Introduction: Aclima Quality Assurance

March 10, 2023

Version 1.1

Introduction

This document provides a high-level, introductory overview of Aclima's mobile monitoring methodology and a general approach to our quality assurance system, which is covered in detail in subsequent documents. In particular, this document outlines the specific characteristics of the mobile measurement approach that inform unique quality assurance considerations besides the use of standard methods to assure that the data from individual devices meets specific accuracy specifications. An understanding of these characteristics provides a useful foundation for the more detailed QA documents. These Quality Assurance documents ("Mobile Ambient Air Pollutant Measurement Quality Assurance System" and "Hyperlocal Ambient Concentration Estimate Validation and Quality Assurance System") describe the processes that Aclima scientists, engineers, and operations staff use to ensure our data are of satisfactory quality to support user needs.

Aclima uses mobile monitoring sensor networks to assess air quality and climate pollution at hyperlocal levels across regions, cities, and neighborhoods. Mobile air pollution monitoring fleets provide a flexible method to measure concentrations of a broad range of air pollutants and greenhouse gases over large, user-defined geographic areas and at higher spatial resolution than traditional monitoring techniques can provide. Aclima's fleet deploys on all public and accessible roadways within a user-defined area. The hyperlocal measurements produced by mobile monitoring can identify localized pollution sources as well as spatial gradients of pollutants across and between neighborhoods.

Aclima has developed custom sensing systems for scalable collection of air quality and greenhouse gases onboard mobile platforms. Aclima Mobile Nodes (AMNs) measure the following pollutants: CO, CO_2, NO, NO_2, O_3, CH_4, C_2H_6, TVOC, BC, and $PM_{2.5}$, and are installed in Aclima-operated fleet vehicles. Aclima measures a wide range of pollutants that can adversely impact human health and ecosystems (CO, NO_2, O_3, $PM_{2.5}$, NO, BC), contribute to climate change (CO_2, BC, CH_4), are related to biomass burning (BC, CO), or may relate to industry, agricultural, odors, or energy issues (TVOC, CH_4, C_2H_6).

Mobile monitoring methodology supports a number of data products:

- **Hyperlocal, block-by-block spatial resolution** enabled by fast time-response sensors
- **Wide geographic coverage** at the hyperlocal resolution enabled by fleet of roving vehicles
- **Detection of local emissions sources** enabled by fast time-response sensors
- **Source identification** through measurement and correlation of multiple species

Aclima's sensing system measures ambient air pollution and greenhouse gases at 1-Hz time resolution. Our mapping methodology is designed to drive each road multiple times, balancing sampling across different days of the week and times of day. The time-resolved data collected on-road enable high-resolution spatial analyses, the outputs of which support exploration of different use cases. A fundamental output from mobile monitoring is the ability to produce maps of air pollution concentrations at high spatial resolution. These maps highlight typical concentrations over a defined measurement period, generally either one year or one season (quarter), revealing persistently high and low pollution concentrations at the street level. In addition, time-resolved data from individual drives can be analyzed for times when measured pollution concentrations vary substantially from average local background levels as a result of local emission sources. The detection of higher-than-average measurements on repeat visits to the same location is an indication of a persistent localized emission source. These analyses can be reported for individual pollutants or combined, which can help suggest the source of the emissions.

Aclima's primary data product goals:

1. **Show areas that have relatively higher and lower pollution in a geographic region at high spatial-resolution**:
   Data Quality Objectives:
   - Produce yearly or seasonal estimates of ambient pollution concentrations from measurements balanced over the contract time period and at diverse times of day and night, weekdays and weekends, to adequately address seasonal and diurnal variations in the data.
   - Spatial distribution of data throughout the entire user-defined geographic area.
   - Annual or seasonal estimates delivered with credible intervals at the contracted spatial resolution sufficient to enable assessment of the significance of differences in pollution levels.
   - Enable pollution estimates at ~100 m road segments (sometimes referred to as "address-level").

   Pollutants:
- O_3, NO, NO_2, CO, CO_2, CH_4, $PM_{2.5}$, and BC

2. **Identify probable locations of air toxic emissions sources**
   Data Quality Objective:
   - Produce geo-located clusters of TVOC source indications to support follow-up investigation by identifying enhancements above background in the form of peaks in the 1-Hz sensor output that have a signal to noise ratio of at least 3.

   Pollutants:
   - TVOC, BTEX

3. **Show areas that indicate biogenic methane emissions sources**

- Produce geo-located areas where enhancements in methane indicate biogenic sources by using to ratio between methane to ethane

Pollutants:

- CH_4, C_2H_6

Characteristics of the mobile measurement approach

Mobile mapping allows measurement of the variability of air pollution at high spatial resolution. Air pollution concentrations have significant variability over time and space, which means that the creation of geospatial, time-integrated maps from spatially-resolved measurements is complex. It is important to consider both dimensions when designing a mobile sampling strategy and calculating representative concentrations from mobile measurements.

Air pollution concentrations vary over time scales that range from less than a minute to months. Short time scale variability can be observed near sources, like a plume from a passing vehicle or a campfire, where changes in wind direction and speed shift where the plume blows and dissipates. **Within-day variability** is caused by time patterns of emissions (e.g. morning and evening rush hours) and meteorology and its resulting changes in atmospheric dynamics (e.g., changes in the boundary layer height or intensity of sunlight). **Over the year** and **day-to-day variations** are caused by emissions sources that change from day to day or week to week, seasonal changes in the weather, and changes in regional concentrations caused by synoptic-scale meteorology. Changing source emissions may include those in the immediate vicinity of the measurement as well as those from long-distance transport and even intercontinental sources.

Spatial variability in air pollution over the scale of a city block, between neighborhoods, or between cities mainly arises from the location of and distance from sources, effects of urban design such as street canyons, and differences in microscale weather, like variations in temperature and wind speed and direction that arise from local and regional topology.

By definition, mobile sampling captures the variability of pollutants over time and space and while there is a benefit to the unique capability of observing differences in pollutants over space, it comes at the expense of not having detailed information at any one location over time, which is a benefit of stationary monitoring. Given the temporal dynamics of emission sources and the atmosphere, measurements obtained during a single visit to a specific location cannot be generalized into a typical value for that location. Thus, multiple measurements are required at each geospatial location over time in order to obtain an adequate statistical sampling of pollutant levels at that location, and the spatially resolved data products must represent an aggregation over long temporal scales (typically seasonal or annual for Aclima's standard data products). Additionally, because the spatial component of the data is captured as a function of time, i.e. while the car is moving, the key challenge in producing maps from the mobile data is determining what part of the time-resolved signal in a measurement area comes from true spatial variability as opposed to temporal changes that are spatially homogeneous, but sampled at different times in different locations.

In summary, a fundamentally sound sampling strategy that aligns with Aclima's primary goals must meet the requirements of obtaining a statistically representative number of passes or samples at each location in the geographic area of interest, and the specific times that those samples are collected must be balanced across all of the relevant temporal scales over which the atmosphere varies (hourly, day-to-day, seasonally, etc).

Data processing, availability, and guidance

Yearly or seasonal estimates of ambient pollution concentrations are not produced until data collection is complete and the data are verified. These annual concentration estimates are calculated using a data-driven modeling framework that uses the verified data for all passes on that road segment and incorporates additional sources of data that provide information on broad regional spatial trends and region-wide temporal trends. The model results in the best estimate of the annual average concentration for each pollutant that retains the true spatial variability of the data at the hyperlocal scale while accounting for biases that may result from the mobile method sampling at different times in different locations.

Data from active mapping before the year is complete are processed daily and made available for advanced users via Aclima Pro. To support visibility into emerging trends during data collection, a First Available Data view is available after each quarter of driving is complete. This map view displays which road segments have measured higher or lower, relative to the average of the area as a whole. This view shows emerging trends calculated directly from the data, using all passes completed on each 100 m road segment. The First Available Data view, by definition, displays data in areas where collection is still underway and is unverified. Therefore, the view will change as more measurements are collected. Caution should be taken when making any decisions based on incomplete or unverified data.

Mobile vs. stationary monitoring

It is important to note how data products from mobile monitoring differ from traditional regulatory stationary ambient air quality monitoring data. As discussed above, air pollution concentrations vary both spatially and temporally. Ambient concentration estimates from mobile measurement methods excel at capturing variability at hyperlocal, block-by-block length scales but do not provide the detailed information at any one location over time that comes from traditional regulatory air quality monitoring. This high spatial resolution of Aclima's resulting data products supports identification of emissions sources as well as information on neighborhood-level variability in air pollution concentrations. The mobile mapping method is not a reference method designed to support the National Ambient Air Quality Standards (NAAQS), which are supported by a network of stationary reference monitors. Thus, data products from the mobile method do not support assessment of compliance with NAAQS.

Aclima's approach to quality assurance

Given the unique sampling approach, Aclima's data quality is much more complex than simply a measurement quality objective (i.e. precision and bias) on the sensor performance or the 1-Hz measurements. Individual sensor performance is, of course, a critical aspect, but a more holistic approach is required to understand overall uncertainty in Aclima's data products.

Aclima's Quality Assurance documentation is organized to outline the instrument, sampling, measurement, data processing, and analysis methodologies that support our data products. Our approach to designing a quality assurance system at Aclima can be generalized as:

- Maximize performance of each individual mobile sensing platform in terms of uptime, accuracy, and precision
- Apply advanced statistical models to account for temporal sampling artifacts and generate associated confidence intervals for the final data products
- Characterize and quantify all distinct sources of uncertainty (to the extent possible) from the device/sensor level, through the sampling methodology, to the statistical processing that goes into generating the final temporally aggregated geospatial data products

The documentation accompanying this overview goes into detail of the processes and procedures that guarantee that Aclima's mobile measurements are of the highest data quality achievable and that the subsequent calculation of analysis products include quality assurance steps that take into account the specific complexities that arise from the mobile measurement approach. We divide the documents into two parts. The first covers Aclima's process from the assembly of our nodes through calibration, driving, and verification of the 1-Hz data from the vehicles. The second describes how the 1-Hz data is used with modeling to produce our ambient concentration estimates.