OCN 390: Field Methods

Week 12

Reading Scientific Journal Articles

(Refer also to notes from lecture by Peter Fritzler)

Reminders/Grading

- This isn’t a hybrid class…
- Field journals are finished but participation points are still on the line

Participation/Field Journal:	25%
Assignments:	25%
Story Map:	25%
Final Report:	25%

Story Map Requirements

- You must tell a cohesive story touching on all of these topics, with several sentences for each (not necessarily in this order):
  - What was the motivation for your study?
  - What were your methods and procedures?
  - What did you learn? Results? Provide both quantitative results and also how they fit into the context of your study.
  - What challenges did you face? How will you make improvements prior to final report? How would you recommend that others overcome those in future semesters? What other data will you collect? What other analysis/analyses will you perform?
  - Conclusion: tie it all together.
- You must include ≥ 3 hyperlinked citations of peer-reviewed research described in context. Other hyperlinked references to papers, websites as needed.
- You must use ≥ 3 original images and/or videos of field site, sensor, field journal, etc. Include images from web (with citation) if they add to story.
- Image or written out version of your field checklist
- Preliminary data, nicely visualized **(at least 1 interactive map with your data and 1 time-series plot with your data)**. Interactive map should be made like last week's homework and embedded in Story Map. Time-series can be either an image of an Excel graph, python graph, or interactive graph.
- **EVERYONE must submit a link to their team's Story Map, even if three or four of you are submitting the same link.**
- **EVERYONE is to submit an additional paragraph sent via Canvas (not in Story Map) describing your contributions to all aspects of the team project to date.**

You will present to class on Apr. 12

- From where you are sitting, I will scroll and your team can divide up or ask one person to describe to the class what we are seeing. Aim for 5-10 minutes. Do not read exactly off of screen but tell the story of your Story Map

Quiz

(Write your name on top of page or, if on zoom, send me email of photo in < 15 mins)

1. **BLOCK DIAGRAM:** Draw a block diagram containing the **four physical components** other than the breadboard and indicating **all connections** necessary for stable functioning of the device.
   Draw each part as a **labeled rectangle** and **label all connections clearly**, differentiating voltage levels as needed on power lines.
   Ensure that any crossing wires carefully show whether they are connected or not using previously discussed notation.
   Note: Only one rectangle should be used for the Adalogger/microcontroller combination; these do not count as two of the four, just one component.

2. **FIRMWARE:** Assuming you have the CO2 concentration stored in a variable named “CO2” and that at the time of code execution, CO2 = 702, write the lines of Arduino code required to print to your serial monitor the following:
   The current CO2 concentration is 702

3. **THE PROCESS OF SCIENCE:** What particular feature that we covered in last week’s video and lecture makes science reliable? Write 3-5 sentences.

Final Report

Pulling together all the pieces

Learning Outcomes:

After completing OCN 390 students should be able to:

- Evaluate and synthesize information from various sources to develop testable hypothesis as part of a planned research project [IL1, IL3, WI1]
- Use the library catalogue, online indexing databases, and appropriate reference collections to locate relevant sources of information and/or data. [IL1, IL2, IL5, WI3]
- Use appropriate technologies and methodologies to collect data required to test hypotheses generated as part of a planned research project [QRE2, IL1]
- Use relevant mathematical, statistical, time-series, or spatial methodologies to analyze, evaluate and interpret data as part of a planned research project.[QRE1, QRE2, QRE3]
- Synthesize results and, in combination with literature, support or refute hypothesis(es) and/or predictions [IL3, WI1, QRE2]
- Summarize project, using knowledge of the results/findings, in a research paper that explores linkages between the project results and any societal, legal or economic implications of the study [WI2, WI4, WI3, WI5, IL4, IL5]

Format: Scientific Publication

Required sections:

- Introduction: what did you set out to do?
- Methods: how did you do it?
- Results & discussion: what observations did you make? Quantitative & qualitative, including what did and didn’t go well and what more could be done in the future.
- Conclusions: what did you learn?
- References: whose work did you build off of?

Additional Requirements: Citations

- You are required to cite scientific literature, ≥ 4 citations of peer-reviewed research described in context.
- Cite in the place where the reference is relevant (usually intro, methods, and/or discussion)
- In the text body, use the format (though not exact wording) of "as previously determined by Gamble et al. (2015), …"
- In the references section, write out full reference as a list like: "Gamble, D., Lastname2, B., Lastname3, C. (2015) Title of paper. Journal name. Web address."

Details

- 6–10 pages, 12 point Times New Roman font, 1″ margins on all sides, 1.5 spacing
- 3–5 figures, including at least two data analysis figures, described in context. Figures can be up to 3″ high x 6″ wide. You must describe the figure in the paper and it must be clear why you included it in order to receive credit.
- No fewer than 2 paragraphs for each main section (intro, methods, results & discussion, conclusion)

Methods Section

- As this is a Field Methods course, I will grade the Methods section most strictly.
- I will be looking for description of your methodological approach to fieldwork, including planning and execution as well as data analysis.
- Describe the parts of the sensor, where someone could access the code for the sensor, what data analysis software you used, etc.
- **Remember reproducibility.** Another reasonably well trained scientist should be able to pick up your report and reproduce the study (even if not the findings).

Individual vs. Teamwork

- Fine to share data, analytical approach, discussions about what you did, what you learned
- Cannot share actual writing; that must be fully independent to meet writing intensive requirement for this course!

Example

Atmos. Meas. Tech., 10, 2383–2395, 2017
https://doi.org/10.5194/amt-10-2383-2017

Atmospheric Measurement Techniques
Open Access
EGU

Evaluation and environmental correction of ambient CO_2 measurements from a low-cost NDIR sensor

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- Martin, C. R., Zeng, N., Karion, A., Dickerson, R. R., Ren, X., Turpie, B. N., & Weber, K. J. (2017). Evaluation and environmental correction of ambient CO2 measurements from a low-cost NDIR sensor. *Atmos. Meas. Tech.*, ~~*10*(7), 2383-2395~~. doi:10.5194/amt-10-2383-2017
- DOI = digital object identifier: what we use to catalog publications, data, code
- URL could also be: https://amt.copernicus.org/articles/10/2383/2017/

Abstract: not required

Abstract. Non-dispersive infrared (NDIR) sensors are a low-cost way to observe carbon dioxide concentrations in air, but their specified accuracy and precision are not sufficient for some scientific applications. An initial evaluation of six SenseAir K30 carbon dioxide NDIR sensors in a lab setting showed that without any calibration or correction, the sensors have an individual root mean square error (RMSE) between $\sim$5 and 21 parts per million (ppm) compared to a research-grade greenhouse gas analyzer using cavity enhanced laser absorption spectroscopy. Through further evaluation, after correcting for environmental variables with coefficients determined through a multivariate linear regression analysis, the calculated difference between the each of six individual K30 NDIR sensors and the higher-precision instrument had an RMSE of between 1.7 and 4.3 ppm for 1 min data. The median RMSE improved from 9.6 for off-the-shelf sensors to 1.9 ppm after correction and calibration, demonstrating the potential to provide useful information for ambient air monitoring.

Intro:

- Why measure CO2?
- How have we measured CO2 historically?
- What are recent research efforts, discoveries, and gaps?

1 Introduction

Carbon dioxide (CO_2) is a major greenhouse gas, with fundamental importance to Earth's climate. Since measurements started at the Mauna Loa Observatory in the 1950s (Keeling et al., 2005), the global mean concentration of CO_2 has steadily risen from the preindustrial mole fraction of approximately 280 $\mu mol\,mol^{-1}$ of dry air (parts per million, or ppm) to today's level exceeding 400 ppm. These observations, both from flask samples and state-of-the-art continuous measurement instruments, have a typical compatibility goal of ~ 0.1 ppm, recommended for observations at background global network sites (World Meteorological Organization, 2013). Flask-based measurements require observers to collect samples, which are subsequently transported to a lab for analysis, at significant cost. Continuous in situ CO_2 analyzers located at towers do not suffer from these regular costs, but these high-precision analyzers can cost upwards of USD 100 000 per site, plus any additional costs for calibration gases and installation of equipment and inlet lines. High-accuracy CO_2 observations are thus relatively sparse compared to other climatological variables such as temperature and precipitation.

Recent research efforts have focused more locally and on the use of networks of observing sites that use instrumented towers similar to what is used for global monitoring, but applied to the urban environment (Pataki et al., 2003; Briber et al., 2013; Kort et al., 2013; McKain et al., 2012; Turnbull et al., 2015). High-accuracy observations from these tower sites are then used to create inversions to estimate the total greenhouse gas flux from the urban area in question (McKain et al., 2012; Bréon et al., 2015; Lauvaux et al., 2016). However, due to the cost of these networks being comparable to ones at the global scale, the observation towers are still sited at a relatively low density of typically 3 to 12 sites in a sin-

Intro (cont'd):

- What is your goal?

In this paper, one of these small NDIR CO_2 devices is assessed by determining its accuracy with and without environmental corrections. Section 2 describes the CO_2 sensor and its Allan variance, the other instruments included in the system, and the data collection and processing methodology. Section 3 describes the calibration and shows the stability of the reference high-precision gas analyzer, and the initial results from the NDIR sensor are shown in Sect. 4. In Sect. 5, two methods are described to determine functional relationships and coefficient values to correct the observed values of the instrument for environmental variables and Sect. 6 discusses the potential utility of observations from this sensor after correction and temporal averaging.

Methods:

- Sensor model
- Useful specs

2 Instruments and methods

To test the validity of using low-cost sensors for scientific applications, a sensor package was implemented consisting of various off-the-shelf components. The K30 sensor module (K30) from SenseAir (Sweden) is the low-cost NDIR CO_2 observing instrument used in this study[1]. The K30 is a microprocessor-controlled device with on-board signal averaging and has a measurement range of 0 to 10 000 ppm, observation frequency of 0.5 Hz, and resolution of 1 ppm. The manufacturer's stated accuracy of the K30 sensor is ±30 ppm ±3 % of reading (SenseAir, 2007) for the 0.5Hz raw output. Additional NDIR sensors were initially evaluated be-

Methods (cont'd):

- Data collection: they use a Raspberry Pi and universal asynchronous receiver/transmit serial and Inter-Integrated Circuit serial

For data collection, a Raspberry Pi (RPi) computer is used (Raspberry Pi Foundation, 2015). The RPi is a credit-card-sized (approximately 6×9 cm) computer running a full Linux distribution, allowing for easy customization and usability, that is priced at around USD 25. The K30 is connected to the RPi over universal asynchronous receiver/transmitter (UART) serial and the BME280 over Inter-Integrated Circuit (I^2C) serial. An image of the complete sensor package is available in Fig. 1. Data are archived on the RPi and uploaded to a centralized data storage and processing server. The LGR collects and archives its own data, but an RPi is used here as well to collect the data from the LGR over a local area network and transfer them to the same centralized server. The added computational power of an RPi over traditional data loggers allows for the ability to archive two levels of data: the raw data collected every 2 s and 1 min averages.

Methods (cont’d):

- Description of the experiment

2.2 Experiment

The need to quickly and effectively evaluate a relatively large number of sensors under conditions with relatively stable CO_2 led to the use of a rooftop observation room on the University of Maryland campus in College Park, Maryland. Because this rooftop room had limited access, and it was not part of the building’s HVAC system, it served as an ambient evaluation chamber with minimal influence from human respiration. The room was slightly ventilated for the entire evaluation period to allow outside air to slowly diffuse into the room, with a small household box fan also in the room to ensure that the air was well mixed. The room also fea-

Methods (cont'd):

- Data processing/analysis

2.1 K30 Allan variance

Allan variance (Allan, 1966) is a measure of the time-averaged stability between consecutive measurements or observations, often applied to clocks and oscillators. In addition, an Allan variance analysis can be used to determine the optimum averaging interval for a dataset to minimize noise without sacrificing signal. Figure 2 shows the Allan deviation (the square root of the variance) for one K30's raw 2 s data when exposed to a known reference gas. The original 2 s data show the maximum noise, with a standard deviation comparable to the manufacturer's specifications of ±30 ppm, but averaging for even 10 s drops the variance significantly. According to this analysis, the optimum averaging time, when the Allan variance is at a minimum (Langridge et al., 2008), is approximately 3 min; longer averaging times do not reduce the noise. The other sensors were found to perform similarly. For the subsequent analysis, an averaging time of 1 min is used, as the Allan variance is only slightly higher than for 3 min, and 1 min observations allow for resolution of atmospheric variability at shorter timescales.

Results

- Description of the figure(s), description of statistics

4 Initial K30 results

Figure 4 shows the original time series of data recorded during the evaluation experiment described in Sect. 2.2. The top panel shows raw CO_2 mole fractions reported by six K30 sensors as well as the LGR analyzer, each of which is located in the same rooftop evaluation chamber. The middle panels show the reported atmospheric pressure and temperature values from one BME280 sensor and the water vapor mole fraction from the LGR. Then, the bottom panel is the difference between the original recorded K30 value and the corrected LGR recorded CO_2 mole fraction with the calibration periods removed.

Over this 4-week period, the LGR observed an ambient variation of CO_2 with an average value of just over 423 ppm and a standard deviation of just under 21 ppm. There is dis-

Discussion

- Can be part of one section called "Results and Discussion" or separate
- Put results in context
- What do you think that the quantitative values are telling you about the sensor, the environment, your experiment, etc.?
- Can be new discoveries about nature, about the sensor, or even things that didn't go as planned

6 Discussion

6.1 Time averaging

There are two observations to note based on the evaluation and analysis. First, both before and after the multivariate regressions, there are frequent shifts in the sign of the difference between each K30 and the LGR; these sudden changes occur at or around sunrise most days. Because of the rapid change in atmospheric CO_2 concentration at this time, the ambient calibration chamber may not be well mixed during this time period. Each K30 is located in a slightly different location in the ambient calibration chamber and is approximately 1 to 2 m away from the LGR inlet. This effect, combined with the different response time of the K30s compared to the LGR, can lead to dramatic differences between what each K30 observes and what the LGR observes at the same timestamp for a short period of time each day.

Tables

- Not required, but helpful
- Can use instead of one of the figures if it helps you tell your story

Table 1. Root mean square error in ppm between the CEAS LGR and each K30 NDIR sensor's 1 min averaged data for the original dataset before correction, at each step of the successive regression correction (correcting for (1) zero/span, (2) atmospheric pressure, (3) temperature and (4) water vapor mixing ratio) and after the multivariate regression correction. Each value shown is for a regression calculated using data from the entire evaluation period.

	Original	Zero/span	Pressure	Temp.	q (final)	Multivariate
K30-1	6.9	3.3	2.7	2.7	2.1	1.8
K30-2	5.4	3.5	2.2	2.2	1.9	1.7
K30-3	10.9	6.0	5.0	4.9	4.5	4.3
K30-4	20.8	3.7	2.5	2.4	1.9	1.7
K30-5	8.3	3.7	2.6	2.6	2.2	2.0
K30-6	15.2	4.9	3.6	3.5	2.7	2.2

Conclusion(s)

- What did you learn?
- Not just numbers, but summary of your discovery

7 Conclusions and future work

The K30 is a small, low-cost NDIR CO_2 sensor designed for industrial OEM applications. Each of the sensors tested falls within the manufacturer's stated accuracy range of ± 30 ppm $\pm 3\,\%$ of the reading when compared to a high-precision CEAS analyzer, but these ranges are not particularly useful for scientific applications aimed at measuring ambient atmospheric CO_2. If these sensors are individually calibrated, selected for stability and corrected for sensitivity to temperature, pressure and RH, the practical error of these sensors is < 5 ppm, or approximately $1\,\%$ of the observed value. The final RMSEs of the six K30 ranged between 1.7 and 4.3 ppm for 60 s averaging times. Averaging for 200 s further reduces the noise by about $30\,\%$, but longer times did not further improve precision. With errors in this range, these instruments could be used in a variety of scientific applications, including observations at high spatial density to better represent the

Conclusion(s) (cont'd):

- Future plans/next steps
- For the purposes of this class, what would you recommend that next year's students do?

In the future, further analysis will be performed evaluating the K30 as well as other low-cost CO_2 sensors in a laboratory setting with controlled temperature, pressure and relative humidity. A Picarro cavity ring-down spectroscopic greenhouse gas analyzer will be used as a high-precision control and the various instruments will be subjected to ambient air as well as periodic reference gases. From this lab analysis, we hope to determine the theoretical maximum performance of these sensors in a controlled environment. This subsequent study will additionally attempt to quantify any long-term drift over the course of multiple months.

References

- Please put year after authors in your final report

References

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Can we cite that paper toward the citation requirement?

- Yes, if you do it in context!