

# GreenCube



## Closeout Report 2008

Contact – [Kristina.Lynch@Dartmouth.edu](mailto:Kristina.Lynch@Dartmouth.edu)  
Dartmouth College – Dept. of Physics and Astronomy  
6127 Wilder Lab  
Hanover, NH 03755  
[www.dartmouth.edu/~aurora/greencube.html](http://www.dartmouth.edu/~aurora/greencube.html)

# Contents:

2008 Campaign Overview	2
Flight Systems	3
Electronic Systems	5
Project Goals	6
Preflight Testing and Debugging	6
Flight Data	12
Data Analysis	13
Flight Tracks	23
Lessons Learned and Conclusions	25
Future Plans	25
Appendix	28

## 2008 Campaign Overview

The 2008 GreenCube campaign was a great success. Over the past year the undergraduates with the help of engineering personnel at the Lynch Rocket Lab, designed, built, and tested a “Cubesat” prototype called “GreenCube.” A cubesat is a 10 cm x 10 cm x 10 cm cube-shaped spacecraft initially defined and developed at CalPoly. The GreenCube is a small spacecraft that is three cubesats combined spatially to create a 10 cm x 10 cm x 30 cm object. The complete 2008 campaign consisted of two missions, one on June 3<sup>rd</sup> 2008, and the second on November 20<sup>th</sup>, 2008. The first mission was a flight systems infrastructure test. The purpose of this test was to verify the predicted functionality of the balloon, parachute, and GPS systems, as well as the launch and recovery operations. This flight did not fly the actual GreenCube. Instead it only flew with the GPS and radio systems on board. The second flight was an electronics, data reception, and computer test. This flight did fly the actual GreenCube that was developed at Dartmouth, and obeyed all size and weight restrictions set by CalPoly cubesat standards. Specifically this flight tested the three-axis magnetometer, six thermistors, and computer board. Both flights were launched from Newport Vermont around 10 am, and both landed nearby Wentworth Location in Maine. The flights took approximately two hours. The payloads from each flight were retrieved intact the day of the respective launches.

The first flight contained two packages; the first package contained the GPS, radio and modem, and the second contained a radio locator that transmitted a beacon signal on 121.775 MHz. On this flight it was verified that the GreenCube could be tracked real-time using a GPS system that transmits its location every 30 seconds onto the APRS network.<sup>1</sup> The GPS data was received and interpreted using an APRS-specific software known as UI-View 32. Furthermore, this software plotted the location of the balloon on a detailed map of the New England area. Moreover, the location of the payload was relayed to the internet and the position and altitude of the balloon were observable online at aprs.fi. This flight also was the first time the balloon was released. The balloon ascended as predicted to an expected altitude of 90,000 feet and burst, at which point the packages descended back to the ground at a controlled rate using an 8-foot parachute. The predicted burst altitude came from balloon flight data from Dave Klumpar's group in Montana, which uses a similar setup as ourselves in sounding

---

<sup>1</sup> For more information on the APRS network see [www.aprs.org](http://www.aprs.org)

balloon missions.<sup>2</sup> Although there were no specific regulations on a payload of the GreenCube's weight and size, as a safety precaution many FAA FAR 101 requirements were met.<sup>3</sup> After touchdown, the payload was tracked and recovered by a team equipped with an independent radio and computer system for GPS tracking, as well as a directional antenna tuned into the frequency of the radio locator beacon.

The second flight (the GreenCube's maiden flight) also contained two packages. The first package contained everything the first package contained in flight 1, as well as a three-axis magnetometer, six thermistors and a computer board. The magnetometer measured the Earth's magnetic field on three orthogonal axes throughout the flight. The thermistors measured temperature at six points inside the first package also throughout the duration of the flight. The data were taken and transmitted every thirty seconds, in order to keep the APRS network open to other users. The magnetic field strength data can be used to extrapolate the orientation of the package during the flight. The thermistors were stand-ins for future scientific instruments. The second payload on this flight was the exact same as on the first flight. This mission was tracked the same as the first time, and was recovered very close to the location as the first flight.

## Flight Systems

Both missions implemented the same flight system. Each flight train began with a Kaymont<sup>4</sup> 1500 gram latex balloon. The bottom of the balloon was tied to an 8-foot nylon parachute from "The-Rocketman."<sup>5</sup> The bottom of the parachute was tied to the first payload in each flight, the bottom of which was tied to the second payload. Between each element of the flight train, 2 to 3 feet of slack was given in the rope. The rope used was 230 lb breaking strength braided nylon line from Reef Scuba.<sup>6</sup> The balloon was filled with enough helium such that the entire flight train would ascend at a rate of 1000 feet per second. The calculations and procedures for the filling and launching process are given in the Mission Readiness Review document.<sup>7</sup>

---

<sup>2</sup> See [spacegrant.montana.edu/borealis/](http://spacegrant.montana.edu/borealis/) for more information

<sup>3</sup> For a complete listing of FAA regulations see [http://www.eoss.org/pubs/far\\_annotated.htm](http://www.eoss.org/pubs/far_annotated.htm)

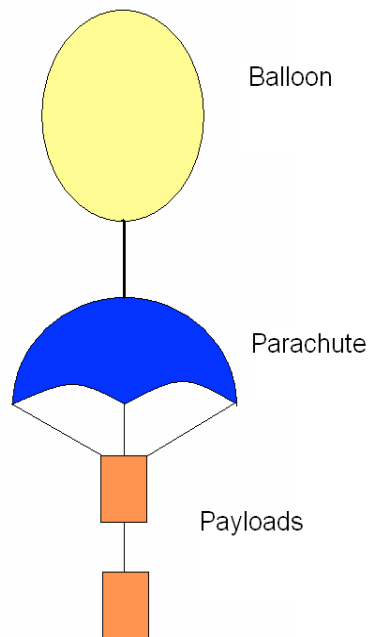
<sup>4</sup> See [www.Kaymont.com](http://www.Kaymont.com)

<sup>5</sup> See [the-rocketman.com/chutes.html](http://the-rocketman.com/chutes.html)

<sup>6</sup> See [www.reefscuba.com/ropewebbing.htm](http://www.reefscuba.com/ropewebbing.htm)

<sup>7</sup> See [www.Dartmouth.edu/~aurora/greencube.html](http://www.Dartmouth.edu/~aurora/greencube.html)

See the next page for pictures and diagrams of the flight train.



Above is a general layout for the flight train.



The flight train being released on November 20<sup>th</sup> 2008.

To see details on the flight systems look at the Interface Control Document (ICD) on the

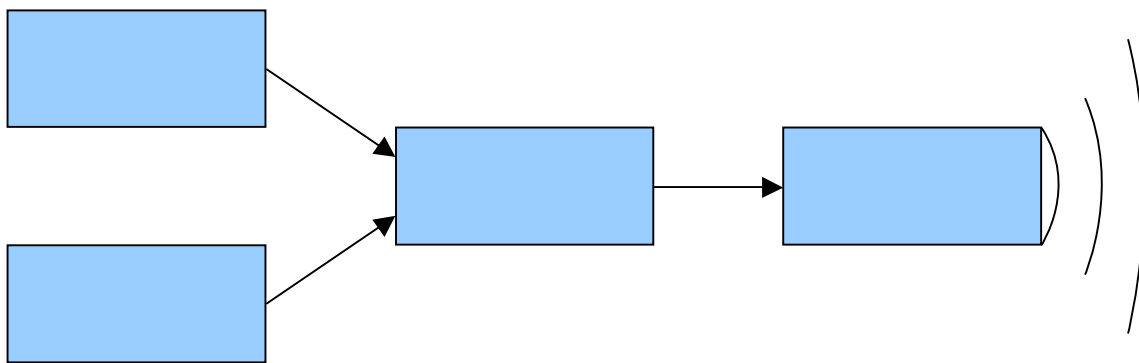
# GPS

website [www.Dartmouth.edu/~aurora/greencube.html](http://www.Dartmouth.edu/~aurora/greencube.html) **Modem** **Radio**

## K111 Electronic Systems

As stated before, on board each flight were two payloads. The first payload contained a Garmin GPS and antenna, an Argent Tracker 2 OT2M<sup>8</sup> modem, a Yaesu radio transmitter, and in addition (on the second flight) a three-axis Billingsley magnetometer, six thermistors, and a computer board known as the K111. The GPS, modem, radio, magnetometer, and thermistors were all purchased items, however the K111 was completely designed in house by undergraduates, with the help of electrical engineers during the winter and spring of 2007. The second payload on both flights contained a radio transmitter that broadcast a beacon on 121.775 MHz.

The electronic systems in the first payload operated as follows. The GPS, magnetometer, and thermistors relayed their data to the Tracker 2 modem. The GPS data came in directly to the modem, while the thermistor and magnetometer data were relayed in single packets through the computer board into the Tracker 2 modem on a separate channel than the GPS. The modem then takes all the data and relays every thirty seconds it to the radio transmitter where it is broadcast on 144.390 MHz. See the diagram below for clarification.



To see further details on the electronic systems see the Interface Control Document (ICD) on the website [www.Dartmouth.edu/~aurora/greencube.html](http://www.Dartmouth.edu/~aurora/greencube.html).

---

<sup>8</sup> See [www.argentdata.com/catalog/product\\_info.php?cPath=22&products\\_id=73](http://www.argentdata.com/catalog/product_info.php?cPath=22&products_id=73)

## Project Goals

The overall goals for this project are given below:

- Achieve burst altitude of 90,000 feet
- Track payload using GPS for the entirety of the flight
- Receive data from the magnetometer and thermistors for the entirety of the flight
- Locate and recover the payload after landing

Each of these goals was met during both of the flights, with the exception of reception of data from thermistors and magnetometer on the first flight, as these were not on board.

## Preflight Testing & Debugging

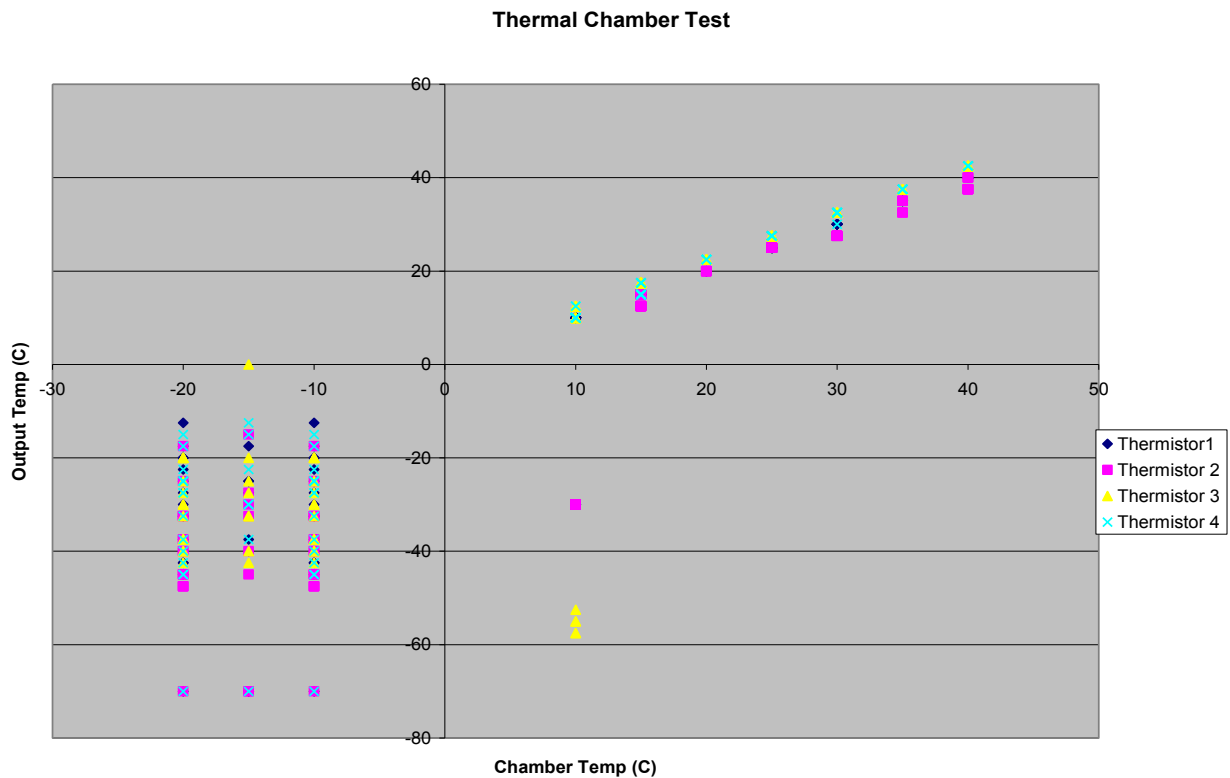
During the summer before the November 2008 launch, much testing was performed on the electronics of the GreenCube. One of the main concerns was how to transmit the magnetometer and thermistor data. For the GPS data this was simple. The GPS output its data in a specified APRS format, and was routed into port A of the Tracker 2 OT2M modem, which was specifically designed for handling APRS packets. The modem would then relay the data to the radio, which would transmit it on the APRS frequency. However the magnetometer and thermistor data was not in the APRS format. As such it needed to be passed through the modem as "KISS" data, or user specified format data. However, due to the fact that the modem was specifically designed for the APRS network, this was not as easy as it sounded. Furthermore, due to inconsistent online literature on how to format KISS data properly, the problem was prolonged further. Finally however, with the help of Scott Miller, the designer of the Tracker 2, as well as Phil Bracikowski a graduate student in the Lynch Rocket Lab, the correct data format and modem settings were achieved and the data was properly transmitted from the GreenCube to the ground.

### *Thermal Testing*

In this test the cube was placed in a thermal chamber and then subjected to temperatures ranging from -20 to 40 degrees Celcius. This test served two purposes: to ensure the cube could operate in the range of temperatures it would encounter during a

flight up to 100,000 feet and to obtain the mathematical equation that allows for the conversion of the digital K111 thermistor output into temperatures in degrees Celsius.

The results of the thermal test were inconclusive. Though the cube remained operational and output data for all of the temperatures, the thermistor digital outputs lost their linearity and became scattered for temperatures less than 10 degrees Celcius. This problem may be the result of malfunctioning thermistors or bugs in the computer CPU code.



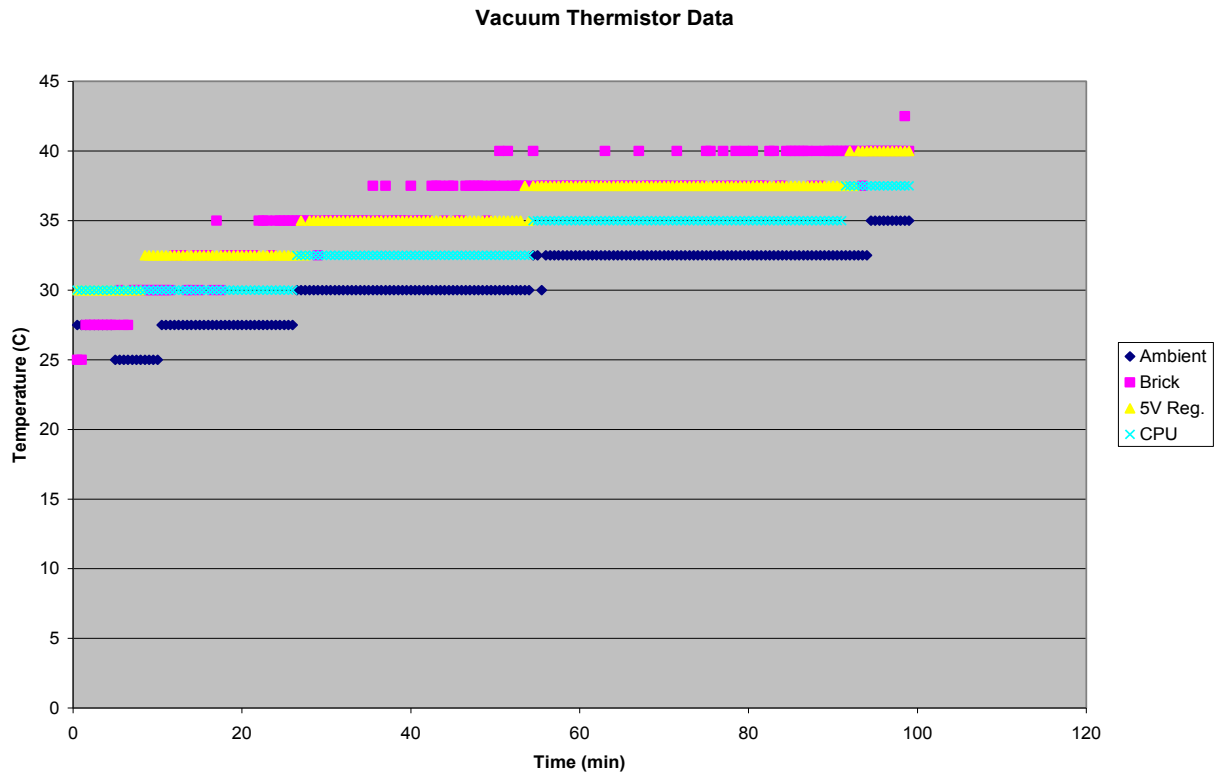
### *Vacuum Testing*

In this test the cube was placed in a vacuum chamber and then subjected to pressures of about 5 Torr for 60 minutes. The purpose of this test was to ensure that the GreenCube could operate at the low pressures it would encounter during the flight. The primary concern with its operation at low temperature was overheating due to the limited atmosphere and consequent limited cooling by convection. By attaching the working thermistors to the different circuit board elements that produce the most heat, the CPU, 5 volt regulator and 24V-12V brick, the vital temperatures of the cube could be



monitored.

The vacuum test proved that the cube could operate at low pressure for the duration of a flight. After 100 minutes of operation at 5 Torr none of the on-board components reached temperatures in excess of 40 degrees Celcius proving that overheating should not be an issue during the flight.

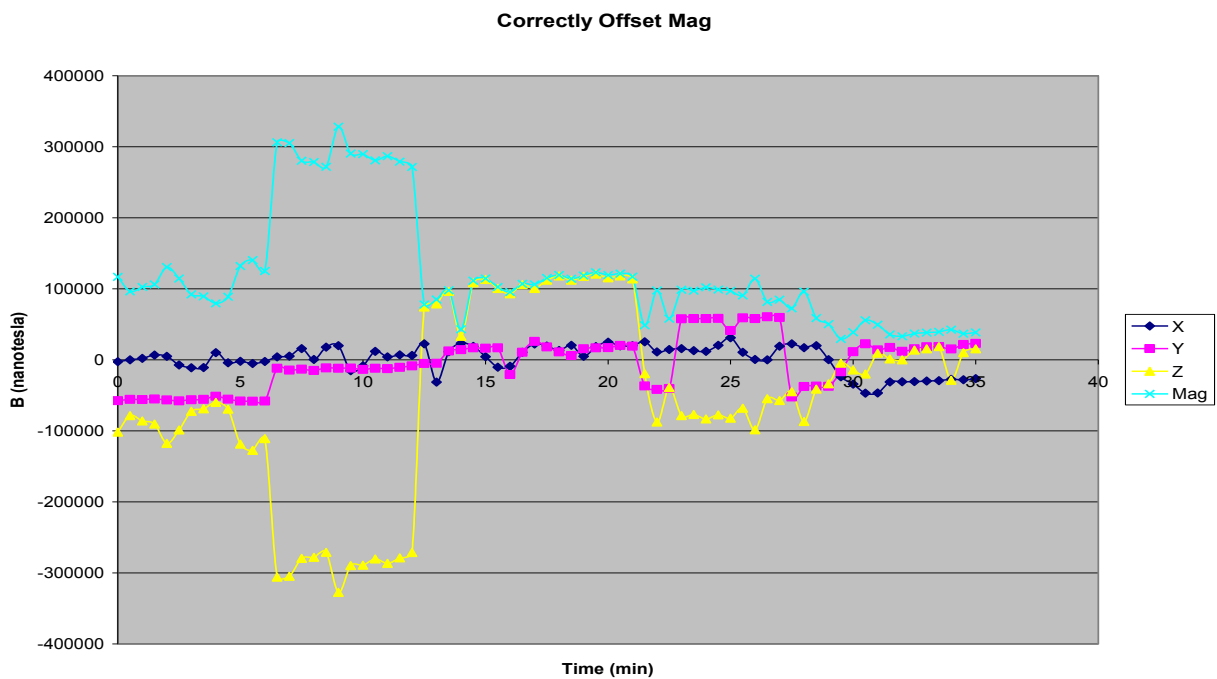
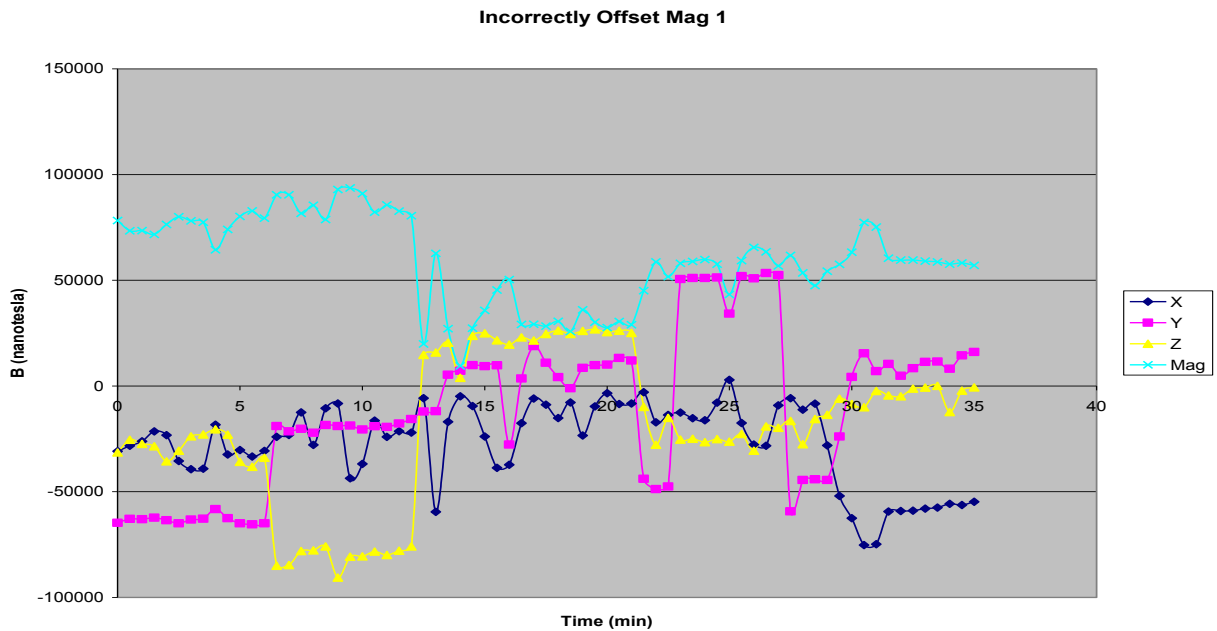


### *Magnetometer Calibration*

The third test was a calibration of the magnetometer. To see if the magnetometer was functioning correctly, the GreenCube was rotated about its various axes while the digital magnetometer output was monitored and recorded. After offsetting the digital output by half of the digital output range in order to obtain a positive and negative field and then scaling it appropriately, it was clear that the offsets were incorrect due to the greatly varying field magnitude. By maximizing and minimizing the digital outputs along each axis more accurate offsets were obtained.

Due to its expense and the fact that a properly magnetometer was not necessary to accomplish the communication-oriented goals of the GreenCube flight, the

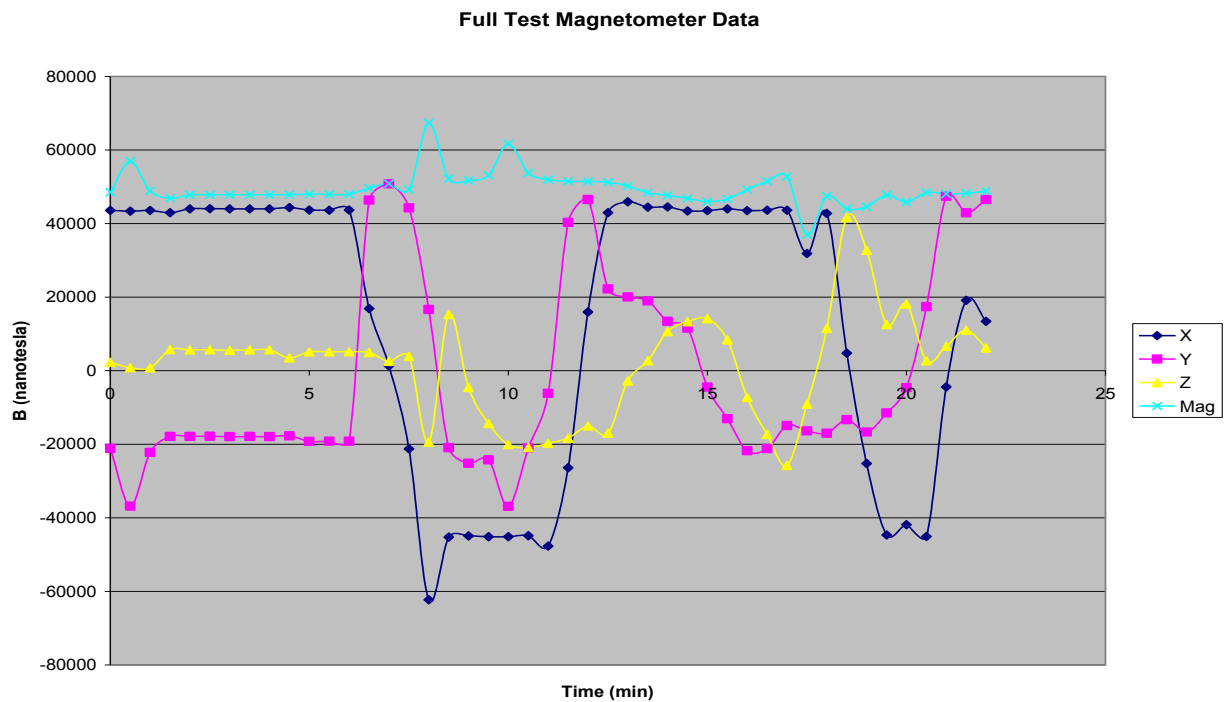
magnetometer used in the cube was one that had endured a previous crash that resulted in damage to the magnetometer and subsequent repair. Consequently, the imperfect magnetometer data was expected even after determining the various axis shifts and is probably due to misaligned axes or another magnetometer malfunction that resulted from the previous crash.



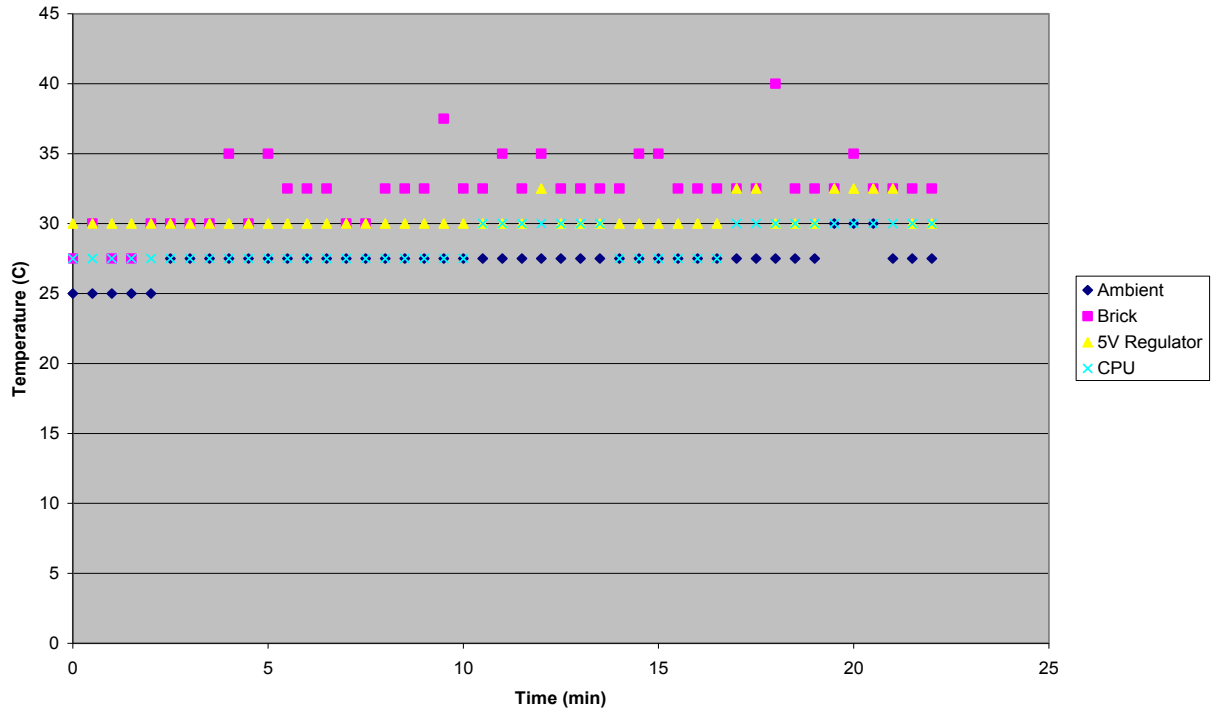
## Full Test

To ensure that all of the systems within the GreenCube were operational before launch, a full run-through was conducted. In this test the cube was set up and run as if it were being flown. This included running the cube off of a contained battery pack and transmitting the data through the radio to the computer instead of through a direct serial connection with the computer.

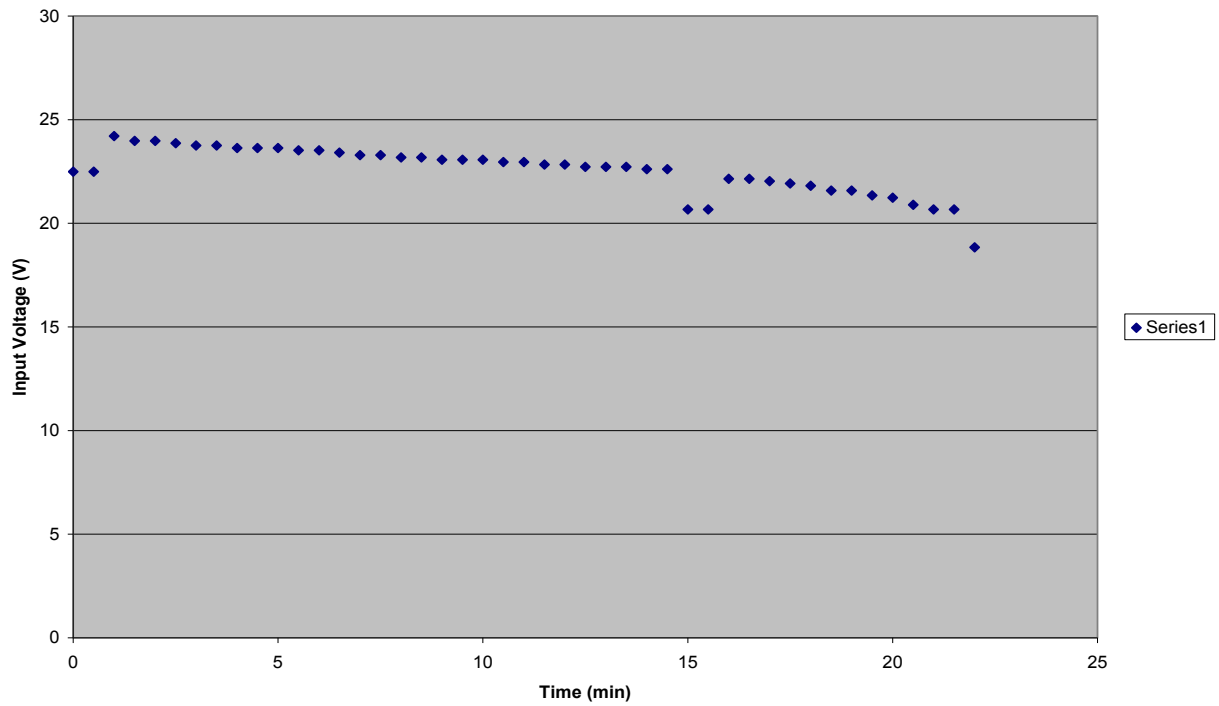
The full test proved that the GreenCube was fully operational and ready for launch. The radio communicated data effectively to the computer, and the data demonstrated responsive and sensical magnetometer and thermistor outputs. Additionally, the input voltage from the battery pack stayed sufficiently high.



Full Test Temperatures

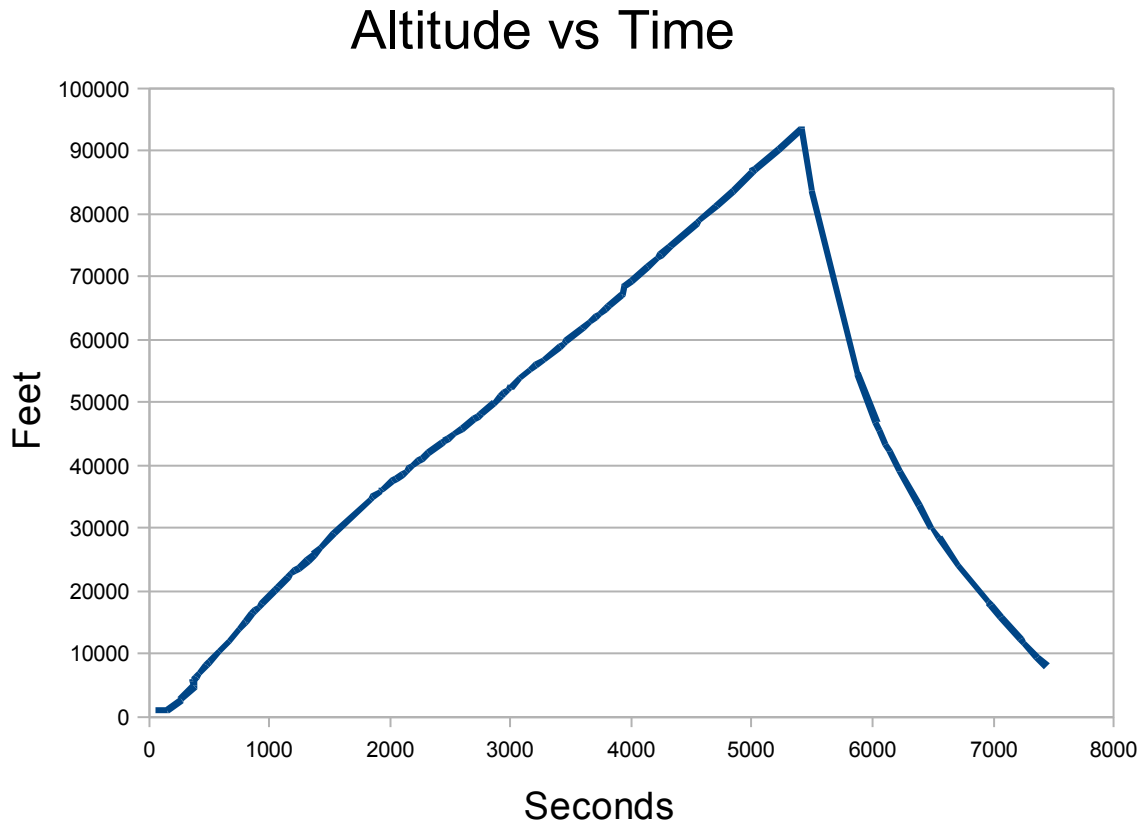


Full Test Input Voltage



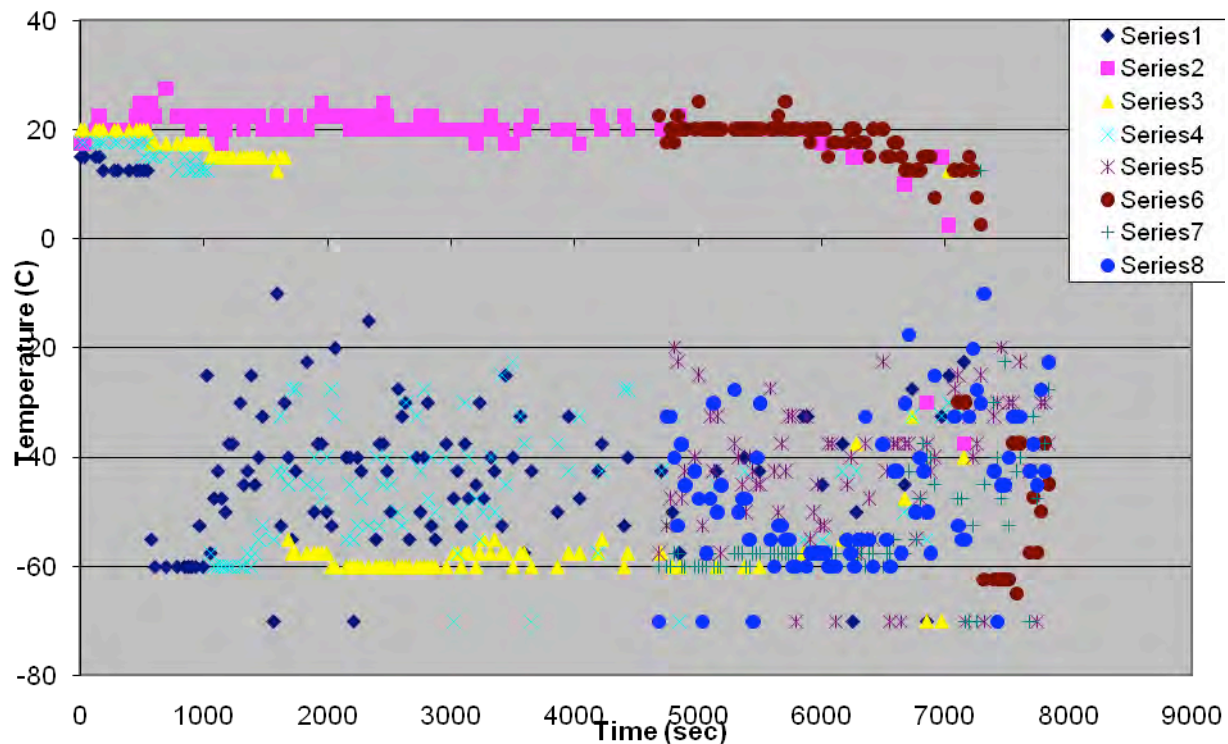
## Flight Data

The magnetometer, thermistors, power monitor, and altitude data received is plotted below.



The above graph plots the altitude of the GreenCube vs time for the November 20<sup>th</sup> launch. The slope of the ascent shows that the GreenCube rose at approximately 1000 feet per minute as predicted. The exponential behavior of the descent is due to the fact that the parachute does not open until the payload reaches the thicker air of the lower atmosphere, thus the payload does not slow down until it reaches that point.

## Temperature Data



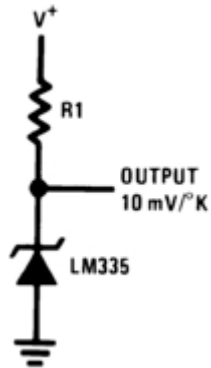
The above graph shows temperature in degrees Celsius plotted against time. The first four data sets show launch team data and the last four show data recorded by the recovery team. As during testing, the thermistor output lost linearity below 10 degrees Celsius. Post-flight testing showed this to be the result of an error in the K111 board circuitry.

## Data Analysis

As seen in the magnetometer plots, two of the axes show a generally sinusoidal behavior. This is expected as the payload is likely rotating about its vertical axis during flight, thus the components of the Earth's magnetic field perpendicular to the payload's vertical axis would vary in strength sinusoidally. Likewise, the component of the magnetic field parallel to the vertical axis of the payload does not vary by much, as the payload does not swing much during the flight except immediately after launch.

The thermistor output lost linearity and became scattered at temperatures below 10 degrees Celsius. Further testing revealed this to be the result of an error in building the circuit. The thermistors should have been set up as in the following diagram, as part of

a resistor divider.<sup>9</sup>



In the greencube circuit, a potentiometer was unintentionally added in series with the thermistor, which caused the current to be too low for proper functioning.

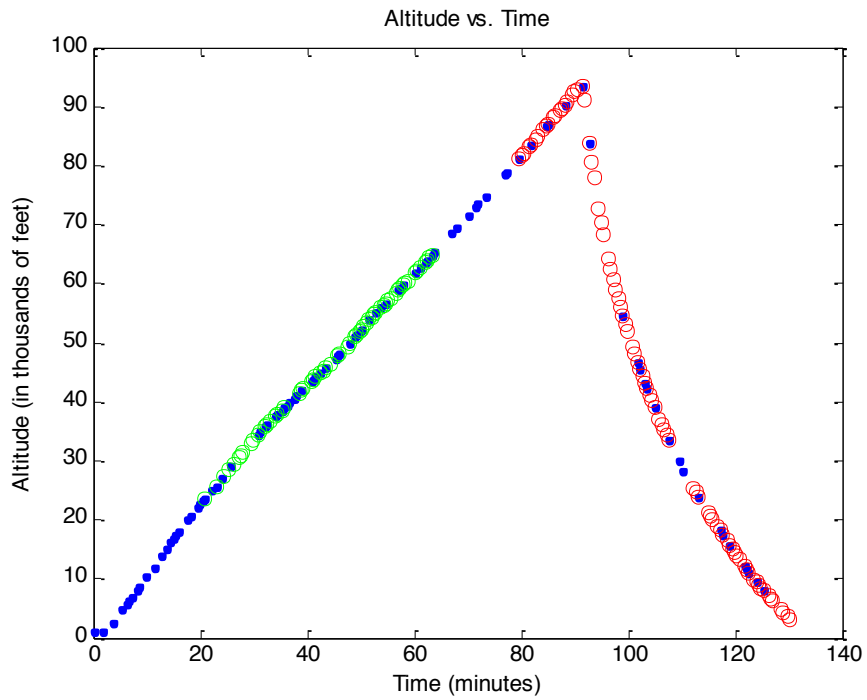
### GPS Data

The GPS data from the November 20<sup>th</sup> flight was analyzed to look for evidence of gravity waves, possibly shown by deviations from a smoothed trajectory, as a starting point for further research on future GreenCube flights.

---

<sup>9</sup> <http://www.national.com/mpf/LM/LM135.html>

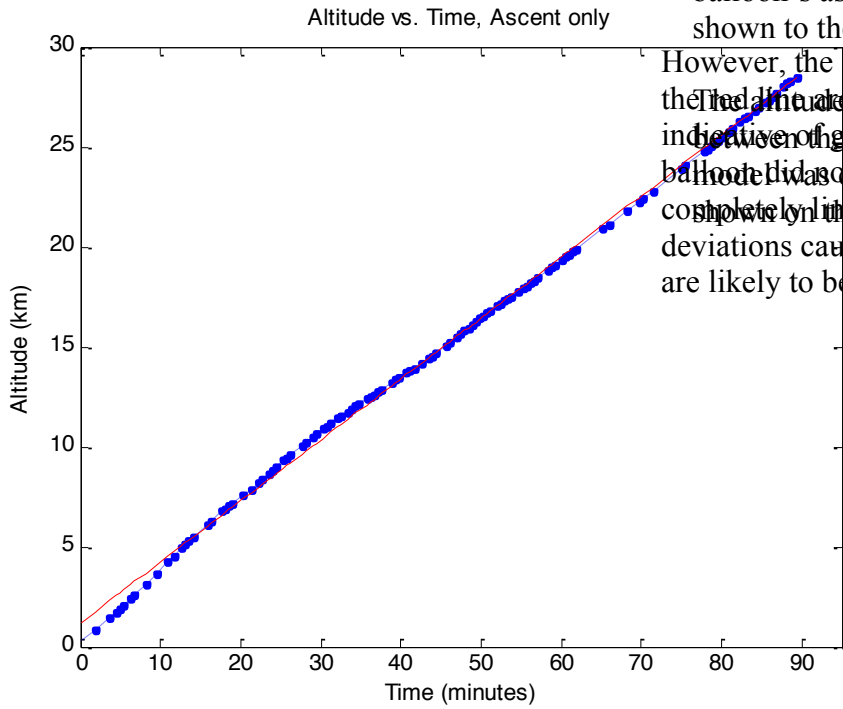
## Altitude vs. Time



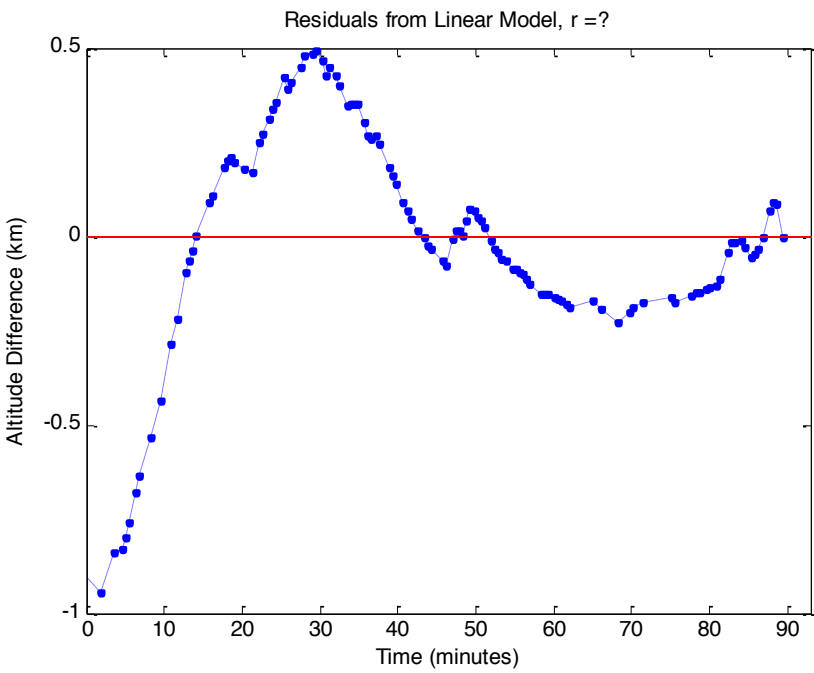
The above image shows the balloon's altitude profile. The blue marks indicate the GPS data recorded during the flight, while the green and red data points were recovered by the first and second recovery teams, respectively.



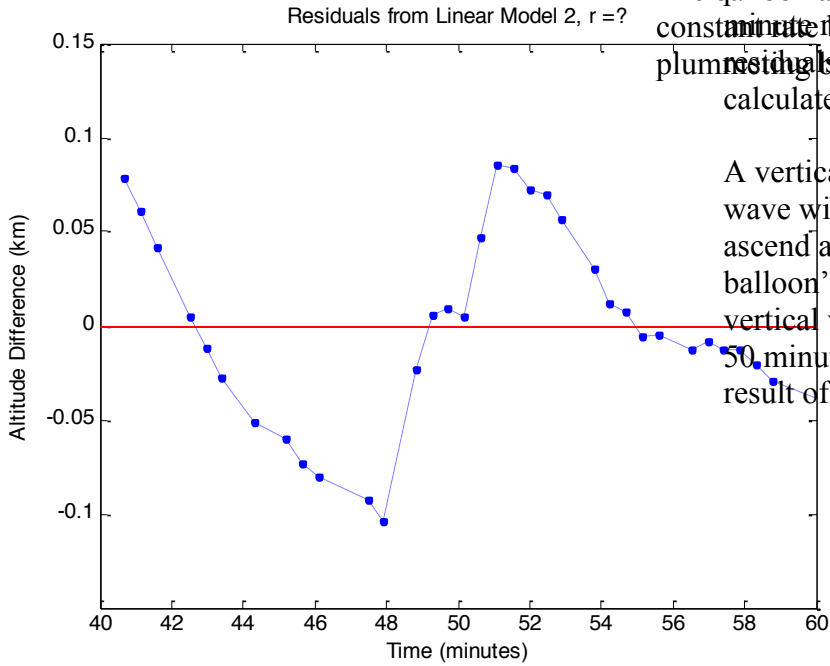
The balloon's ascent is shown to the right in red. The difference between the balloon's actual (blue) and the linear model (red) is shown to the right in red.



However, the large deviations from the model are difficult to indicate of gravity waves, as the balloon did not follow a completely linear ascent. Rather, deviations caused by gravity waves are likely to be smaller.

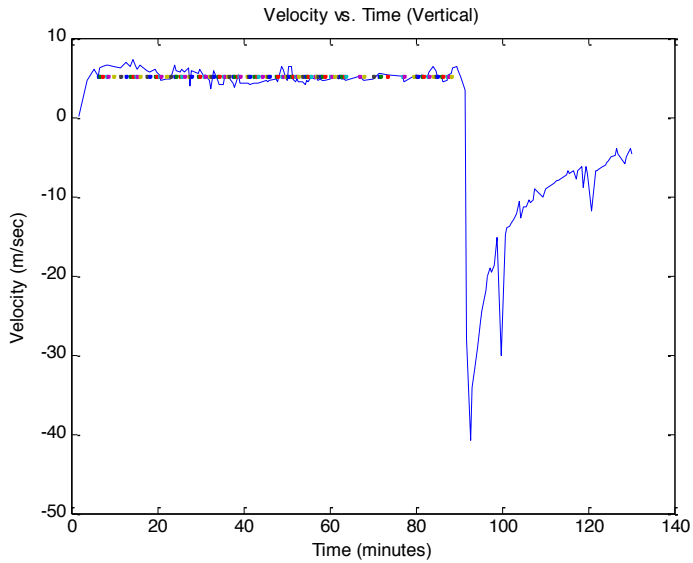


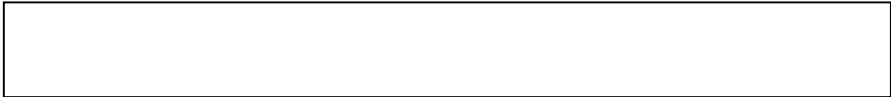
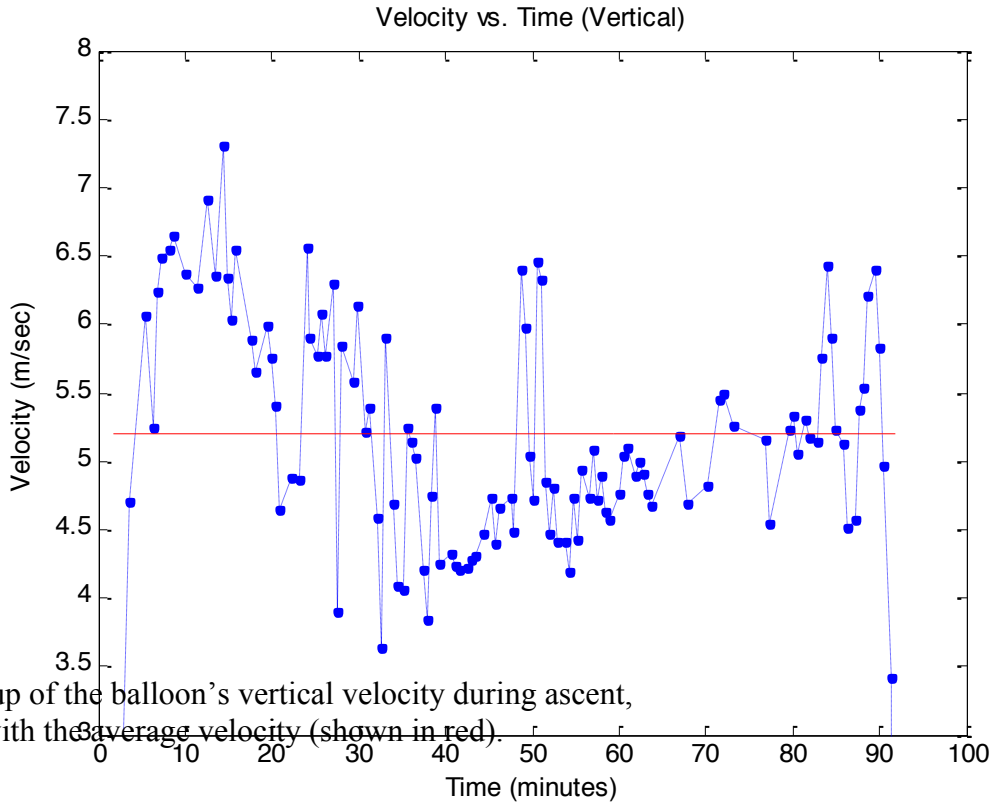
The graph to the left was constructed using a new linear model, one that encompasses data from the balloon's ascent at  $t = 40$  to  $t = 60$  minutes before. Once again, the residuals from the model were calculated.



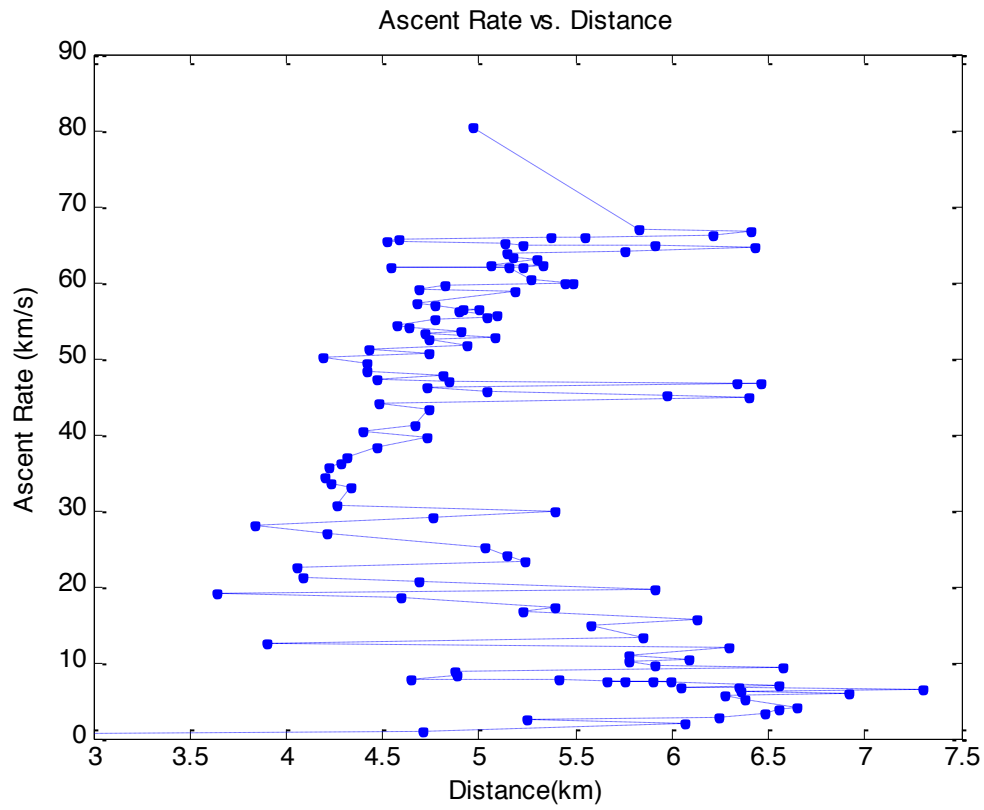
A vertically propagating gravity wave will cause the balloon to ascend at a faster rate. The balloon's sudden increase in vertical velocity around  $t = 48$  or  $50$  minutes could have been the result of a gravity wave field.

### Ascent Rate vs. Time





## Ascent Rate vs. Distance



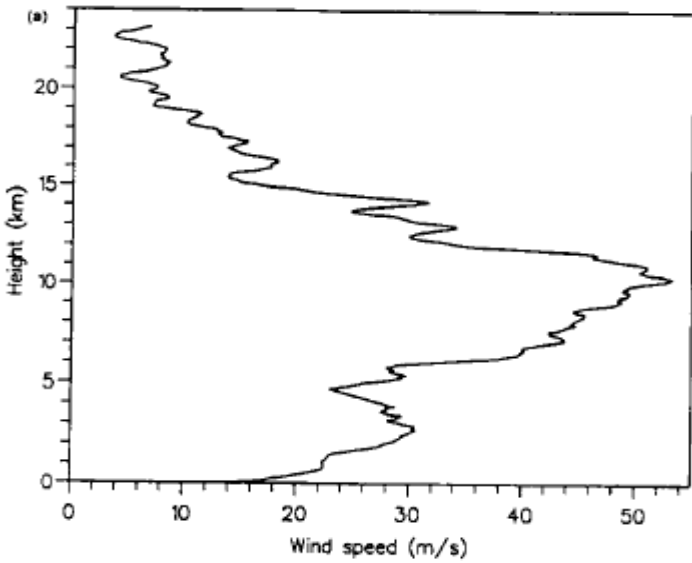
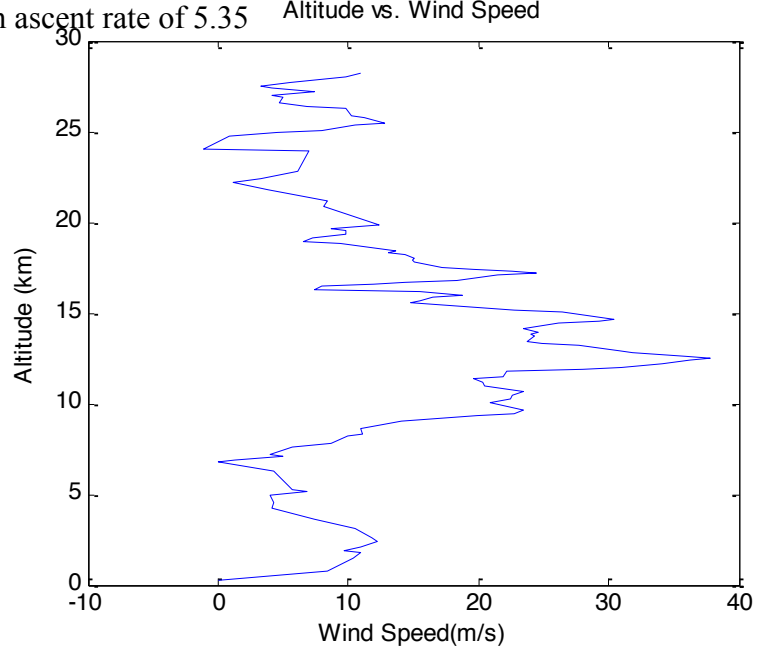
Distance refers to the horizontal displacement from the balloon's launch point. This was calculated by projecting the balloon's path onto the surface of the Earth. The direction in degrees from the launch site was not taken into account. Rather, it is the polar distance away from the launch site. The curvature of the Earth was taken into account.

Altitude vs. wind speed graph  
 indicates that the balloon travels  
 vertically at the same speed as  
 wind.

Figure 2(a) from Shutts:  
 Profile from radiosonde launched  
 at 1335 GMT on 6 October 1989  
 (sonde C).

Steady trapped lee waves  
 Ascent rate fluctuations of about  
 2m/s.

Mean ascent rate of 5.35



<sup>10</sup> Shutts, G. J., P. Healey, S. D. Mobbs. "A multiple sounding technique for the study of gravity waves." *Q. J. R. Meteorol. Soc.* 120(1994): 59-77.

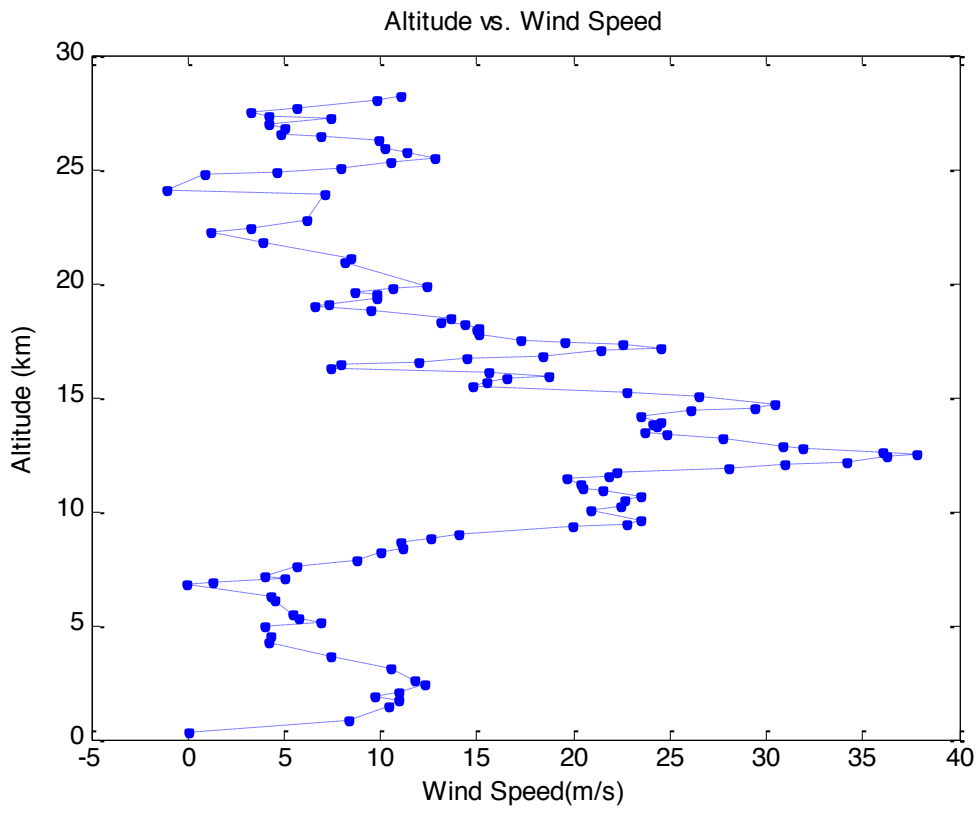


Figure 5(b) from Shats.  
Profile from radiosonde launched at 1345  
GMT on 6 October 1989 (sonde D).  
Steady trapped lee waves  
Ascent rate fluctuations of about 2m/s.  
Mean ascent rate of 5.21

### Altitude vs. Ascent Rate

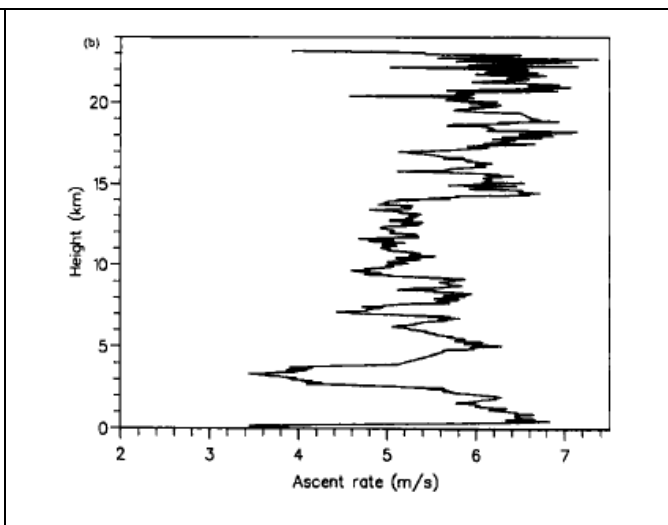
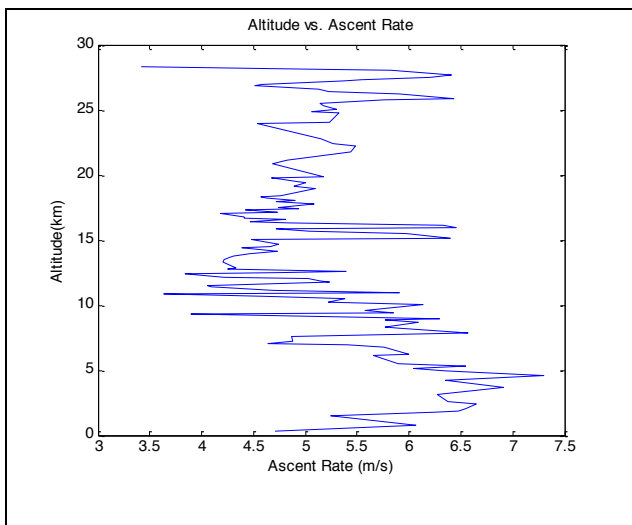
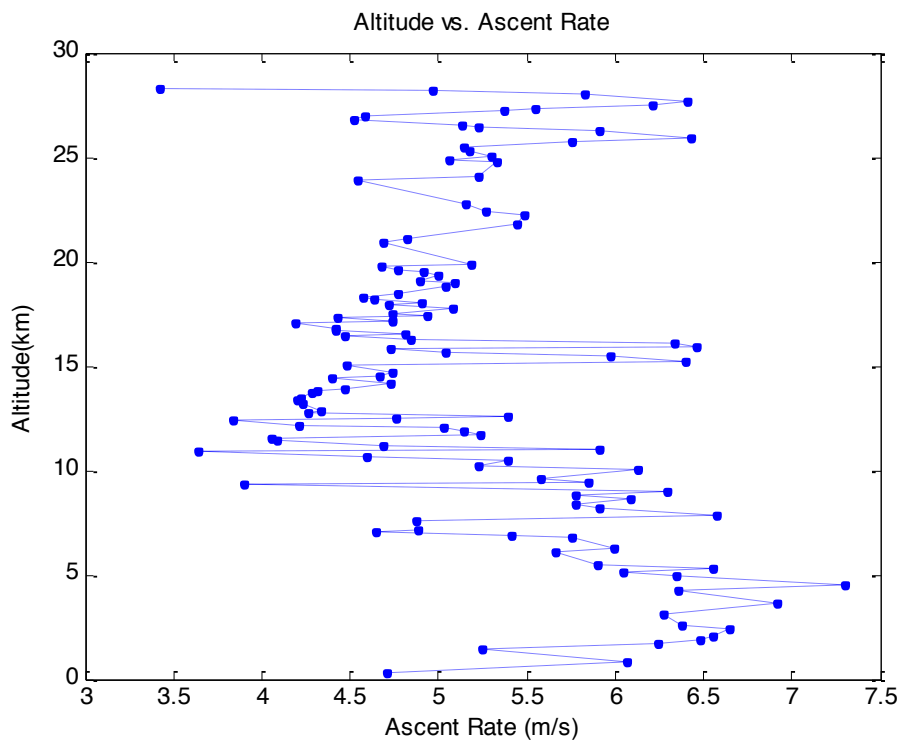
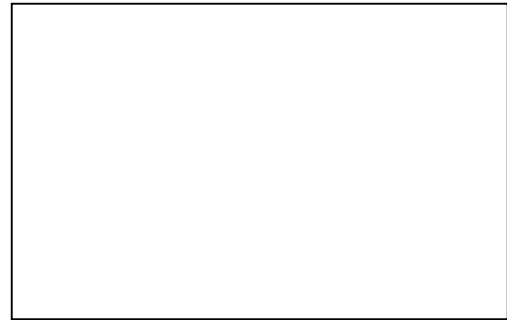
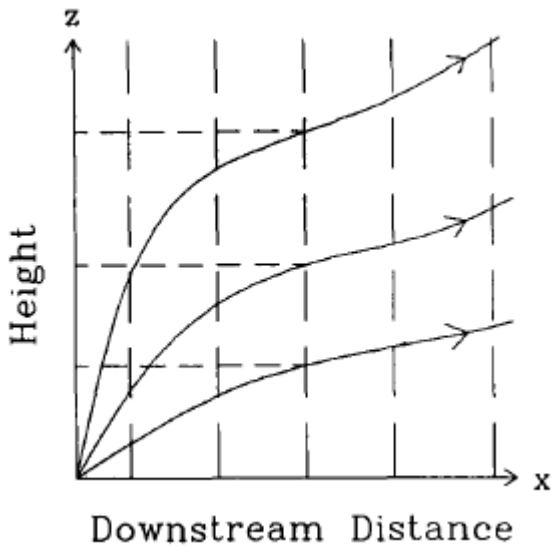
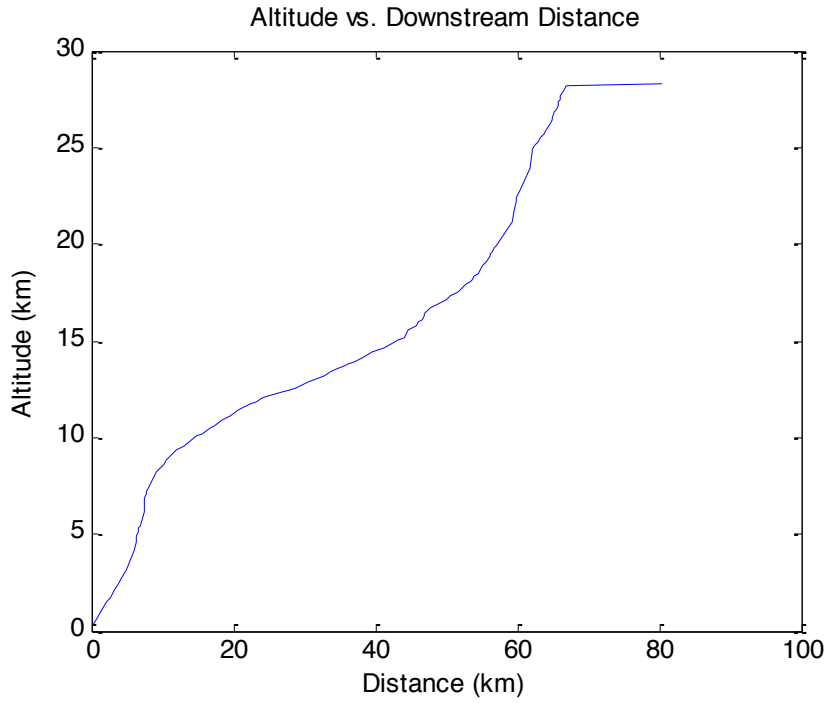


Figure 1 from Shutts:  
 Schematic diagram of three sondes flying through a wave field with vertical lines of constant phase (denoted by dashed lines). Since the ascent rates are different, each sonde arrives at a given phase line at a different height.

**Altitude vs. Downstream Distance**

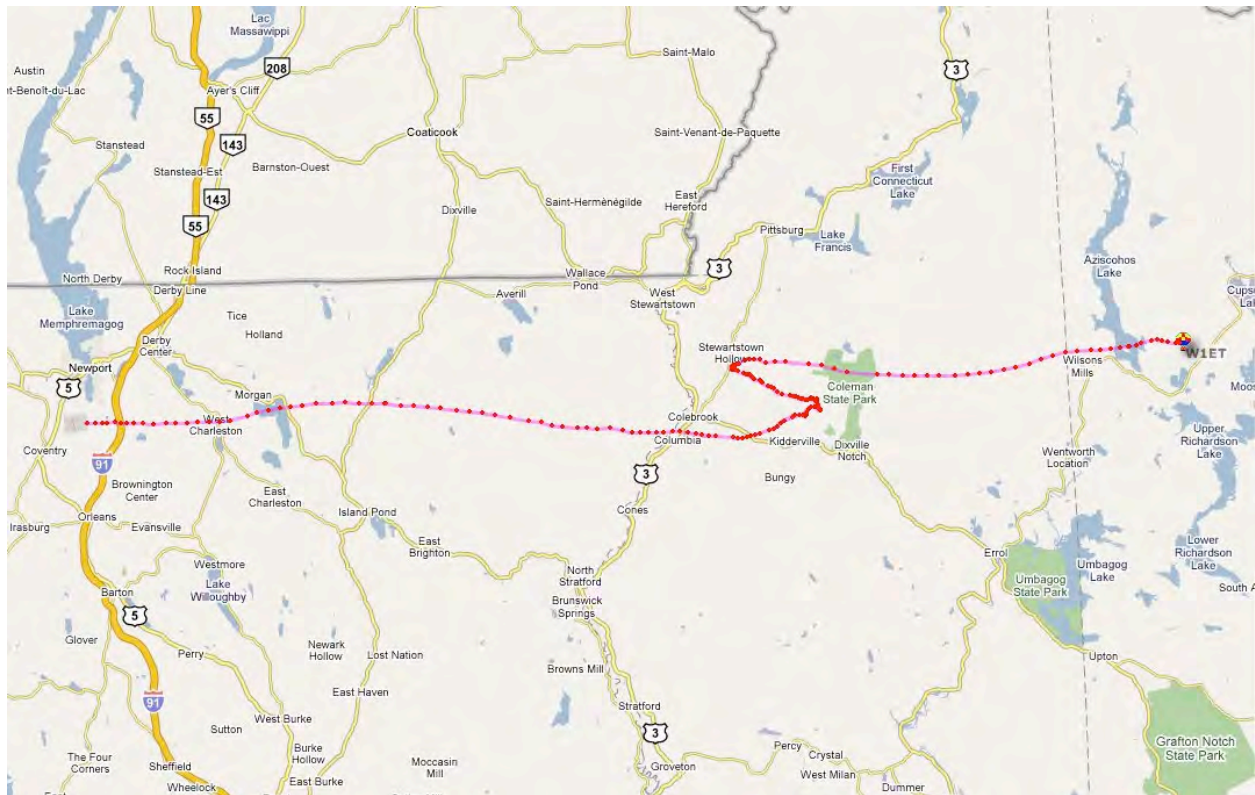




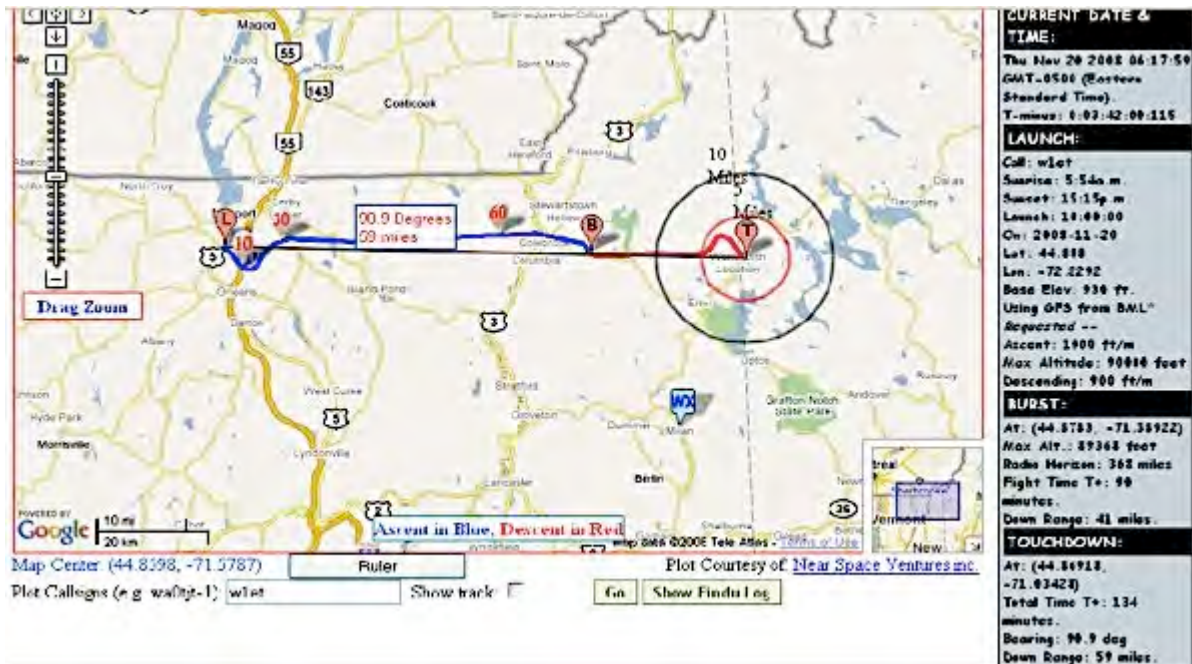
One of the main things learned from the data received is that it would be favorable to have a higher rate of reception than just once every thirty seconds. The magnetometer plots in particular display very rough sinusoids. It would be more useful to have a higher resolution on these plots in order to extrapolate the payload's orientation to a greater degree of exactness.

## Flight Tracks

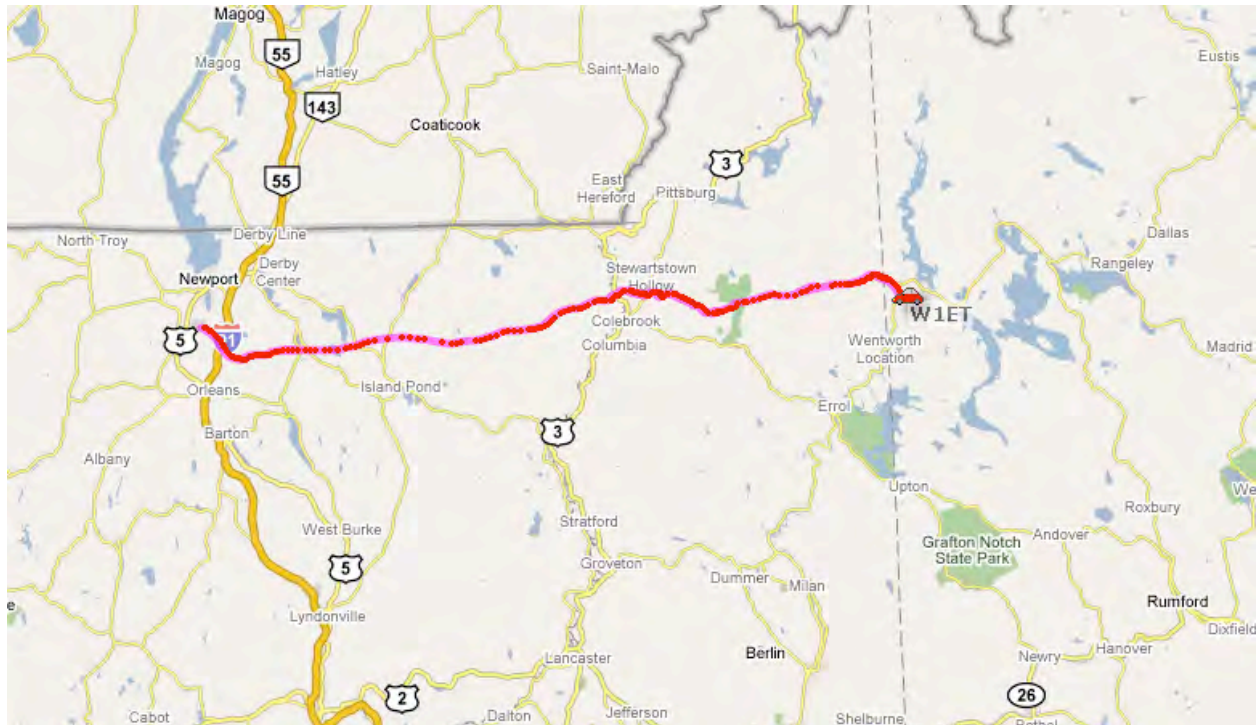
The tracks of both flights are shown below next to their corresponding track predictions. Track predictions were made using the "Balsoft" software from [www.eoss.org](http://www.eoss.org).



Shown above is the flight track for the June 2008 balloon.



Shown above is the Balsoft flight track prediction for the November 2008 launch.



Shown above is the flight track for the November 2008 launch.

As shown by the previous November figures, the actual tracks of the flights very closely matched the predictions. Unfortunately, the flight track prediction for the June launch is no longer attainable; however, both times the payloads landed within ten miles of the predicted landing location. This gives the GreenCube recovery team great confidence in using the software for predicting the tracks of future flights.

## Lessons Learned and Conclusions

The GreenCube team learned many lessons through the two flights. Among other things, some of the main lessons were about launch and recovery procedures. However the most important lessons learned from both flights is about the data acquisition. The magnetometer plots show how important it is to have a higher data rate from the payloads. Thus the payloads must transmit more often than just once every thirty seconds. The reason the payloads transmitted at this rate was due to the fact that the APRS network is a common frequency that many people use. As such, the GreenCube team did not want to “hog” the frequency by transmitting very often and thus not letting others use the network. Therefore, if the payload is to transmit at a higher rate, it must transmit on a different frequency than the APRS frequency.

This brings up another problem however, the problem of tracking. Recall, the payloads were tracked because specific APRS software was able to interpret the GPS data and plot the position of each flight on a detailed map of New England. However, if the data is not transmitted on the APRS frequency, then this software will be useless. Thus a new tracking method must be implemented.

There were many other lessons from the 2008 campaign. To see an extensive list turn to the appendix.

## Future Plans

The GreenCube project has a wide open future. First, the balloon infrastructure developed for the two flights this past year can be reused on future flights. On future missions the thermistors could be replaced with other scientific instruments to take specific measurements. The GreenCube team is currently discussing several future measurements to be made for future scientific flights. Some possibilities include measuring atmospheric gravity waves with pressure sensors, taking night time ambient

light measurements with a photometer, testing a new tracking method using ground based radio instead of GPS, and taking upper atmosphere particulate measurements. This would all be theoretically performed using SURP funding from the NASA Jet Propulsion Laboratory.

Separately, Professor Lynch, the PI for the project is trying to use GreenCube-like payloads on auroral sounding rockets to take measurements of plasma density irregularities in the upper ionosphere. Several GreenCubes would be loaded onto a sounding rocket in “peapod deployers.” These GreenCubes would be released in the upper ionosphere to take their measurements. Currently, Phillip Bracikowski a graduate student in the group is working on adjusting the GreenCube designs to fit inside a peapod deployer on board a sounding rocket in conjunction with NASA Wallops Flight Facility and funded by NASA/EPSCOR.

# Appendix

## Lessons Learned

### General:

1. Program the K111 to add timestamps to each transmission, not just the GPS transmissions.
2. And/or add a counter index to the data transmissions (ie. 1, 2, 3 ... etc.)
3. Add a "fake" 1 PPS to the K111, so that the data transmits even when there is not GPS fix.
4. Transmit data on personal frequency, not APRS so we can transmit more often the just once every 30 seconds.
5. Designate a launch safety officer.
6. Figure out a way to transmit data more frequently than every 30 seconds, would be nicer to increase resolution of mag data
7. Protect use 9-pin from line.
8. Test the recovery printers before leaving Hanover.
9. Make sure to check the weather at the proposed landing site.

### Launch:

1. More than one person should be holding balloon at all times, and all people holding balloon should be wearing gloves
2. There should be a separate launch checklist for warm and cold weather. Our

cold weather launch required some on site improvising in order to keep the batteries warm until launch.

3. Always make sure there is more than enough helium at launch site, whether this means a site visit or ordering another cylinder just in case.
4. Use larger more robust tarp and tie down method for gustier days.

#### Recovery:

1. Set clearly defined recovery team leader in advance to make final decisions.
2. Implement search plan before leaving Hanover.
3. Add "panic button" to GreenCube.
4. Bring mini-repair kit.
5. Set plan for GreenCube getting stuck in a tree.
6. Have smaller recovery team, limit at say four people.
7. Obtain key to second college grant before leaving Hanover.
8. Bring extra coax.
9. Triple check UI-View software before leaving Hanover.
10. Keep Phil on recovery team.
11. Always go to first waypoint before using direction finding equipment.
12. Find more robust design for home-made ELT.
13. Require and test more hand held radio equipment to bring along.
14. Bring whistles and enough hand held GPS units.
15. Don't need to set up staging so far away from predicted landing location because the EOSS tracks are pretty accurate.





For any questions please contact us here at the Lynch Rocket Lab.