Balloon-borne methane and radiation measurements

Bryant N. Fong,[*] and Micaela Wine[†]
Arkansas State University, Jonesboro, AR, 72401, USA

Ed Roberts[‡]
Pottsville High School, Pottsville, AR, 72858, USA

and
J. Tillman Kennon[§]
Arkansas State University, Jonesboro, AR, 72401, USA

---

[*] Project Consultant, Department of Chemistry and Physics.
[†] Undergraduate Student, Department of Chemistry and Physics.
[‡] Secondary Science Teacher.
[§] Professor of Science Education, Department of Chemistry and Physics.

The BalloonSAT program is a high altitude research and education outreach program at Arkansas State University. Weather balloons carried a Geiger counter that measured X-ray, β, and γ radiation profiles together and a methane sensor (Arduino and MQ-6 detector) in payload boxes to 30 km (90,000 ft) over the past five years. Payload boxes were foam containers for water resistant and floating abilities in possible water landings, no modifications beyond securing sensors to the payload box were made. Methane and radiation measurements are not directly related, but collected independently and flown on many flights together and therefore presented together. A radiation peak related to decreasing cosmic radiation and increased secondary radiation, or Pfotzer maximum at 10-15 km was found. Lower tropopause temperatures were related to higher radiation counts at the Pfotzer maximum. Methane is 30 times more potent as a greenhouse gas than carbon dioxide. A linear calibration curve was made with known concentrations of methane at various temperatures to convert voltage readings into concentrations. The low temperatures and pressure were not found to significantly impact concentration measurements. Methane concentration was found to decrease with altitude similar to satellite and Unmanned Aerial Vehicle (UAV) measurements. BalloonSAT does not collect data that can replace satellites, but proves to be an effective instrument in identifying radiation and methane profiles in the troposphere and lower stratosphere comparable to other balloon-borne, UAV and satellite studies.

I.Introduction

BALLOONSAT is an educational outreach and scientific research program at Arkansas State University. Weather balloons reach into the lower stratosphere (100,000 feet, 30 km) for high altitude experiments and atmospheric measurements including temperature, water vapor (as humidity), pressure, methane, and carbon dioxide. The program actively involves secondary and college level students in inquiry and project based learning experiences (Fig. 1). Measurements occur throughout the ascent providing concentrations throughout the air column. GPS transmissions allow for balloon tracking and real time altitude updates throughout the balloon flight. This paper describes a project that readily integrates technology and programming into the classroom. Previous papers share experiences in establishing a new balloon program and document high student engagement and ownership of their science projects. One highlight is students collect "real data" and not textbook created data making the science more relevant to their learning experience. [1–3]

Fig. 1 The BalloonSAT program engages students across a wide variety of ages.

Methane is the third most important greenhouse gas after carbon dioxide and water vapor. It plays a key role in tropospheric chemistry, and therefore air quality issues though oxidation by hydroxyl (OH) radicals. High altitude concentrations are suspected to increase because ground level methane measurements increased, and expected to continue to increase to 1873 ppm by 2020, a 14% increase of methane levels in 1984 at current trends. [4] Methane detectors are usually bulky, high cost ($1K and above), and reserved exclusively for specialized researchers. Previously, evacuated bottles were carried to various altitudes to measure the methane concentration at that altitude. This allows only for a few samples each launch. Using an Arduino based system, atmospheric methane measurements were recorded using weather balloons. By having a balloon-borne sensor, sampling occurs across the entire air column, alleviating concerns of daily and temporal variation when vial sampling across a week.

Arduino is an open-source single board computer using a Java environment coding structure. Several other projects using Arduino are available online. A SD card allows for larger data storage and expedited data extraction. An MQ-6 detector which detected liquefied petroleum gas (LPG), methane and smoke (incompletely burned biomass) was flown on several flights.

In this study, atmospheric methane and radiation profiles were measured with high-altitude balloons. These atmospheric measurements are important to identify the contribution these factors may have global climate change implications.

II. Method

Weather balloon launches consisted of 1600-2000 g latex weather balloons with instruments and high altitude experiments attached via a payload line. Usually, balloon flights lasted 90-120 minutes and reach up to 26 km (100,000 feet) and travel distances 5-10 miles (Fig 3) and tracked by radio. At higher altitudes, the balloon expanded due to the pressure difference between the Earth's surface and at high altitudes, until the balloon burst and the payload return to the surface. Attached to the payload line was a parachute that slowed descent after balloon burst.

Methane data was collected across five flights from April 2014-May 2015. Changes in gas concentration and temperature create proportional changes in the resistance of the sensors, which were recorded as millivolts. Calibration of the methane sensors used 99.99% methane mixed with compressed air. The MQ-6 sensor was more sensitive to changes in concentration and temperature than the MQ-2. Calibration was first done with different concentration of methane by mixing pure methane and compressed air at room temperature. The same concentration was subsequently measured at decreasing temperatures to mimic the conditions of the upper troposphere. The sensor package included an Arduino Uno with MEGA 2560 processor and 5V input voltage attached to a methane sensor with a digital transistor to switch on/off the sensor (Fig 2). The system was powered by one 9V battery. Detector response was measured via analog output. The circuit diagram and coding was based on tropospheric gas detectors in Atmospheric Monitoring with Arduino (Di Justo & Gertz, 2013). Analog data and elapsed time were collected onto an SD card. The elapsed time was then correlated to altitude from GPS in the Anasonde system.

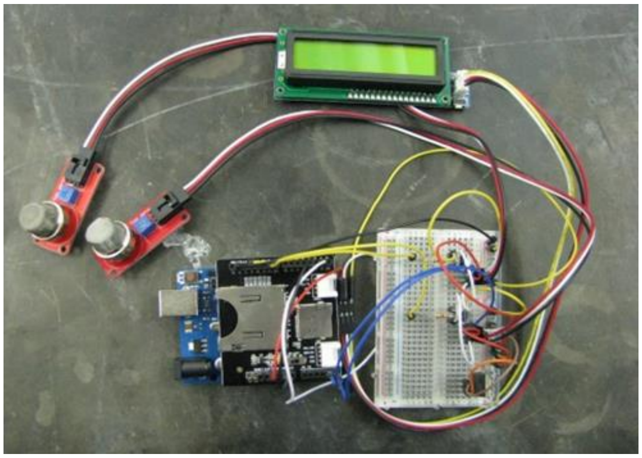

Fig. 2 Arduino system with methane sensors. A SD card module is also shown which stores flight data. The LCD screen shown is used only during launch to make sure accurate data is collected.

Radiation data was collected by with an Aware RM-60 Pro Radiation monitor, powered by two 9V batteries. The radiation monitor was attached to an Anasode system which collected altitude, temperature, relative humidity, and pressure powered by 4 AA batteries.. The Geiger counter collected generic β and ɣ radiation. Though the sensor was sensitive to α radiation, none were recorded as the sensor was mounted inside a Styrofoam box which blocked α radiation.

III.Results and Discussion

Atmospheric methane and radiation measurements were taken during ascent. Both atmospheric measurements mirrored those of ascent, but had a larger error due to the rapid descent of the balloon.

A. Methane Measurements

The MQ-2 sensor was found to be sensitive to both temperature and concentration. Arduino millivolt measurements were transformed into ppb concentrations with two calibration curves, one of varying concentrations at constant temperature (y=0.206x+506.32, R^2=0.913), and the second of same concentration at different temperatures (y=9.037x-2106.9, R2=0.983). Both calibration curve have high correlation values (R2>0.8).

Methane concentration was highest at the surface and near the tropopause, the division between the troposphere and stratosphere. The methane concentration was greater at the surface due to proximity to point source emissions. In the lower part of the troposphere (5-10 km), oxidation of hydrocarbons by OH radicals produce CO_2, H_2O and CH_4 products. On average CH_4 can last eight to nine years before oxidized into CH_3 and CO_2 molecules, longer compared to other atmospheric species. Around 10% of CH_4 can be transported into the stratosphere (15-50 km) and oxidized. Since water vapor in the stratosphere is low, the indirect process changes the climate impact of methane by 15%.

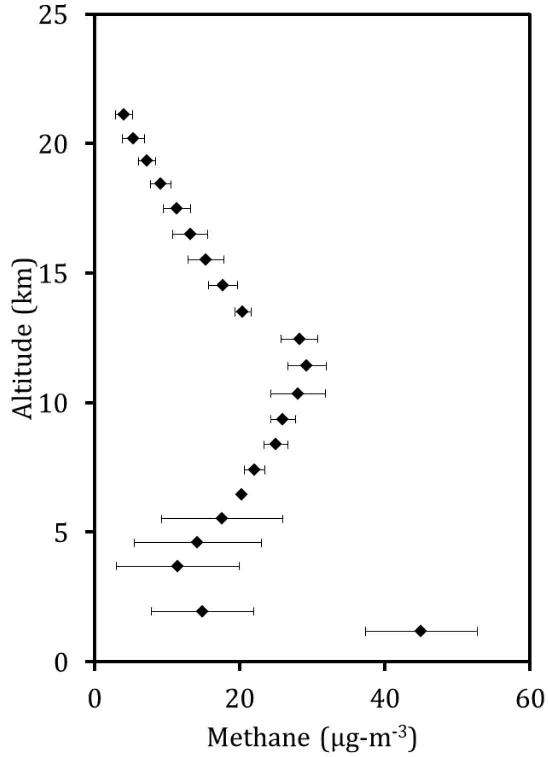

Fig. 3 Methane profile measured with balloon borne MQ-2 detector. This is an average of four flights.

B. Radiation measurements

Atmospheric β and ɣ radiation measured as counts per interval were found to be near-zero at the surface and increase throughout the troposphere, until reaching a maximum at 15-20 km near the tropopause (Fig. 4). The inverse relationship between cosmic radiation decreasing and secondary radiation increasing at lower altitudes causes the highest radiation dose to be near the tropopause at 10-15 km. This maximum radiation exposure may also be referred as the Pfotzer maximum. [5] Measurements throughout the year did not show any significant difference across seasons. This was most likely due to few flights in the winter months. During the winter, long balloon tracks (>50 mi, 80km) and inclement weather prevented balloon flights. In addition, atmospheric radiation may regulate temperature and consequently tropospheric and stratospheric weather. Higher radiation exposure was found at the tropopause with lower temperatures (R^2=0.67).

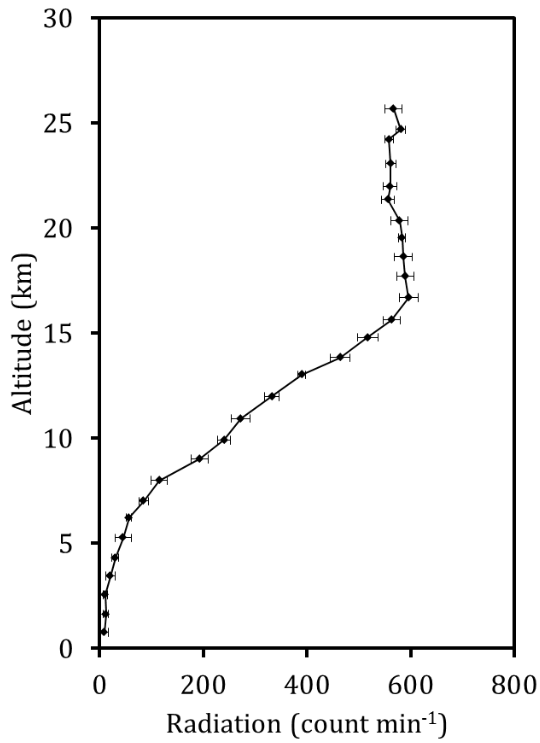

Fig. 4 Methane profile measured with balloon borne MQ-2 detector. This is an average of four flights.

IV. Conclusion

Methane profiles were found to be greatest at the surface and decrease exponentially at increasing altitudes due to greater distances from point source methane emissions. The concentration of methane decreases in the stratosphere (25-30 km) due to infrequent transport of methane from tropospheric altitudes. Arduino based sensors collect similar methane profile measurements to other instruments with added lightweight and inexpensive benefits. Continuous profile measurements using balloons is advantageous to air sample techniques because concentrations are measured throughout the air column on a single period rather than only at certain altitude.

Funding Sources

Funding provided by Arkansas Space Grant Consortium.

Acknowledgments

The authors acknowledge all teachers and students involved in the BalloonSAT program. Special thanks to Caleb Bryan, Jennifer Sullivan, and Dr. Ben Rougeau at Arkansas State University-Jonesboro

References

[1] Coleman, B. J. S. M., and Mitchell, M., "Active Learning in the Atmospheric Science Classroom and Beyond Through High-Altitude Ballooning," *Journal of College Science Teaching*, vol. 44, 2014, pp. 26–30.

[2] Fong, B. N., Kennon, J. T., and Roberts, E., "Integrating BalloonSAT and Atmospheric Dynamic Concepts into the Secondary Classroom," *The Physics Teacher*, vol. 54, May 2016, pp. 264–267.

[3] Larson, S. L., Armstrong, J. C., and Hiscock, W. A., "The first frontier: High altitude ballooning as a platform for student research experiences in science and engineering," *American Journal of Physics*, vol. 77, 2009, p. 489.

[4] Tarasova, O., Koide, H., Dlugokencky, E., Montzka, S. a, and Butler, J. H., "The state of greenhouse gases in the atmosphere using global observations through 2012," vol. 16, 2014, p. 9121.

[5] Pfotzer, G., "Coincidence Counter Measurements of the Intensity Depth Curve," *Zeits f Phys.*, vol. 102, 1936, pp. 23–58.