Dartmouth Greencube 2

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Anthony J. Mannucci, (PI), Tracking Systems and Applications Section (335)
Kristina A. Lynch, (Co-PI), Department of Physics and Astronomy, Dartmouth College

A. OBJECTIVES

The GreenCube project stems from Professor Lynch's interest in small, autonomous science payloads for multipayload auroral sounding rockets, and from Professor Millan's interest in small, cubesat-like orbiters for future science missions.

The goals of the GreenCube project are (1) to maintain a scientifically interesting, student-driven balloon-borne CubeSat program in Dartmouth Physics; (2) to incorporate new design features into small payloads for Low Cost Access To Space (LCAS) class auroral sounding rocket proposals by Prof Lynch; (3) on a longer timescale, to incorporate designs into Professor Millan's future plans for small orbiters, which potentially could include student-driven cubesats.

The specific goal of GreenCube 2 was to use the GreenCube infrastructure to collect and understand data, especially GPS and temperature data, pertaining to gravity waves. GreenCube 2 was the first GreenCube mission to pursue a true science goal rather than just infrastructure development.

B. APPROACH AND RESULTS

Greencube 2 described here is a follow-on to the Greencube 1 project. The students found that preliminary measurements from the Greencube 1 flight GPS system showed indications of gravity waves in the wind velocity measurements; determined that a higher data rate was necessary and increased it from a 30-sec cadence to a 6-sec cadence; revisited the temperature measurements from Greencube 1 and changed the circuitry to support exterior thermistor measurements; built a second copy of the Greencube; and launched, flew, and recovered both payloads in August of 2009.

Two adjacent Greencubes were flown on two high altitude sounding balloons which reached approximately 90,000 feet altitude before bursting. The payloads then descended via parachute and were retrieved using the real-time GPS track received through the ham radio system. The balloons flew over the Presidential Range of mountains and were recovered in Maine. The flight time was approximately two hours.

GPS data was transmitted to the ground crews in real time over the course of the flight. GPS position vectors and timestamps were recorded and transmitted every five seconds, as shown in Figure 1. Much like Greencube 0 and Greencube 1, the payloads of Greencube 2 ascended in a roughly linear fashion. After the balloon burst at the flight apogee, the balloons descend in a roughly exponential profile. As the atmosphere becomes denser at lower altitude, the parachute creates more drag, lowering the ascent rate. Both balloons burst between 25 and 28 km in altitude, well within the preflight prediction of 80,000 to 90,000 feet.

The velocity of the balloon was derived from the recorded position and time data by dividing the distance between GPS position coordinates by the time delay between them (usually 5 seconds). In this manner, both the speed of the payload and its heading were calculated. Horizontal velocity profiles are shown in Figure 2. The team made an important assumption that the velocity of the payload at any given moment is the same as the wind speed, i.e. the payload accelerates nearly instantaneously with the wind. The payload profiles look almost identical, indicating that they ascended through similar atmospheric features. As the balloons approach 5km in altitude they enter the jet stream and accelerate very rapidly. After achieving about 15 km in altitude the balloons begin to slow down. Gravity waves may be causing the many small-scale fluctuations seen in these horizontal velocity profiles.

Also flown aboard the payloads were five thermistors which recorded temperature data. Data from the thermistors were transmitted approximately every 10 seconds. Before analyzing the temperature data, the data from all five thermistors were averaged so that one temperature profile was derived from each payload. The data were also converted into potential temperature to follow convention. Potential temperature θ is defined as $\theta = T\left(\frac{P_0}{P}\right)^{\frac{R}{c_p}}$, where P is the pressure, P_0 the reference pressure, R is the gas constant of air, and c_p is the specific heat at constant pressure. The reference pressure used was 1000 millibars. Because the GPS data and temperature data were handled by two different systems, they therefore were reported at different rates. The time stamps sent out on each radio transmission represented times corresponding to the GPS data but not necessarily the temperature data. The temperature data were splined with the GPS data to determine when and at what altitude the temperature data were recorded.

To start our gravity wave analysis we transformed our velocity data into components. A look at the compass heading of the balloon over the course of its ascent shows that the balloon oscillated in direction around a 120 degree heading. Therefore, we designed a new coordinate system that better reflected the direction of the balloon, in which the “along” velocity shows movement in the direction of the prevailing winds, and the “across” velocity registers movement perpendicular to the prevailing winds. When the new coordinate system is applied, the oscillations are more pronounced and the heading changes are more apparent. The fluctuations in horizontal velocity are strongest perpendicular to the balloon’s path.

Combining the position and velocity data on a quiver graph allows for a glimpse into two slices of the atmospheric velocity vector field above Mount Washington (Figure 4a). At first glance, the velocity vector profiles look very similar. Features are the same across lines of equal altitude. There is no obvious time or range dependence. However, a closer look shows some slight changes along lines of equal altitude.

For example, along the 14 km altitude contour, a peak in the cross component velocity can clearly be seen just above the contour on both payloads as they ascend through this area. However, when payload 1 descends the peak occurs exactly on the contour, and payload 2’s peak occurs below this contour. The change in altitude of this atmospheric feature is indicative of either a change with respect to time or distance of this feature.

We can use this phase change to measure the horizontal wavelength of this feature. The change in altitude of two vertically propagating wave structures can be used to calculate the horizontal wavelength of the structure as shown in Figure 4b. Because the horizontal wavelength is proportional to the change in altitude, the peak to peak change in altitude of one full vertical wavelength can be used to calculate the horizontal wavelength. $\lambda = \frac{\Delta altitude}{slope\ of\ red\ line}$.

In Figure 4a, we plotted lines connecting similar features. Rather than connecting peaks, however, we chose to connect the nodes together. The nodes represent a change in the across velocity from southeast to northwest. The lines with the greatest slope are located between 13 to 16 km in altitude. These lines describe the atmospheric features with the greatest change. The phase change becomes zero at increased altitudes. The line around 14.5 km had the greatest slope at -17.36 m per km distance. The peak to peak vertical wavelength of payload 1's ascent measured 1.3 km. Therefore, the minimum horizontal wavelength we observed was 76.5 km. The balloons themselves only collected reliable data above 10 km altitude and less than 40 km. Therefore, the structure is so large that horizontal distance is a negligible factor in determining the across velocity.

Starting at 15 km altitude the balloon makes repeated fan-like patterns in which the balloon sharply changed direction and then gradually returned to its normal heading. The largest of such fluctuations occurs at 15 km, corresponding with the tropopause and therefore the largest change in temperature. The other prominent sharp accelerations occur at 17.8 and 20.5 km altitude, which are the same regions that correspond to the second and third largest changes in temperature. This could be indicative of an atmospheric shear layer, an area of the atmosphere where the velocity of the wind is vastly different from the layers above and below it. This sudden change in velocity of the gas would change the balloon's heading and cause it to record a very different temperature. To conclude, the large changes in temperature and velocity occur together, and indicate that the payload is passing through a discontinuous shear layer.

In addition to the Greencube payloads, each balloon also carried a commercial camcorder on its lower secondary payload (designed to carry an emergency locator transmitter (ELT).) These cameras captured HD video of the Earth from the balloon altitudes, including images of cloud formations which bore the signs of atmospheric gravity waves (Figure 5).

C. SIGNIFICANCE OF RESULTS

The GreenCube team met its science goals by collecting temperature and GPS data as well as camera footage which were then analyzed in an attempt to locate gravity wave signatures.

The GreenCube program addresses JPL's interests in enhancing student preparation for a professional career in space systems/science at JPL or elsewhere. The students have gained experience with instruments of particular interest to JPL, such as GPS and magnetometers, as well as with analysis techniques for multi-point in-situ geophysical observations.

D. NEW TECHNOLOGY

N/A

E. FINANCIAL STATUS

The total funding for this task was $25,000, all of which has been expended.

G. PUBLICATIONS AND PRESENTATIONS

[A] Umair Siddiqui, Max Fagin, Sean Currey, & Amanda Slagle, “Dartmouth GreenCube: Multiple Balloon Measurements of Gravity Waves over New Hampshire,” Colloquium, Dartmouth College, Hanover, NH, November 20, 2009.

[B] Phil Bracikowski, Fagin, Currey, Siddiqui, Lynch, Slagle, “GreenCube and RocketCube, Low resource sensorcraft for atmospheric and ionospheric science”, AGU Fall Meeting, San Francisco, SM33C-1586, December 2009.

[C] Phil Bracikowski and Umair Siddiqui, CalPoly CubeSat conference, spring 2009.

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H. REFERENCES

None.

J. FIGURES

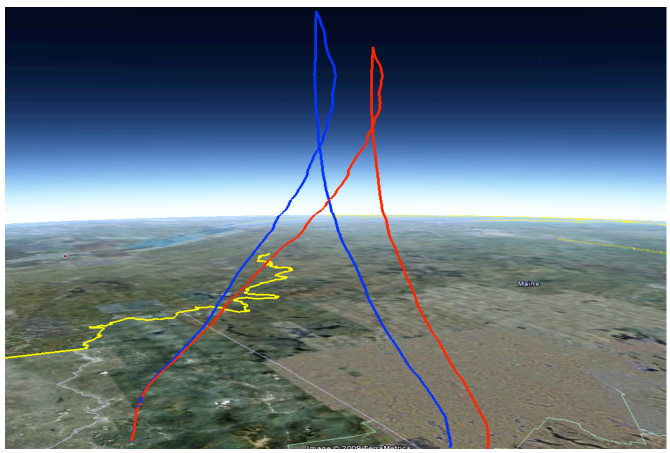


Figure 1. The above graph is a plot of all position coordinates for both payloads created using Google Earth. The blue trajectory belongs to the first balloon launched (Payload 1) and the red belongs to the second balloon launched (Payload 2). Payload 2 was launched 90 seconds after Payload 1.

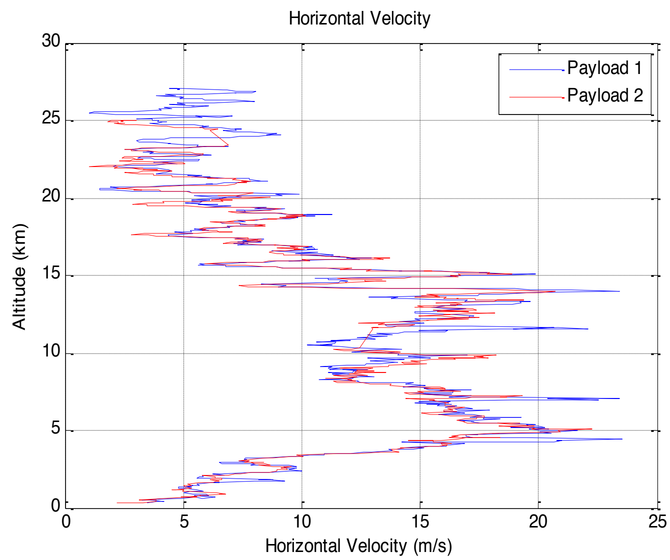


Figure 2. The graph above shows the horizontal velocity profiles of both payloads as they ascended to apogee.

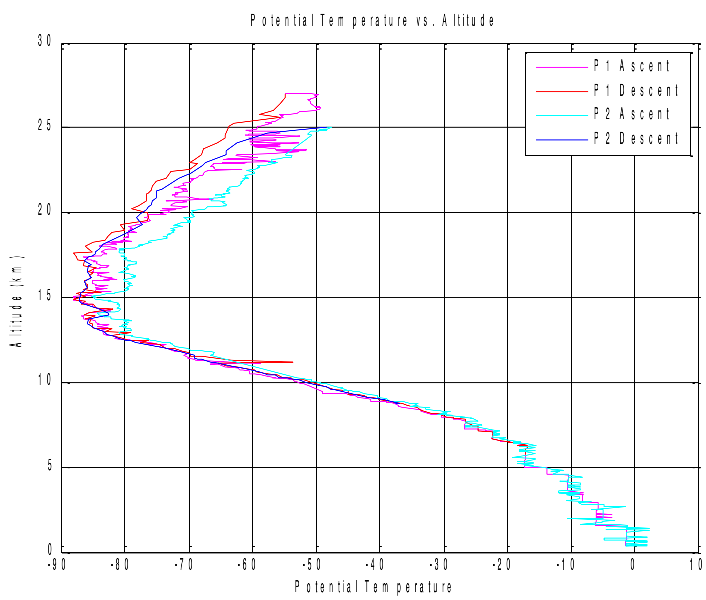
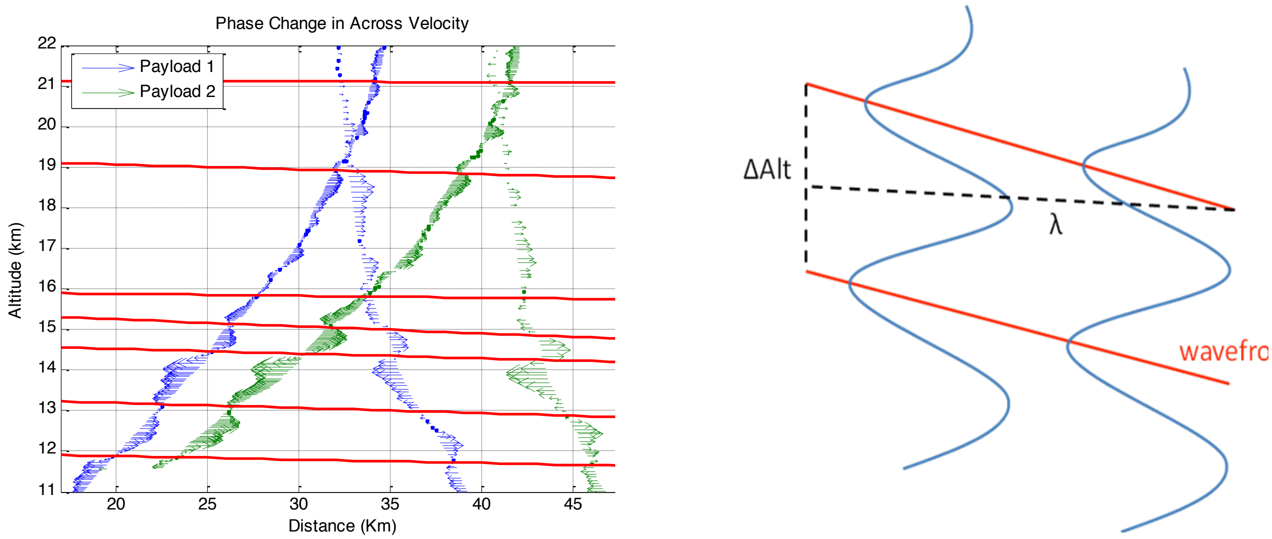


Figure 3. Average potential temperature for each payload plotted against altitude



Figures 4a and 4b. 4a is a quiver plot showing the “across” (perpendicular to prevailing winds) component of payload velocity plotted along payload trajectory. The red lines connect atmospheric features detected by payload 1 with corresponding features detected by payload 2. Note that the lines are not perfectly horizontal, suggesting that the two payloads encountered the same features at slightly different altitudes. 4b shows a clearer example of the concept. In this figure, the vertical wavelength λ is given by $\lambda = \frac{\Delta altitude}{slope\ of\ red\ line}$.

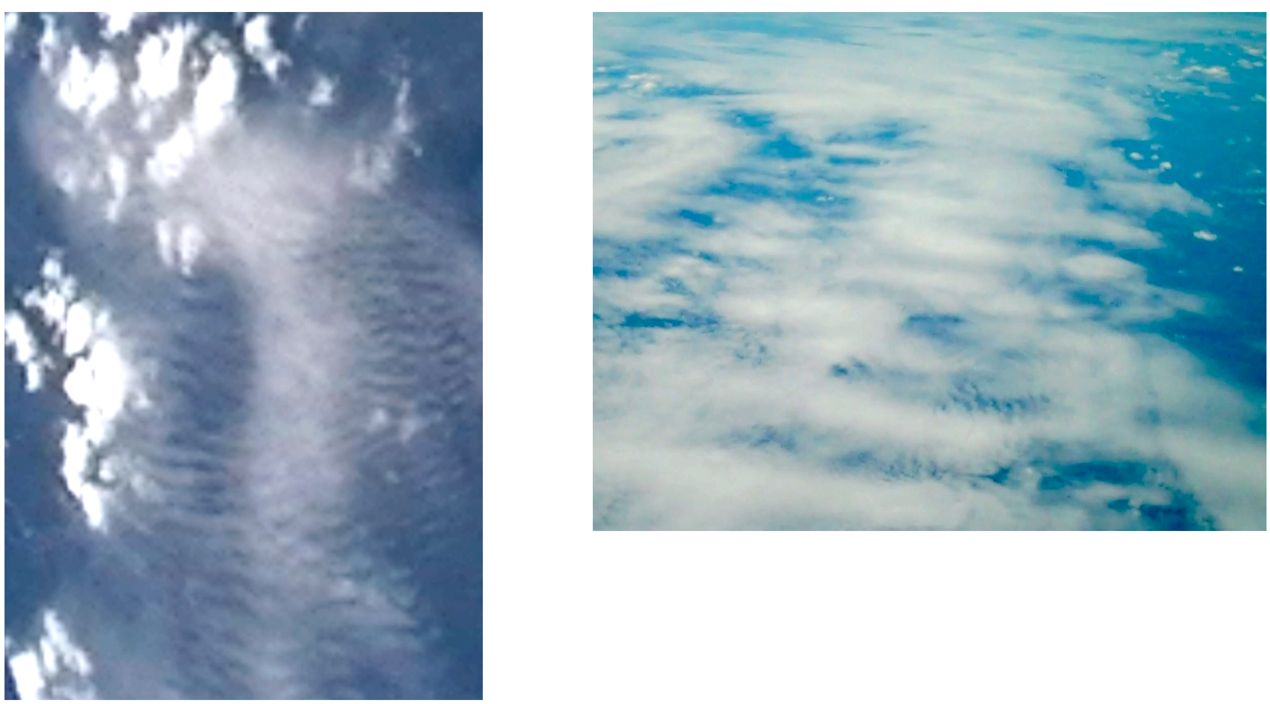


Figure 5. Gravity wave features captured by the cameras