Solar Eclipse 2017 Illinois Launches: Temperature, Spectrometer, Video, and Waves

Matthew B. Orvis[1], Jeff F. Dailey[2], Hank D. Voss[3]
NearSpace Launch, Inc., 8702 E 825 S, Upland, IN, 46989

During the August 21, 2017 Solar Eclipse that swept across North America, NearSpace Launch (NSL) took a group of 70 people to Logan College in Carterville, IL, near the center of the Eclipse path, where we were fortunate to have good viewing. Several balloons, loaded with sensors, were launched, with a follow up calibration launch a few weeks later in addition to ground images. This paper presents the results and observations from the analysis of the data collected from those launches. Payloads and sensors included cameras, spectrometers, temperature sensors, and GPS tracking. The cameras were live (1280x720) and HD (1920x1080) video cameras with memory cards, oriented upwards at the Sun's inclination, and downwards to observe the Moon's shadow. These cameras had a combination of telephoto lenses and solar filters to view all different types of images (eclipse, shadows, chromosphere, limb, burst, descent). A chromosphere solar image during totality was serendipitously observed from a lake reflection based on the geometry. The spectrometers with 50-100 nm resolution measured electromagnetic radiation absorption lines in the UV and visible light ranges, showing data at different points in the Eclipse. The temperature sensors data is consistent with the National Weather Service (NWS) troposphere and stratosphere radiosonde predicts, although there are some unique features associated with the eclipse cooling. Fortuitously, one of the balloons was in the tropopause (-73C) during totality and indicated a small temperature drop. There were also different wind effects that were observed through the GPS tracking, both horizontally and vertically.

I. Introduction

During the August 21, 2017 Solar Eclipse NSL successfully launched two balloons with a follow-up temperature calibration balloon launch on September 15. The launches were targeted for student STEM learning, public outreach, new instrumentation testing and exciting new research and data analysis. Some of the key advancements include the following:

1. Over 230 K-12 students were involved in several launches, several undergraduate students, and over 50 people participated in the launch activates as Public Outreach. We also had several radio station interviews and the local radio station (Ramsey, IL) WJLY participated in the launch and public outreach broadcast.
2. Accurate temperature profiles are difficult to make without significant planning. The goal is to have nearly identical ascent and descent profiles using proper instrumentation techniques of slowing the decent down, locating probe about 10 m below the balloon neck, locating probes on 15 cm booms, and using a certified micro-silver sensor.

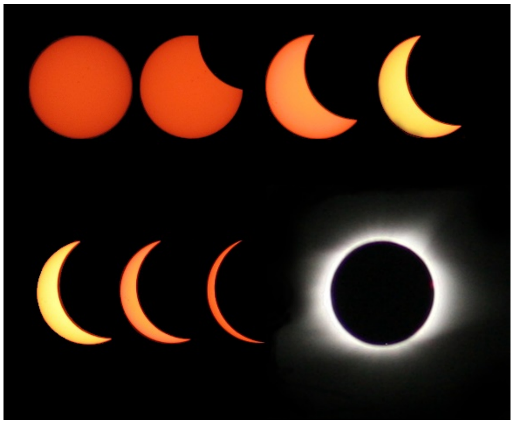

Fig. 1 Photos taken from our ground cameras during the eclipse using a solar filter. No solar filter was used during totality on the last panel. (Photo credit: John Pugsley & Karen Marvel)

[1]Project Engineer, 808 990 4488, mattorvis@nearspacelaunch.com

[2]Chief Engineer, 260 241 0409, jfdailey@nearspacelaunch.com

[3]CEO & Chief Scientist, 765 618 3813, hankvoss@nearspacelaunch.com

3. Temperature profiles where compared to the certified NWS weather balloons and models.
4. The Eclipse Pod 1 payload was fortuitously in the tropopause at the time of totality and the temperature was observed to drop quicker at this time. Still under investigation as to source of cooling.
5. Live video to peak altitude was used on all three flights with good signal strength. Eight video cameras recorded data on memory sticks. Thousands of detailed images were recovered of earth limb, clouds, sun, chromosphere, totality, eclipse, eclipse shadows, and solar reflections.
6. A serendipitous lake refection was recorded near end of totality of the eclipse chromosphere.
7. A strong Stratosphere wind shear with turbulence was observed with wind reversal. Vertical ascent rates also showed significant vertical wave motions after eclipse totality.
8. The new UV-Optical spectrometers performed well on both eclipse flights and recorded 1000's of spectra. The primary solar absorption lines where observed and absorption lines of atmosphere gases with altitude.

Previous work presented ([1], [2], [3], [4], [5]) shows the atmospheric program for making measurements with the NSL instrumentation. Previous work on the NSL data and GPS tracking system are given in references ([6], [7]).

II. STEM and Public Outreach

For both the Eclipse launches and the Post-Eclipse launch, we had a large turnout of families, students, and curious observers. Fig. 2 and Fig. 3 show group photos of both of those events.

Fig. 2 Group photo of those who attended the eclipse launch and viewing party in Carterville, IL.

A group of about 70 people, mostly from Indiana, joined us on August 21, 2017 Launch at Logan College in Carterville, IL for our eclipse viewing event. For the Post-Eclipse launch, we launched at a K-12 school in Jonesboro, IN of around 200 students to take part in it.

Fig. 3 Group photo of the post-eclipse calibration launch at the K-12 school in IN, The King's Academy. Note the live 5.8 GHz video antenna dish on the tripod near balloon for direct viewing. Students were given a short summary about balloon launches and many good questions were asked by the students. One of the students was selected to launch the balloon and another student to start the countdown.

III. Balloons

Table 1 Specifications of Eclipse launches

	Eclipse – August 21, 2017		Sept 15, 2017
Pod Name	**Pod 1**	**Pod 2**	**Post-Eclipse**
Launch Time	17:29:56	18:01:13	14:31:18
Max Altitude	28943 m	28224 m	26520 m
Altitude at Totality	16000 m	7500 m	NA
Avg Ascent Rate	5.2 m/s	6.6 m/s	7.1 m/s
Instruments	UV Spectrometer	UV Spectrometer	
	2 x RunCam	4 x RunCam	1 x RunCam
	4k Live Cam	Shadow Cam	4k Live Cam
	PIN CR Particles	PIN CR Particles	
	2 x Temperature	2 x Temperature	2 x Temperature
	GPS	GPS	GPS

During the eclipse and post-eclipse events, we had a total of four balloons launched. The first was simply a scout balloon to test weather conditions, establish a baseline, and time our set up and launch procedures. The following three primary launches contained the science experiments and instruments to collect data during the eclipse, and then to test similar atmospheric data for comparisons and calibration. Table 1 lists these three balloon launches with some basic specifications. Figure 4 shows Eclipse Pod 1 and Eclipse Pod 2, listing the common features, as well as calling out some of the instrumentation.

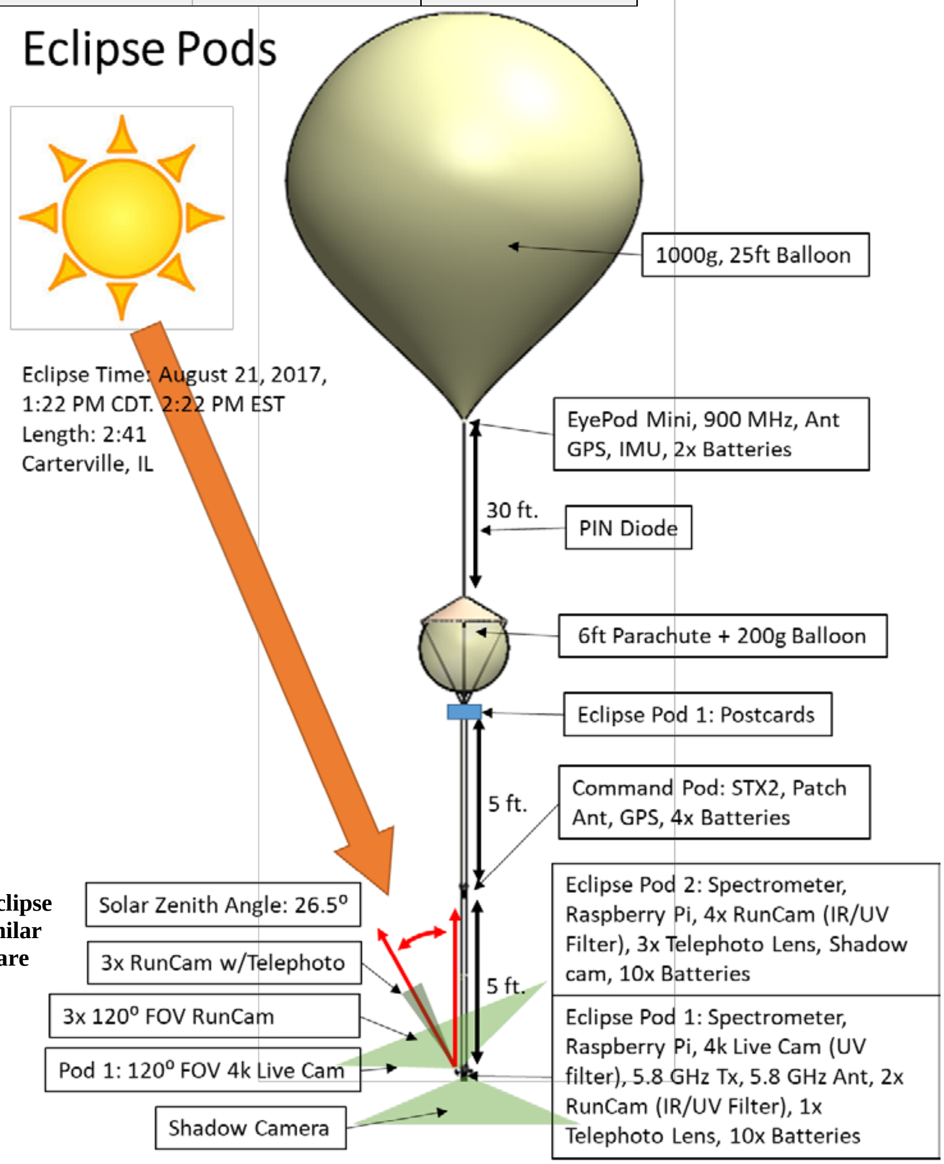

Fig. 4 Illustration of both Eclipse launch payloads. Both have similar components, while differences are

IV. Imaging Data and Results

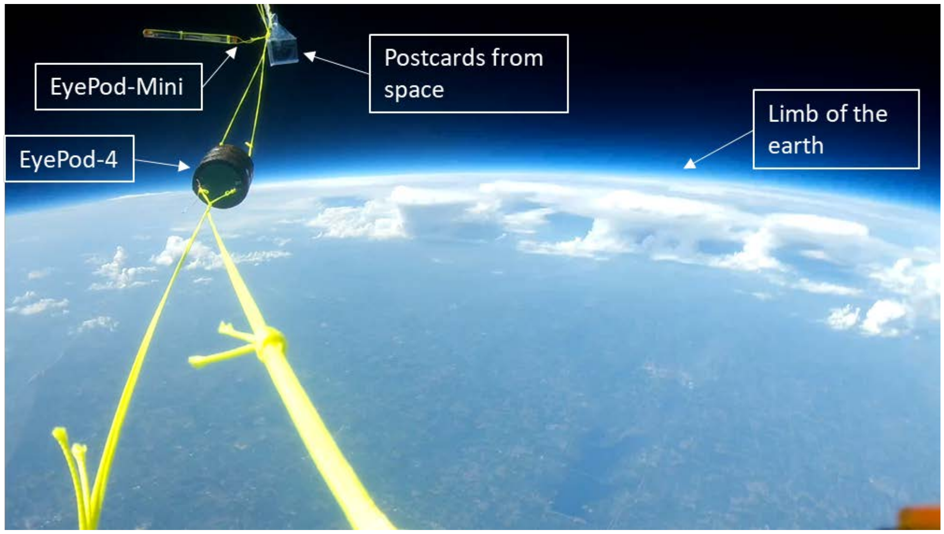

Fig. 5 Picture from one balloon pod near 30,000 m. Important features are called out in the picture. Note the distant clouds all around the launching site.

On board the three balloon launches were eight functional video cameras, with six on the two primary eclipse launches, and two on the post eclipse launch. Fig. 5 shows a picture from Eclipse 2 pod near 30,000 m. The limb of the earth can clearly be seen, along with the earth's curvature (slightly exaggerated due to the lens). Some of our payload can be seen as well, with the EyePod-4 as our command pod for telemetry and tracking, and the EyePod-Mini for high speed 900MHz data and redundant tracking. All who attended the event were able to fill out a "Dream Big" postcard that we then flew to near-space. There were 65 postcards that were collected, then certified to altitude after the flight recovery, and then mailed out for each recipient to receive a "postcard from space". Everyone of all ages really enjoyed writing on the cards with address, text and diagrams and sending them to themselves and their friends.

Several of the on-board cameras were fitted with telephoto lenses, and several of those had solar filters to view the sun while not in totality. Fig. 6 shows superimposed images of the corona of the eclipse, with different contrast settings, from telephoto lenses without a filter. The dark circle of the moon blocking the sun's light is visible. Of note, 2 corona jets are distinctly visible coming out of the sun. The locations of these match with known data of the sun.

Fig. 7 Superimposed and sharpened images of the eclipse from balloon Run Cam and 4K Live Cam camera.

From our horizontal facing cameras, the shadow of the moon was visible passing along its trajectory across the center of the US. In Fig. 7, we see the Eclipse shadow visible on the surface of the earth. Of note is the gradient of light intensity. The shadow is darkest on the left where the earth is still in full totality. As it moves right across the picture, the shadow is less and less intense as the sun moves out of totality.

Fig. 6 Picture from the Eclipse Pod 2 showing the moon's shadow on the earth. The balloon, parachute, and Command are above the tether. The eclipse bright edge is just emerging with the bright light.

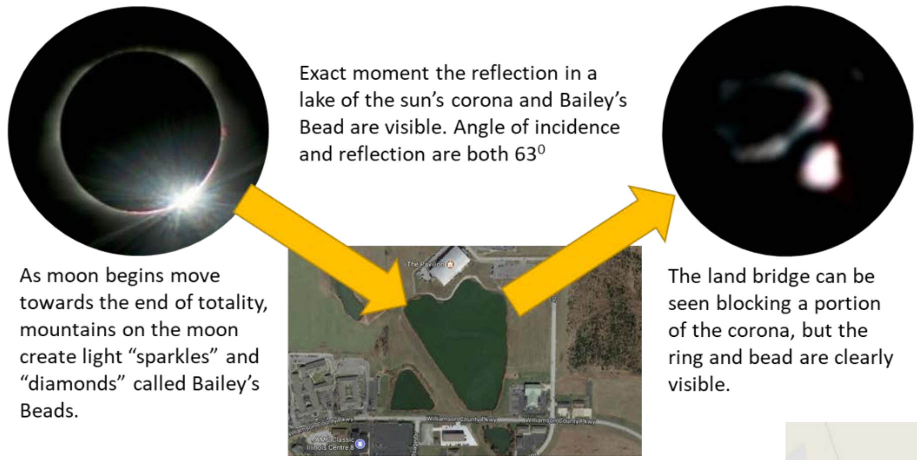

Fig. 9 Diagram of corona reflection from lake to shadow cam

An incredible discovery, and stroke of amazing luck, was the viewing of the sun's reflection during totality in a small lake that we were passing over. Since it was during the time of totality, as expected the sun's corona is what is visible. Fig. 8 shows a diagram illustrating the dynamics of this event, while Fig. 10 shows several still images taken at 1 second intervals show a consistent oval ring with a bright exterior spot. After discovering the location of the reflection, it was found to be in a body of water with a land bridge crossing it. It is possible that this land bridge is the cause of the dark line cutting through the corner of the corona's reflection. Geometry calculations (Fig. 9) of the balloon's angle with the lake match with the known azimuth and elevation angles of the sun reflection during the eclipse. The width of the lake is about 3x larger than needed to fit the reflection of the eclipse within its banks (~½^0). The ground wind at this time was very still for good optical reflection.

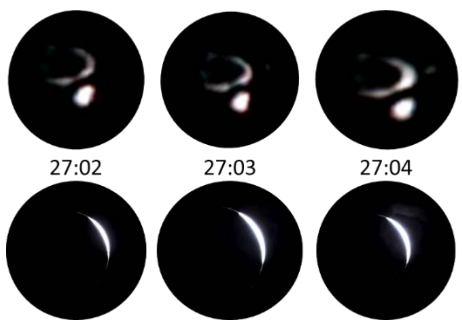

Fig. 10 Still images taken at 1 second intervals of corona reflection, compared with eclipse pictures at same time.

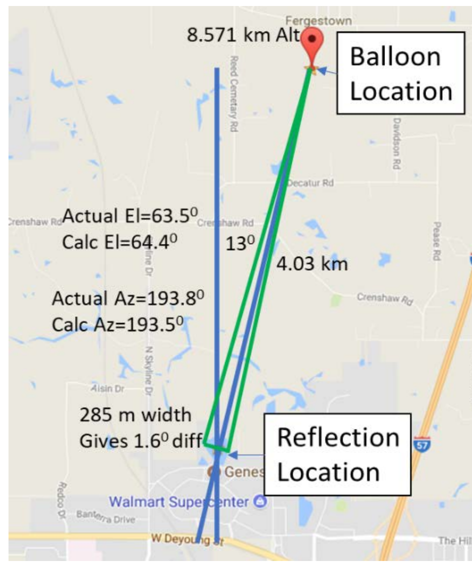

Fig. 8 Diagram showing calculations verifying the corona reflection.

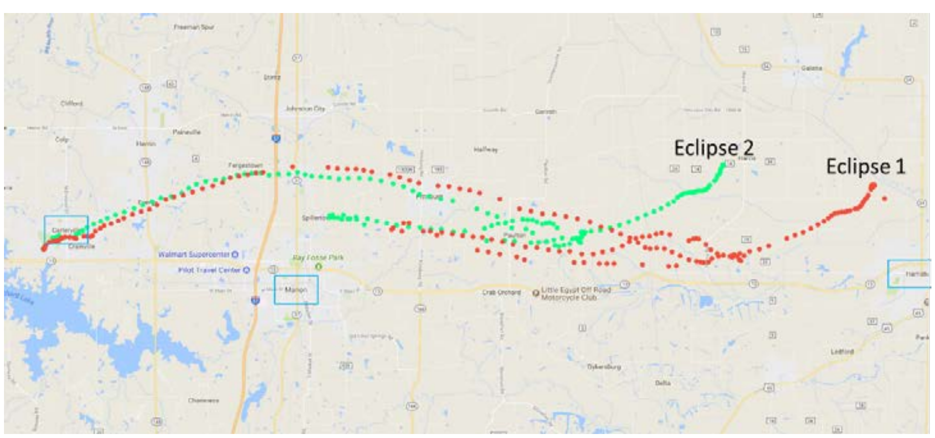

Fig. 11 Ground map of first launch Eclipse Pod 1 and second launch Eclipse Pod 2 flight paths. Both balloons were in the totality region the whole time. In the stratosphere both balloons reverse direction.

V. Instrument Data and Results

Both Eclipse Pod 1 and Pod 2 had eastern trajectories once launched, as can be seen in Fig. 11. Due to the difference in ascent rates, they had differing flight times, burst heights, and distant between their landing sites. Note the loop in the stratosphere and the reverse backtrack motion.

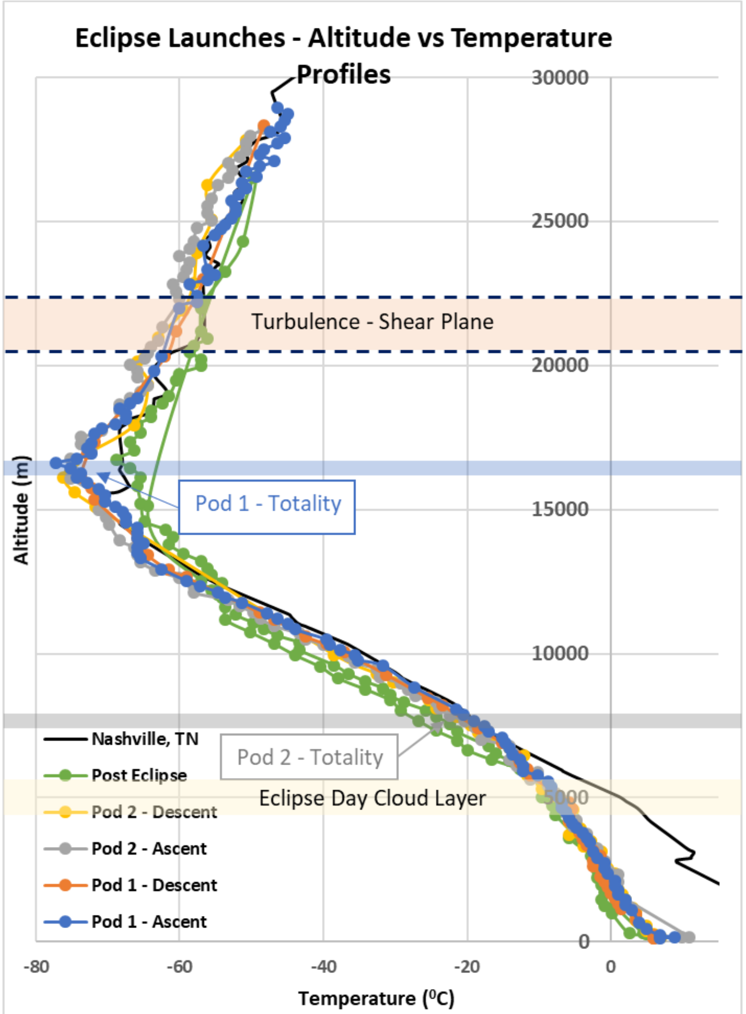

Fig. 12 Altitude vs temperature profiles of eclipse pods 1 and 2, the post eclipse launch, and the recorded Nashville, TN temperature data on August 21, 2017

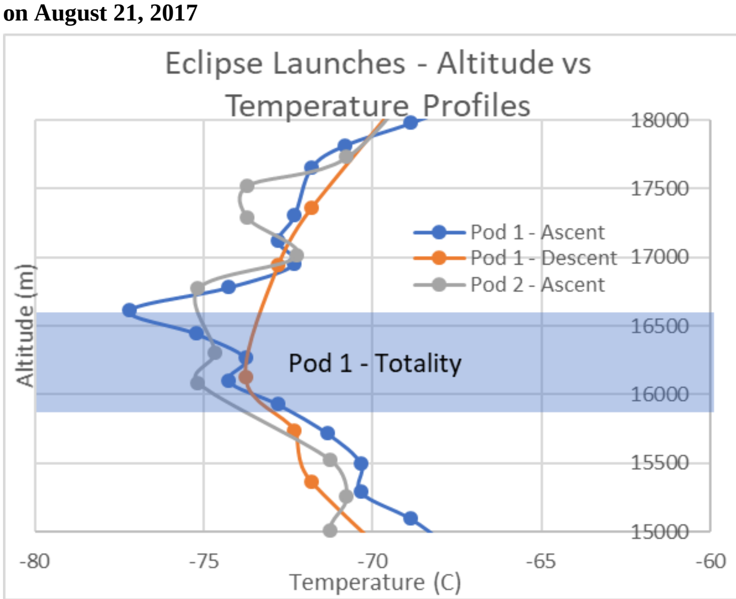

Fig. 13 Close-up of altitude vs temperature profiles of eclipse launches.

One of the main experiments on board was temperature sensors, and fascinating data was collected. In Fig. 12, altitude profiles of the two eclipse and post eclipse launches can be seen, showing both ascent and descent legs. Along with these, the recorded NWS Nashville, TN temperature profiles is shown, to verify our data. In the temperature profile, it can be seen that the ascent and descents of the two launches very nearly match up with each other. However, before and after the tropopause, there are very clear differences in the ascent and descent temperature profiles of Eclipse Pod 2.

The balloon pod measurements fit very well with the official recorded temperature in Nashville. Note that, for Eclipse Pod 1, during the Eclipse in the tropopause it diverges very sharply from the Lincoln and Nashville temperatures, dropping below them by about 5 ^{0}C. The Post-Eclipse launch temperature data shows a similar effect, with temperatures slightly reduced during the eclipse. More testing is required to verify the heat capacity calculations and calibrations.

Fig. 13 shows a close up view of the temperature vs altitude profile of both ascent and descent legs of both pods. As you can see, when Eclipse Pod 1 experiences totality, there is a sharp decrease in temperature of about 4 ^{0}C. After it moves out of totality, the temperature quickly rises back to -73 ^{0}C, the level it was at before totality. Confirming this effect is the descent temperature of the Eclipse Pod 1. The raw data shows the temperature almost exactly equal to the ascent profile, except for the reduced temperature when in totality.

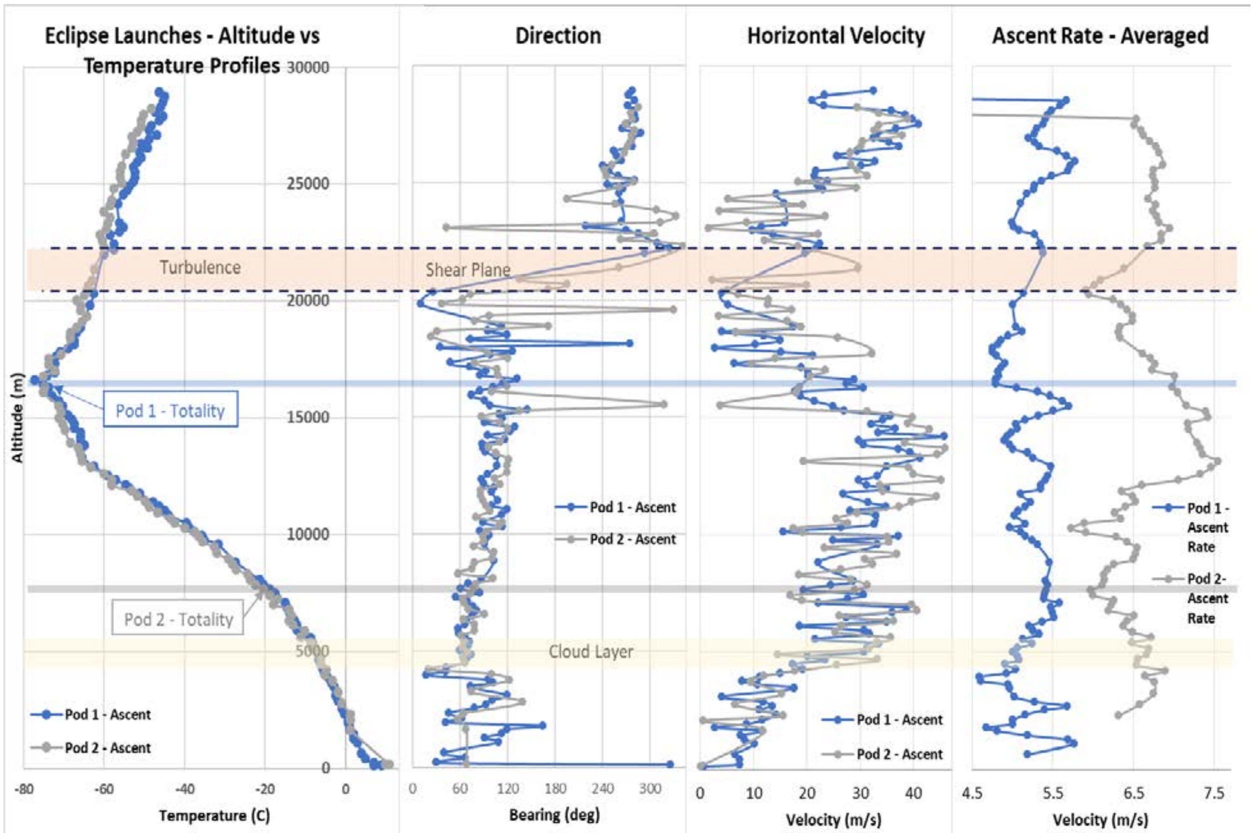

Fig. 14 Altitude ascent profiles of both launch Pods for Temperature, Horizontal direction and velocity, and Ascent rate.

Altitude profiles of the two eclipse launches are found in Fig. 14, showing only the ascent legs for visual clarity. Observing the ascent rates of the two pods, it can be seen that they both experience a substantial decrease in vertical velocity directly before each pod enters totality. After this, their response differs, although both do trend back towards an increase in ascent rate. There is a clear shear plane between 20000 and 25000 meters that can be seen affecting the direction, horizontal velocity, and ascent rates. There is a known cloud layer around 5000 m that day, and the effect of it can be seen in the knees of the temperature profiles, as well as in the stabilizing of the direction.

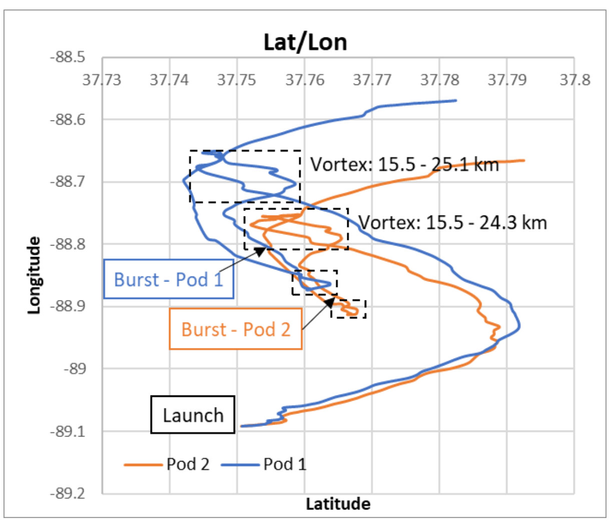

Fig. 15 Lat/Lon plot of the 2 eclipse pods showing vortices in the flight paths.

Fig. 15 is a not-to-scale plot showing the paths of the two pods. Both paths show two distinct loops in their travel. When comparing these loops with the altitude profiles of each pod, it is found that, for each pod, the two loops occur on either side of the burst, with each loop in the altitude range of about 15.5 – 25 km. This demonstrates vortexes in the atmosphere that the balloons were caught in.

Fig. 16 shows our altitude and temperature data as a function of time. This allows us to correlate the temperatures of the two launches at the same altitude, and find any potential errors in calibration that need to be taken into account.

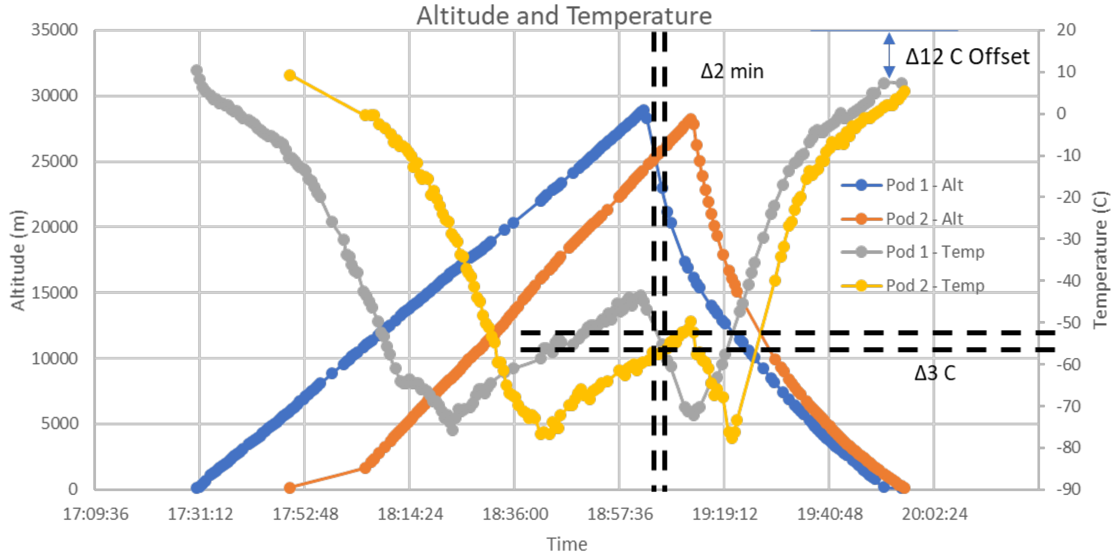

Fig. 16 Altitude and Temperature vs time of both eclipse pods.

VI. Spectrometer Data and Results

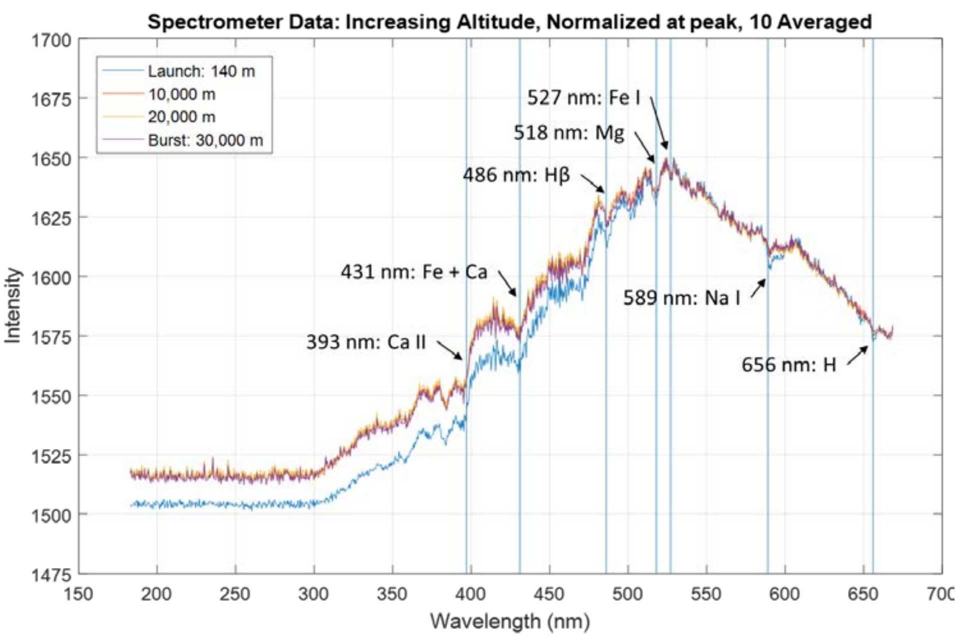

Fig. 17 Spectrometer data of Eclipse Pod 1 at increasing altitudes. These spectra are normalized at the peak, to show differences in trends, averaged in sets of 10.

Spectrometers were flown on both of the Eclipse launches, but not on the Post-Eclipse launch, since that is known data. Spectrometer data of four different altitudes during the flight is seen in Fig. 17. Each spectrum is an average of 10 spectra to reduce noise. The known absorption lines from the Sun are marked on the plot, and it is clear that each of these lines shows up in the data. Note that in the shorter UV wavelengths, there are much higher intensities at 10,000 m and above, showing that the atmosphere absorbs much of the UV light. However, towards the longer wavelengths in the visible spectrum, there is no difference in intensity at different altitudes, showing that the atmosphere allows almost a full transmission of visible frequencies.

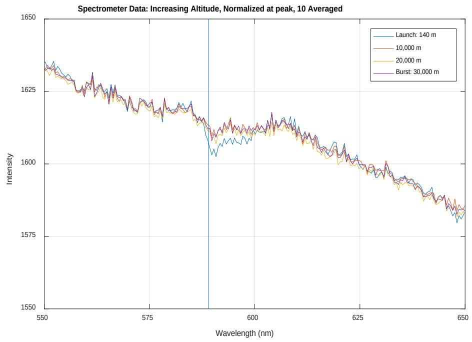

Fig. 18 Close up of spectrometer data of Eclipse Pod 1, centered around 590 nm. Shows differences in absorption lines with altitude.

We see a spectrum of interest centered around 590 nm. Fig. 18 is spectrometer data of four different altitudes during the flight, zoomed around that wavelength. Each spectrum is an average of 10 spectra to reduce noise. The Na I absorption line resides at 589 nm. This is of interested because there is a clear difference in the intensity of this line at the ground vs at the higher altitudes. This shows the potential of different absorption of this element at altitude.

Fig. 19 shows spectrometer data of 10 spectra spaced at 5 minutes apart, starting at totality. Each spectrum is an average of 5 minutes to reduce noise. Each spectrum is staggered in the intensity range by 25 units for visual clarity. The known absorption lines from the Sun are marked on the plot, and it is clear that each of these lines shows up in the data. Notice as the sun moves out of totality, that the intensity of the wavelengths increases greatly. As the intensity increases, the absorption lines begin to show as well.

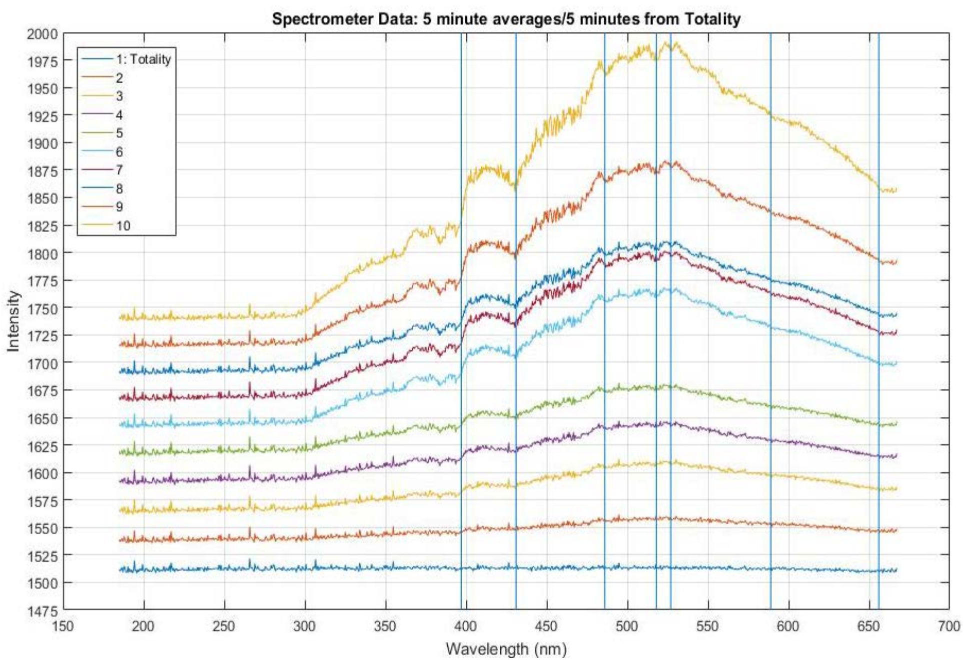

Fig. 19 Spectrometer data of Eclipse Pod 1, taken every 5 minutes, and spaced by 25 units for visual claritv.

VII. Conclusions

The NSL Eclipse program was very successful for the student STEM learning, public outreach, new instrumentation development and exciting research and data analysis. Some of the key advancements include the following:

1) Over 200 K-12 students were involved in several launches, several undergraduate students, and over 50 people (Public Outreach) participated in the launch activates. Hands on class room talks were given at WJLY and at the K-12 school. We also had several radio station interviews and the local radio station WJLY participated in the launch and public outreach broadcast.

2) Temperature profiles were nearly identical on ascent and descent due to the new instrumentation technique of using a small balloon in the parachute to slow free-fall, probe located about 10 m below the balloon neck to reduce flow turbulence, probes on 15 cm booms, and silvered sensor.

3) Temperature profiles agreed well with the NWS weather models with our eclipse temperature being slightly cooler during the eclipse.

4) Eclipse 1 payload was fortuitously in the Tropopause at the time of totality and the temperature was observed to drop quicker at this time. Still under investigation as to source of cooling.

5) Live video worked well during the three flights. Eight video cameras recorded data on memory sticks. Thousands of detailed images were recovered of earth limb, clouds, sun, chromosphere, totality, eclipse, eclipse shadows, and solar reflections.

6) A serendipitous lake refection was recorded near end of totality of the eclipse chromosphere.

7) A strong Stratosphere (20-22km) wind shear with turbulence was observed with a loop to 180-degree reversal in winds. Vertical ascent rates also showed significant vertical wave motions (from 6.5 to 7.5 m/s) after eclipse totality.

8) The new UV-Optical spectrometers performed well on both eclipse flights and recorded 1000's of spectra. The primary solar absorption lines where observed and absorption lines of atmosphere gases with altitude. Blackbody radiation distributions where measured with altitude showing the increase of radiation and decrease of absorption lines with altitude especially in the UV range.

VIII. Acknowledgements

We would like to acknowledge the Indiana Space Grant Consortium (INSGC) grants from 2016 to 2018 with contract number 4103-79966 and the NSL Independent Research funding to support this work. Also, a special thanks to Karen Marvel for organizing the student program at Logan University and for the K-12 TKA school post eclipse launches. John Pugsley ran the ground eclipse pictures and Karen Marvel ran the ground chromosphere pictures. This work would not be possible without the many software contributions from Dr. Stefan Brandle, Dr. Art White, Nate White and John Pugsley. WJLY radio station kindly provided free space for 70 of us to sleep overnight in their facilities, camp outside and stage our educational activities. Also, thanks to Logan University in Carterville, IL for graciously making their facilities available with security for eclipse launching on 21 August 2017.

IX. References

[1] H. D. Voss, J. F. Dailey and S. J. Snyder, "High-Altitude Balloon Launches and Hands-On Sensors for Effective Student Learning in Astronomy and STEM," in *Earth and Space Science: Making Connections in Education and Public Outreach, ASP Conference Series*, 2011.

[2] H. D. Voss, N. A. Ramm and J. F. Dailey, "Understanding High-Altitude Balloon Flight Fundamentals," in *3rd Annual Academic High Altitude Conference*, 2012.

[3] N. Yajima, N. Izutsu, T. Imamura and T. Abe, "Scientific Ballooning," Springer, 2009, p. 213.

[4] H. D. Voss and J. F. Dailey, "Express Launch: A New Capability for NearSpace," in *4th Annual Academic High Altitude Conference*, Upland, 2013.

[5] H. D. Voss and D. Takehara, "Strengthening Balloon Programs: University and Business Collaborations, Research, Outreach, and Internal Support," in *5th Annual Academic High Altitude Conference*, Grand Forks, ND, 2014.

[6] J. Dailey and H. voss, "EyePod-3: An all-in-one Global Data & Tracking Module," in *5th Annual Academic High Altitude Conferennce (AHAC)*, North Dakota, 2014.

[7] H. D. Voss, J. F. Dailey and e. al, "TSAT First Results and Globalstar Coverage Link," in *CubeSat Workshop of 26th Annual AIAA Small Satellite Conference*, Logan, UT, 2012.

[8] Ocean Optics, "STS-UV," 2017. [Online]. Available: https://oceanoptics.com/product/sts-uv-microspectrometer/. [Accessed August 2017].

[9] University of Wyoming, College of Engineering, "Sounding," 2017. [Online]. Available: http://weather.uwyo.edu/upperair/sounding.html. [Accessed August 2017].