Hi everyone! I'm Alex Pate, I'm an applied math major at Colorado School of Mines, and I'll be a senior this fall. My mentors this summer were Elizabeth Thompson at PSL and Dongxiao Zhang at PMEL. My project was on extracting cloud fraction estimates from saildrone sky camera images taken during the atomic campaign in the tropical Atlantic east of Barbados.

The motivation behind this project is that cloudiness is an essential metric of the climate system and clouds help regulate the rate of climate change. However, it's difficult to measure cloudiness from autonomous vehicles using traditional methods like a ceilometer, radar, or lidar because it's hard to mount those on unstable, power-limited vehicles in a harsh environment. The ocean-going observing system for weather, ocean, and climate is becoming increasingly autonomous, using things like saildrones, shown here, to cover more area and time, so it's important that they have a way to measure cloudiness. Saildrones don't have a quantitative method of measuring clouds but they do have sky cameras. So, the goal for this project was to develop an algorithm to measure areal cloud fraction from saildrone sky camera images, using atomic 2020 data.

So, here is another picture of a saildrone and its four camera views: up, down, and left and right, which look pretty much the same. I focused on the upward facing images instead of the left and right ones. I considered and worked some on a few different methods of finding the cloud fraction, including a couple different neural networks, but I eventually decided on directly analyzing each pixel's RGB values, and found that the red to blue ratio was a good indicator of if a pixel was cloud or clear sky.

Here's an example of using red to blue ratio to classify the pixels: all the pixels in the original image on the left that have a red to blue ratio greater than 0.84 are classified as clear sky and are colored black to show the results on the right. You can see that it works pretty well, but there's still the area around the glare from the sun where some clear sky pixels aren't black - they're being classified as cloud.

So, I tried increasing the threshold to 0.93, and you can see that makes the algorithm get a few more pixels around the glare correct, but it also makes it misclassify several cloud pixels around the edge of the image as clear sky. This problem is even clearer in the next example.

We're back to the original threshold of 0.84, and we can see that most of the clear sky pixels aren't being colored black, they're being misclassified as cloud.

Increasing the threshold to 0.95 only causes the same problem as in the first example image: some cloud pixels being misclassified as clear sky. In this case, those clouds are thin, but they are there, which is something I'll come back to.

To try to make the algorithm more accurate, I isolated the glare by finding the pixels with an average RGB value of more than 200 - everything else is colored black. This bright area is not considered in computing the cloud fraction - it's not counted as cloud or clear sky.

So, here's the final algorithm. Find and ignore glare pixels, which are colored yellow in the bottom image, where the average RGB value is greater than 240, which is the number I found works better for more images. Find and ignore pixels outside of the camera's field of view, which are colored red in both images, where the average is less than 20. Find and count cloud pixels, which aren't colored in the images, where the red to blue ratio is greater than 0.84. Find and count the remaining, clear sky pixels, which are colored black and use the counts of cloud and clear sky pixels to find the cloud fraction. The top example image shows a very cloudy sky and has a computed cloud fraction of 0.979, and the bottom example shows a less cloudy sky with some sun glare and a computed cloud fraction of 0.741. While we can see that the computed cloud fractions make sense for these two images, this algorithm does struggle with some things.

For example, it struggles with differentiating between thin clouds and dark cloud-free sky, like during and close to night time. In the bottom image, there is some dark clear sky along the right side that's being misread as cloud; the cloud fraction for this image should be less than the 0.384 that's been found. We saw earlier that finding and ignoring the pixels directly in glare areas only helps so much. And, finally, it only computes cloud fractional area, and doesn't consider cloud opacity or depth, which are also important parts of cloudiness. Due to the first bullet, this algorithm is not yet ready for night time, sunset, or sunrise images.

Despite these challenges, there are periods of time when the algorithm works fairly well. Here's a case study from January 18th of the computed cloud fraction and the difference between the measured downwelling longwave radiation from the saildrone and the estimated clear sky longwave radiation. This difference should be a good indicator of cloud fraction because clouds emit longwave radiation in all directions, and we can detect that at the surface using pyrgeometers, which are hemispheric just like the upward saildrone cameras, so it should be comparable to the images and their computed cloud fractions. _ We can see that the two lines generally change together, which shows that the cloud fractions for this time period are fairly accurate.

However, if we extend the time period by about an hour, we run into the dark cloud-free sky problem. The image in the corner was taken during sunset on January 18th and clearly has a very low actual cloud fraction, which follows the longwave radiation difference at that time being very low. But, its computed cloud fraction is very high because most of its dark cloud-free sky is being misclassified as cloud.

This algorithm can be used to study clouds further with other atomic measurements. _ And some things I think would improve the cloud fraction estimates are: including spatial conditions to help classify thin cloud, and hazy or dark cloud-free pixels, and to help classify glare _ and developing a convolutional neural network regression model using cloud images and ceilometer measurements of cloud fraction taken from a ship during piston. And finally, I plan to present my results at the AGU meeting in december.

Thank you all for listening.