Calibration and Modification of Off-the-Shelf Gas Sensors for Monitoring Earth's Atmospheric Chemistry

Byron Millet, Spencer Shupe, John E. Sohl, Weber State University Departments of Chemistry and Physics

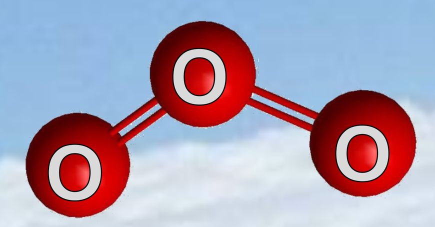
Abstract

The purpose of this study was to develop a method using an off-the-shelf commercial carbon dioxide sensor for the determination of CO_2 concentrations in the Earth's stratosphere. The sensor was flown on a high altitude helium balloon twice in 2012. Data from those flights indicated the sensor failed due to environmental conditions. An isobaric experiment was performed which determined the sensor failure is likely due to the low temperatures encountered in the stratosphere. A small heater to compensate for the low temperatures will be constructed and evaluated using the WSU HARBOR group's environmental test chamber and prepared for test on an upcoming HARBOR flight.

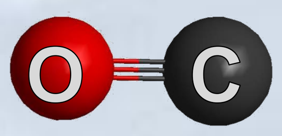
Important Gasses of the Stratosphere

The chemistry of the stratosphere is dominated by the high levels of solar radiation present throughout the region where free radicals and excited states of molecules are common.
The most important gas in this region is ozone. Other gasses that are of importance are carbon dioxide, carbon monoxide, and NO_x.

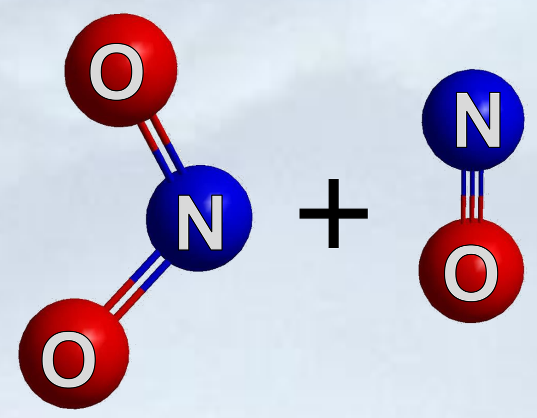
Ozone is the most important molecule in the stratosphere due to its absorption of high energy UV radiation from the sun.



Carbon dioxide is the most well known greenhouse gas and is the main focus of the current study.



Carbon monoxide is a greenhouse gas that also plays an important role in the photochemistry of the stratosphere.



NO_x is a combination of both nitrogen monoxide and nitrogen dioxide and plays an important role in the chemistry of the stratosphere, as the main mechanism for ozone removal.

Bode, B. M. and Gordon, M. S. *J. Mol. Graphics Mod.*, *16*, 1998, 133-138.

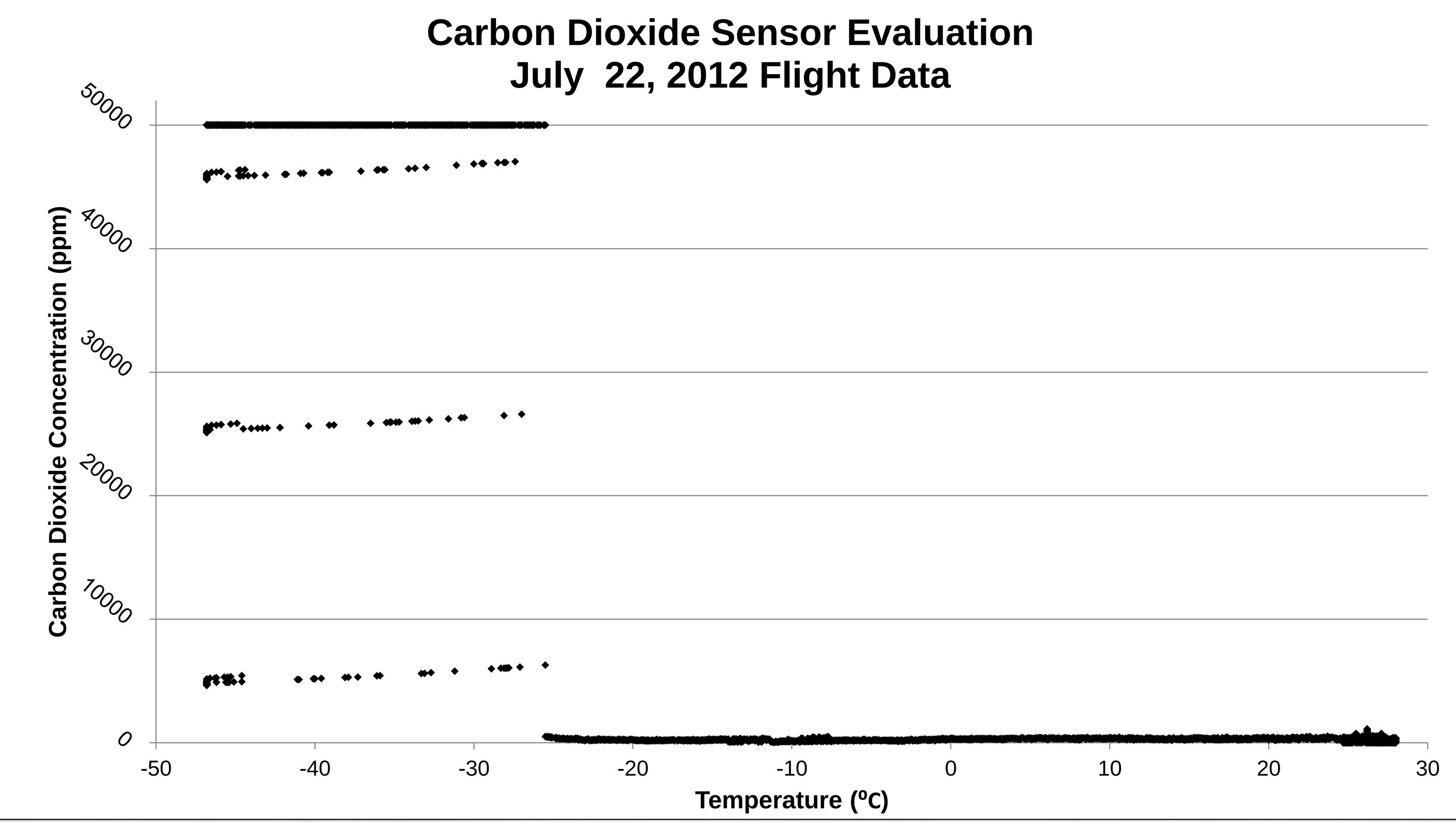
Detection of Carbon Dioxide

The sensor used in this study is a readily available commercial carbon dioxide sensor that uses non dispersive infrared (NDIR) absorption spectroscopy to determine the concentration of carbon dioxide. The sensor has a stated temperature range of 0-50^{0}C and was designed for use at atmospheric pressure. To determine performance of the sensor at the pressure and temperature conditions in the stratosphere, the sensor was flown by the HARBOR team two times in 2012.

The carbon dioxide sensor that was flown by the HARBOR team. This is an non dispersive infrared (NDIR) absorption sensor that uses an IR LED as the light source for the absorbance measurements. Other sensors are also being tested but have not yet flown.

Flight Data

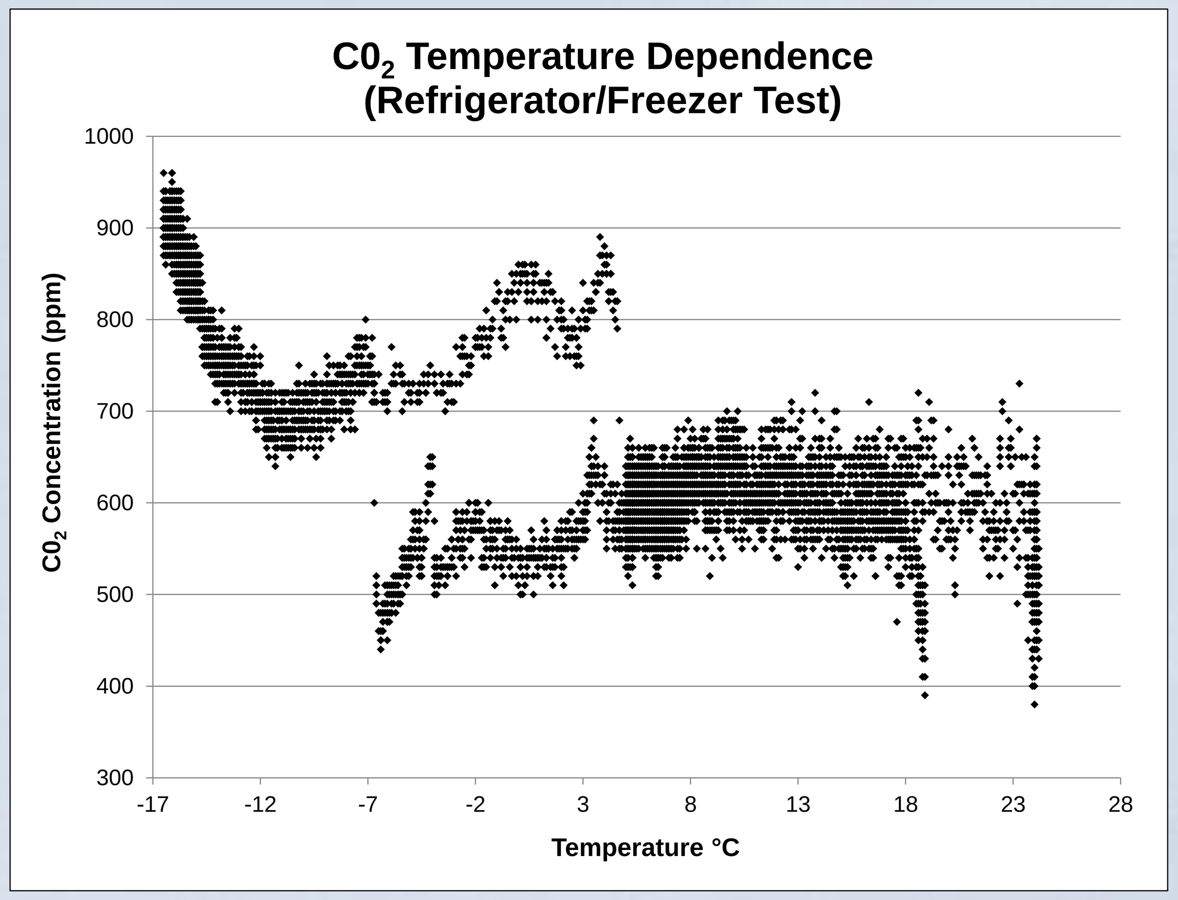
The results of the flight data show clearly that once the temperature drops below -25^{0}C, the concentration readings began to fluctuate widely indicating a sensor malfunction. There are several factors that likely contributed to the sensor malfunction during the flights: temperature, pressure, and/or humidity.
The sensor outputs both temperature and humidity readings which appeared to function normally and indicated that when the sensor began to malfunction, both the temperature and humidity were dropping. Pressure data have not yet been fully analyzed.



Flight data show clearly that concentration readings, which should be in the parts per million range, begin to fluctuate wildly over several parts per thousand once the temperature drops below -25 °C.

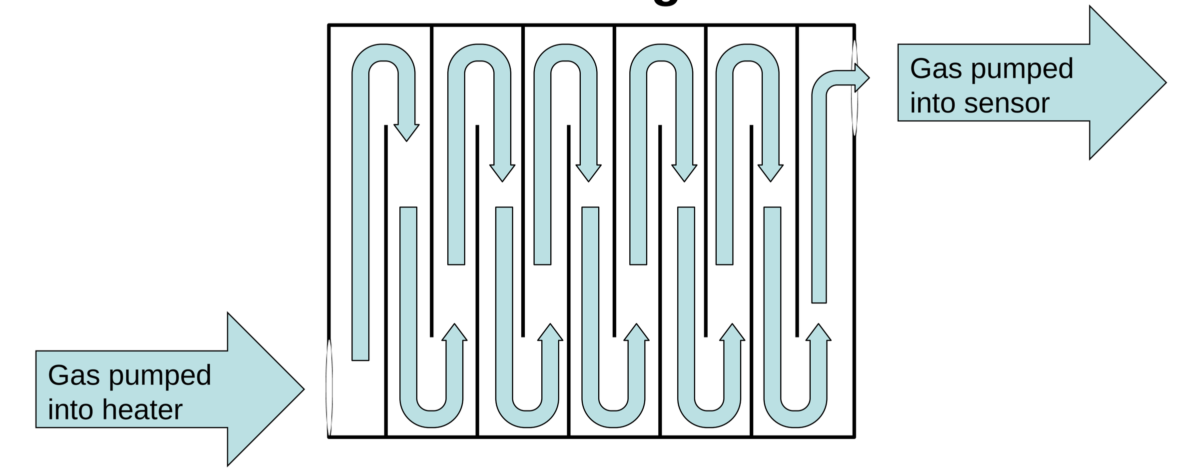
Isobaric Analysis

To determine the effect of low temperature on the sensor, an isobaric analysis was performed testing the sensor at a temperature range of -17.6 °C to +24.2 °C. It was found that at temperatures lower than approximately -17 °C the sensor malfunctions very notably (see graph above). At temperatures between -15 °C and +5 °C the sensor appeared to malfunction on a slightly lower scale as shown in the graph below.



The temperature dependence of the sensor was evaluated by placing it in a refrigerator and a freezer. The resulting data, shown here, shows that from -10 °C to +5 °C the concentration data shows a unstable "double-value" effect. Below -10 °C the sensor response increases until at less than -17 °C (shown in the flight data graphed above), the readings begin fluctuating wildly.

Heater Diagram



Atmospheric gas is pumped into the heater with a small electric pump. The fins present inside the heater increase the path the gas has to travel through the heater, increasing the time the gas is exposed to the higher heat. The preheated gas is then output directly to the sensor. Thermal sensors at the opening and exit will monitor performance.

Compensation for Low Temperatures

Because the sensor fails at low temperatures, a heater will be constructed to preheat the gasses going into the sensor. A small pump will feed a steady stream of atmospheric gasses into a heater composed of a small copper box with electric heater tape applied. The gas will flow through the box which outputs directly into the carbon dioxide sensor.

Further Calibration

Further work will be done to calibrate the sensor at low pressures using the HARBOR group's environmental test chamber. An experiment will be performed to compare the sensor's concentration reading with calculated concentrations using partial pressures of a mixture of nitrogen and carbon dioxide inside the test chamber. This data will be used to evaluate the effect of pressure on the accuracy and precision of the sensor.

The environmental test chamber was developed by the HARBOR group in 2012. This chamber allows for the precise control of pressure conditions and gas composition.

Acknowledgements

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