Infrared Photography, Atmospheric Spectroscopy, and Solar Corona Photography using a High-Altitude Ballooning Platform

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In the fall semeseter of my freshman year (2010), I took a freshman seminar entitled 'Spaceflight with Ballooning'. My team and I were required to construct a payload with a creative science experiment which would be carried to 90,000 feet into the stratosphere using a helium-filled weather balloon. As part of my team's creative science experiment, we used a near infrared camera along with a visible light camera and programmed both of them to take pictures every 30 seconds in flight. Our aim was to study whether infrared light could reveal more about some of the features of the earth's atmosphere and topography than visible light. This was done by analyzing the pictures taken by both cameras at the same time, so they revealed the same view in visible and infrared light. This allowed us to observe the differences in features captured by the cameras. The purpose of the project was to give freshman the opportunity to come up with their own science experiment and also to introduce them to near-spaceflight through high-altitude ballooning.

Having learned the basic principles of high-altitude ballooning, I plan to work on another high-altitude project that will involve taking photographs of the solar corona and doing solar spectroscopy at different altitudes in the atmosphere. The solar corona photographs will be taken using a shadowed-camera like the LASCO coronagraph on the SOHO orbiting observatory. To acquire solar spectra, I will build a simple solar spectrograph which will utilize a diffraction grating to spread sunlight into its constituent colors and a programmable still camera or video camera, to record images of the spectra at a series of altitudes during the flight. This project may help open an interesting research avenue for high-altitude ballooning which would be related to studying coronal mass ejections, solar wind and space weather.

I. Introduction

Near-spaceflight refers to sending scientific payloads to an altitude that is high enough to qualify as the "near-space" environment, defined as the region of the earth's atmosphere above 75,000 feet and below 330,000 feet[1]. At the University of Minnesota, near-space or high-altitude ballooning is a project funded by the Minnesota Space Grant Consortium and allows students to carry out science experiments in near-space by designing, constructing, launching, and recovering payload boxes. Payloads are lifted by a helium-filled latex balloon that has a diameter ranging from 7 to 10 feet on the ground and can expand to dimensions reaching 30 to 50 feet across. The experiments include, but are not limited to, atmospheric environments, weather studies, measurement of solar radiation, electric field experiments, and biological experiments. The payload is safely returned to earth by parachute when the balloon bursts. For tracking the payload, we use GPS and radio transmitters, as the recovery can take place anywhere from 5 to 150 miles away from the launch site, depending on how under or over-loaded the balloon is and the intensity and altitude of the jet stream.

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The objectives of my freshman seminar team included the measurement of relative humidity, atmospheric pressure, and temperature in different parts of the atmosphere. Our creative experiment was the infrared camera, which took pictures of the atmosphere along with a normal still camera. The purpose of this creative experiment was to check the validity of our hypothesis that infrared light could reveal more features from the atmosphere than visible light alone. To measure the relative humidity, atmospheric pressure and temperature, our payload box was equipped with a HOBO data logger[5] and Verhage weather station[6]. A Balloon SatEasy[7] flight computer was installed to process and save the data. Once our payload was recovered, we analyzed the data so as to learn the temperature, relative humidity and pressure fluctuations and patterns in different parts of the atmosphere. Our cameras took pictures after a certain interval and we analyzed these pictures together for our creative science experiment.

Based on my experience with high-altitude ballooning from my freshman seminar, I will be doing an Undergraduate Research Opportunities Project (UROP) on atmospheric spectroscopy and solar corona photography from a high-altitude ballooning platform.

II. Freshman Seminar High-Altitude Project

A. Payload Design

Our payload's design had a simple goal: carry out a scientific experiment using an apparatus that is able to prevent the experiment from falling or freezing to failure. In our experiment, we wanted to measure temperature inside and outside the capsule, relative humidity, and pressure. We also wanted to compare images from an infrared and visible light camera.

To measure temperature, relative humidity, and pressure, we had a sensor attached to a flight computer, which recorded the data. To analyze the infrared images of the earth, a pair of cameras were placed side-by-side inside the payload box. One camera shot images in near infrared, and the other camera took pictures in the visible spectrum. The capsule itself had to be large enough to handle all the equipment inside, but could not be so large as to disrupt the rest of the payloads that were attached to the same balloon in the form of a stack. The payload had to be constructed in a manner so as to handle intense cold and violent shaking as the balloon and parachute is affected by the wind. The thermometer and cameras required access to the outside, yet we did not want cold drafts to come in. To handle these problems, there were several design ramifications that had to be considered during the payload's construction.

To keep the components warm at high altitudes, a resistive heater was placed inside the box. The team chose to supplement this heater by building the capsule out of a purely black material, providing warmth to the electronics even when the air in the upper stratosphere is too thin to conduct much heat from the heater to the equipment. Our heater was tightly strapped into place to prevent items inside from bouncing against each other and causing damage. We had three separate systems in the box: the weather system, the camera system, and the heating system.

B. Launch and Recovery

The launch took place on 30th October 2010 at 10:05 am. The launch site was a school ground in Pierz, 80 miles Northwest of Minneapolis. It was a cold, sunny morning, and the temperature was 43 Fahrenheit. Before the launch, all the payload boxes were attached to one another and to the balloon by means of rigging strings. We ensured that all our components were in place and switched on our cameras, flight computer and heater before sealing the box. We were fortunate that it wasn't windy as it is a challenge to keep the balloon stable while filling and the launch becomes tough due to the balloon swaying due to the wind.

Based on the information from an online near-space tracking website, we headed to Barron, Wisconsin, which is 76 miles Northeast of Minneapolis and was the predicted landing site for this launch. As we were on our way to recover the balloon, we learned that it had offshoot its destination by about 45 miles and landed in an area covered with trees at Holcombe, Wisconsin. Much to our disappointment, we could not go to recover our payload due to shortage of time. One of our teaching assistants for the seminar, Philip Hansesn, recovered the payload along with the parachute.

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[5] HOBO U12 Data Loggers. URL: http://www.onsetcomp.com/data-logger

[6] Paul Verhage Near Space Weather Stations. URL: http://www.nearsys.com/catalog/sensor/weather.htm

[7] Paul Verhage Balloon SatEasy Flight Computers. URL: http://www.nearsys.com/catalog/balloonsat/easy.htm

C. Result and Analysis

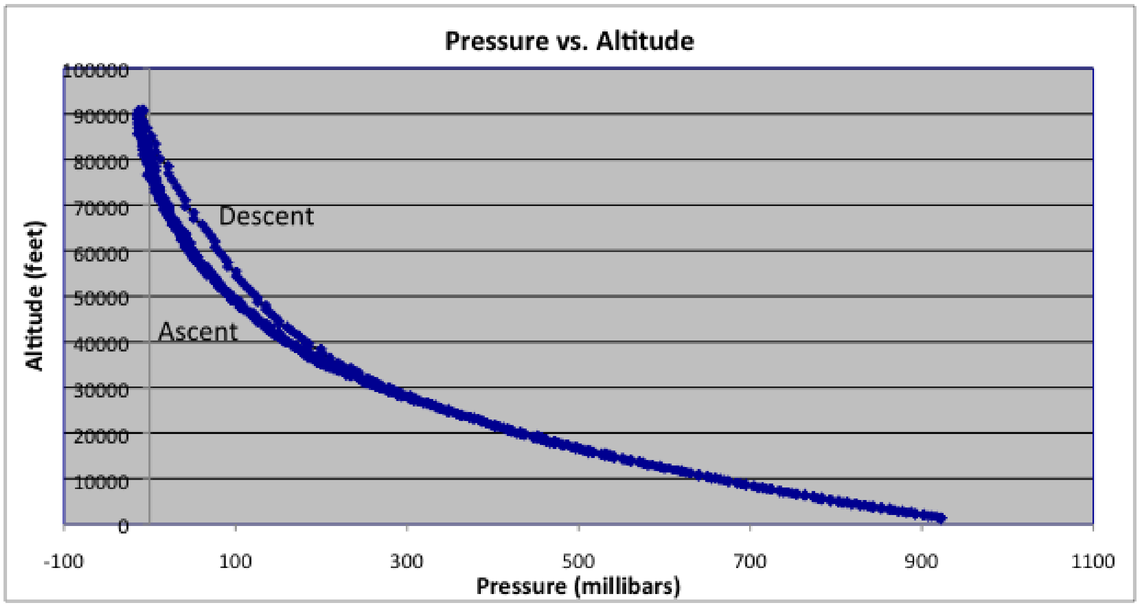
Following the recovery, we extracted the data from the flight computer and HOBO. The flight computer and HOBO had recorded data and both our cameras had taken pictures.

1. *Time of flight*

Graph 1. **Altitude vs Time**

The HOBO and Balloon SatEasy (BSE) recorded the altitude our balloon reached before it burst. According to these instruments, the altitude at launch was 1223.4 ft above sea level, and the balloon burst at 90,859.5 feet above sea level, at which point the balloon was an hour and fifty-two minutes into flight. We landed at a site, which was 1304.57 feet above sea level at 12:31pm. So the total time of light was one hundred and forty six minutes.

2. *Pressure*



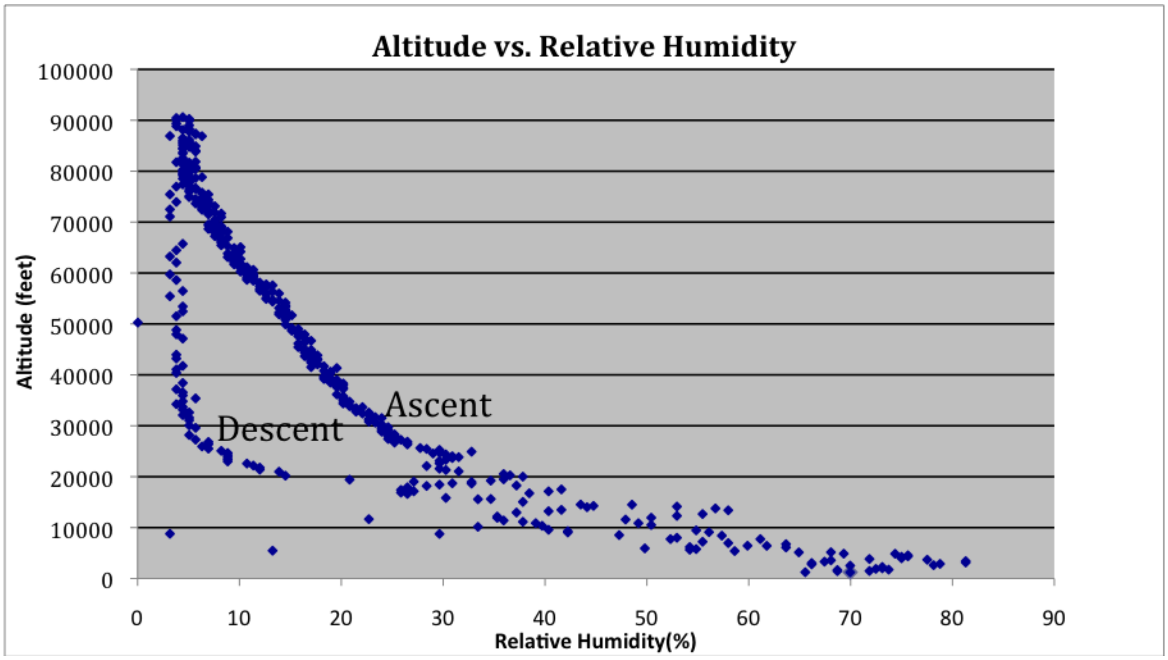
Graph 2: Altitude vs. Pressure

Our prediction that pressure decreases with altitude was based on the fact that the density of air decreases with an increase in altitude, and so the molecules of air are farther apart than they are at sea level. There is a direct relationship between pressure and density. Our BSE recorded the pressure at the launch site to be 982 millibars, at an altitude of 1223.4 feet above sea level. Our balloon burst at 90,859.5 feet above sea level, at which instance the pressure recorded, was -12.9 millibars. Pressure cannot be a negative value, which tells us that the manufacturers calibration is inaccurate under these extreme conditions. The last positive recorded value of pressure was 1.978 millibars at about 85,000 feet, which is still inaccurate as at that altitude, pressure should be above 25 millibars. After giving it a lot of thought, our group figured that this inaccuracy could be due to calibration error in the instrument, or due to the air being too thin, accompanied with the fact that the payload may have experienced free fall after the balloon burst.

After observing the trend in the graphs, we found that the pressure decreased with an increase in altitude. This trend agreed with our prediction. The offset between ascent and descent values is due to the pressure sensor struggling to keep up during the rapid descent just after the burst.

3. Relative Humidity

Relative humidity showed a rather irregular pattern. This was expected, as cloud layers in the atmosphere are areas of high humidity, due to the concentration of water molecules, while in the rest of the atmosphere; relative humidity decreases with an increase an altitude.

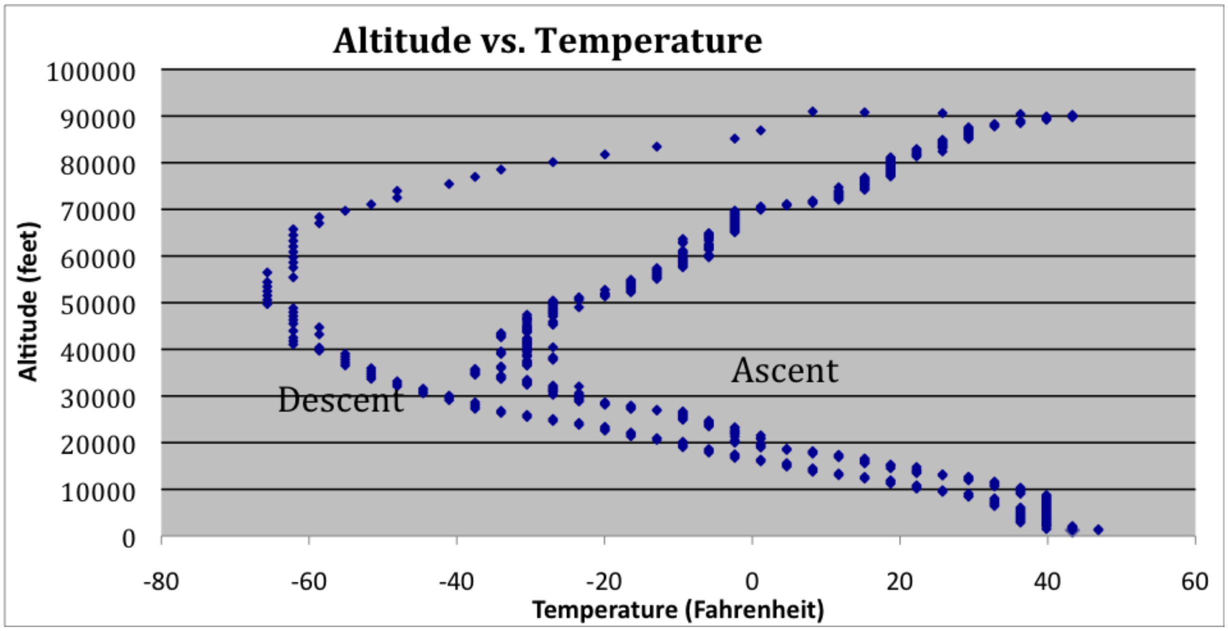


Graph 3. **Ralative Humidity vs. Altitude**

The ‘lag’ in relative humidity observed in the graphs indicate that the air circulation kept the instruments dry and that our payload box carried a sample of dry air downward with it, or trapped dry air.

Considerable spikes in relative humidity occurred between 15,000 and 20,00 feet, when the balloon traveled through layers of cloud, due to which there were sudden increases in relative humidity.

4. Temperature



Graph 4. Temperature vs. Altitude. *The graph shows that the temperature variation during the descent is faster than that during the ascent.*

As we had expected, the temperature decreased from 38.2 degrees Fahrenheit at launch to -46.6 degrees Fahrenheit at 34,839 feet, after which the average external temperature increased till 90,122.4 feet where it reached a high of 40.1 degree Fahrenheit (HOBO data). After the balloon burst, the temperature decreased to a low of -64.2 degree Fahrenheit at about 55,329 feet and then increased till the time we landed. Surprisingly, during ascent, the temperature at about 55,000 feet was around -22 degree Fahrenheit. This led us to observe the general trend in our Altitude vs. Temperature graphs and think about factors that could have caused such a drastic difference.

Graph 4 indicated that the temperature variation during the descent was much more drastic than that during ascent, especially the decrease in temperature. Our team thought about the wind chill factor, as the box descended at a much faster rate than it ascended. An important fact, which we thought about, was that in still air, the air next to the capsule would be a local hot spot as it is slightly warmer than the atmosphere. This would have been the case during the ascent. On the other hand during descent, the payload is in a state of freefall. The airflow of freefall replaces the local hot spot with new air. This keeps the temperature difference (and therefore heat loss) to a maximum. The increased parachute effectiveness at low altitudes reduces this effect.

5. Creative Science Experiment

The team's creative science experiment involved comparing the pictures from an infrared camera with those of the visible light camera and attempting to see how different ground features and the atmosphere absorbed or reflected infrared light.

Since the sensitivity of infrared cameras is more than those of visible light cameras, they can capture a spectrum beyond the visible light spectrum, which is captured by normal cameras.

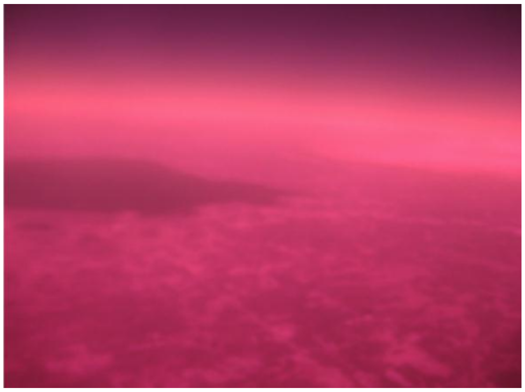
Infrared light has a longer wavelength than visible light, due to which cameras tend to be sensitive to infrared light. To avoid this, manufacturers install filters in all cameras to hamper the infrared light from reaching the sensor. On the other hand, when a visible light-blocking filter is added, only infrared light is captured.

The camera we used for our scientific experiment had its infrared light filter removed. Teaching Assistant Seth Frick helped us modify the camera to capture the infrared spectrum. He did this by using the dark region of an exposed and developed film negative as the visible light filter. However, since infrared light has a longer wavelength than visible light, the camera was thrown slightly out of focus with the adjustment. So our camera was essentially a 'Near Infrared camera'. However, the team made some interesting observations after comparing the pictures taken from both the cameras.

Picture 1. Water bodies and freshly tilled soil in visible light.

Picure 2. Water bodies and freshly tilled soil seen in infrared light.

Picture 3. Mille Lacs Lake.



Picutre 4. Mille Lacs Lake in infrared.

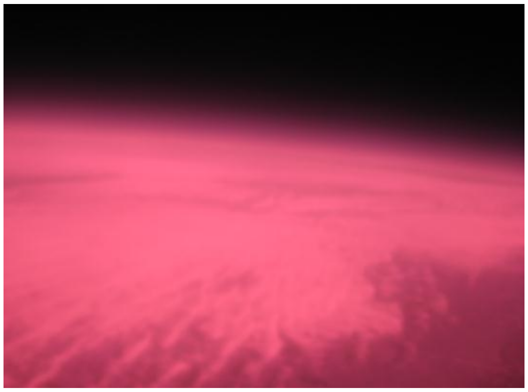
Picture 5. Visible light camera captured Haze.

Picture 6. Infrared camera imaged Mille Lacs Lake through Haze.

Picture 7. Mille Lacs Lake is invisible to the naked eye.

Picture 8. Mille Lacs Lake is visible through the infrared camera.

Picture 9. Visible light camera captures a glow.



Picture 10. Infrared light camera image lacks glow.

In Picture 1 and 2, we notice the lake in both images, and a freshly tilled field to the left of the lake. The infrared image shows the near complete absorption of infrared light by the lake and the considerable absorption by freshly tilled soil. Pictures 3 and 4 support our observation, and we notice how Mille Lacs Lake is clearly visible as a dark patch in the picture 4, but less visible in the visible light image, picture 3.

In picture 5, it is noticeable how visible light reflects strongly from a layer of clouds, but the infrared light reflects to a lesser extent as is seen from the apparent thinness of the clouds in the near-infrared image. From these photos, we learn that infrared light has a greater ability to penetrate cloud layer then visible light. This characteristic helps us see through a thin layer of clouds or haze, and notice features such as the Mille Lacs Lake in picture 6. In picture 7, while Mille Lacs Lake is invisible to the naked eye, the near-infrared image picture 8 captures it as a dark patch due to its ability to penetrate the atmosphere better than visible light. This ability of infrared light to penetrate deeper into the atmosphere is also observed in pictures 9 and 10, which were taken at 88,000 feet, moments before the balloon burst. In picture 10, we notice the lack of "glow" off the upper reaches of the atmosphere in the near-infrared image.

Reference picture 1 (see Appendix) was taken just under a minute after the launch, but due to lack of synchronization, it was hard to pair it with a visible light image. This picture captures some trees and a school football field in the lower left hand corner. These features reflect infrared light considerably, which supports the fact that chlorophyll, which is present as the green pigment in plants, strongly reflects infrared light.

It is noticeable that the photos taken by the near-infrared camera are out of focus. This was the main drawback we encountered as part of our project. The same camera took reference Picture 2 (see Appendix) after it flew on another flight. Seth Frick adjusted the focus of the camera before this flight and as a result, this picture is sharper than the one's our near-infrared camera took. However, we make the same observations in this picture, and the lakes appear darker due to large amount of absorption of infrared light, and the tree cover appears to be reflecting significant amount of infrared light.

Reference pictures 3 and 4 (see Appendix) show the Sun. When compared, it is observed that the boundary of the Sun is visible in picture 4 and the glare caused by the reflections is reduced when compared to picture 3. This observation may be useful in devising a camera that would be able to capture defined images of the Suns corona.

Reasons for penetration

The higher penetrating power of infrared light as compared to visible light can be attributed to the phenomenon of scattering of light in the atmosphere. Scattering in the atmosphere is due to the combination of Rayleigh scattering and Mie scattering. Rayleigh scattering of light is due to particles smaller than the wavelength of the incident light while Mie scattering is the scattering of light due to spherical particles [2]. In the case of infrared light, there is a reduction in scattering due to its longer wavelength as compared to visible light, and thus higher penetration through the atmosphere. The penetration through the atmospheric haze is the reason why the sky has a darker color in the near infrared photographs.

III. Atmospheric Spectroscopy and Solar Corona Photography

The relatively faint solar corona that always encircles the bright disk of the Sun cannot be imaged from the ground (except during a total solar eclipse of the Sun) due to Raleigh scattering of sunlight by the atmosphere [3,4]. Similarly, solar spectroscopy (studying the wavelengths of light emitted by the Sun) is complicated by the absorption of certain wavelengths of sunlight as it passes through the Earth's atmosphere [5]. These wavelengths may be difficult to distinguish from genuinely “missing” wavelengths, known as Fraunhofer lines, which are absorbed by the atmosphere of the Sun itself and never emitted into the solar system. Moreover, due to its relatively higher temperature, the Sun's corona gives out emission lines of unexpected wavelengths due to the ionization of certain elements present in it.

In my UROP I will take, solar corona photographs using a shadowed camera like the LASCO coronagraph on the SOHO orbiting observatory. One challenge will be to find a camera whose sensitivity can either be fixed or will automatically adjust quickly enough that it can image the corona. To acquire solar spectra, a simple solar spectrograph will be built using plans published recently in Make magazine [6]. The spectrograph may be modified using a rotating filter wheel, to obtain individual spectra in the vicinity of specific colors of light. A programmable still camera or video camera will be used to record the images of the spectra at a series of altitudes during the flight. To test the effectiveness of this home-built spectrograph, there is the possibility of flying a commercial Red Tide spectrograph that in use by Minnesota Space Grant's suborbital rocketry payload project.

It is not yet clear whether or not I will need to actively deal with the natural swinging and spinning of the payload during the flight. If occasional temporary pointing in the direction of the Sun will suffice, I may not need active pointing mechanisms that sense the direction of the Sun and point the payload toward it. Previous experiments with high-altitude payloads have shown mechanisms can cease to function properly in the extreme conditions (especially the low temperatures) during near-space missions. However, if collecting good data requires precision pointing and/or long time exposures, I will work with other students on the ballooning ream who have experience in this field, electronics and interface systems to develop such a mechanism and test its feasibility.

The time allocated for doing this project will be utilized in five phases: Theory and Research; Designing the payload; Building and Testing the Design; Flying the Mission; Data Analysis and Presentation. The project will begin in July 2011 and is expected to be complete by September 2011.

IV. Conclusion

The infrared experiment and its results provide a good picture of a basic high-altitude ballooning endeavor. We learnt some essential skills related to high-altitude ballooning and the results of the project provided us with an insight what can go wrong in such projects, which in turn is useful for the enhancement of further projects such as the upcoming solar corona photography and spectroscopy project.

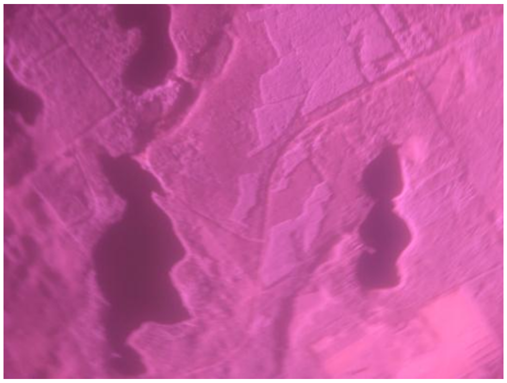
When the infrared photography experiment was assigned, the team's members had no experience with circuit boards and electrical components. During the course of the freshman seminar, we learnt some basic concepts related to circuits and gained significant experience by building electrical components such as the flight computer that were flown on the payload. If the group were to do the same project again, we would definitely overcome the shortcomings that were faced. With more availability and efficient use of time, the team could have made a scale to better analyze the near-infrared photos that were taken. As some areas of the photo have been darker in the infrared photos, it could indicate that the particular area was emitting more infrared radiation. Comparing the photos of the objects whose temperature and infrared radiation were known could make a scale. A legend could then be made to estimate the temperature and amount of infrared radiation present in the atmosphere. Although the infrared photos could have been analyzed more precisely, there was a major component that needed to be perfected in order for the project to have been more efficient.

Two cameras were used to capture near-infrared and visible light. Synchronization of the cameras so that they both take pictures of the same view at the same time was essential to the experiment. Even though the cameras seemed to be synchronized before launch, after analysis we realized that the time intervals that the cameras had taken pictures had gradually drifted apart. Without synchronized pictures, it was much more difficult to compare visible light photos with the near-infrared photos. It was also difficult to figure out and assign a time stamp to each photo. The greater complexity of the UROP may require an altogether different design for the payload box, one that is designed only for the purpose of the particular experiment and is capable of dealing with the possible hurdles in the experiment, such as swinging and spinning of the payload during the flight

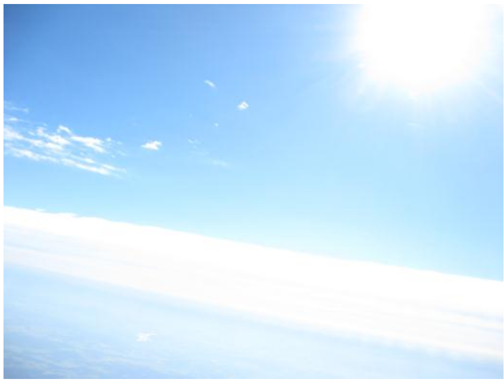
Studying the Sun’s corona is an important research avenue today due to the effects coronal mass ejections, space weather, and solar wind have on the Earth. Such phenomena can cause disturbances in the Earth’s magnetic field and even temporary enlargement of the atmosphere, increasing atmospheric drag on low-earth-orbit satellites. Solar spectroscopy is useful to learn about the atmosphere of the Earth as well as the composition of the Sun’s corona. The solar corona photographs and spectrograph obtains through this project will prove instrumental for further research in this field. The knowledge and experience gained through the experimentation and data analysis of this project may also be useful in the Minnesota Space Grant Consortium’s outreach opportunities.

Appendix (Additional Photographs)

Reference Picture 1. Infrared light and green plants (see page 7 for discussion).



Reference Picture 2. Taken from another flight showing water bodies and tree cover (see page 7 for discussion).



Reference Picture 3. Image of the Sun (see page 8 for discussion).

Reference Picture 4. Image of the Sun from in Infrared (see page 8 for discussion).

Acknowledgments

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