MARK6 MEMO #011

MIT, HAYSTACK OBSERVATORY
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To: ngEHT Recorder Group
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Subject: Mark6 Hypobaric Chamber Thermal Testing, Sep 28, 2023

1 Overview

Testing was undertaken of the current (AMD-based) Mark6 hardware in the hypobaric chamber to demonstrate that it is capable of being operated in accordance with a typical EHT observing schedule over a period of about 16 hours while writing to hard disk (HDD) at an aggregate data rate of ∼32Gbps (32.896Gbps). The air pressure of the chamber was maintained between -42kPa and -39kPa relative to the air pressure in the lab.

2 Equipment Configuration

The equipment use for this test was as follows:

1. 1x Upgraded Mark6 with expansion chassis. The current model is based on an AMD EPYC 7282 16-Core CPU, operating system was Centos 7.9 running dplane v2.00 and cplane v2.1.1.
2. 4x 80TB Mark6 modules (8x Seagate ST10000NM0016-1T 10TB HDD) and associated SAS cables.
3. 2x R2DBEs.
4. 4x SFP+ network cables.
5. 1x EHT M&C computer.
6. 1x 2048MHz/1PPS timing distribution board and associated SMA cables.
7. 1x 10MHz, and 1PPS timing reference.
8. 1x 1Gbe network switch and associated cables.
9. 1x Hypobaric chamber with water chiller/circulation system (to keep chamber temperature near ambient).
10. 1x Raspberry Pi (RPi) SBC with temperature probes for internal Mark6 temperature monitoring.
11. 2x 6 outlet power strips.

The Mark6 and an expansion chassis were loaded with into the hypobaric chamber, positioned on the upper shelf and populated with four 80TB modules taken from the EHT media pool. Two R2DBEs along with the associated timing distribution box were located underneath the shelf supporting the Mark6. The R2DBEs were connected to timing distribution box which was subsequently connected to the 10MHz and 1PPS reference signals fed through the side of the hypobaric chamber. The two digital (channel 0/1) outputs of each R2DBE were connected to (one to each of the four) 10G network ports of the Mark6 using 6ft long copper network cables with SPF+ connectors. The RPi SBC was powered from a USB port of the Mark6, and positioned to the side of the R2DBEs. The four temperature probes provided by the RPi were then fed in through an open PCIe slot at the back of the Mark6 and positioned in the following locations:

1. On the CPU heatsink.
2. Between the two 10G network interface cards (Intel XXV710).
3. Between the two host-bus-adapter cards (ATTO H12F0GT).
4. At the air inlet to the motherboard compartment (just behind the disk modules).

The temperatures were logged every four seconds throughout the duration of testing. The Mark6, RPi SBC and both R2DBEs were connected to a 5 port 1G network switch which was connected to the main monitor and control (M&C) computer (kept outside of the chamber). The R2DBEs were booted from the M&C using the standard EHT configuration scripts.

Figure 1: The Mark6 and expansion chassis in the hypobaric chamber. The two R2DBEs and timing distribution box are underneath the support shelf. The RPi SBC is to the left of the R2DBEs, while the black air circulation fans and radiators are visible to the right side. The water circulation hose and 1G network switch are visible just beneath the R2DBEs.

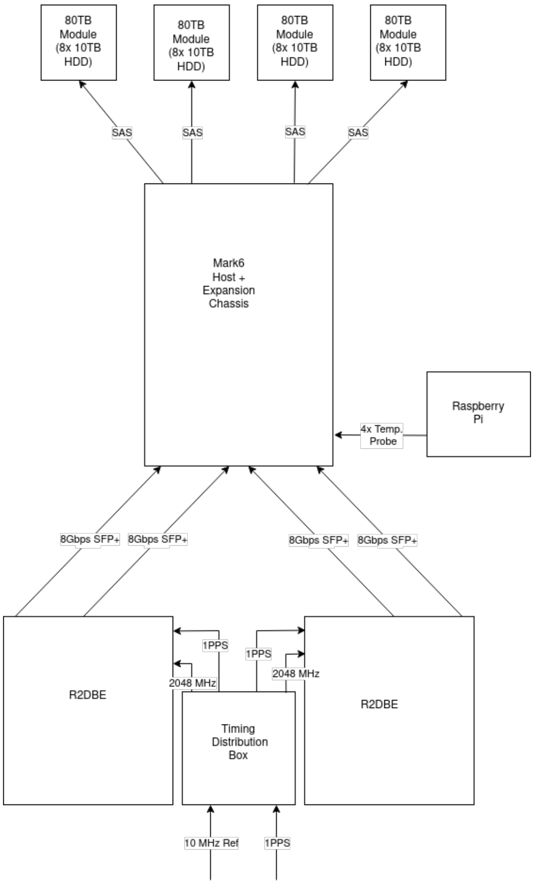

Figure 2: The overall signal flow of the test. The timing distribution box feeds 1PPS and 2048MHz clock signals to each R2DBE synthesized from a reference source. The 8Gbps output of each of the two channels per R2DBE were then connected via ethernet to the four (SFP+) 10G network ports of the Mark6. Each channel was assigned to a single 80TB module. The raspberry pi provided four temperature probes fed in through an open PCIe slot in the back of the Mark6 to monitor temperature of the CPU, NIC, HBA, and air inlet.

3 Testing Procedure

The testing of the Mark6 system was carried out as follows. First the RPi temperature probes were placed at the aforementioned probe points inside the Mark6 and fed out through the back panel. Then the Mark6 and expansion chassis together with RPi were loaded into the hypobaric chamber and populated with 80TB modules. Next, the R2DBEs along with the timing distribution box were loaded into the chamber and cabled together appropriately. The R2DBE (signal) inputs were left unconnected. Then the (1G) control network was cabled via the 5-port switch to the external M&C computer. The R2DBEs were then configured to send data and all 4 data links were connected to the Mark6's 10G input ports (eth2, eth3, eth4, and eth5). Communication between the Mark6 and R2DBEs was then verified and the recording group and input streams of the Mark6 were configured as follows (each module consuming data from one stream):

```
>> input_stream=add:r2dbe2:vdif:8224:50:42:eth2:172.16.2.16:4001:1
>> input_stream=add:r2dbe3:vdif:8224:50:42:eth3:172.16.3.16:4001:2
>> input_stream=add:r2dbe4:vdif:8224:50:42:eth4:172.16.4.16:4001:3
>> input_stream=add:r2dbe5:vdif:8224:50:42:eth5:172.16.5.16:4001:4
>> input_stream=commit
>> group=open:1234
```

A quick test recording was done to verify that data from the R2DBEs was being properly captured. Next the water circulation system was turned on, and a short (2 hour), test schedule run at ambient temperature and pressure was executed to verify everything was functioning as expected with the chamber door wide open. This consumed about 7% of the module space. After the quick test, the chamber door was closed and the vacuum pump was turned on. The needle valve controlling the air leakage rate was adjusted until the chamber pressure gauge remained stable at -42kPa relative to ambient pressure in the lab. The analog air temperature gauge on the front of the chamber was checked to read 70F. A remote login to the recorder was initiated and a 16 hour simulated schedule composed of 5-15 minute long scans with gaps of 2-3 minutes between each scan was generated with the following command:

```
create-schedule.py -t 16 -d 60 -s 300,900 -i 120,300 -e qcheck -c Ho -n -u qcheck -x
```

and launched using `M6_CC -f ./qcheck.xml`. Upon completion of the simulated schedule the dplane and temperature logs were retrieved, and the consumed module capacity was about 61%. The analog gauges on the front of the hypobaric chamber were checked to ensure that the temperature and pressure were in the expected range and were found to read (68F and -39kPa). A script was used to verify that all the scatter-gather data fragments for each scan were present and the packet loss (fill) rate was zero. Afterward, as a control, another ∼5 hour simulated schedule was run with the chamber left at the ambient lab pressure (but with the door closed and water circulation system running).

4 Results

Upon completion of the test schedule the dplane logs were collected and the reported number of good packets collected per stream was compared to the expected number (125000/s). For each scan the reported fill (or dropped) packets was zero. A scan_check was run on each scatter-gather fragment to check for timing issues (or VDIF header corruption) and none was detected. A deep inspection of the VDIF data was not done, since the R2DBE signal inputs were unconnected and the sample statistics are not meaningful.

4.1 Air pressure

Since there was no continuous digital monitoring of the chamber air pressure, we relied on an analog pressure gauge attached to the front of the chamber to measure the pressure difference between the lab and the chamber interior. At the start of the schedule the reading of this gauge was -42kPa, and at the end of the schedule it read -39kPa, an analog temperature gauge mounted alongside this pressure gauge simultaneously read 70F (21.1C) and 68F (20C) respectively. Nominally, the (dry) atmospheric pressure as a function of altitude, h, is given by:

$$P_h = P_0 e^{-\left(\frac{gMh}{RT}\right)} \tag{1}$$

where P_0 is the pressure at sea level (101.3 kPa), g is the gravitational acceleration ($9.81 m/s^2$), R is the universal gas constant, T is the temperature in Kelvin, and M is the molar mass of dry air (0.02897 kg/mol). Neglecting the altitude of the lab (125m), and assuming the gauge pressure $P_g = P_h - P_0$, implies that the equivalent altitude of the chamber is given by:

$$h = -\left(\frac{RT}{gM}\right) \log\left(1 + \frac{P_g}{P_0}\right) \tag{2}$$

From this equation and the temperature and pressure readings at the beginning and end of the experiment, we can deduce the equivalent altitude for the environment in the hypobaric chamber was somewhere roughly between 13.7-15.0 kft. The calculated values are given in the table below.

	Gauge Pressure (kPa)	Temperature (C)	Equivalent Altitude (m)	Equivalent Altitude (ft)
start	-42.0	20.0	4591.6	15064
end	-39.0	21.1	4185.5	13731

Table 1: The pressure and temperature readings of the hypobaric chamber at the beginning and end of the simulated schedule and the equivalent altitude.

4.2 Temperature logs

The temperature was monitored at the four aforementioned locations within the recorder during the course of this experiment. Plots of the temperature as a function of time for each location are shown in figures 3 to 10. These plots are provided in pairs. The first showing the temperature at each measurement location for a short (∼5 hours) simulated schedule carried out the ambient temperature and pressure of the lab (roughly 70F, sea-level), and the second plot showing a longer (∼16 hours) simulated schedule carried out in the chamber in a simulated high-altitude environment. All plots are shaded red while the recorder was actively recording, and unshaded during idle time.

For the most part, the air temperature at the recorder's ventilation inlet was fairly stable during each simulated schedule, not varying much more than about 1-1.5C during the course of the measurement, and remaining elevated by about 3C on average in the simulated high-altitude environment as compared to the lab environment.

The temperature of the CPU heatsink sensor had the greatest variation during the simulated schedule, changing by about 2C between active recording and the idle state while in the lab environment, and by about 3C between the two states while in the simulated high-altitude environment. The average temperature of the CPU heatsink was also remained about 5C hotter in the high-altitude environment. The temperature of the sensor monitoring the NIC had the least variation between recording and idle states, maintaining a relatively stable temperature throughout the simulated schedule, and with the average temperature difference (3C) between lab and high-altitude largely explained by the increase in average inlet air temperature. Of all the individual components that were monitored, the HBA's appeared to experience the largest temperature increase (roughly 8.5C) when moving from the lab to the high-altitude environment. However, their temperature variation between active and idle states remained around roughly 0.5C in both environments.

At no point during the test did the system experience any thermal stress reported by the kernel (CPU clock throttling, kernel panic, or other syslog messages).

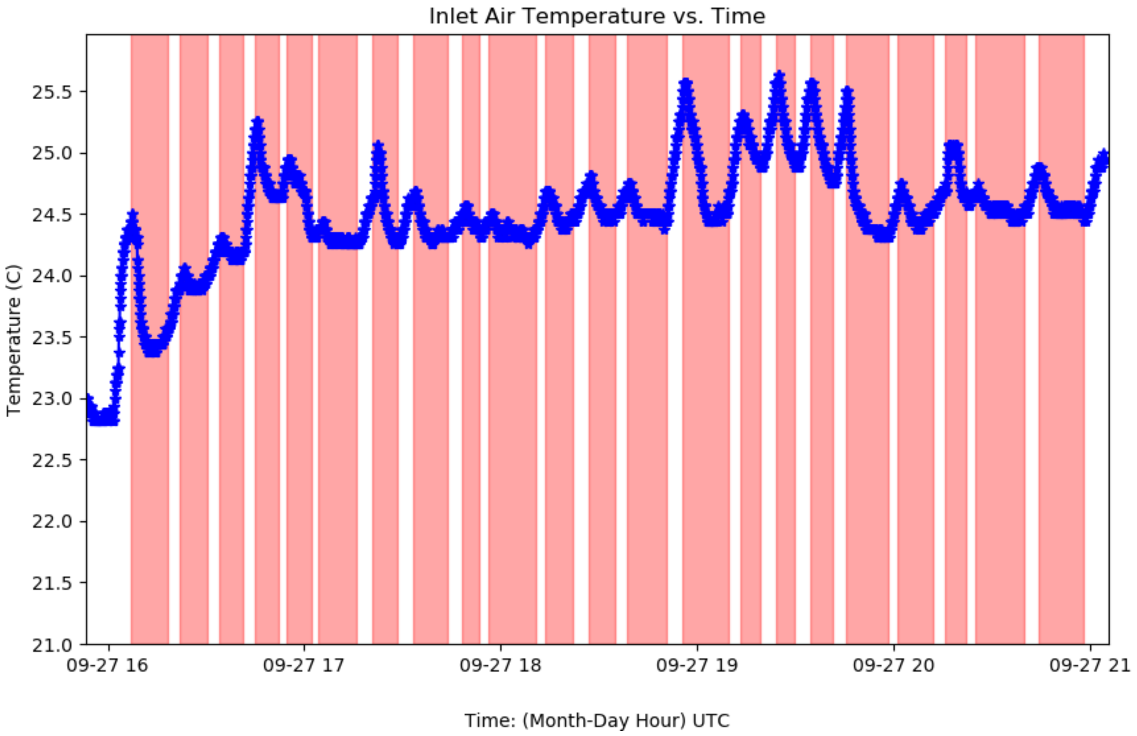

Figure 3: Air inlet sensor temperature during a ∼5 hour simulated schedule at ambient air pressure (Red shading: recorder active, No shading: recorder idle).

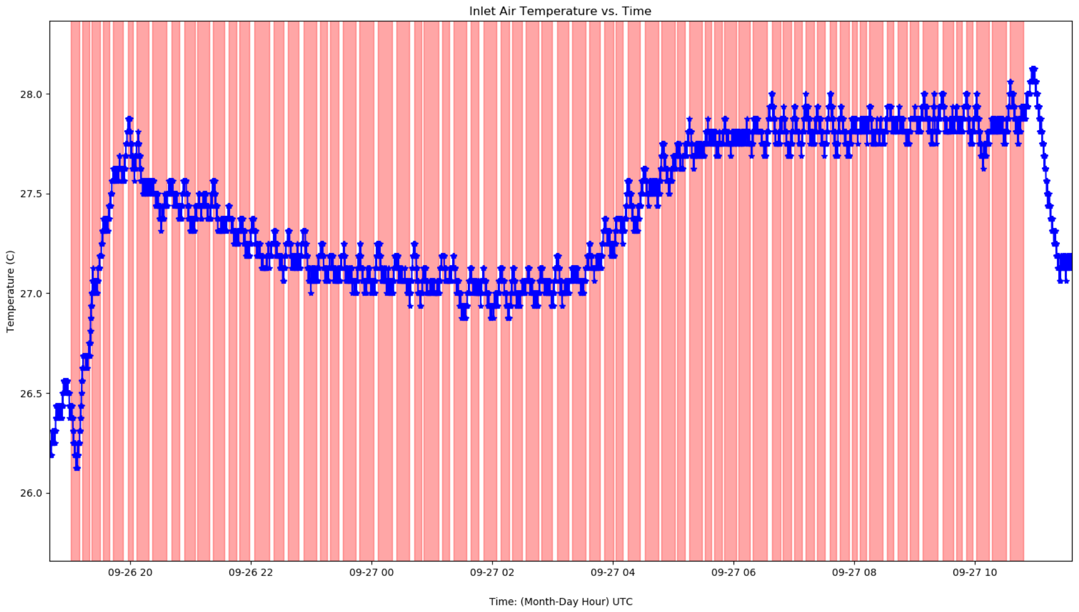

Figure 4: Air inlet sensor temperature during a ∼16 hour simulated schedule at high altitude air pressure (Red shading: recorder active, No shading: recorder idle).

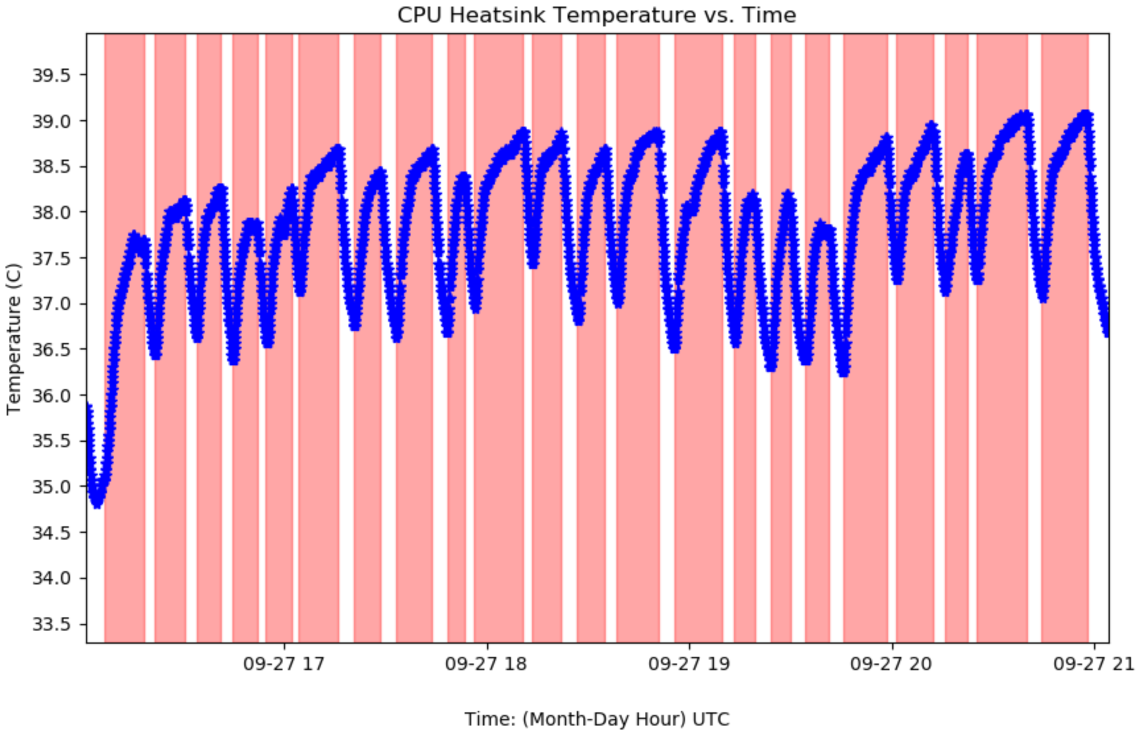

Figure 5: CPU heatsink sensor temperature during a ∼5 hour simulated schedule at ambient air pressure (Red shading: recorder active, No shading: recorder idle).

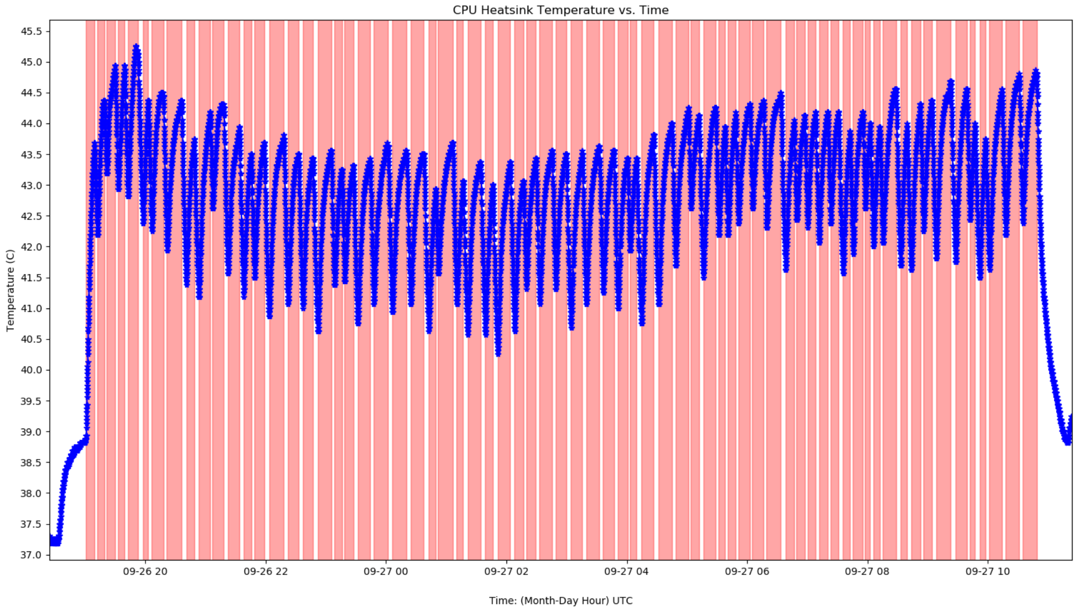

Figure 6: CPU heatsink sensor temperature during a ∼16 hour simulated schedule at high altitude air pressure (Red shading: recorder active, No shading: recorder idle).

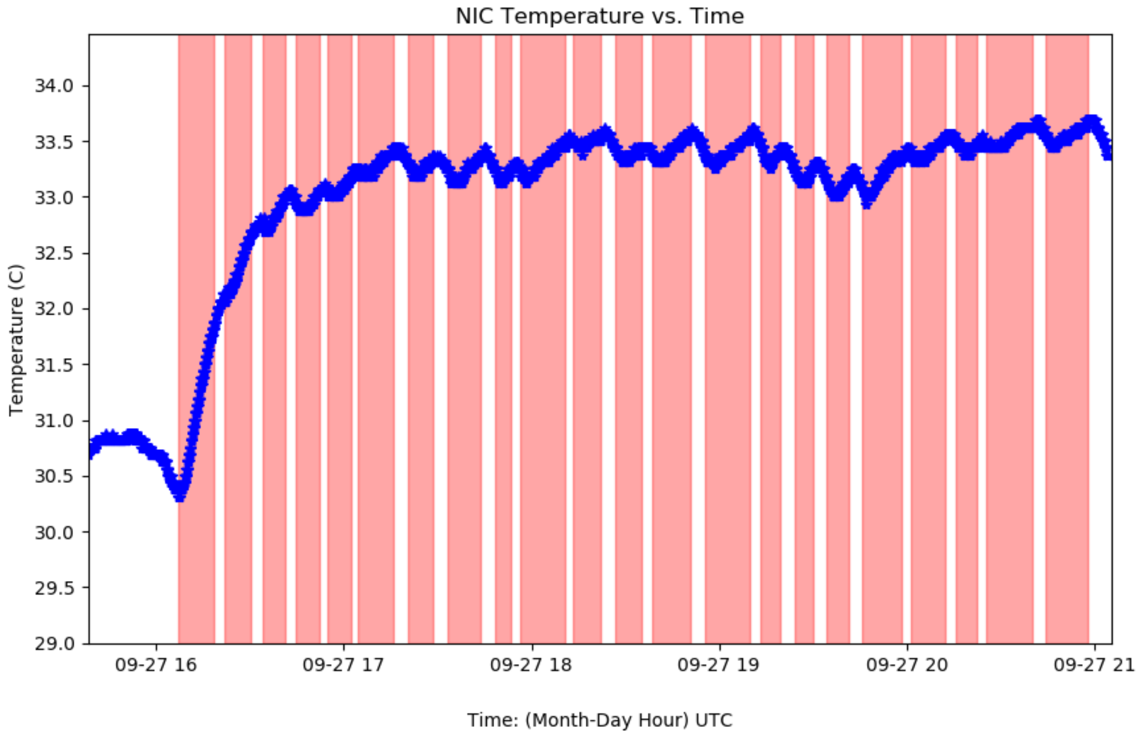

Figure 7: NIC sensor temperature during a ~5 hour simulated schedule at ambient air pressure (Red shading: recorder active, No shading: recorder idle).

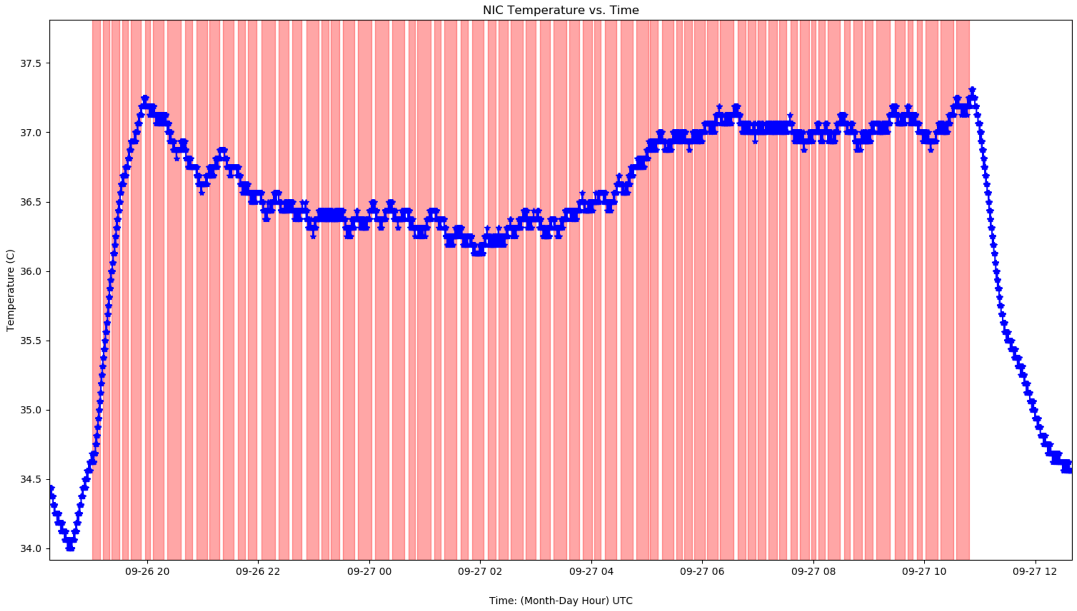

Figure 8: NIC sensor temperature during a ~16 hour simulated schedule at high altitude air pressure (Red shading: recorder active, No shading: recorder idle).

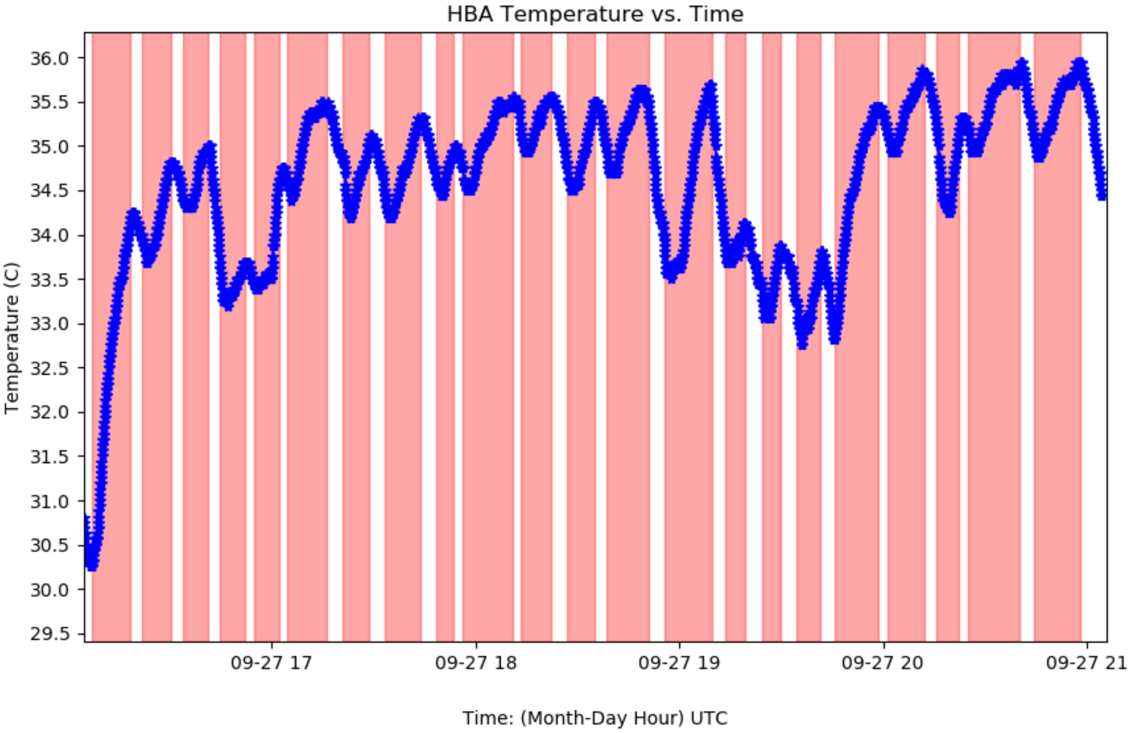

Figure 9: HBA sensor temperature during a ∼5 hour simulated schedule at ambient air pressure (Red shading: recorder active, No shading: recorder idle).

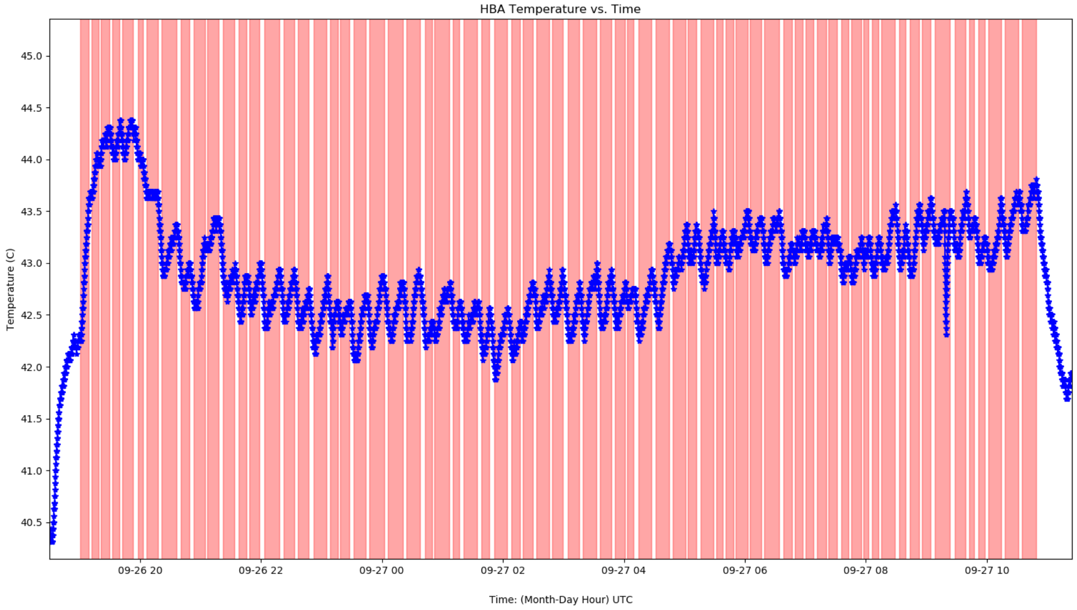

Figure 10: HBA sensor temperature during a ∼16 hour simulated schedule at high altitude air pressure (Red shading: recorder active, No shading: recorder idle).