1. INTRODUCTION

This study presents a comprehensive analysis of Space Acceleration Measurement System (SAMS) measurement data from 3 triaxial sensor heads collected over 9 months aboard the International Space Station (ISS). Focusing on the 0.2–1 Hz frequency range, the analysis primarily captures the ISS's structural mode responses, which are predominantly influenced by crew activities such as locomotion, exercise, and operational tasks. Key qualitative findings highlight consistent hour-of-day patterns, sensor cross-consistency, the significance of higher acceleration magnitudes and more variability thereof during crew wake/active hours, and implications for operational planning and structural health monitoring. Additionally, the study is intended to inform the impact of structural vibrations on the SpaceX Dragon vehicle's tank sloshing/fluid dynamics. The insights gained provide a comprehensive foundation over the 9-month span of interest at the 3 SAMS sensor locations closest to a typical Dragon vehicle docking location, the Node 2 Forward (N2F) docking port of the ISS.

The ISS visiting vehicle configuration depicted in Figure 1 on page 3 shows Crew-9 Dragon docked at the N2F port of the ISS along with 3 colored dots at the 3 SAMS sensor head locations used in the analyses for this document:

1) SAMS sensor 121f05 in JPM1F1
2) SAMS sensor 121f02 in COL1A1
3) SAMS sensor 121f08 in COL1A3

2. QUANTIFY AND QUALIFY

The intent of the processing and analysis of SAMS acceleration measurements was to give a statistical accounting of a large volume (9 months) of SAMS data at 3 sensor head locations in the form of hour-of-the-day (GMT) percentile statistics for acceleration values: vector magnitude, X-, Y-, and Z-axis. In this way, we can see how factors related to hour-of-day separate themselves in the form of acceleration statistics of P5, P25, P50, P75, and P95 – see the legend information depicted in Figure 2 on page 4 for details on how boxplot markers (shown later in this document) map to percentile statistics.

The remainder of the technical narrative in this section references the following 12 figures:

- The 3 figures on 3 consecutive pages starting with Figure 3 on page 5 show the acceleration vector magnitude summary (percentile) statistics for the 3 sensor locations.
- The 9 figures on 0 consecutive pages starting with Figure 6 on page 8 show the per-axis summary (percentile) statistics for each of the 3 sensor heads.

ISS Structural Response

The 0.2 to 1 Hz bandpass filter targets structural vibrations, capturing the natural frequencies excited by mechanical interactions. The measurements provide key insights into the vibrational behavior of the ISS, particularly during operational crew activities, locomotion, and exercise. Crew activities can influence the vibratory environment of the ISS up to higher frequencies (typically below 10 Hz), but this analysis specifically focuses on the 0.2 to 1 Hz range as per the study's objectives.

Patterns

Across all three sensors in the two modules, lower acceleration activity (indicated by tighter boxplots and less spread) is observed during the early morning and late evening hours. This reduction aligns with decreased operational activities during these times, such as crew off-duty periods and sleep, resulting in minimal locomotion pushoffs/landings and no exercise. Conversely, higher acceleration activity is detected during the remaining hours of the day, correlating primarily with active crew engagements.

Outliers and Extremes

More frequent and pronounced outliers, specifically at the 5th (P5) and 95th (P95) percentiles, occur during daytime hours across all sensors. This indicates higher variability and the presence of occasional extreme vibrational events during periods of increased crew activity.

Cross-Sensor and Directional Consistency

Despite being located in different modules, the sensors exhibit similar overall patterns in response to structural vibrations. This suggests that global factors, such as orbital dynamics and platform-wide structural responses, dominate the ISS's acceleration profile within this lower-frequency regime. Additionally, the Z-axis consistently demonstrates higher sensitivity and greater variability in acceleration measurements, likely due to the vertical orientation of structural elements and the nature of docking activities that induce more pronounced vibrations along this axis.

Operational Impact

This analysis can inform and guide the scheduling of science experiments and other sensitive operations by identifying periods of lower vibrational activity, thereby minimizing potential interference. The observed increase in vibrational activity during specific hours underscores the necessity for continuous vibrational monitoring to mitigate potential impacts on structural health and ensure the longevity and safety of the ISS infrastructure.

Structural Health Monitoring

The acceleration data serves as a valuable tool for tracking the long-term fatigue and dynamic behavior of the ISS structure, enabling the identification of potential risks for structural degradation over time. When integrated with other Structural Health Monitoring (SHM) techniques, such as modal analysis and finite element modeling, this data facilitates the early detection of anomalies, thereby ensuring the integrity and safety of the platform through proactive maintenance and intervention strategies.

Impact for SpaceX Dragon Tank and Fluid Sloshing

This nine-month investigation into the vibratory frequency regime (0.2–1 Hz) highlights the dynamic interactions between crew activities and the ISS's structural vibrations. Periods of crew locomotion, exercise, and operational tasks are primary contributors to the observed outliers and increased acceleration variations in the SAMS data. These structural vibrations can, in turn, influence fluid dynamics within the SpaceX Dragon tank, potentially leading to fluid sloshing phenomena that must be accounted for in tank design and operational protocols.

3. CONCLUSION

This analysis of acceleration measurements from the Space Acceleration Measurement System (SAMS) shows **consistent hour-of-day patterns**, where onboard time is kept in Greenwich Mean Time (GMT). It highlights how the crew's activities on the International Space Station (ISS) cause vibrations in the station's structure, especially in the low-frequency range of **0.2 to 1 Hz**. These low-frequency vibrations are important because they can affect how fluids behave inside the spacecraft — *for example, perhaps causing liquid fuel to slosh in the tanks of the Dragon vehicle*.

By examining statistical summaries (like percentiles) of the SAMS data, we have a solid foundation for assessing and predicting how the ISS responds to movements and **actions of the crew during wake hours, and less so during sleep**. Understanding these structural responses helps in planning operations, optimizing activity schedules, and maintaining the overall health of the space station.

In future studies, we may focus on adding data from more SAMS sensors in different locations on the ISS. This will help us better understand, via more empirical data, how the station moves and vibrates in these different areas. You might think of the ISS as a solid object, but in this low-frequency range (0.2 to 1 Hz), it does not act like a completely rigid body. Instead, it's more like a giant metal bridge that can (and should by design) sway slightly.

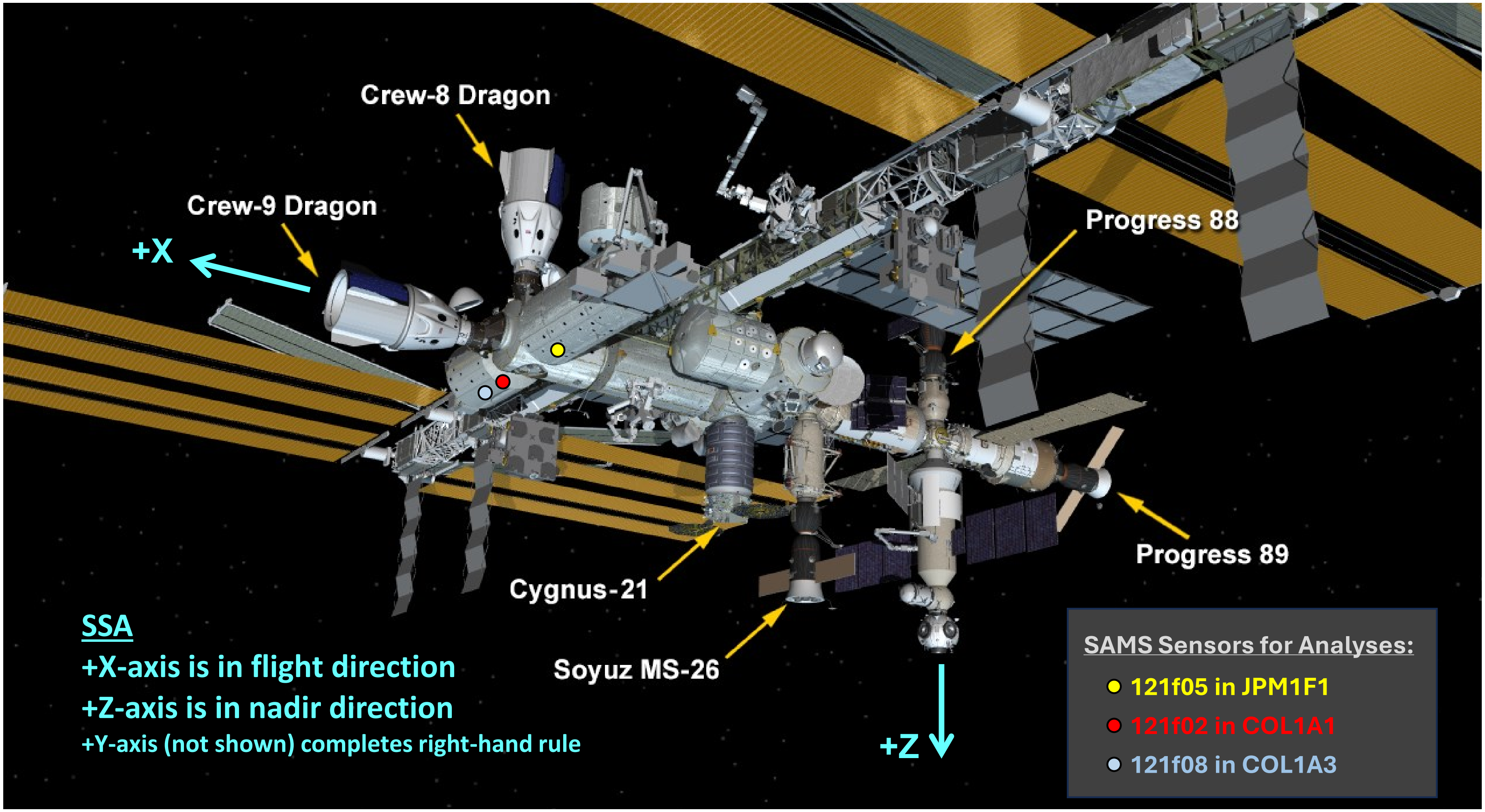

Fig. 1: ISS Visiting Vehicle Configuration on GMT 2024-09-26.

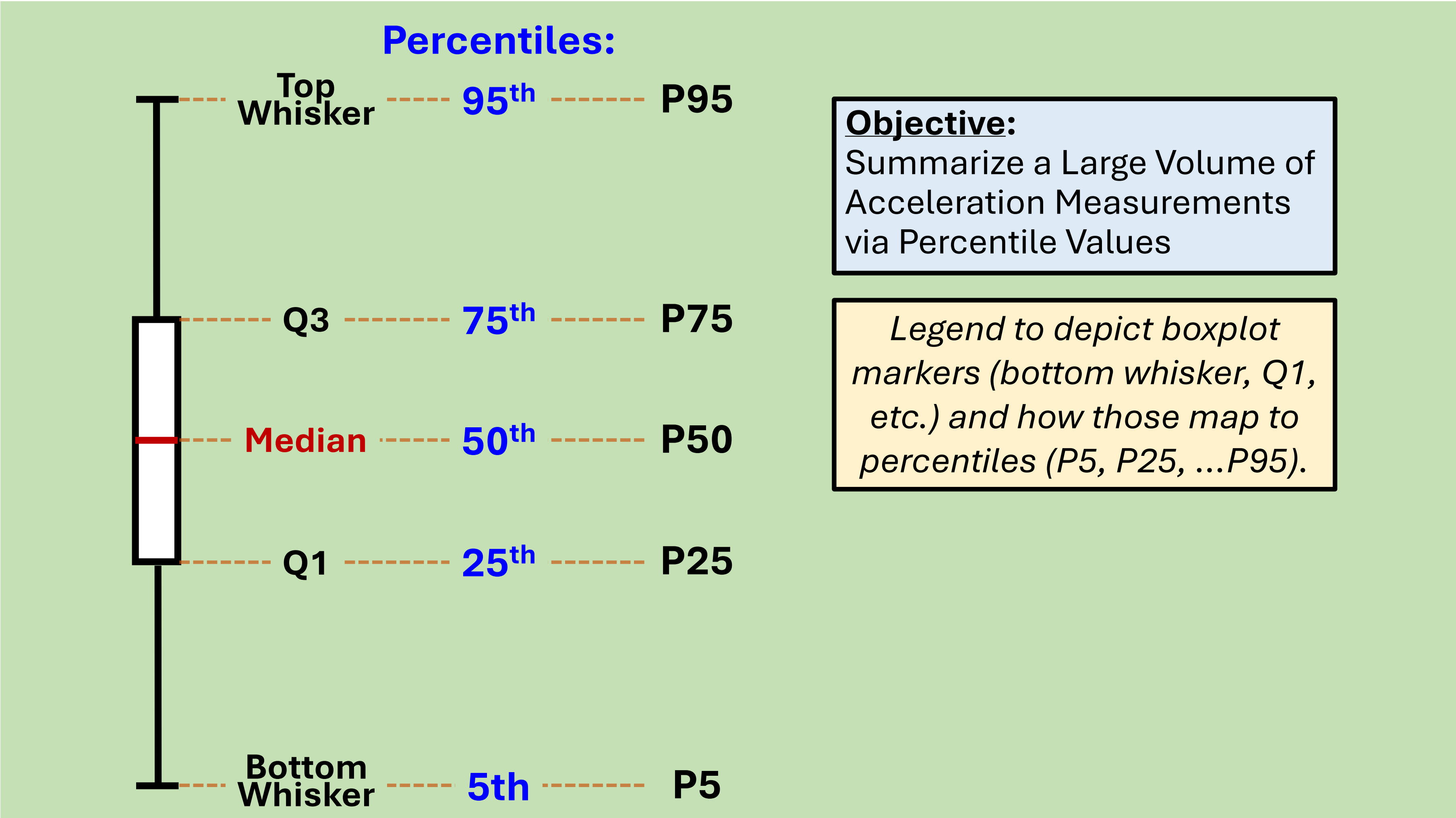

Fig. 2: Legend for Boxplot Statistics Shown in Later Plot Figures.

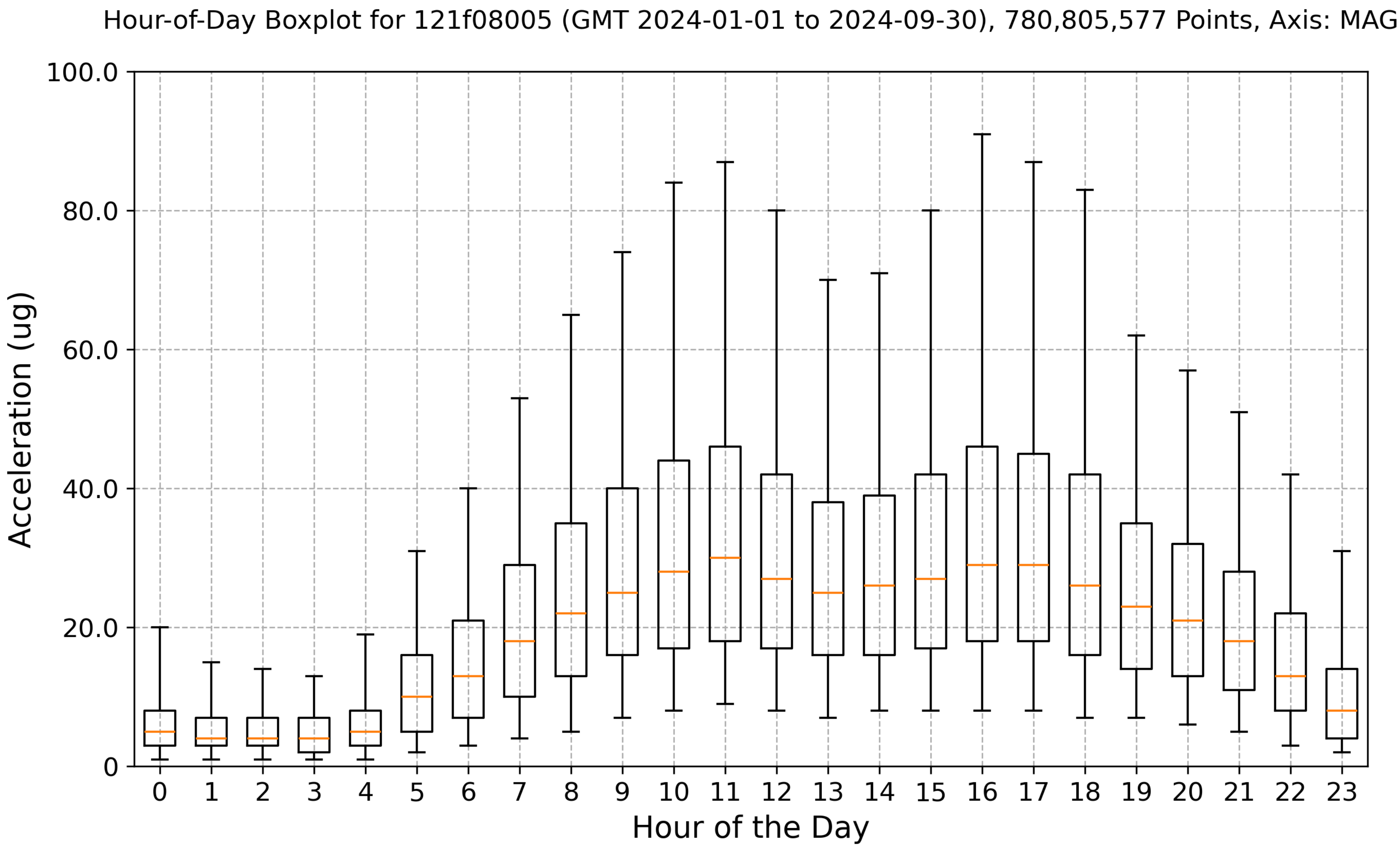

Fig. 3: SAMS Sensor 121f08 in COL1A3, Bandpass Filt.: 0.2 to 1.0 Hz, 9-Month Statistical Summary, Acceleration Vector Magnitude.

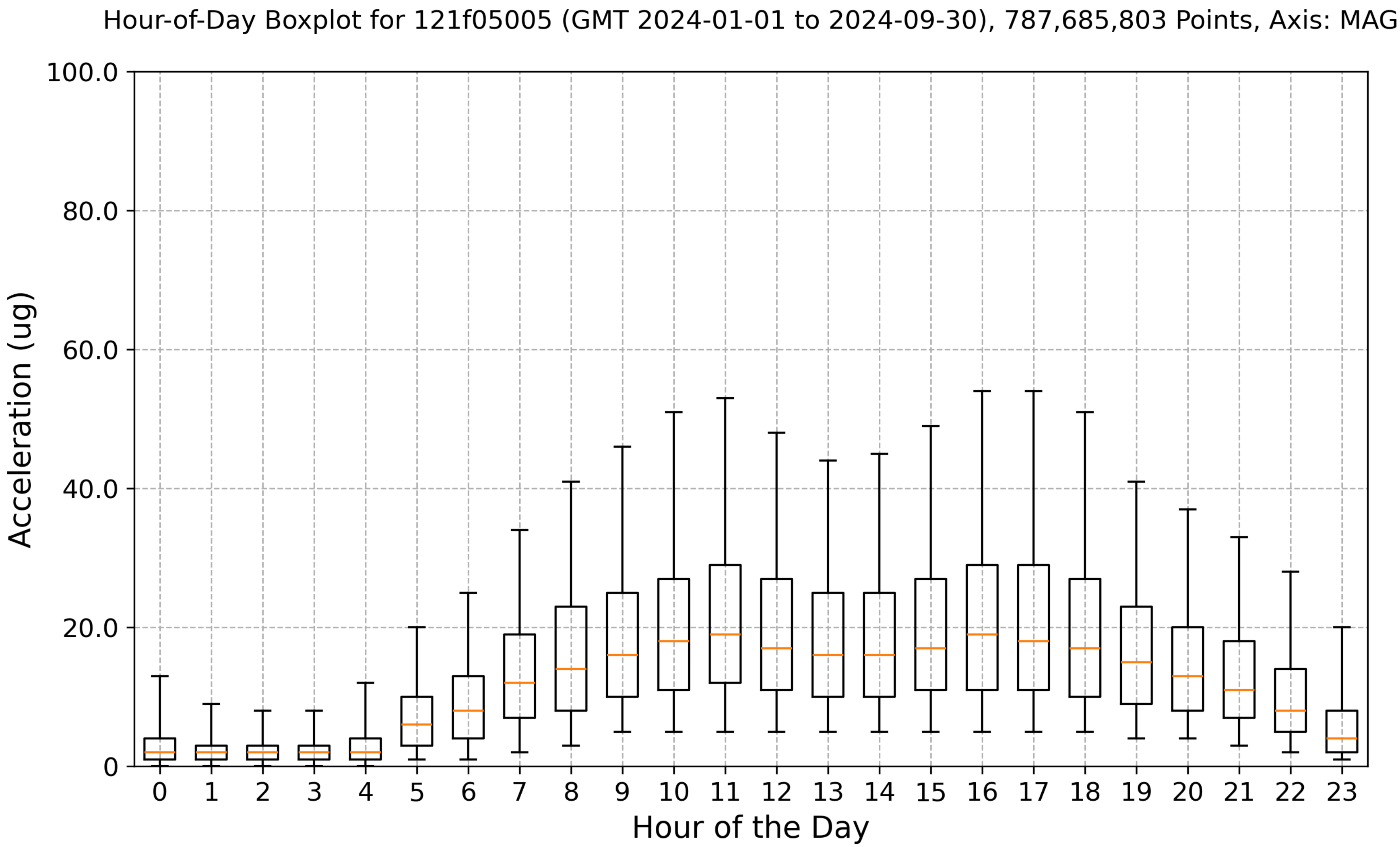

Fig. 4: SAMS Sensor 121f05 in JPM1F1, Bandpass Filt.: 0.2 to 1.0 Hz, 9-Month Statistical Summary, Acceleration Vector Magnitude.

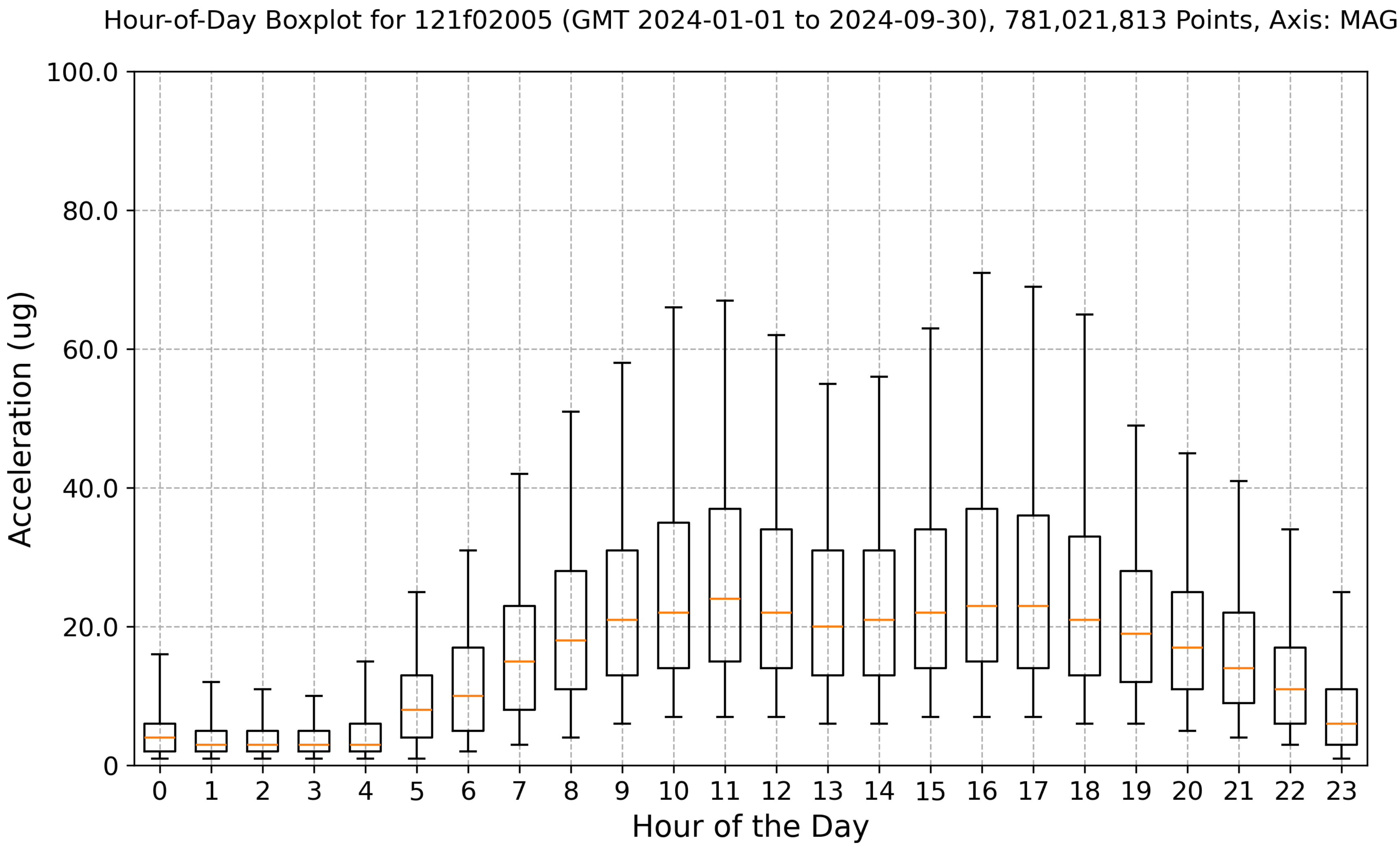

Fig. 5: SAMS Sensor 121f02 in COL1A1, Bandpass Filt.: 0.2 to 1.0 Hz, 9-Month Statistical Summary, Acceleration Vector Magnitude.

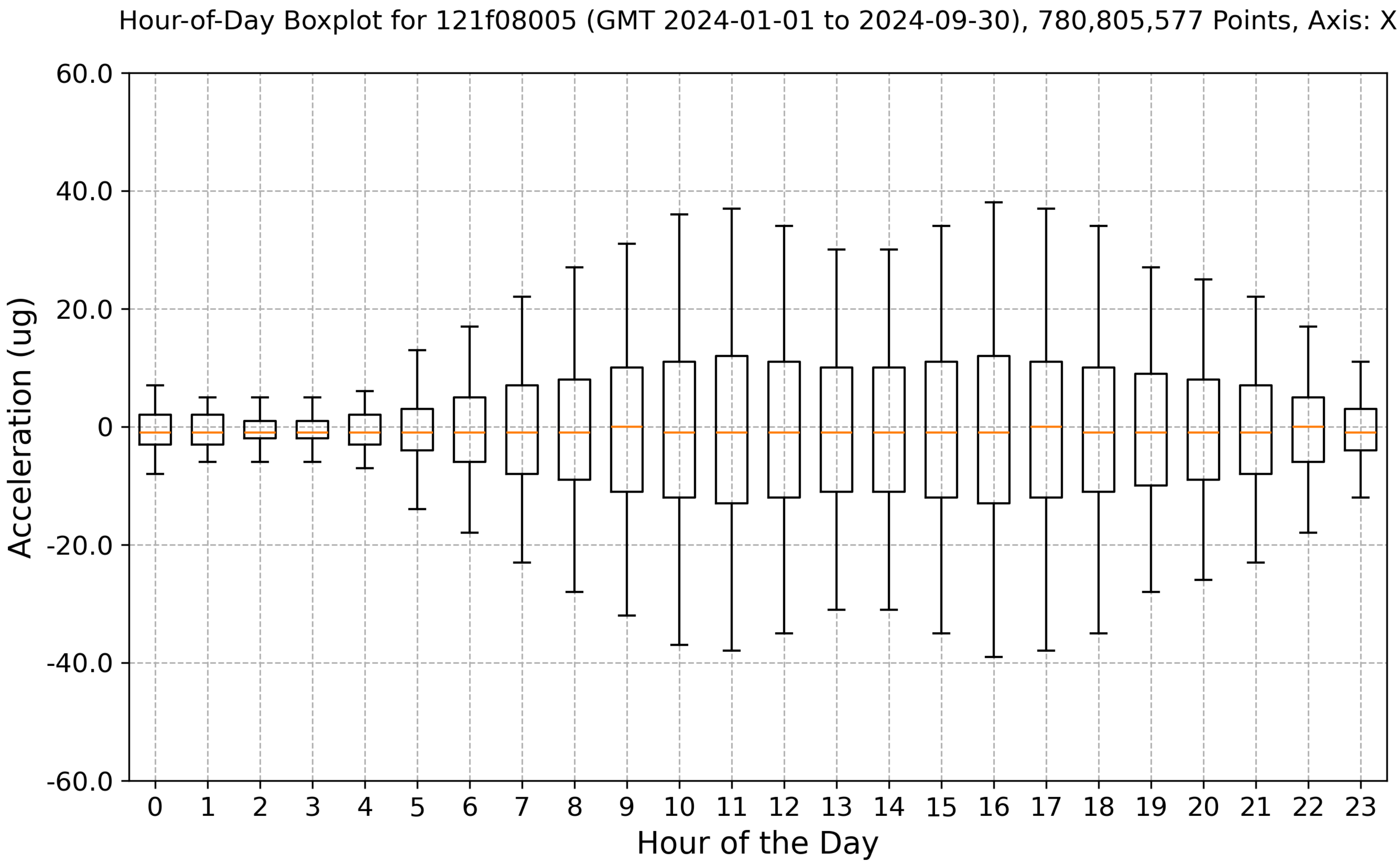

Fig. 6: SAMS Sensor 121f08 in COL1A3, Bandpass Filt.: 0.2 to 1.0 Hz, 9-Month Statistical Summary, X-Axis Acceleration.

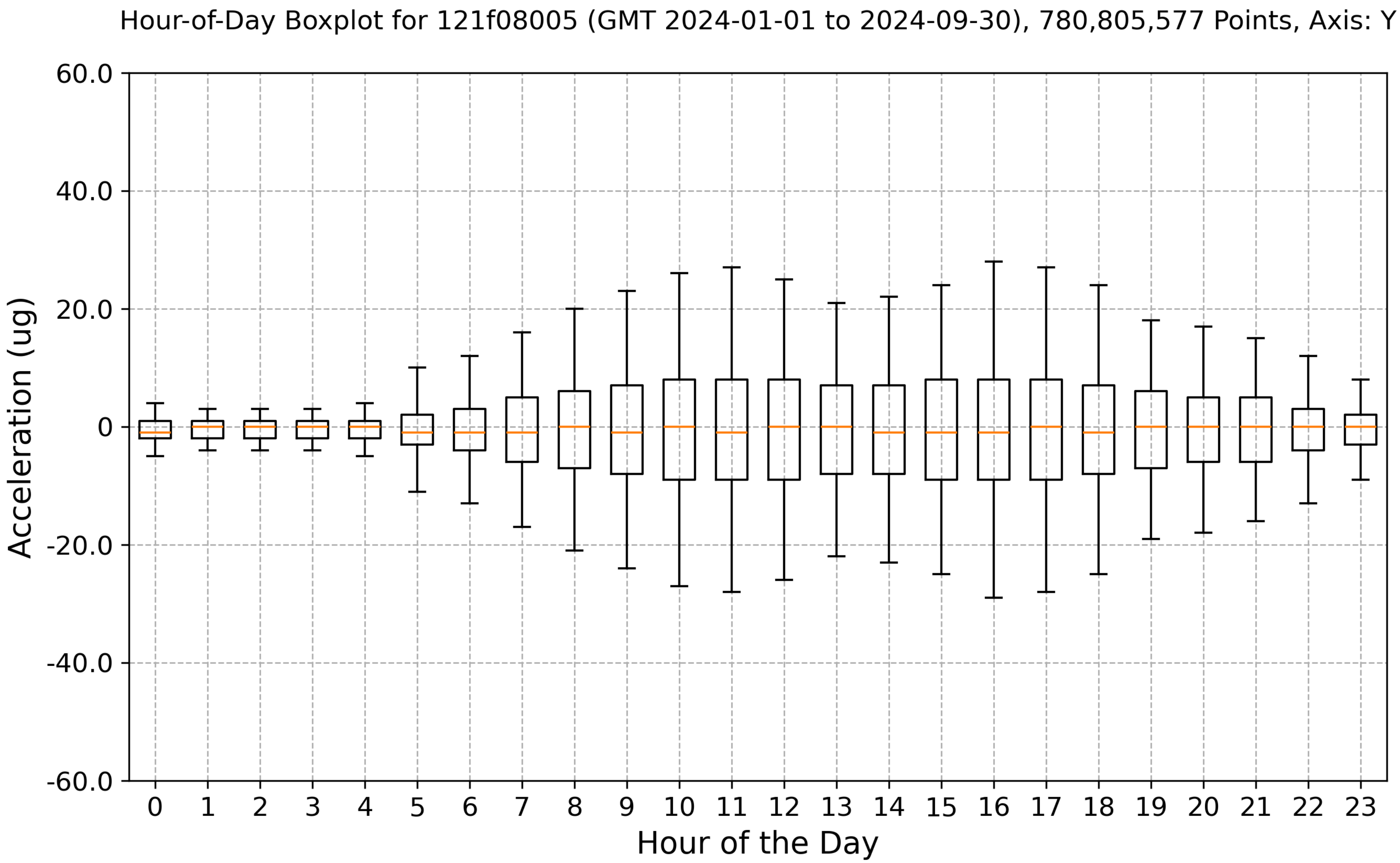

Fig. 7: SAMS Sensor 121f08 in COL1A3, Bandpass Filt.: 0.2 to 1.0 Hz, 9-Month Statistical Summary, Y-Axis Acceleration.

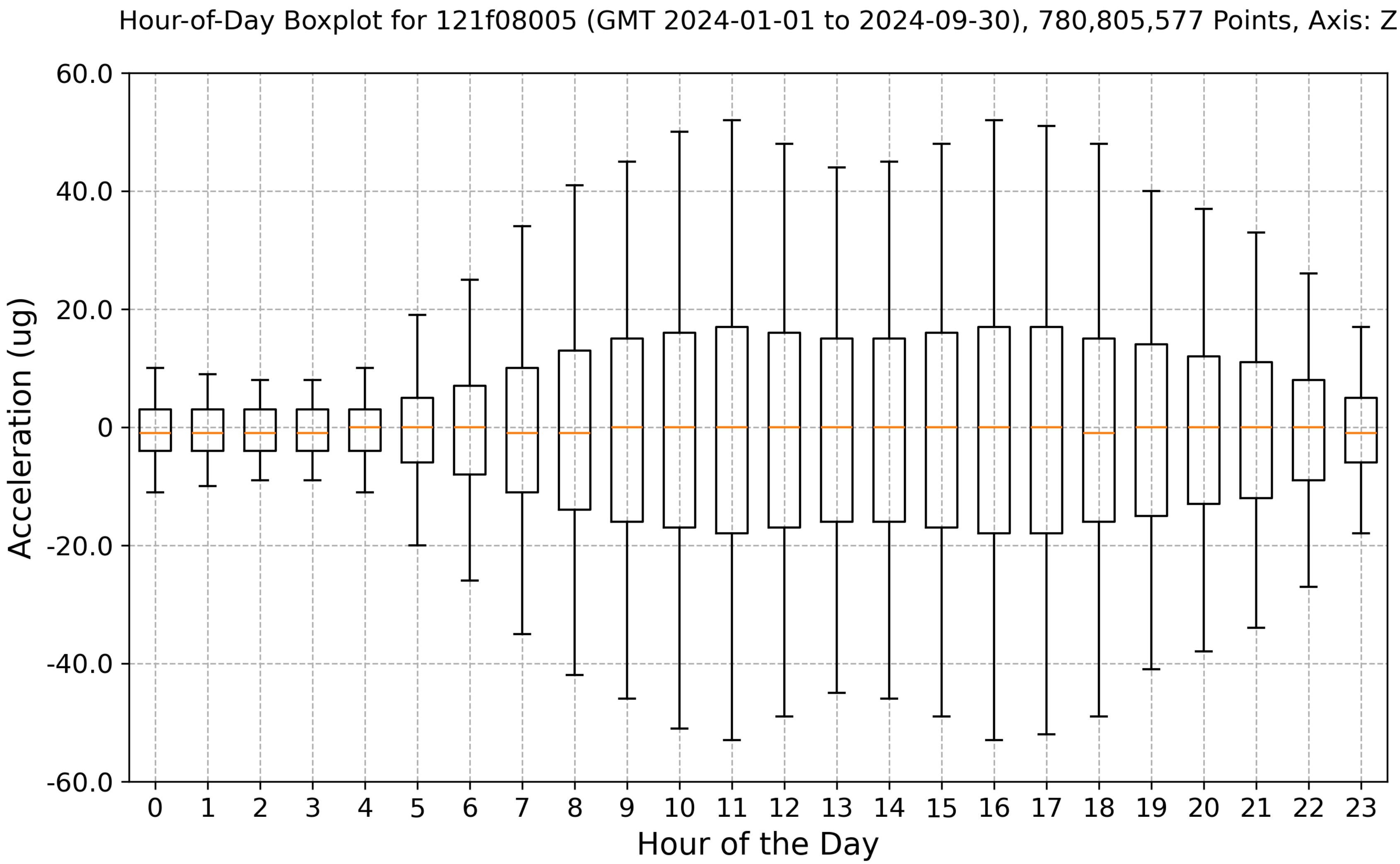

Fig. 8: SAMS Sensor 121f08 in COL1A3, Bandpass Filt.: 0.2 to 1.0 Hz, 9-Month Statistical Summary, Z-Axis Acceleration.

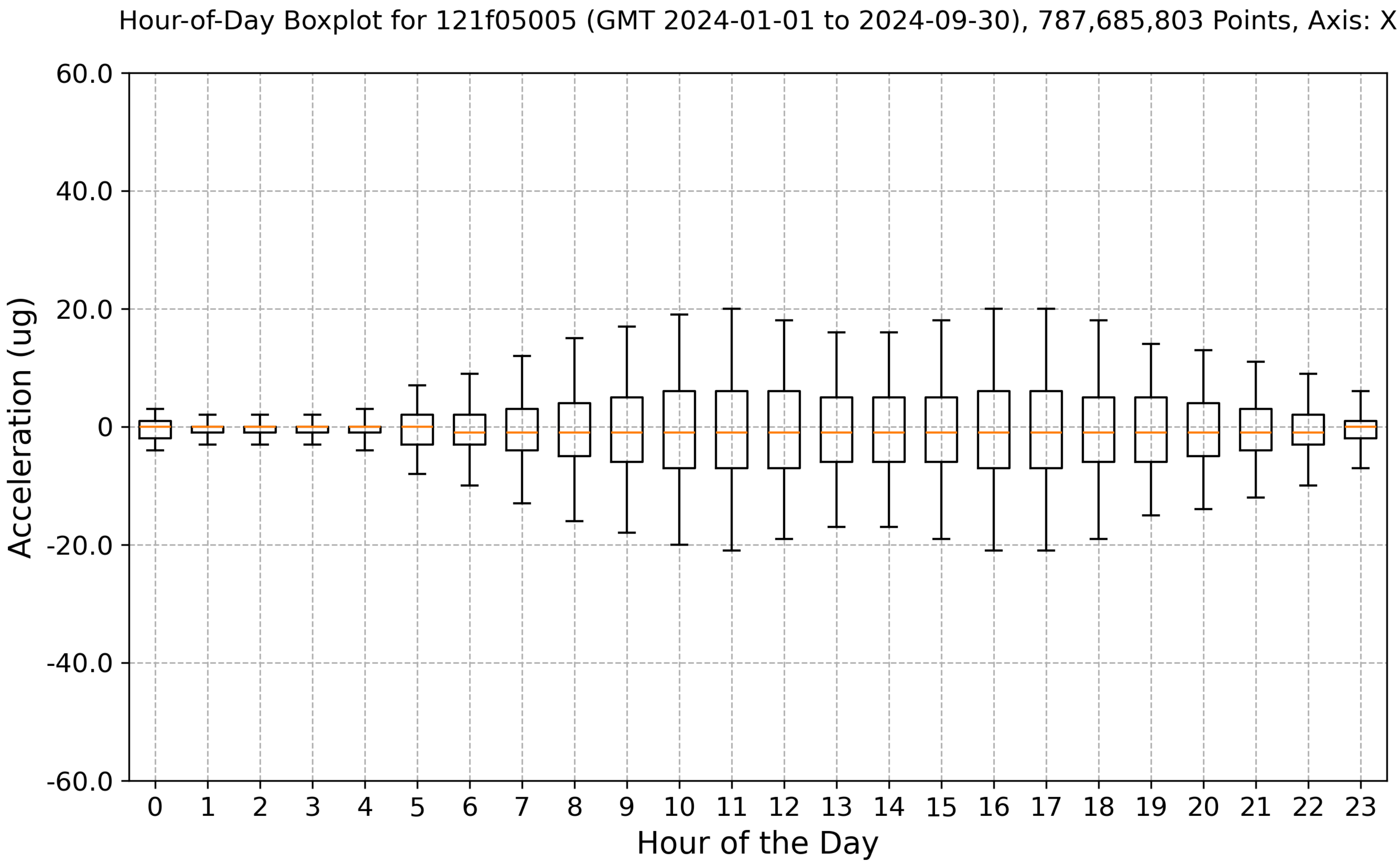

Fig. 9: SAMS Sensor 121f05 in JPM1F1, Bandpass Filt.: 0.2 to 1.0 Hz, 9-Month Statistical Summary, X-Axis Acceleration.

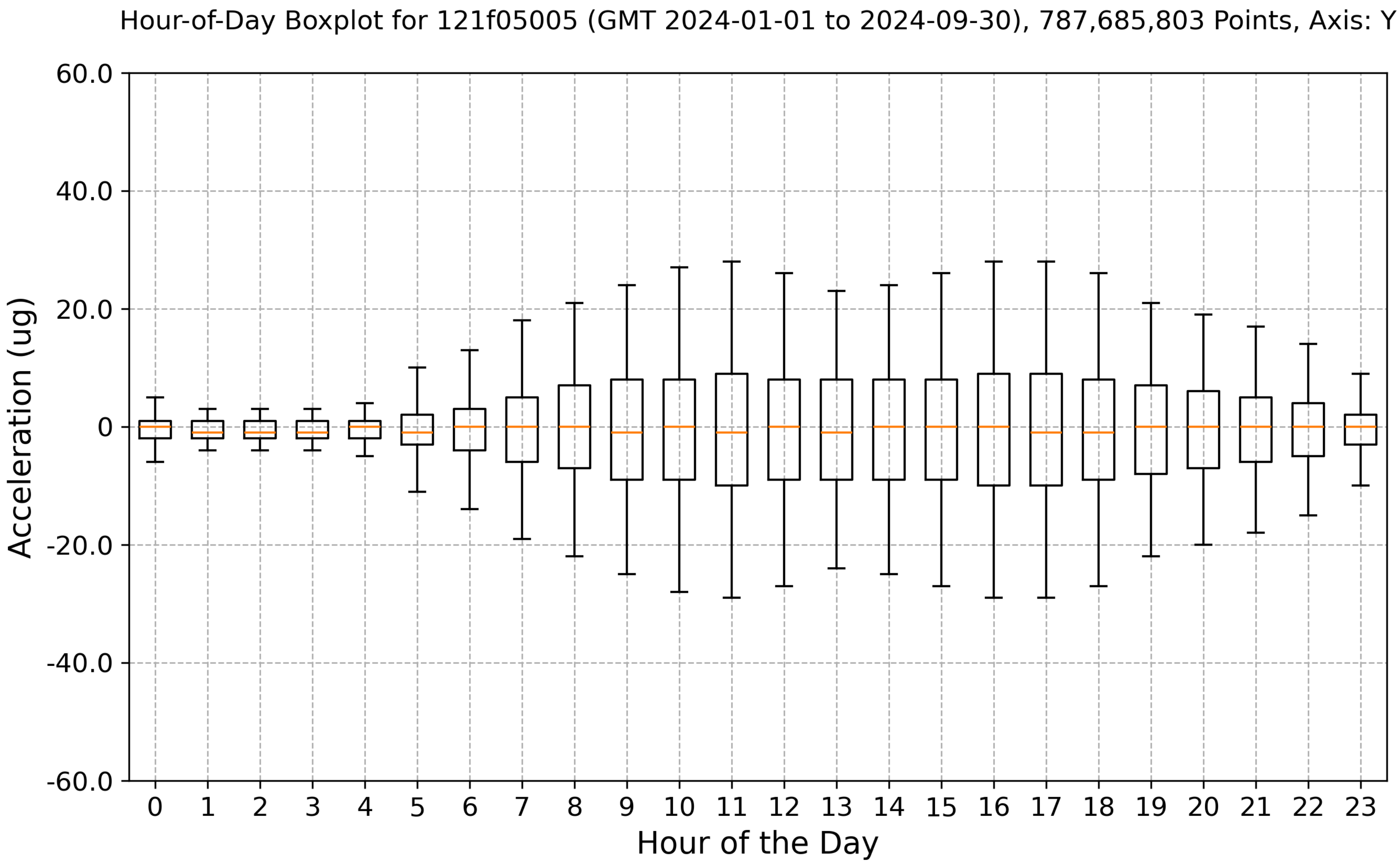

Fig. 10: SAMS Sensor 121f05 in JPM1F1, Bandpass Filt.: 0.2 to 1.0 Hz, 9-Month Statistical Summary, Y-Axis Acceleration.

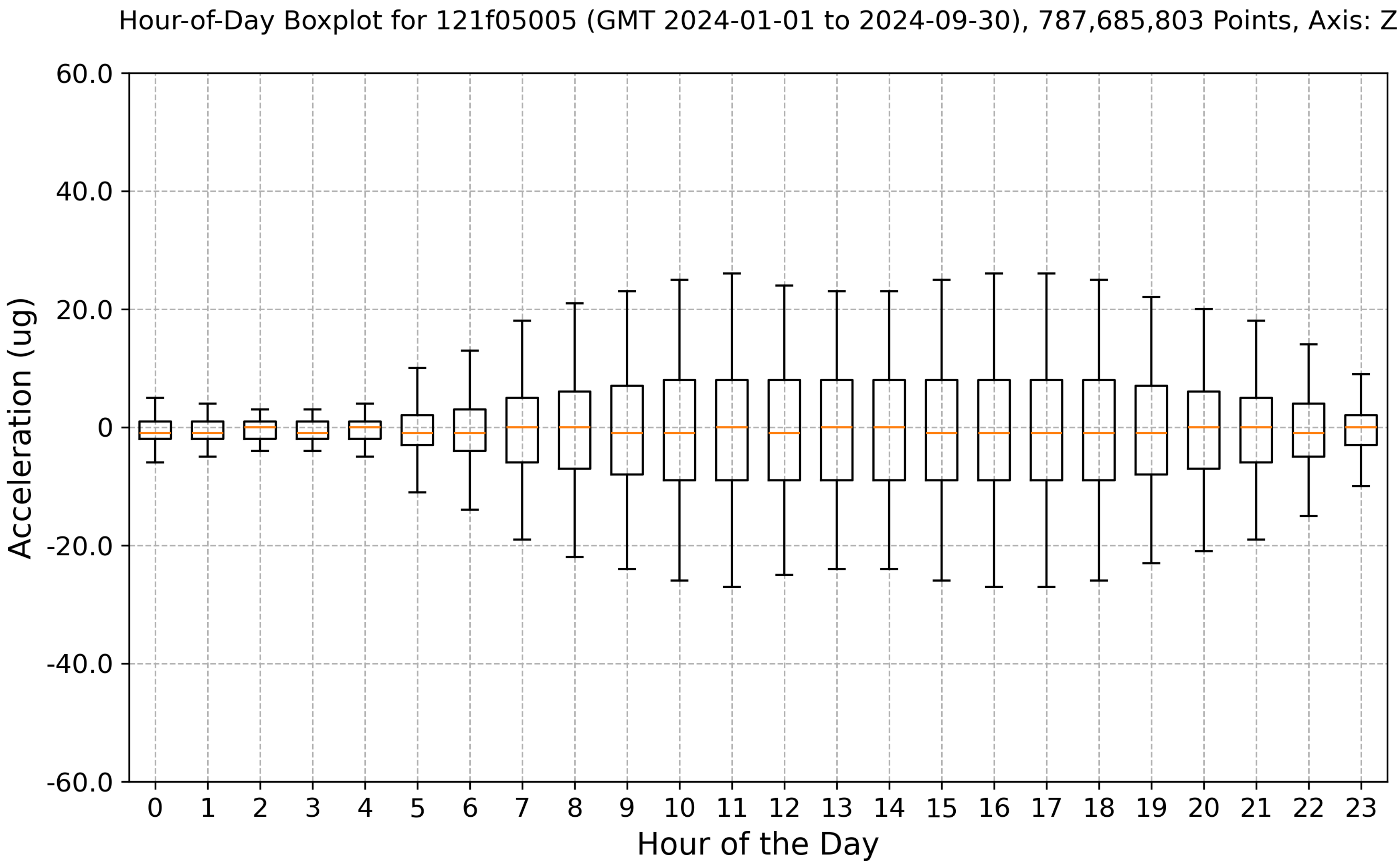

Fig. 11: SAMS Sensor 121f05 in JPM1F1, Bandpass Filt.: 0.2 to 1.0 Hz, 9-Month Statistical Summary, Z-Axis Acceleration.

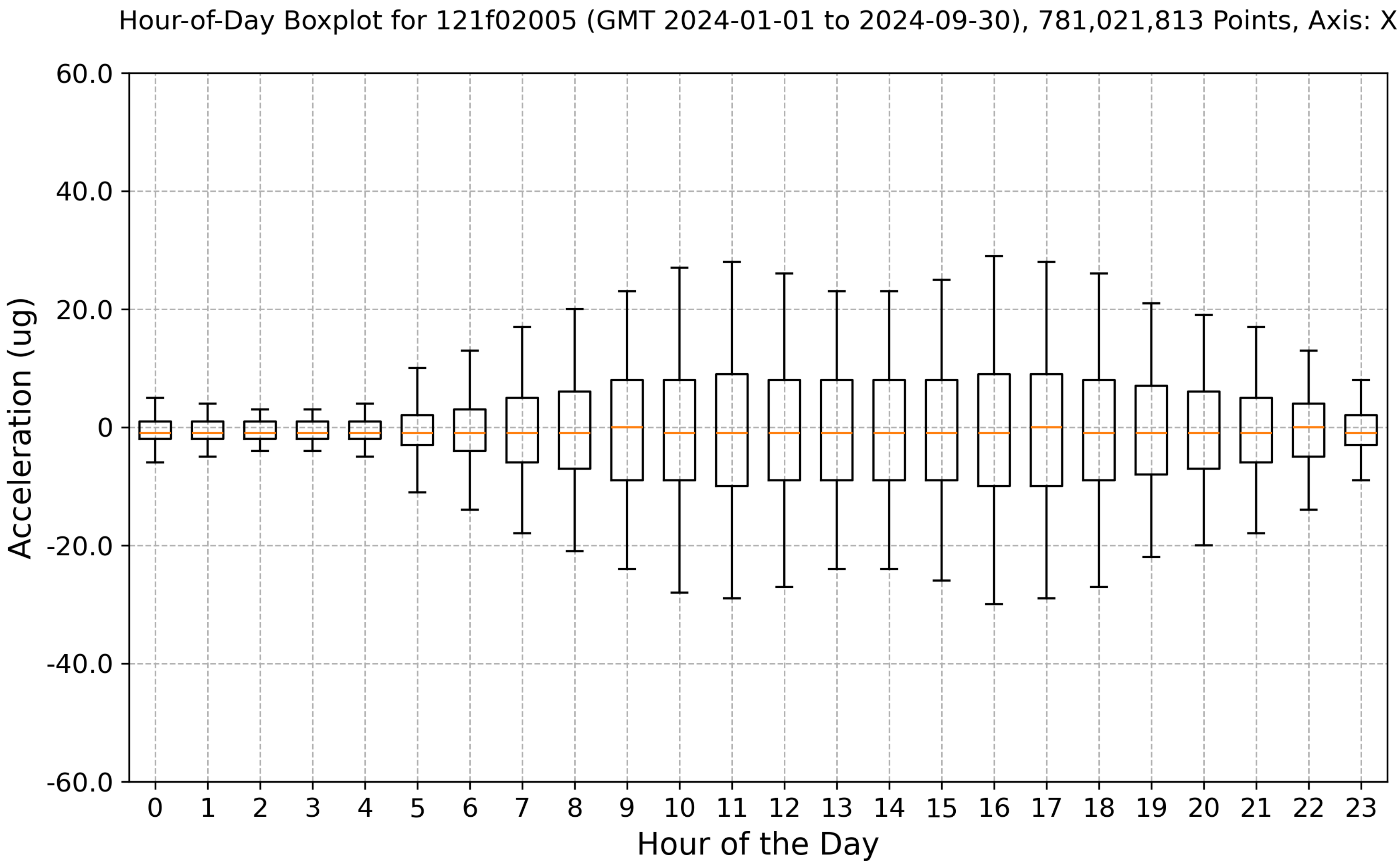

Fig. 12: SAMS Sensor 121f02 in COL1A1, Bandpass Filt.: 0.2 to 1.0 Hz, 9-Month Statistical Summary, X-Axis Acceleration.

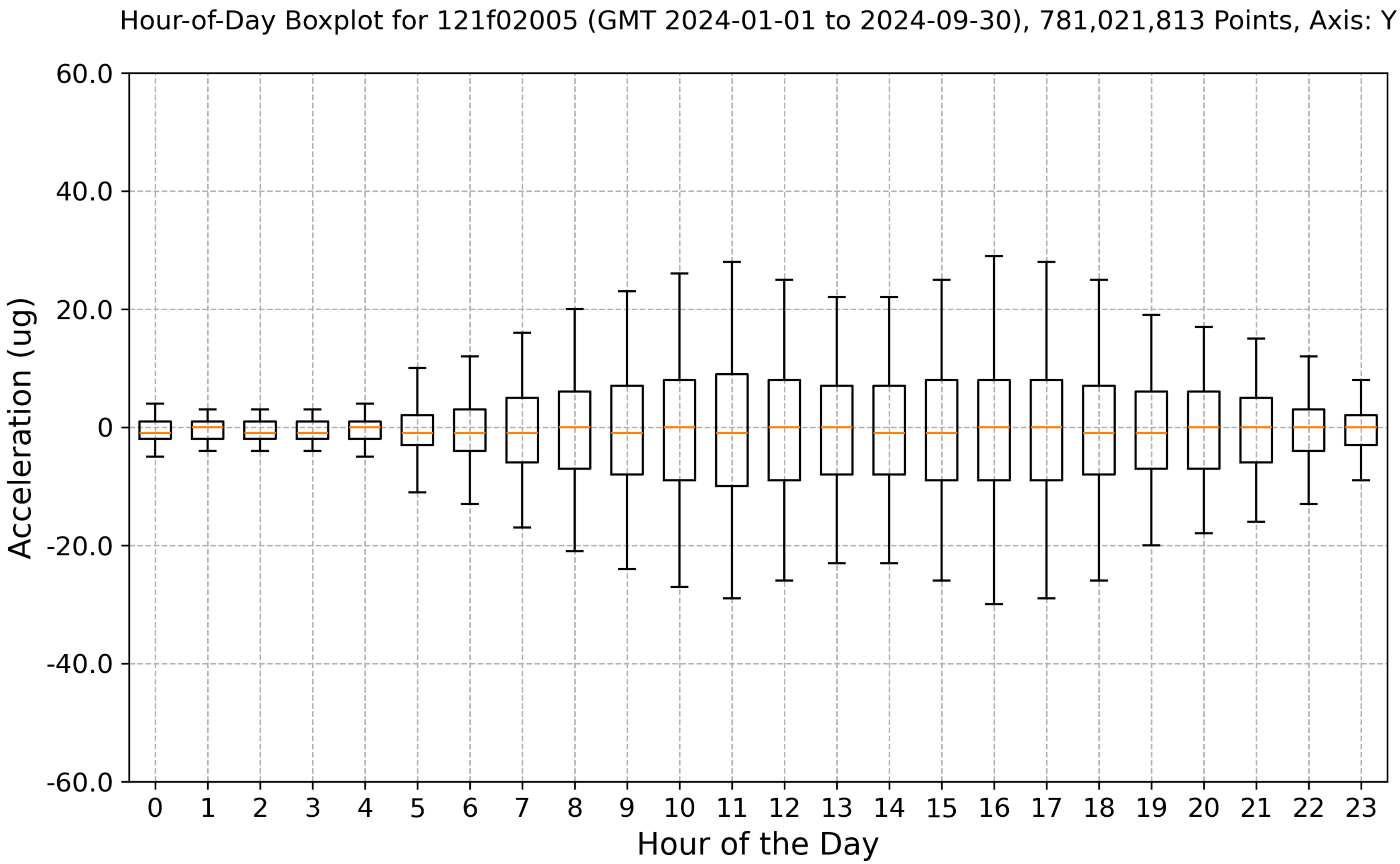

Fig. 13: SAMS Sensor 121f02 in COL1A1, Bandpass Filt.: 0.2 to 1.0 Hz, 9-Month Statistical Summary, Y-Axis Acceleration.

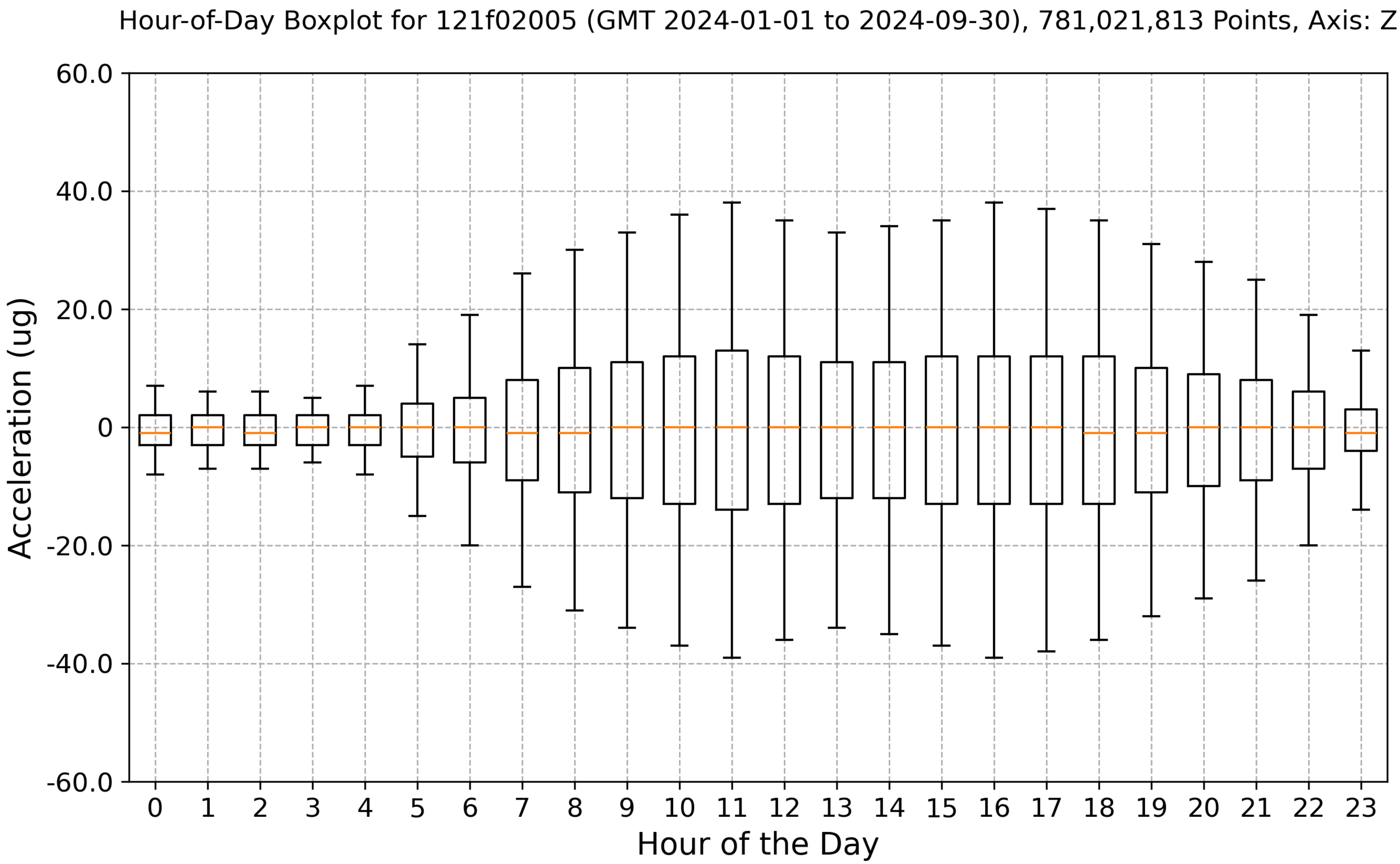

Fig. 14: SAMS Sensor 121f02 in COL1A1, Bandpass Filt.: 0.2 to 1.0 Hz, 9-Month Statistical Summary, Z-Axis Acceleration.