Case Study: Comparison of Ozone in the Mountains and Plains of Colorado

2B Technologies is the principal sponsor of the Global Ozone (GO3) Project, a citizen science outreach program for middle and high schools around the world. More than 100 schools have participated in this project over the past six years. Ozone measurements are made using Model 106-L (FEM) ozone monitors and uploaded to the GO3 Database once every 15 minutes (5 minutes for a few stations that use Model 202 or 205 ozone monitors) along with measurements of temperature, pressure, relative humidity, wind speed, wind direction and rainfall obtained with a Davis Vantage Vue weather station. More than 11 million lines of data containing ozone and met parameters have been uploaded to date. The data are publicly available and can be plotted on Google Earth, graphed online and downloaded as files at the GO3 data site:


Scientists are encouraged to make use of GO3 Project data. Nearly 50 schools in Colorado have monitored ozone for periods ranging for a few months to a few years. An interesting observation is that ozone measurements at mountain sites such as Aspen, Black Hawk and Estes Park are often higher than in much larger cities such as Denver, Boulder and Fort Collins along the front range. As an example of very recent data, we show below the results for June 2015 at our monitoring station at 9,200 ft elevation in Black Hawk, CO and our 2B Tech station in Boulder, CO at 5,300 ft.

Those who live in the mountains, partly because of the clean, fresh air, would be surprised to know that ozone levels tend to be higher on average than Colorado's urban areas and have more frequent excursions to levels above 75 ppb (the current 8-hr NAAQS) during summer months.

This phenomenon has consistently been observed by GO3 monitoring stations over the past few years. High ozone levels in the mountains were observed in last summer's FRAPPÉ (Front Range Air Pollution Photochemistry Experiment) as well. A number of factors that may contribute to the higher than expected ozone levels include: 1) In the mountains ozone seldom drops to low levels at night, as it does in the plains, probably because of the lack of formation of a stable nocturnal boundary layer and lack of a
continuous nighttime NO source to titrate the ozone. Thus, daytime photochemical production of ozone begins from a higher background level. 2) UV radiation, which drives the photochemistry through OH production, is higher at higher altitudes. And, 3) Contributions from stratosphere-to-troposphere transport along tropospheric folds is greater at higher altitudes, especially during winter and spring. More studies are required to sort out the relative contributions of these and possibly other factors.

Ozone measurements at the 2B Tech GO3 station in Boulder, CO for the month of June 2015.

Ozone measurements at the JKL Cabin and Wildlife Preserve GO3 station in Black Hawk, CO for the month of June 2015.
2B Technologies Receives NIH/NIEHS Grant in Support of New Technology Development for GO3 Treks

We are pleased to announce that 2B Tech has received a Phase 2 Small Business Innovative Research Grant (SBIR) from the National Institute for Environmental Health Sciences (NIEHS) of the National Institutes of Health (NIH). The nearly $1 million grant will fund the development of new technologies for use in the GO3 Treks project over a period of 2 years. In GO3 Treks students in schools around the US use pocket-sized instruments to measure air pollutants along “treks” of their own design. Air pollutant measurements are uploaded to the web where they are displayed as 3D plots on Google Earth maps embedded within blogs where students, teachers and scientists discuss the results.

In the previously funded Phase 1 project, which demonstrated feasibility, approximately 4,000 students at more than 50 schools created and discussed more than 350 treks of ozone and black carbon in and near their communities. The students learned about the sources, transformations and sinks of air pollutants by acting as citizen scientists, forming and testing their own hypotheses using real scientific instruments. Highlights include comparisons of rural vs urban exposures, comparisons of pollutant levels along busy and residential streets, a trek at a hydraulic fracturing site, treks from urban areas into the mountains and over large bodies of water, and investigation of emissions from different sources such as lawnmowers and buses. One school explored an area that is known to have an underground coal mine fire and even launched the ozone monitor on a balloon to 30 km (100,000 ft) where ozone in the stratosphere was measured.

The Phase 2 grant will allow other species, such as CO, CO₂, NO₂ and particulate matter (particle count and estimated PM₂.₅), to the current suite of air pollutants (O₃ and black carbon) that can be measured using personal monitoring devices. A particularly exciting innovation is that the instruments will communicate wirelessly with a smart phone so that treks can be displayed graphically in real time using the phone’s location services and continuously uploaded to the web where the results are shared with the general public.

Note (required by NIH): This content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Introducing 2B Tech's Summer Interns

This summer, 2B Technologies has been fortunate to have a team of five inspiring interns, each helping with a unique aspect of our company. From programming to developing GO3 curricula to sales, each intern has been helping with tasks that have benefited both our company and their personal and professional growth as young members of our nation’s workforce.
Jason Prince, an undergrad at Stanford University and 2B Tech intern for the past five years, is currently working on software for a data management framework that will go into many of our instruments. Jason plans to concentrate his studies in the areas of physics and creative writing, while envisioning a future career in film writing or a company startup that does contract engineering.

David Kopala is a junior at Northglenn High School and is currently helping 2B Tech develop mobile device applications, including a soon-to-be-released app that will perform ozone unit conversions and calculations for the ozone industry. David has already founded his own company, Quantum Tech LLC, and he hopes to attend MIT and eventually open his own custom integrative prosthetic company.

Our sales intern for the summer is Stan Hung who attends the Leeds School of Business at CU-Boulder. Stan has been assisting with marketing and sales lead generation for 2B Tech. A major focus has been helping us learn more about potential markets in his home country of Taiwan and in mainland China.

Luke Greenidge, a high school junior who is already taking classes at Front Range Community College, has been helping with various tasks, including creating a Black Carbon Installation Video for the GO3 Project, manufacturing various instrument subassemblies, and learning how 2B instruments are designed and built. Luke plans to obtain a mechanical engineering degree at CU or CSU and is saving to buy a car in the near future.

Danielle Desalvo is the GO3 Project’s intern for the summer. She is a senior at CU majoring in Environmental Studies. Danielle has been assisting with the Black Carbon Experiment by creating project materials for teachers and students and filming GO3’s Black Carbon Installation Video. She has also been analyzing various ozone graphs from schools all over the world that are currently participating in the Global Ozone Project. Danielle foresees herself starting a non-profit organization that provides clean drinking water to people in places that currently do not have access to such a vital part of life.
2B Technologies is pleased to work with such motivated young individuals who both inspire us and help mold the future of our nation's workforce in the areas of engineering, programming, sales, environmental outreach, and non-profit work.

**Featured Product: Model 405 nm NO₂/NO/NOₓ Monitor**

The Model 405 nm NO₂/NO/NOₓ Monitor is a new, innovative optical instrument designed for measurement of atmospheric nitrogen dioxide (NO₂), nitric oxide (NO) and total reactive oxides of nitrogen (NOₓ = NO + NO₂). In this instrument NO₂ is measured directly by absorbance at 405 nm with high precision and accuracy. NO is measured by conversion with ~100% efficiency using the highly selective reaction of NO with ozone (O₃). Total NOₓ is obtained by addition of NO and NO₂.

Unlike chemiluminescence instruments where NO₂ must be converted to NO using either a molybdenum or photolytic converter with highly variable efficiencies, in the Model 405 NOₓ Monitor nitrogen dioxide is measured directly by absorbance, analogous to an ozone monitor. Because NO₂ has a much lower absorption cross section than ozone, a miniature White cell is used to produce a long absorbance path of ~2 m to achieve approximately the same sensitivity. The wavelength of 405 nm was chosen because no other species found in ambient air has significant absorbance at that wavelength, making the Model 405 nm extremely selective for NO₂.

Compared to the conventional chemiluminescence method, the Model 405 nm is highly portable and low in power consumption. The criteria pollutant NO₂ is measured directly. Compared to the recently introduced CAPS method, the Model 405 nm measures NO in addition to NO₂, has a much lower power requirement, and is lower in cost.

![Model 405 nm NO₂/NO/NOₓ Monitor™](image)

**Features:**

- Direct absorbance of NO₂ at 405 nm
- Measurement modes: NO₂ only; NO only; NO₂, NO and NOₓ
- Linear dynamic range: 0-10,000 ppb (0-10 ppm) for NO₂; 0-2,000 ppb (0-2 ppm) for NO and NOₓ
Precision: Greater of 2.5 ppb or 2.5% of reading for 20-s average; greater of 1.8 ppb or 1.8% of reading for 1-min average  
- Accuracy of greater than 2.5 ppb or 2.5% of reading  
- Multiple analog outputs including USB, RS232, 0-2.5 V Analog, Optional 4-20 mA Analog  

For more detailed information on the Model 405 nm, see Model 405 nm.

**Air Pollution News: Peat Fires and Haze in Southeast Asia**

In a CNN feature article focusing on the haze problem in Southeast Asia, it is noted that according to a 2012 report of the World Health Organization (WHO) nearly 7 million people die worldwide every year from air pollution-induced illnesses such as heart disease, stroke, lung cancer, chronic obstructive pulmonary disease, and child respiratory infections. Southeast Asia has been an area known for increasing levels of air pollution throughout the past twenty years, most notably for its dense haze episodes. The WHO notes that, out of the 3.7 million deaths due to ambient air pollution in 2012, 1 million occurred in Southeast Asia. China and India are well-known today as producers of air pollution due to rural to urban migration and the ever-increasing industry and coal-fired power plants, but often forgotten is Indonesia and the haze produced by the country's "$50 billion palm-oil industry."

![An Indonesian Woman Covers her mouth and nose in Riau Province during a peat fire (Photo Source: CNN)](Image)

The largest production region for palm-oil in Indonesia lies in Riau province, where peat land is cleared and dried by the use of fire, leaving charcoal-like landscapes. Peat is, as a Climate News Network article notes, partially decayed leaf litter that contains "more carbon than all of the world's forests, heaths, and grasslands" combined. After the peat land is cleared, oil palms can be cultivated. Smoke from burning peat lands is hard to regulate when compared to car, factory, and energy-production emissions; peat fires are also damp, thus taking longer to burn at lower...
temperatures and emitting more damaging smoke than a typical forest fire. CNN mentions that "the emissions from a given peat fire will largely depend on the peat's composition, its burning temperature, and how far below the ground the fire occurs", and, in Indonesia, many of these factors are largely under-researched due to little data collection. Nearly 40% of greenhouse gas emissions in Indonesia come from peat burning, as the country is one of the biggest producers of palm-oil and hosts abundant tropical peat lands, making it "the world's third-largest greenhouse gas emitter after China and the U.S., as well as a leading source of hazardous smoke haze."

The haze produced in Indonesia travels to nearby Malaysia and Singapore through wind currents, contributing to much of the dense fog-like haze that has blanketed the region in the past decade. No long-term studies have been conducted to analyze the relationship between peat smoke and human health, nor have any studies been conducted looking at the chemical composition of peat smoke. As CNN notes "a primary concern... is that peat fires tend to generate larger amounts of fine-grained particulate matter, called PM2.5, than normal forest fires." Landscape fires accounted for nearly 339,000 deaths during a ten year period in the late '90s and early 2000s according to the 2012 Environmental Health Perspectives Study. Lastly, a 2012 study conducted by Miriam Marlier et al. discovered "that between 1 and 11% of Southeast Asia's population was repeatedly exposed to pollution above the WHO's recommended air quality levels during sporadic haze episodes between 1997 and 2006. Elevated exposure during El Nino years caused around 15,000 cardiovascular-linked deaths per year...", thus showing the increasing problem of haze in Southeast Asia. While the composition of the PM$_{2.5}$ produced by peat fires still needs to be studied in more depth, ways to reduce emissions from peat fires must be looked at, along with the reduction of peat fires and palm-oil production, in general.

Interested in measuring particulate matter from forest or peat fires in your area? 2B Technologies' non-profit partner, the GO3 Project,
has the Black Carbon Experiment kit, which quantifies the amount of black carbon in the air. Check it out here.

**Monitoring Tip: Pressure and Temperature Corrections to Ozone Measurements**

A question we often receive from potential customers is, "Are your ozone monitors pressure and temperature corrected?" The answer, of course, is yes. In fact, nearly all modern ozone monitors output ozone mixing ratios that are temperature and pressure corrected. It is useful, however, to consider the origin of this question and what temperature and pressure correction really means. The very earliest ozone monitors, introduced in the 1960s, were not corrected for temperature and pressure, because microprocessors were not yet available to do the calculations in real time. Instead, instrument manuals typically provided formulas for making those corrections.

Temperature and pressure correction is required because the National Ambient Air Quality Standard (NAAQS) for ozone is based on a mixing ratio rather than a concentration. The mixing ratio of ozone is the fraction of air molecules that are ozone, which for ambient air measurements is usually expressed as parts-per-billion by volume (ppbv or more commonly just ppb) and sometimes as parts-per-million by volume, (ppmv or ppm). Mixing ratios are commonly used in atmospheric chemistry, because when a parcel of air moves from one altitude (pressure) to another, the mixing ratios of all the components of air stay the same (e.g., oxygen remains at ~21% mixing ratio) even though the concentration (molecules/cm\(^3\)) changes by about a factor of 2 for every 5 km of altitude.

UV absorbance uses the Beer-Lambert Law to fundamentally measure ozone concentration in units like molecules/cm\(^3\), not ppb. To convert to ppb, we need to divide by the total concentration of air molecules and multiply by \(10^9\). The total concentration of air molecules is easily obtained using the ideal gas law, \(N/V = P/kT\) if we know the pressure and temperature within the detection cell where the ozone concentration is measured.

Uncorrected ozone monitors can cause some confusion because they are calibrated for a specific temperature and pressure. The standard pressure is usually defined as 1 atmosphere or 1 bar, which are nearly identical, but the temperature might be 0 °C, 25 °C, or some other temperature. To correct such ozone monitors to true mixing ratios, you need to know the standard pressure, \(P_{std}\), and standard temperature, \(T_{std}\), defined for that monitor. The formula for making the correction is

\[
X_{true} = X_{meas} \left( \frac{P_{std}}{P_{cell}} \right) \left( \frac{T_{cell}}{T_{std}} \right)
\]

where the temperatures are absolute and expressed in Kelvin. We recently encountered this problem when calibrating an IN USA ozone monitor using our Model 306 Ozone Calibration Source. The calibration factors seemed far out of line until we realized that the
instrument was not pressure and temperature corrected and we were doing the calibration at 5,300 ft altitude.

If you are using a 2B Technologies instrument, you can be assured that the mixing ratio output by the instrument is a true mixing ratio, properly corrected for temperature and pressure. However, it is a good idea to check the cell temperature and pressure being output on the LCD and in the serial data to make sure that they are reasonable values. Typically, the cell pressure will be a few mbar lower than ambient pressure, and the cell temperature will be 5-10 °C warmer than ambient.