Reducing the Frequency of PM Sensor Laser Failures in Extreme Heat

*This document summarizes an approach developed by QuantAQ to extend the operating range of laser-based particle sensors in extreme heat.*

# About

QuantAQ’s patent-pending Dual-Detection particulate matter sensor utilizes laser-based particle sensors to make measurements1. Subjecting lasers to elevated temperatures can cause them to eventually overheat, burn out, and fail. Over the past several years, QuantAQ has been able to gather extensive data about the performance and failure modes of the MODULAIR™ and MODULAIR™-PM sensors across a wide range of operating conditions. Laser failures have increased over the past several years with increased global temperatures and deployments in areas which experience extreme heat events more frequently. To prevent irreversible damage of QuantAQ devices, previous versions of firmware (MODULAIR < 13, MODULAIR-PM < 22) would actively shut off the laser when internal box temperatures exceeded 50ºC. While this strategy was successful in preventing mass failure events of sensor components, customers in warm climates were unable to collect continuous data during large portions of the summer, sometimes losing as much as ten hours of data per day during extreme heat events.

Here, we introduce changes we’ve made to the firmware to improve the operating range of the MODULAIR and MODULAIR-PM devices without the need for any physical hardware changes. In doing so, customers in warm climates can capture significantly more data during extreme heat events without risk of heat-induced failure of the device.

# Solution

Our primary goal was to gather complete 1-minute data and to extend the effective operating temperature range of the device. To do so, we introduced the concept of a device operating state that describes the data collection mode the device is operating under. Both MODULAIR and MODULAIR-PM devices now operate under one of three operating states, as described in Table 1.

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| Operating State | Conditions Active | Description |
| Normal  State = 0 |  | The laser is always powered and data is collected continuously and recorded every 5-seconds locally. Data is averaged to 1-minute and pushed to the QuantAQ Cloud. |
| Power Saving  State = 1 |  | The laser is duty-cycled and you will only collect a portion of the 5-second data. Data are averaged to 1-minute and pushed to the QuantAQ Cloud. |
| Hibernate  State = 2 |  | The laser is powered down until the internal box temperature returns to an acceptable range. All PM data is flagged during this time. |

When the internal box temperature is below 47.5ºC, everything operates normally, and data is recorded both at the 5-second level locally and 1-minute on the QuantAQ Cloud. Once the internal box temperature reaches 47.5ºC, the device enters a “Power Saving” mode whereby we begin to duty-cycle the laser power. In this mode, each minute of data is comprised of three steps: (1) the laser is turned on and allowed time to warm up; (2) measurements are taken every 5 seconds and recorded locally; and (3) the laser is turned off to allow the laser to cool down and prevent overheating. After the entire minute has elapsed, the available 5-second data points are averaged to 1-minute and sent to the QuantAQ Cloud. The current operating state of the device is recorded both locally on the SD card and in the QuantAQ Cloud enabling you to understand under which mode data were collected at any point in time. The operating state is stored as an integer and is documented above in Table 1 in the first column.

# Results

With this new approach, we have extended the usable range of the device from around 42ºC (107.6ºF) to around 47.5ºC (117.5ºF). Initial test deployments with devices in extremely hot environments have seen substantial improvements in data completeness without any need for active cooling. Figure 1 demonstrates how duty-cycling the laser can reduce the laser temperature and allow for extended operation without losing continuous data.

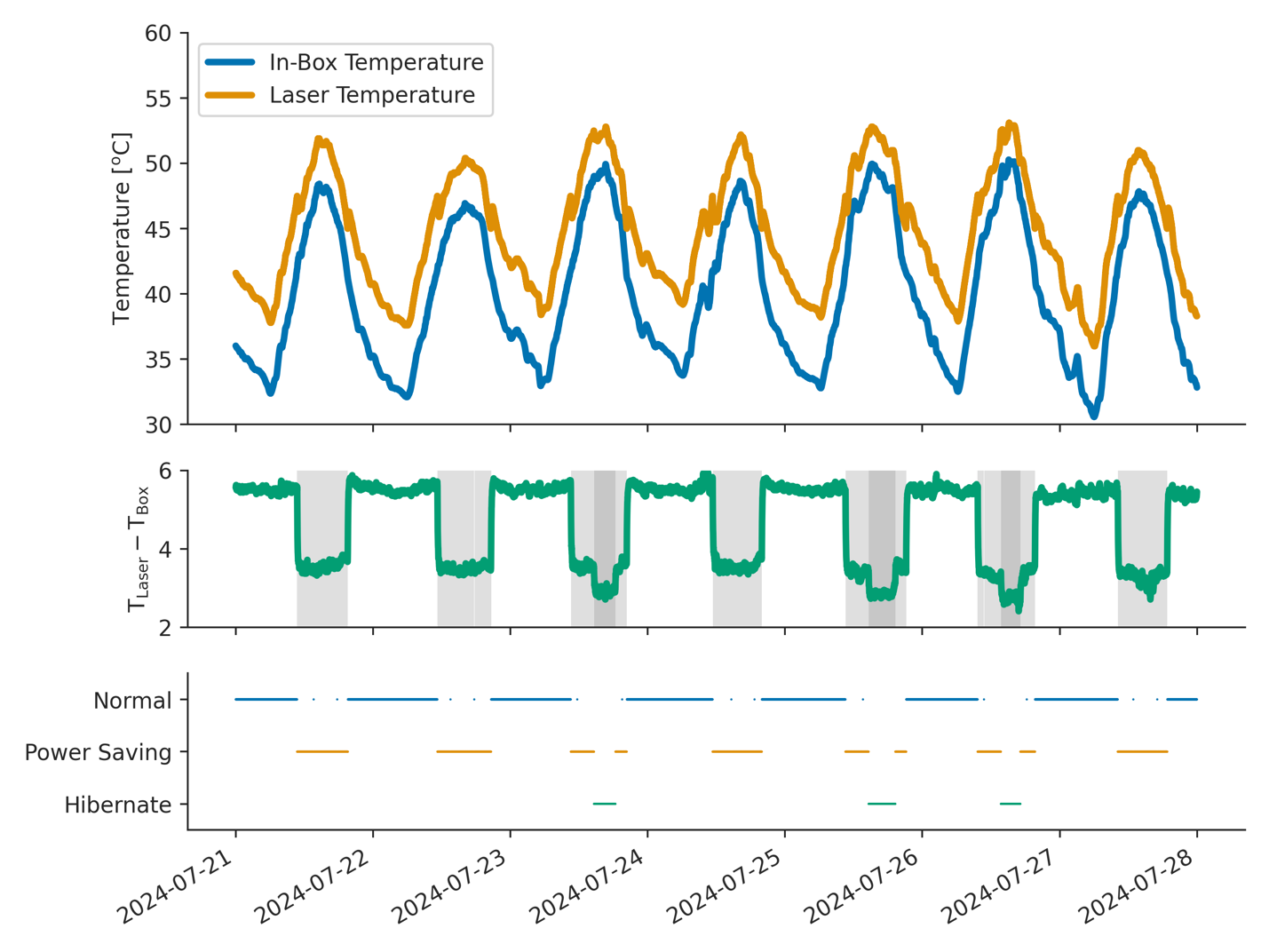


Figure 1. Top panel depicts the measured temperatures inside the box (blue) and the onboard laser temperature (orange) over the course of a week in a hot environment. The middle panel depicts the difference between the laser temperature and in-box temperature (green) as well as the operating state of the device (gray). The bottom panel depicts the operating state of the device over the course of a week. When in the new power saving mode, the laser temperature drops around 2-3ºC which allows the device to operate in higher ambient temperatures.

Under normal operation, there is a 5-6ºC difference between the internal box temperature and the laser temperature due to heat generation by the laser. In addition, the internal box temperature is around 4ºC warmer than ambient conditions but can vary slightly with sensor siting. The lower panel of Figure 1 illustrates the operating mode changing as a function of the laser temperature. When the laser temperature reaches 47.5ºC, the device enters its ‘power saving’ mode and begins to duty cycle the laser. Immediately, we see a drop in the laser temperature of around 2-3ºC. This drop allows us to continue operating the device even while the ambient temperature rises. If the laser ends up reaching 52.5ºC, as it does on July 23rd in Figure 1, we see the device enter the ‘hibernate’ mode where the laser is completely shut off to prevent damage. When this happens, we see the laser temperature drop an additional 1ºC. As soon as the laser temperature cools off, the laser is turned back on and the device continues to collect data.

Overall, this method substantially increases the operating temperature range of all QuantAQ products without a need for physical changes to the device.

# Citing this document

If you would like to reference this document, please use the citation format listed below. For more information, please visit the direct link on Zenodo.

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# References

(1) Hagan, D. H.; Cross, E. S. Introduction to the MODULAIR-PM. **2024**. https://doi.org/10.5281/zenodo.10688216.

# Changelog

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| 2024.08.30 | This is the first release of QAN 005. |