Low-cost HAB platform to measure particulate matter in the troposphere

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Abstract

High-altitude balloons (HABs) are an engaging platform for formal and informal STEM education. However, the logistics of launching, chasing and recovering a payload on a 1200 g or 1500 g balloon can be daunting for many novice school groups and citizen scientists, and the cost can be prohibitive. In addition, there are many interesting scientific applications that do not require reaching the stratosphere. In this poster presentation we discuss a novel approach based on small (30 g) balloons that are cheap and easy to handle, and low-cost tracking devices that do not require a license. Our scientific goal is to measure air quality in the lower troposphere. Particulate matter (PM) is an air pollutant that varies on small spatial scales and has sources in rural areas like biomass burning and farming practices such as tilling. Our HAB platform incorporates an optical PM sensor, an integrated single board computer that records the PM sensor signal in addition to flight parameters (pressure, location and altitude), and a low-cost tracking system. Our goal is for the entire platform to cost less than $500.

Introduction and Objectives

Citizen science projects are scientific investigations in which volunteer citizens partner with scientists on collecting and analyzing data. These projects have been successfully employed in astronomy, ornithology, phenology, seismology, air quality studies and many other areas of science[1,2,3,4], and evidence-based models for developing successful projects have been developed[5]. Citizen science is most successful if an investigation is interesting and relevant to ordinary citizens, and if it can benefit from a large number of people involved in collecting and analyzing data and/or from data collected over large geographic areas[6]. Even though high-altitude ballooning has all of these characteristics, only a relative small number of amateur balloonists and motivated teachers and students are currently engaged in HAB. It has not yet been fully embraced by the citizen science community in the same way, for example, bird counting or monitoring seasonal changes has. This may be primarily due to the relatively high cost of balloons, lifting gas, and equipment and the logistics of constructing scientific payloads and launching commonly used 1200 g or 1500 g balloons. The main objective of this project is to dramatically reduce the cost and simplify the logistics so that anyone can launch a balloon with readily available equipment and supplies, and without prior training and without jeopardizing the quality of the scientific data that is being collected by the citizen scientists.

Scientific Objectives

Because we want to be able to fly payloads on very small balloons that are easy to fill and launch but burst at relatively low altitudes, we focus on light-weight sensors that can provide scientifically meaningful data in the lower troposphere. The data should also be relevant for scientific questions of broad interest to the general public, such as air pollution and climate change.

Particulate Matter

For our first two test flights we used a particulate matter sensor that can detect particles created by agricultural sources in central Illinois, such as tilling, biomass burning and heavy farming equipment. This sensor may also be used for detecting particulate matter that was created by distant sources such as wild fires and was transported over large distances. Ground-level satellite data on particulate matter is uncertain because it relies on assumptions about the free-atmosphere contribution. Thus, our data for the lower troposphere may also allow us to assist with the calibration of ground-level particulate matter values measured by satellites.

Scientific Objectives - continued

Carbon Dioxide

Lightweight CO_2 sensors on very small balloons may be used for measuring emissions from point sources of carbon dioxide. This could be accomplished, for example, by launching balloons through power plant plumes. We also plan to employ the mass-balance approach we have already successfully used with larger balloons to determine landscape-scale carbon dioxide exchange, by comparing measurements of several balloons launched a few hours apart. We will also try to link CO_2 to particulate matter measurements, especially for CO_2 and PM transported over large distances from distant forest fires. Finally, we plan to explore the use of our measurements for calibrating satellite CO_2 measurements.

Ozone

We are planning to explore the use of ozone sensors to measure the export of ozone of an urban air shed, such as that of St. Louis. We will also attempt to correlate ozone concentrations with changes in UVA and UVB transmission through the atmosphere, and explore the use of our data for calibrating satellite ozone measurements.

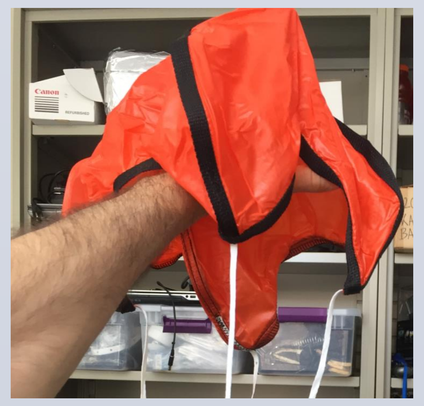
Test Flights

Equipment

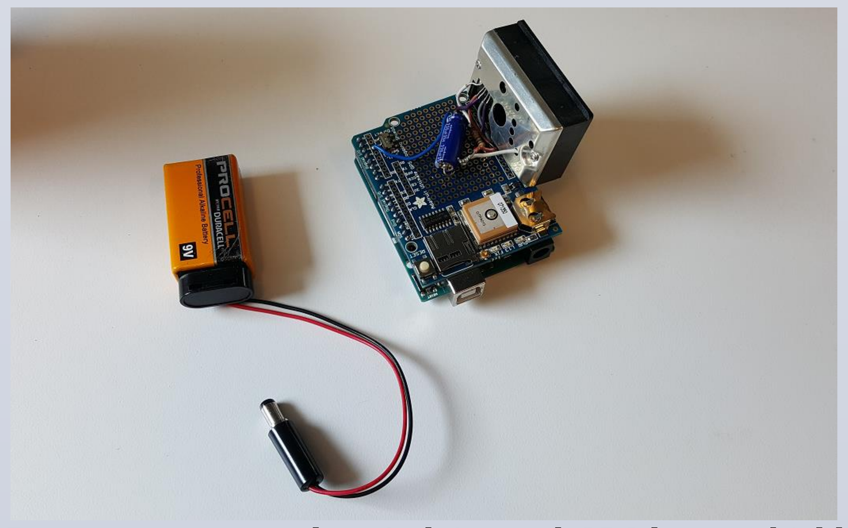
- 30 g Kaymont Totex balloon ($5)
- 2-ft Rocketman parachute ($30)
- SPOT Gen3 tracker ($150 + $150/year data fee)
- Optical Dust Sensor ($12)
- Arduino Uno ($25)
- GPS Logger Shield ($45)
- 14.9 cft Balloon Time helium tank ($45)

Spot tracker after landing

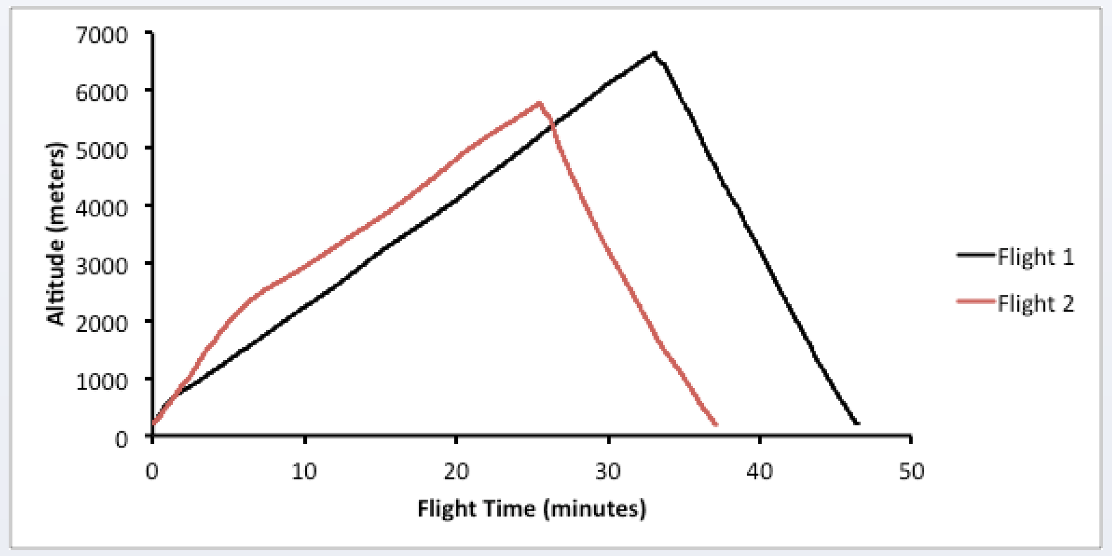
Helium tank purchased at Walmart



2-ft parachute worked well for 200 g payload

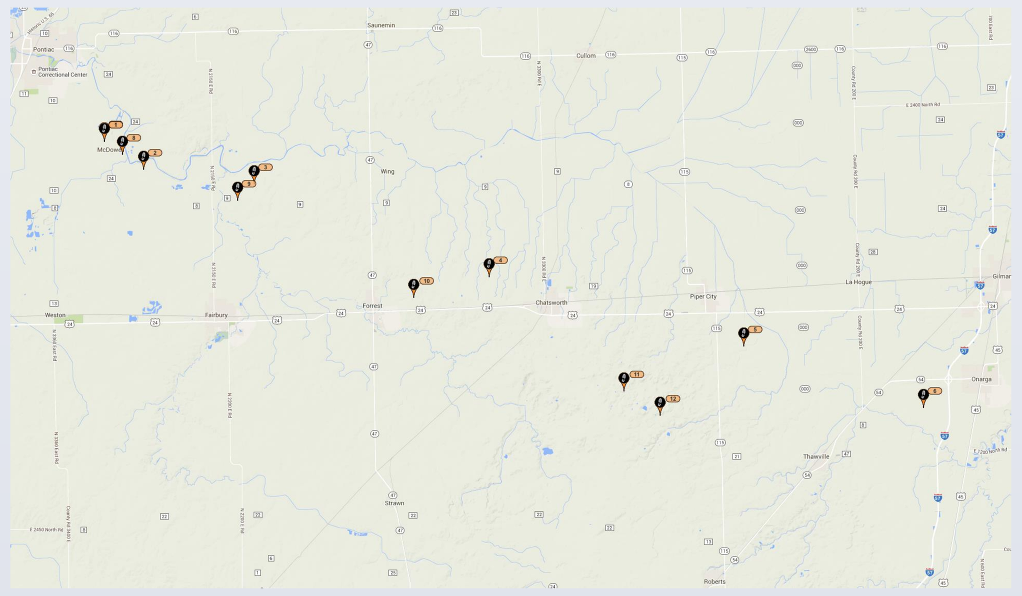


Dust sensor mounted on Arduino and GPS logger shield



Flight 1
Average ascent rate: 3.25 m/s
Descent rate (last 500 m): 6.97 m/s
Burst: 6649 m
Flight time: 46.5 minutes

Flight 2
Average ascent rate: 3.64 m/s
Descent rate (last 500 m): 6.34 m/s
Burst: 5784 m
Flight time: 37 minutes



Flight paths tracked with a SPOT Gen3

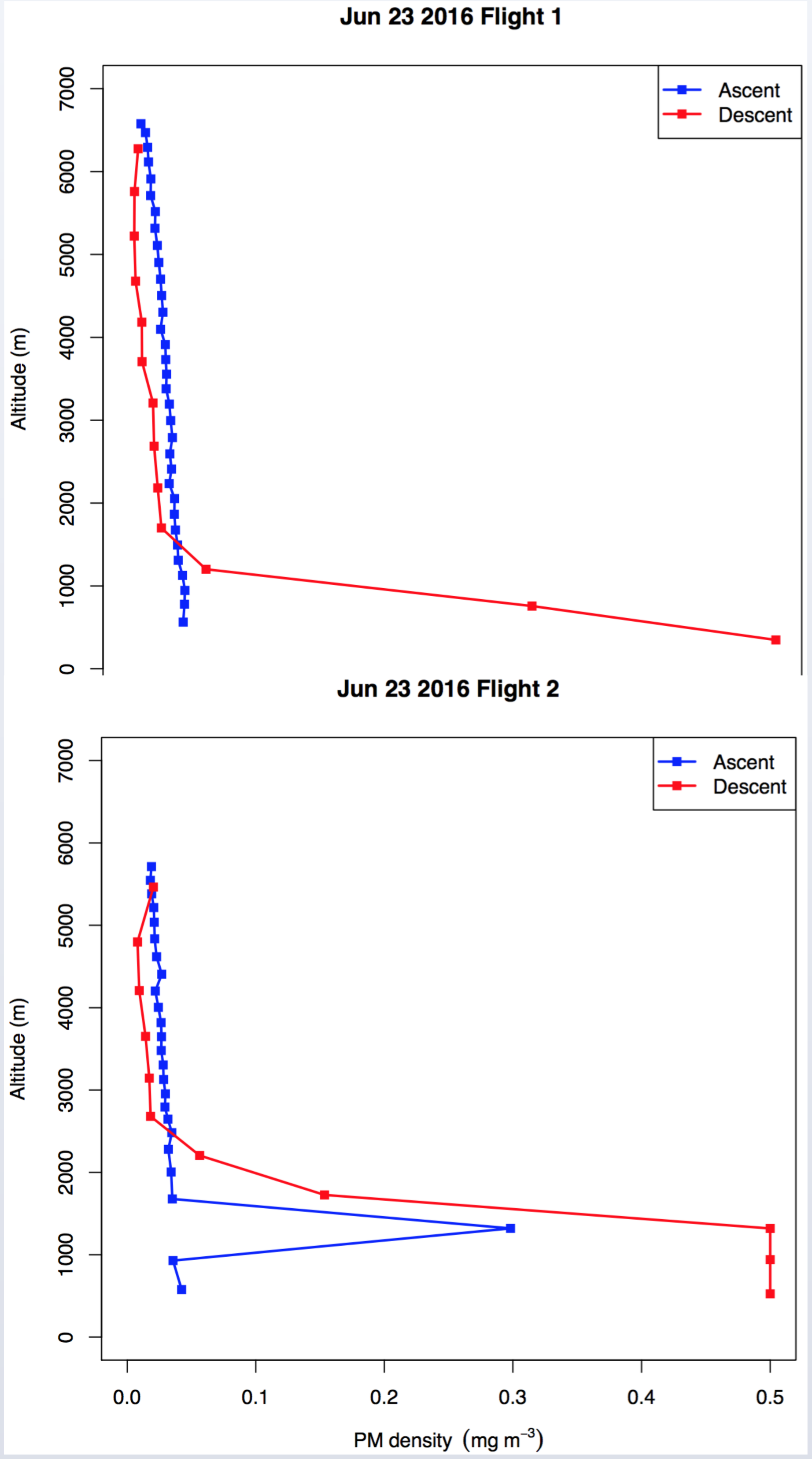
Launch 1

Launch 2

Lessons learned

- Even though the idea of purchasing party balloon helium from Walmart or Target seems like an attractive idea for a citizen science project, we probably will not do this again because of the much higher cost of $3/cft compared to $0.88/cft and $0.56/cft for small 20 or 40 cft tanks purchased from our regular gas vendor. We also don't like the disposable tank. However, it may still be a viable alternative for a citizen scientist if no other source of helium is available.
- The Spot tracker took some getting used to. It only transmits once every 10 minutes and does not provide attitude. After landing it took several minutes before the position of the landing site was received. The SPOT phone app did not show all transmitted positions visible in the browser interface.
- We used 0.6-0.7 kg of lift for our 0.3 kg payload. This is near the maximum a 30 g balloon can handle. We found that it was important to carefully monitor the tension of the balloon skin to avoid a burst during filling.

Sensor Results



Data from both of our test flights show an increase in the measured particulate matter density just before landing. We have not yet determined whether this is due to an actual increase or an artifact of the measurement. In addition, our data from flight 2 shows an increase by more than a factor of six at an altitude of about 1300 m during the ascent. Also clearly visible is a gradual decrease in PM density during both ascends, which may be due to the decreasing air density.

References

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[5]Bonney, R. Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T. Rosenberg, K, V., and Shirk, J. Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. BioScience (2009) 59 (11): 977-984.

[6]Gommerman, L., and Monroe, M. C. Lessons Learned from Evaluations of Citizen Science Programs. EDIS New Publications RSS. University of Florida IFAs Extension.