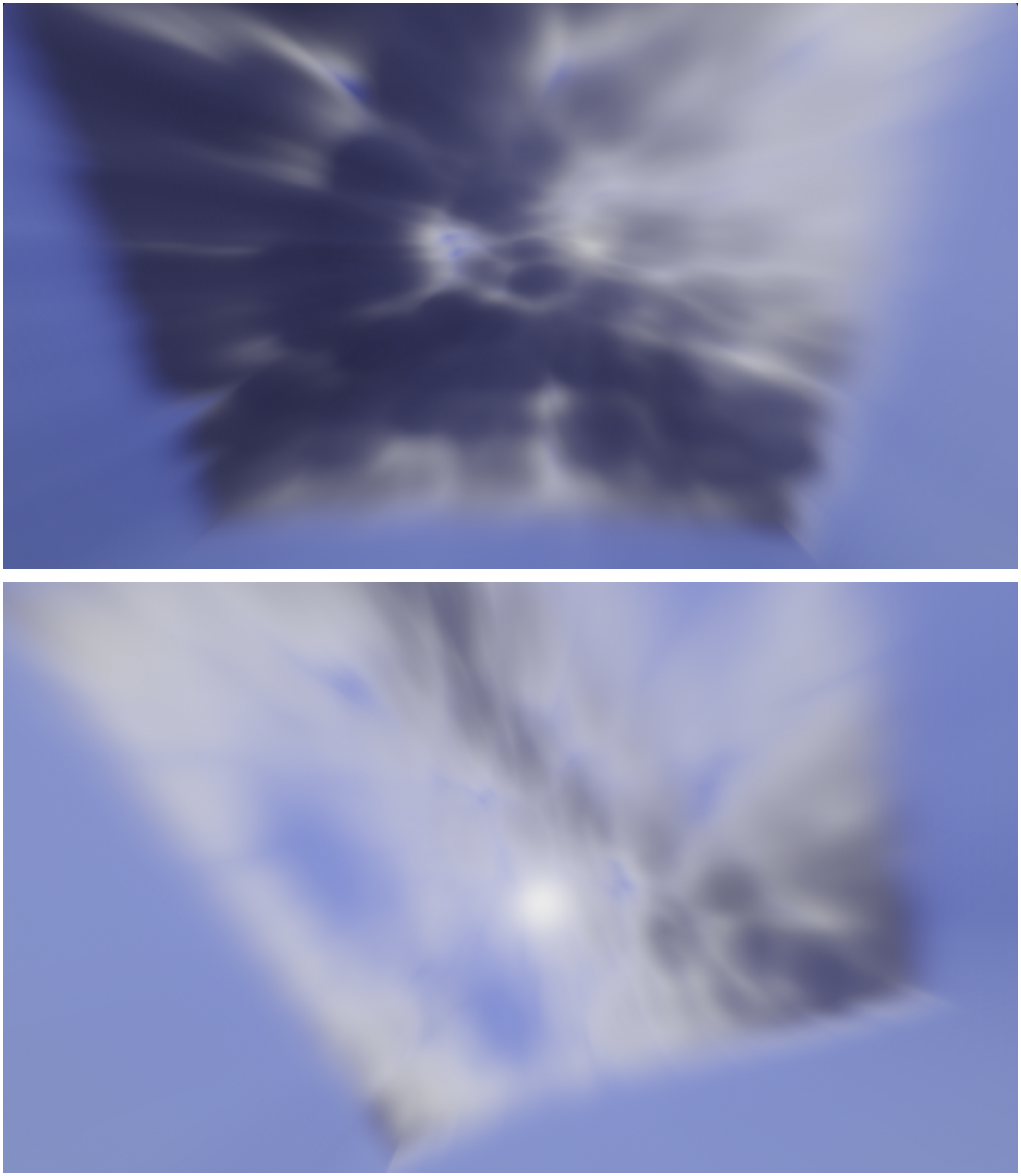


Fig. 4: The images shown from the code show how clouds can darken the light.

Conclusions:

The light simulation code replicates the bouncing of light in an environment using a technique called path tracing. The code was validated by visualizing light bouncing around a room or an outdoor setting, and gathering up the light over multiple samples. I made this to test if my methods would accurately simulate light by generating an image and comparing the output to real-world scenarios.

After the validation was completed, the code was used to simulate light transport in the atmosphere. When the outputted images were compared to images of real-world situations, it matched the images fairly well. This validates the use of path tracing for tracking the effects of gas and clouds on global warming.

I created a light simulation code but I still need to join this together into a program that tracks the amount of trapped light in the atmosphere versus escaped light. Rays that stay for more bounces contribute to more heat while rays that stay for a shorter amount will deposit their energy somewhere else. I can use this to simulate global warming by finding how much and how long rays stay in the atmosphere. The methane, co2, and other gasses are expected to increase the amount of light trapped in the atmosphere. There's a good chance that, at some point, the increased heat will cause more clouds to build up. The thickening of the clouds may lead to the earth cooling instead of additional heating. This cooling may lead to fewer clouds, which would lead to higher temperatures. This would mean that more clouds would begin to form again creating a feedback loop that keeps it from reaching even higher temperatures.

Code:

The code is written in GLSL (OpenGL shader language), the language is similar to c++ and automatically has GPU parallelization to speed up the code. The source codes that I developed for the simulations, which in total is over 2,000 lines in length, are at the following web links:

Atmosphere (the default view is from the international space station):
https://www.shadertoy.com/view/Ns3GzB

Path Tracing:
https://www.shadertoy.com/view/7lt3Dl

Clouds (has other non-physically correct stuff, just the clouds are correct):

https://www.shadertoy.com/view/fs33zB

References:

https://climatekids.nasa.gov/cloud-climate/
https://www.youtube.com/watch?v=DxfEbulyFcY&t=702s
https://www.youtube.com/watch?v=4QOcCGI6xOU&t=369s
https://www.youtube.com/playlist?list=PLujxSBD-JXgnGmsn7gEyN28P1DnRZG7qi