Balloon-borne methane and radiation measurements

Bryant N. Fong,[1] and Micaela Wine[2]
Arkansas State University, Jonesboro, AR, 72401, USA

Ed Roberts[3]
Pottsville High School, Pottsville, AR, 72848, USA

and
J. Tillman Kennon[4]
Arkansas State University, Jonesboro, AR, 72401, USA

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 five flights. Methane and radiation measurements were not directly related, but collected independently and flown and presented together. A radiation peak related to decreasing cosmic radiation and increased secondary radiation, or Regener-Pfotzer maximum at 16 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 can be an effective in situ instrument for measuring radiation and methane profiles.

I.Introduction

BALLOONSAT is an educational outreach and scientific research program at Arkansas State University. Weather balloons reach into the lower stratosphere (87,000 feet, 25 km) for high altitude experiments and atmospheric measurements including temperature, water vapor (as humidity), pressure, methane, and carbon dioxide. The program actively involved secondary and college level students in inquiry and project based learning experiences (Fig. 1). GPS transmissions allowed for balloon tracking throughout the balloon flight.

Methane is an important greenhouse gas along with carbon dioxide and water vapor. High altitude concentrations are suspected to increase because ground level methane concentrations have increased nearly 30% in the past decade.[1] Methane detectors are usually bulky, high cost ($1K and above), and reserved exclusively for specialized researchers. Previously, evacuated bottles were carried to various altitudes using blimps or balloons 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. Arduino is an open-source single board computer using a Java environment coding structure. Data was stored onto an SD card for the larger data storage capabilities and expedited data extraction. MQ-2 and MQ-6 detectors sensitive to liquefied petroleum gas (LPG), methane and smoke (incompletely burned

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[1] Project Consultant, Department of Chemistry and Physics.
[2] Undergraduate Student, Department of Chemistry and Physics.
[3] Secondary Science Teacher.
[4] Professor of Science Education, Department of Chemistry and Physics.

biomass) was flown on several flights. The MQ sensors are a series of gas sensors tuned to a range of gases using a small heater and electro-chemical sensor [2].

The stratosphere radiation environment is the interaction of charged particles of solar and galactic and particles from Earth's surface. [3] Atmospheric β and γ radiation measurements are essential for evaluation of single event effects such as eclipses or volcanic eruptions, risks in aviation and space environment [4-6]. Balloons provided a measurement throughout the profile. In this study, atmospheric methane and radiation profiles were measured with high-altitude balloons. Methane and radiation measurements were collected independently, but collected and presented together. These atmospheric measurements are important to identify the contribution these factors may have global climate change implications.

II.Method

Weather balloon launches consisted of 1200-1500 g latex weather balloons with instruments and high altitude experiments attached via a payload line. Usually, balloon flights lasted 90-120 minutes and reached up to 30 km (100,000 feet) and travel distances 5-10 miles. The balloon expanded during ascent due to the pressure difference between the Earth's surface and at high altitudes, until the balloon burst and the payloads returned 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 methane free air. The MQ-2 sensor was more sensitive to changes in concentration and temperature than the MQ-6. Calibration was first done with different concentrations of methane by mixing pure methane and compressed air at room temperature. The same concentration was subsequently measured at decreasing temperatures (ice bath). In addition, the sensors were tested in a pressure chamber and decreased to 5 mbar. No calibration tests were completed testing the effect of relative humidity, as relative humidity was not expected to have as large impact as temperature or concentration on the sensor measurement. [2] 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 were based on tropospheric gas detectors outlined by Di Justo and Gertz (2013).[7] 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. 1 The payload box with Arduino system with methane sensors (MQ-2 and MQ-6) and the AnaSonde system Geiger counter.

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 AnaSonde system which collected time, altitude, temperature, relative humidity, and pressure powered by 4 AA batteries. The Geiger counter collected generic β and γ 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 throughout the balloon flight (ascent and descent). Both atmospheric measurements during descent mirrored those of ascent, but had a larger error due to the rapid descent of the balloon. Therefore, only data collected during balloon ascent was analyzed and presented. There were no significant variations between flights.

A. Methane Measurements

Both MQ-2 and MQ-6 sensors were flown on all flights. However, the MQ-6 sensor was not found to have any significant change in voltage, and therefore concentration or temperature throughout the air column. Therefore, the MQ-6 data is not presented, as only 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, R^2=0.983). Both calibration curves had high correlation values (R^2>0.9). Pressure was not found to change emissions. The effect of relative humidity was not measured, but not expected to have as significant impact on measured voltage as temperature or concentration. [2]

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%.

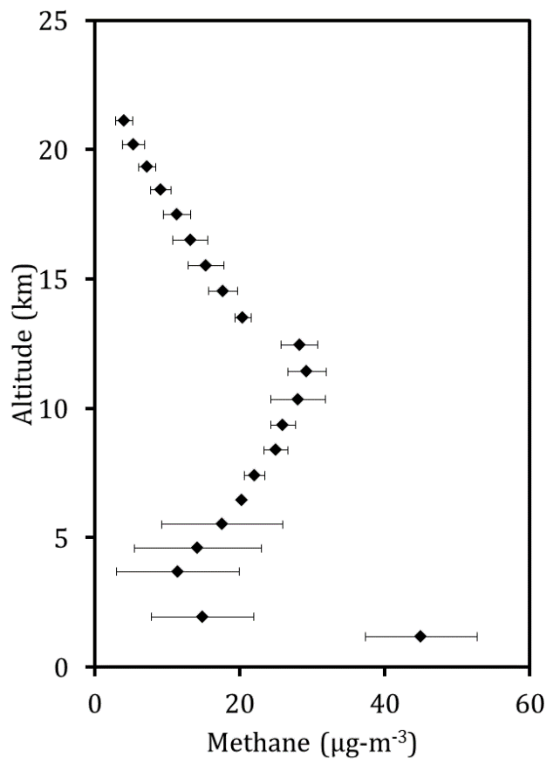

Fig. 2 Methane profile measured with balloon borne MQ-2 detector. The MQ-6 sensor did not measure any changes in concentration.

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 16 km (Fig. 3A). This maximum radiation exposure may also be referred as the Regener-Pfotzer maximum.[8] Measurements throughout the year did not show any significant difference across seasons.. During the winter, long balloon tracks (>50 mi, 80km) and inclement weather prevented balloon flights. Higher radiation exposure was found at the tropopause with lower temperatures (R^2=0.67), (Fig. 3B). This relationship could be related to higher rate of decay of cosmic rays known as muons into different cosmic rays, known as mesons at increasing temperature. At higher temperatures, the atmosphere expands so fewer mesons interact and less muons are detected. Basically, temperature increases lead to higher muons detection. However, an inverse relationship was detected because

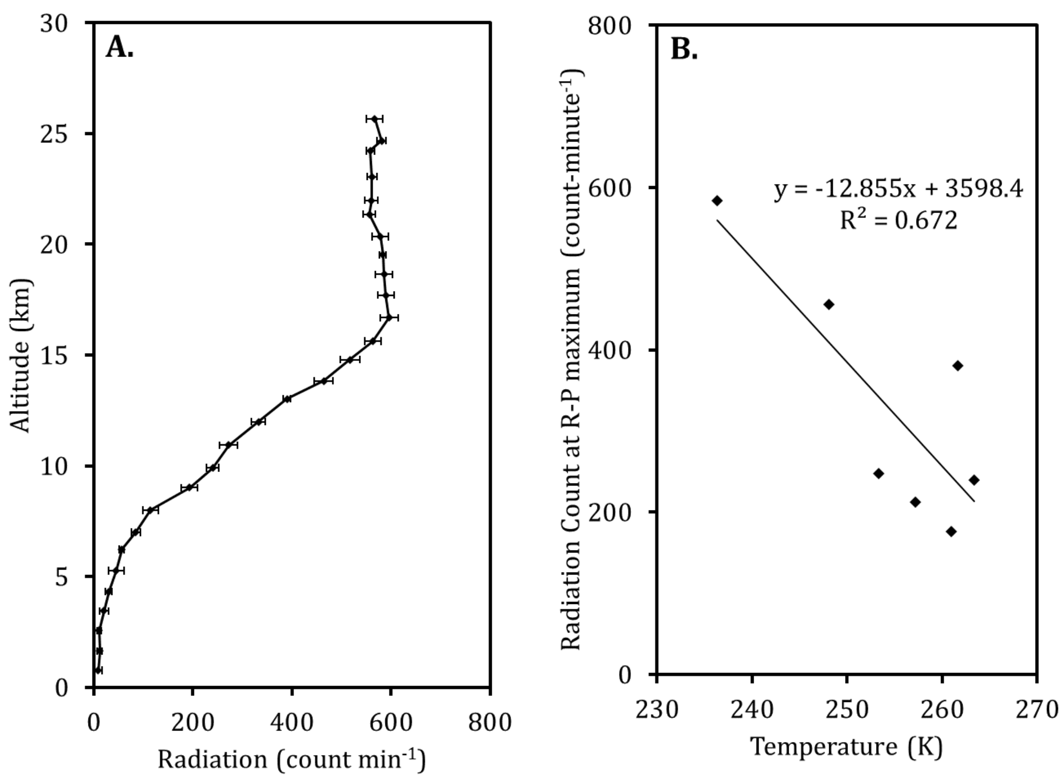

Fig. 2 (A.) Radiation profile measured by on-board Geiger counter. (B.) relationship of Regener-Pfotzer (R-P) maximum with temperature

IV. Conclusion

Methane profiles were found to be greatest at the surface, then decreased significantly at 3 km, and increased at higher altitudes throughout the troposphere (3-12 km). The methane concentration decreased in the stratosphere (25-30 km) due to infrequent transport of methane from tropospheric altitudes. One Arduino based sensor (MQ-2) collected methane profile measurements to other instruments with added lightweight and inexpensive benefits. A second sensor did not collect any data and was not found to be sensitive to changes in concentration or temperature during calibration procedures. Future research will consider calibration of MQ-2 sensor to relative humidity and using other MQ sensors for other gases. Atmospheric β and γ radiation increased in the troposphere and decreased in the stratosphere. This inversion was likely related to a decreased cosmic radiation and increase in secondary radiation at higher altitudes. Balloons found maximum radiation at the troposphere, or at the Regener-Pfotzer maximum. In addition, higher radiation counts at were related to lower temperatures at the tropopause. Continuous profile measurements using balloons capture atmospheric radiation and temperature measurements not captured by air sample techniques.

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