Integrating K12 Outreach with Undergraduate & Graduate Student Research through BalloonSAT: High Altitude Balloons

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The Arkansas BalloonSAT team has successfully launched and recovered 38 BalloonSAT's dating back to the first flight on December 16, 2006. Numerous instruments measuring such things as atmospheric temperature, humidity, radiation, and light intensity have recorded data from different locations over the State of Arkansas. The initial focus of this project was outreach with the k-12 schools, and still involves outreach; however atmospheric research has become a significant component for this endeavor. This ongoing collaborative projection has involved a number of faculty and students from different academic backgrounds, including physics, chemistry, biology, and astronomy among the different ASGC schools who have contributed to this effort. The outreach work with k-12 teachers/students was highlighted in an article *Students at the Edge of Space* published in the journal *The Science Teacher* produced by the *National Science Teachers Association* (January 2008). A photograph taken from a camera mounted in one of the payload boxes flown on Arkansas BalloonSAT 6 made the cover of this journal. This paper looks specifically at light intensity profile measurements from Balloon-borne solar panels. Light intensity was not found to vary significantly considering temperature and voltage effects. At lower temperatures, voltage was found to be higher. BalloonSAT provides an effective inquiry based research for undergraduate students in addition to outreach in k-12 schools.

I. Introduction

PREVIOUS BalloonSAT measurements using solar panels, more specifically photovoltaic cells show light intensity to follow a hyperbola with the focal point at the tropopause. Light intensity increases in the troposphere and then decreases in the stratosphere. The tropopause is division of the troposphere and stratosphere indicated by a temperature inversion. BalloonSAT measurements matched other high altitude studies using weather balloons. [1]

Relevant engineering studies showed solar panel efficiency measured as output increased at lower temperatures.[2] Voltage output in circuits is impacted by temperature, specifically how electricity flows through a circuit by influencing the speed which electrons travel. At higher temperatures voltage (V) is lower due to an increase in resistance (R) assuming that current stays constant, in accordance to Ohm's law (V = iR). Similarly, voltage will increase at lower temperatures due to decreased resistance. Engineers design cooling systems to improve output of solar panels in non-optimal conditions (high heat). Efficiency can decrease 0.5% with each 1°C increase in panel temperature. [3]

Arkansas BalloonSAT initially started as a k-12 outreach program highlighted in a previous article. [4] The program has evolved to include atmospheric research; through outreach is still a part of the program. The research component includes undergraduate and graduate students leading inquiry based research project into an atmospheric issue. An example research project, the investigation into light intensity and jointly solar panel efficiency is explained in this work. The scientific process is described, where first hypotheses were presented to explain the

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measured trends, then literature search and laboratory experiments provided an accurate explanation and conclusion. Previous hypotheses included decrease in scattering, atmospheric reactions and processes that led to a decrease in light intensity in the stratosphere. It was found that solar panel efficiency, how much power a solar panel can produce is inversely related to temperature. A calibration experiment, with a constant light source, and varying temperature was performed to measure the temperature effect on balloon-borne solar panels. A temperature correction factor from the calibration experiment was applied to solar panel measurements aboard a balloon flight.

II. Methods/Materials

Light intensity measurements were collected using 1600g latex weather balloons with 5.5 kg (12 lbs.) of atmospheric monitoring instruments and high altitude experiments. Included on many flights were solar panels (Fig. 1) which measured light intensity and solar panel efficiency throughout the balloon flight. These solar panels were a variety of commercially available solid or flexible photovoltaic cells. Some light intensity measurements were made applying red, blue, green colored filters to distinguish variability in light intensity across different wavelengths of visible light. Light intensity was measured as voltage using a 3.5mm stereo cable and HOBO data loggers (Onset). Temperature was recorded with Ansonde-4 (Anasphere). Balloon flights typically elapsed 90-120 minutes, reaching up to 26 km (100,000 ft). Data presented here was collected during Arkansas BalloonSAT flight ABS -23, in July 2011 over Northeast Arkansas.

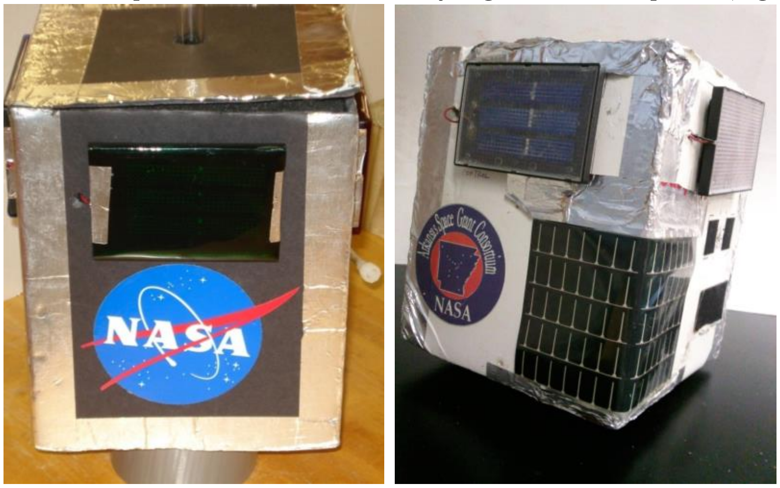

Figure 1. (left) Sealed payload box with colored solar panels. (right) Different payload box with solar panels. Velcro allows for addition and comparison of different solar panels.

Temperature dependence on solar panel voltage was completed with a non-variable light source and a liquid sealed environmental chamber in an ice water bath (Fig. 2). The light source was mounted above the ice water bath and shined light into the chamber. The solar panel was placed at a 45° angle so that light reached the solar panel. HOBO data loggers measured light intensity/ solar panel voltage via a 3.5 stereo cable as well as ambient air temperature in the environmental chamber. This experiment was also carried out in an ice bath with salt to reach colder temperatures due to freezing point depression. Light intensity measurements or solar panel output was then multiplied by a solar output temperature correction factor determined by the calibration experiment.

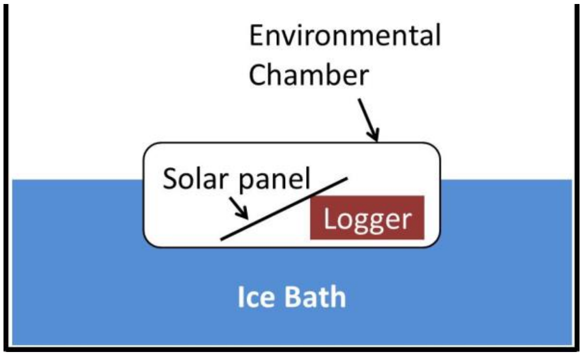

Figure 2. Schematic of light intensity calibration setup. A liquid sealed environmental chamber is placed into an ice water bath with HOBO data logger and solar panel.

III. Results and Discussion

Experiments in environmental chamber found that light intensity was linearly inversely related to temperature. With a constant light source, solar panel output measured as voltage increased with lower temperatures in ice bath and ice bath with salt. The linear relationship was relatively linear, ($y= -0.0068x + 2$, $R^2=0.766$).

Atmospheric profile measurements of temperature and light intensity were taken during ascent as measurements during descent match those of ascent at similar altitudes. Temperature measurements were found to follow standard U.S. atmosphere with temperature decreasing in the troposphere due to greater distances from surface convection cycles and increasing in the stratosphere due to reactions of ozone and ultraviolet radiation which release oxygen and heat.[5]

Comparison of different wavelengths of light using colored solar panels (Fig. 1) show similar trends compared to uncovered solar panels. Overall, light intensity was found to increase within the troposphere (0-15 km) and decrease in the stratosphere (15-26 km) as seen in (Fig. 3), following a hyperbolic trend with the focal point at the tropopause. Two lines are observed, which represents local minima and local maxima observed. This noise is generated from a spinning payload box, with minima measuring when the solar panel faces away from the sun and maxima facing towards the sun. These measurements were matched with video and time stamp oriented on the same direction as the solar panel. The difference between the local minima and local maxima was found to be a constant value, 0.162 ± 0.033 volts. Therefore the difference does not represent a significant difference between total light intensity observed (toward sun, local maxima) and reflected light intensity observed (away sun, local minima).

Light intensity decreases at higher stratospheric altitudes which correlates with warmer stratospheric temperatures compared to colder temperatures at high tropospheric altitudes. After applying a temperature correction to the local minima (Fig. 4), light intensity follows a constant value. Light intensity measurements at the surface and at stratospheric altitudes were found to be equal. Throughout the atmospheric profile light intensity averaged at 1.135 ± 0.045 volts. Operating temperature has a documented effect on electrical efficiency. This includes coefficients for cell temperature, ambient temperature.[2]

The small inversion at 15-20 km at the tropopause, the division between the troposphere and stratosphere may be due to a variety of factors. This includes scattering and absorption of solar radiation by atmospheric particles[6], or condensation on solar panels observed after balloon recovery. The condensation on the solar panel may enhance the solar panel due to internal reflections within the water droplet.

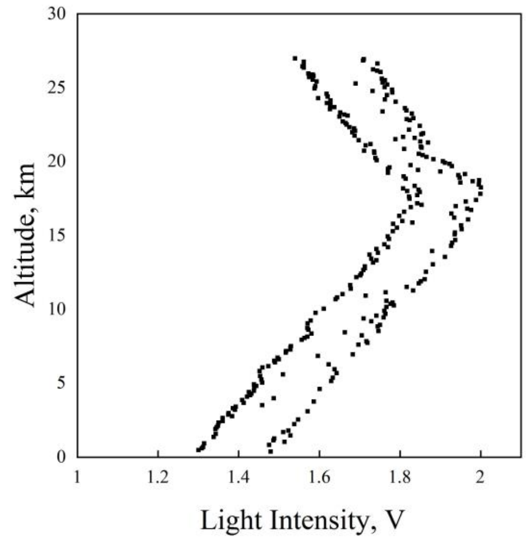

Figure 3. Light intensity measurements as voltage from ABS-23 in July 2011. Two lines are observed representing local minima (away from sun) and local maxima (toward sun).

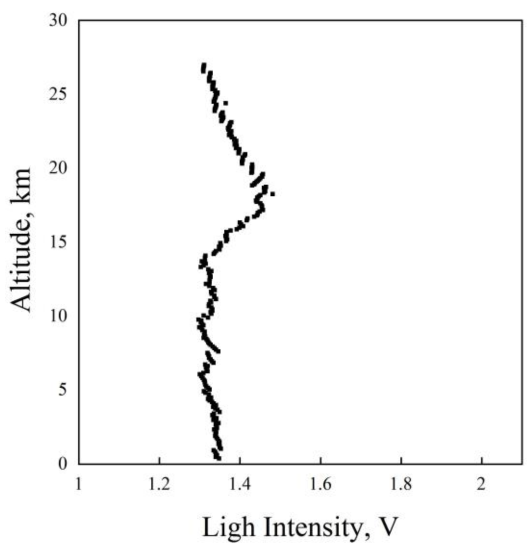

Figure 4. Light intensity stays relatively constant at 1.135 ± 0.045 volts with temperature correction factors added.

IV. Conclusion

Light intensity profile measured as voltage using high altitude balloons and solar panels was found to increase in the troposphere and decrease in the stratosphere. Solar panel voltage was inversely related to temperature with solar panels generating higher voltages at lower temperatures. Light intensity measurements are not indicative of atmospheric properties at measured altitudes, but of temperature.

In this paper, undergraduate students analyzed light intensity profiles in an inquiry based hands-on experiment with both field and laboratory components. Students first created atmospheric light intensity profiles using weather balloons and solar panels in the field, and later explained the observed trends with calibration experiments in the laboratory. BalloonSAT provides an opportunity for undergraduates to design their own research project in addition to k-12 outreach efforts.

Acknowledgments

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