Section 6:

Analysis Techniques for Quasi-Steady Data

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Quasi-Steady Topics for Discussion

- **OARE description**
- **Description of trimmean filter (TMF)**
- **Bias calibration**
- **Data storage**
- **Analysis and display of quasi-steady data**

Orbital Acceleration Research Experiment

- **Three axis Miniature Electrostatic Accelerometer (MESA) with an electrostatically suspended proof mass**
- **Full in-flight calibration station for bias and scale factor adjustments**
- **On-board microprocessor for in-flight experiment control, processing, and storage of data**
- **OARE coordinate system vs. Orbiter body coordinate system**

$$\begin{bmatrix} X_b \\ Y_b \\ Z_b \end{bmatrix} = \begin{bmatrix} X_{OARE} \\ Z_{OARE} \\ -Y_{OARE} \end{bmatrix}$$

Orbital Acceleration Research Experiment

- **OARE data is recorded in an inertial frame of reference**
  - **an acceleration of the Orbiter in the positive x_b-axis direction is reported as a positive x_b-axis acceleration even though a free particle may appear to move in the negative x_b-axis relative to the accelerating Orbiter**
- **Designed to measure low-frequency (< 1 Hz), low-level acceleration (nano-g sensitivity)**
  - **frequency ranges are x-axis 0-1 Hz, y and z axis 0-0.1 Hz**

Orbital Acceleration Research Experiment

- **Typical (STS-78) OARE sensor ranges and resolution**

	X-Axis	Y,Z-Axis
Range	Resolution (nano-G)	Resolution (nano-G)
A	305.2	762.9
B	30.52	60.12
C	3.052	4.578
Range	Full Scale Range (micro-g)	Full Scale Range (micro-g)
A	10,000	25,000
B	1,000	1,970
C	100	150

Trimmean Filter (TMF) Description

- **Necessary to mitigate the effects of higher amplitude, higher frequency accelerations**
  - **removes infrequent, large amplitude, outlier data**
- **TMF utilizes a sliding window to operate on a segment of data of pre-defined length**
- **The sliding window operates such that a segment of the Nth window of data is included in the (N+1)th window, resulting in some portion of data being considered in two consecutive TMF operations (see Figure 6-1)**
- **Most PIMS implementations of the TMF operate on 500 sample window every 25 seconds or on 3000 sample window every 8 seconds**

Trimmean Filter (TMF) Description

- **Consider a window of data of length t seconds (Figure 6-1)**
  - **Step 1 - Divide the data into overlapping segments**
  - **Step 2 - Sort the acceleration data in order of increasing magnitude**
  - **Step 3 - Calculate the parameter Q according to the equation below**

$$Q = \frac{[U(20\%) - L(20\%)]}{[U(50\%) - L(50\%)]}$$

  - where U(x%) is the average of the upper x% of the ordered sample and L(x%) is the average of the lower x% of the ordered sample
  - Q is a measure of the departure of the distribution contained in the sample from a normal distribution

Trimmean Filter (TMF) Description

- **Step 4A - Trim off each tail of the ordered distribution according to the value of the trimmean parameter alpha**

$$alpha(Q) = \begin{cases} 0.05 & Q <= 1.75 \\ 0.05 + 0.35 * \dfrac{(Q - 1.75)}{0.25} & 1.75 < Q < 2.0 \\ 0.4 & Q >= 2.0 \end{cases}$$

- **Step 4B - Calculate the mean of the remaining trimmed distribution**
- **TMF parameters example (Figure 6-2)**

Trimmean Filter (TMF) Description

- For a pure Gaussian distribution of data, 5 percent of the data is trimmed from each tail of the original sorted distribution
- For a given segment of time, a maximum of 40 percent of the data is trimmed off each tail
- Typical values for Q and alpha result in 30-50 percent of the original data being discarded for a nominal shuttle mission

OARE/MAMS Bias Operations

- **OARE bias is caused primarily by dielectric charging of the ceramic insulator material that surrounds the cylindrical axis electrodes**
- **Bias calibrations are nominally performed throughout each mission at regularly programmed intervals**
  - **in-flight correction for bias**
  - **performed for the following additional conditions**
    - sensor instrument temperature change of 5 degrees Celsius since the completion of the last calibration sequence
    - sensor "down ranges" to range not calibrated in the previous calibration sequence
    - ground command initiation

OARE Bias Operations

- **Bias calibration sequence of steps**
  - **50 seconds of data collected**
  - **trimmean filter (TMF) applied to the resulting 500 data points**
  - **sensor is rotated 180 degrees and another 50 seconds of data are collected**
  - **TMF applied to the second 500 data points**
  - **the outputs of the two TMF operations are summed and divided by two**
  - **resulting value represents the bias value**

Analysis and Display of Quasi-Steady Data

Display Format	Regime(s)	Notes
Acceleration versus Time	Transient, Quasi-Steady, Vibratory	• precise accounting of measured data with respect to time; best temporal resolution
Interval Min/Max Acceleration versus Time	Vibratory, Quasi-Steady	• displays upper and lower bounds of peak-to-peak excursions of measured data • good display approximation for time histories on output devices with resolution insufficient to display all data in time frame of interest
Interval Average Acceleration versus Time	Vibratory, Quasi-Steady	• provides a measure of net acceleration of duration greater than or equal to interval parameter
Trimmed Mean Filtered Acceleration versus Time	Quasi-Steady	• removes infrequent, large amplitude outlier data
Quasi-Steady Mapped Acceleration versus Time	Quasi-Steady	• use rigid body assumption and vehicle rates and angles to compute acceleration at any point in the vehicle
Quasi-Steady Three-Dimensional Histogram (QTH)	Quasi-Steady	• summarize acceleration magnitude and direction for a long period of time • indication of acceleration "center-of-time" via projections onto three orthogonal planes

Analysis and Display of Quasi-Steady Data

- **No frequency domain analysis performed on quasi-steady acceleration data**
- **Data recorded at a rate of 10 samples per second**
- **Time domain plot types available**
  - **Raw acceleration data**
    - g vs. t plot of 10 sample per second data
  - **TMF acceleration data**
    - g vs. t plot, t is a function of the TMF interval selected
      - for Canopus Systems, Inc. provided data, TMF interval is 1 data point every 25 seconds
  - **Interval average acceleration data**

$$x_{avgk} = \frac{1}{M}\sum_{i=1}^{M} x_{[(k-1)*M+i]} \qquad k = 1,2,\ldots,\left\lfloor \frac{N}{M} \right\rfloor$$

    - M=number of points in the time series interval selected, typically 1 second intervals
    - N=total number of points in the time series being considered

Analysis and Display of Quasi-Steady Data

- **Time domain plot types available**
  - **Quasi-Steady Three-dimensional histograms (QTH)**
    - displays a summary of acceleration vector magnitude and alignment projected on three orthogonal planes
    - time series analysis using a 2-dimensional histogram for each combination of the three axes: XY, XZ, YZ
    - accumulates the number of times the acceleration vector magnitude falls within user-defined 2-dimensional bins
    - count is divided by the total number of points considered to normalize the results
      - gives a percentage of time representation of the magnitude and orientation of the quasi-steady acceleration vector
      - makes comparisons of quasi-steady data from [QTH plots] STS mission to STS mission or ISS increment to ISS increment more meaningful

Analysis and Display of Quasi-Steady Data

- **Additional options for all time domain plots**
  - **Map quasi-steady acceleration data to the Orbiter CG or to an experiment location**
    - requires use of the vehicle (Orbiter or ISS) body rates and body angles
    - mapping is accomplished via the following calculations
      - determine the acceleration at the CG via

$$a_{CG} = a_{ML} - a_{ggML} - a_{EulerML}$$

      - where ML = measurement location
      - determine the acceleration at the new location via

$$a_{new} = a_{CG} + a_{ggnew} + a_{Eulernew}$$

Analysis and Display of Quasi-Steady Data

- **Additional options for all time domain plots**
  - **Select frame of reference as either inertial or science community**
  - **Select the coordinate system based on vehicle**
    - For Orbiter, use either Orbiter body, Orbiter structural, or specialized coordinate system (i.e., CGF coordinates on USML-2)
    - For ISS, many coordinates systems are available

Post-Mission Quasi-Steady Data Storage

- **OARE data stored on NASA GRC file server** ***beech.lerc.nasa.gov***
- **Each OARE supported STS mission since USML-2 has the following subdirectories under pub/OARE/<mission>**
  - **canopus**
    - stored in ASCII format
    - contains OARE TMF data provided by Canopus Systems, Inc. after the mission
    - data stored in body coordinate system, inertial frame of reference
  - **MAWS data**
    - stored in ASCII format
    - MAWS = Microgravity Analysis Workstation
    - contains analytical prediction data for the quasi-steady environment
    - data available for STS-73, STS-75, and STS-78
    - data stored in body coordinate system, science community frame of reference (opposite of inertial frame of reference described earlier)

Quasi-Steady Data Storage

- **Each OARE supported STS mission since USML-2 has the following subdirectories under pub/OARE/<mission>**
  - **msfc-processed**
    - stored in binary format
    - contains 10 sample per second data where the acceleration data are represented in acceleration units
    - stored in OARE sensor coordinates, inertial frame of reference
  - **msfc-raw**
    - stored in binary format
    - contains completely unprocessed raw data where the acceleration data are represented in raw counts form
    - stored in OARE sensor coordinates, inertial frame of reference

Analysis and Display of Quasi-Steady Data

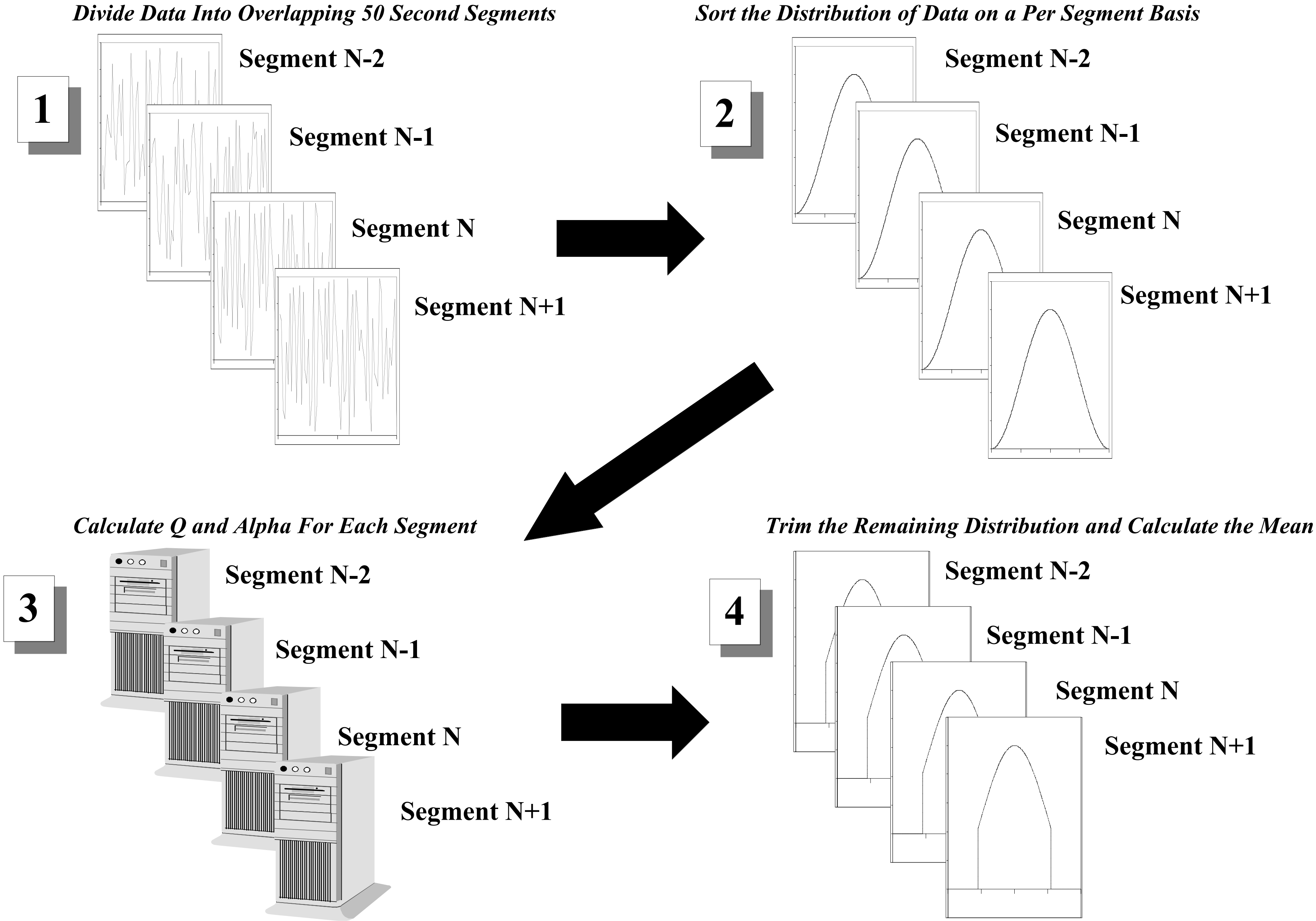
- **Raw OARE acceleration data**
  - **Figure 6-3 LMS Water Dump and Attitude Change**
  - **Figure 6-5 USML-2 Solar Inertial Attitude**
  - **Figure 6-7 USMP-3 Vernier Thruster Firings**

- **TMF OARE acceleration data**
  - **Figure 6-4 LMS Water Dump and Attitude Change**
  - **Figure 6-6 USML-2 Solar Inertial Attitude**
  - **Figure 6-8 USMP-3 Vernier Thruster Firings**
  - **Figure 6-9 USML-2 Supply Water Dump**

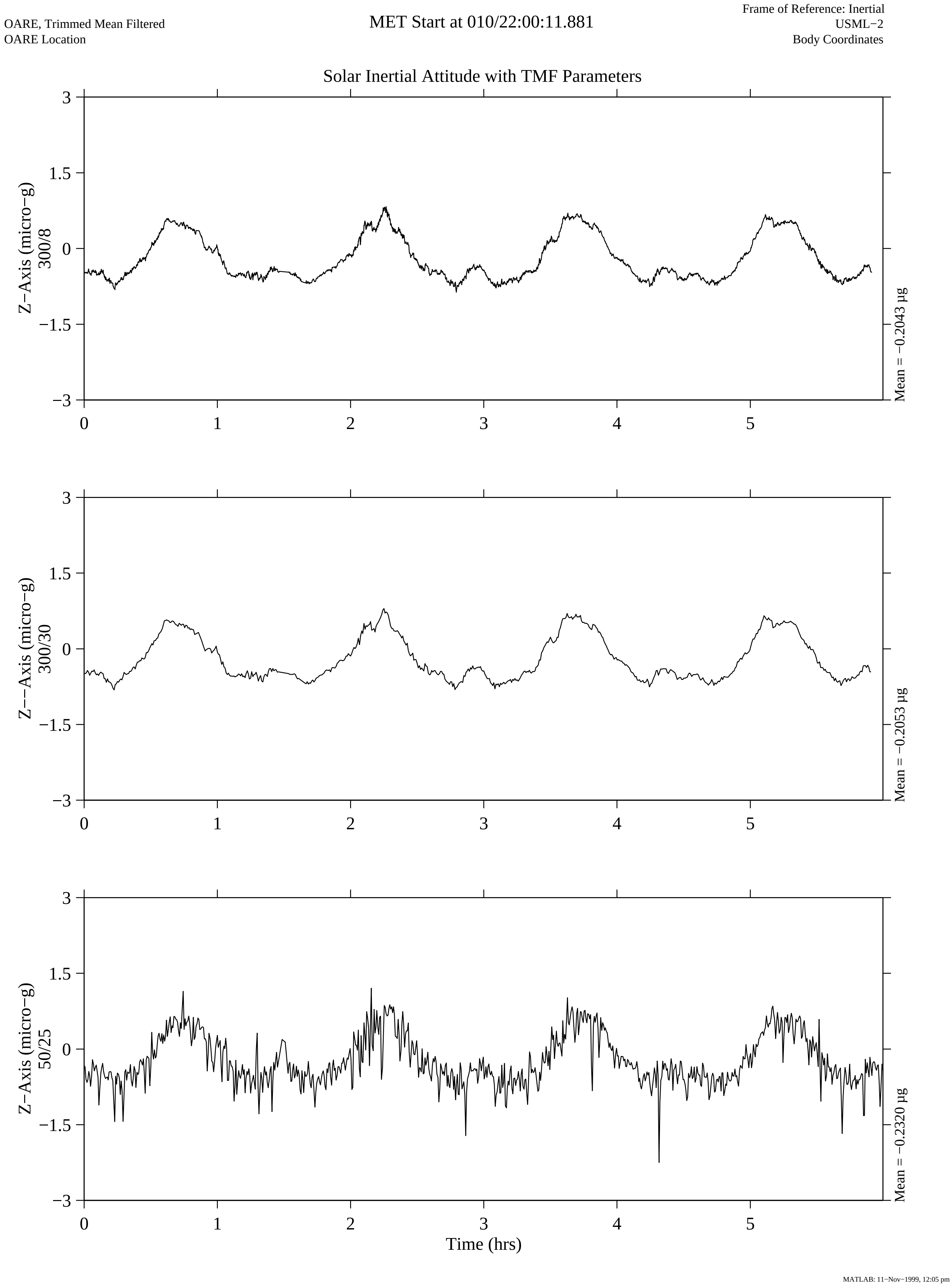
Analysis and Display of Quasi-Steady Data

- QTH plots
  - Figure 6-10 LMS Mission Plot
  - Figure 6-11 USML-2 Solar Inertial Attitude
  - Figure 6-12 USMP-2 Mission Plot
  - Figure 6-13 LMS Crew Active Period
  - Figure 6-14 LMS Crew Sleep Period

TMF Process



MEIT 1999 Figure 6-1



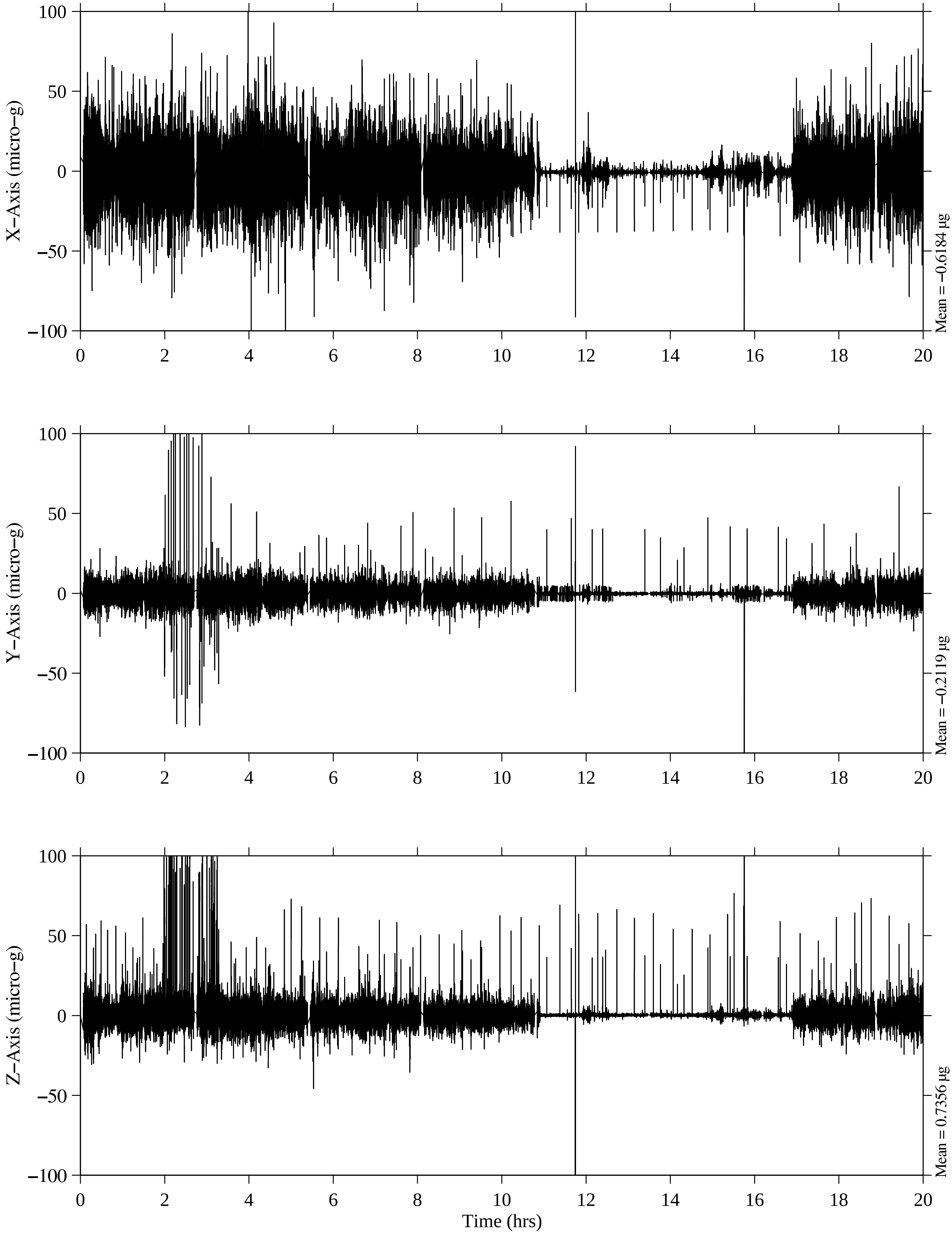
MEIT 1999 Figure 6-2: OARE TMF Data Showing TMF Parameter Comparison from STS-73 (USML-2)

OARE, Raw Data
OARE Location

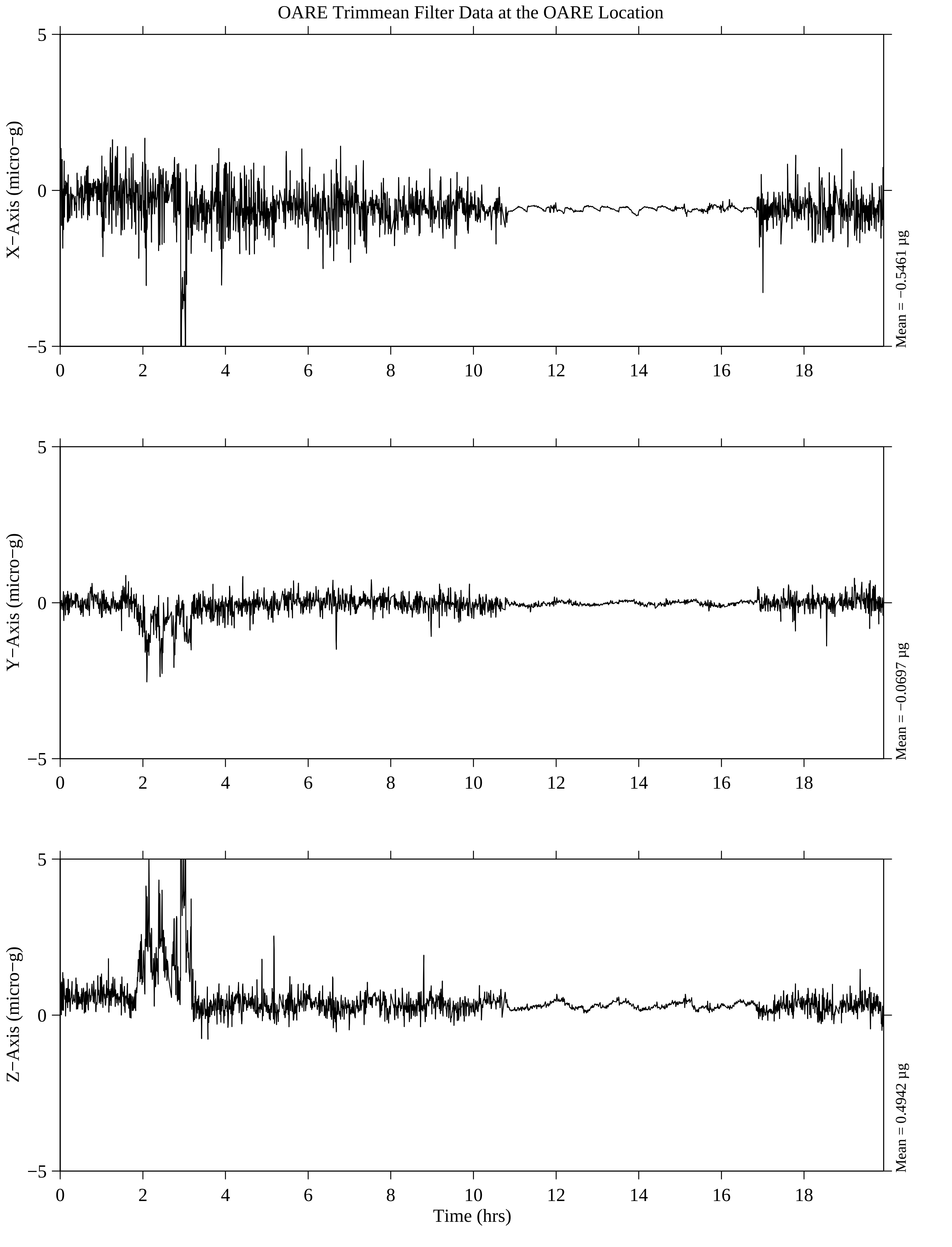
MET Start at 006/00:00:00.000

Frame of Reference: Orbiter
LMS
Body Coordinates

Raw OARE Data at the OARE Location

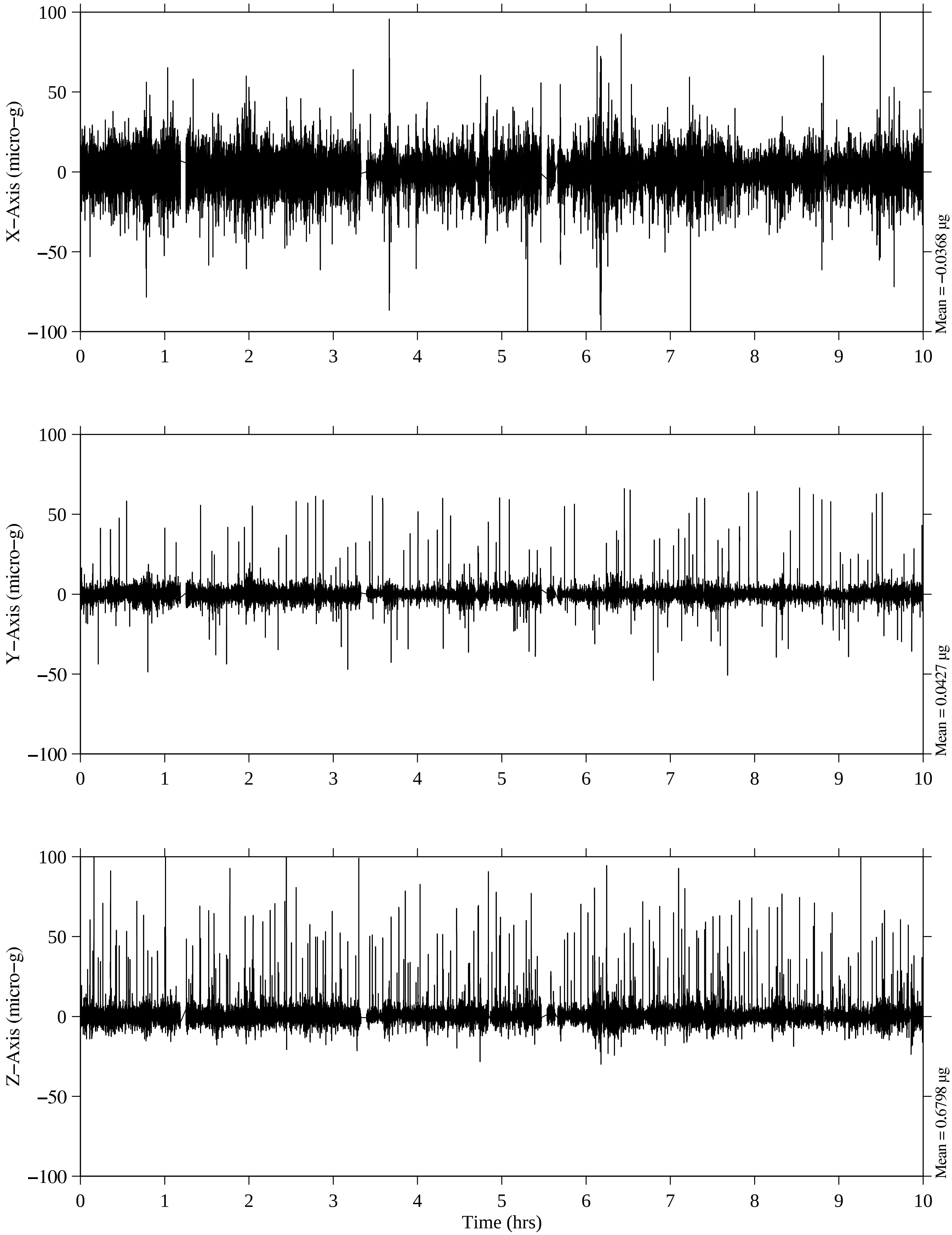


MATLAB: 05−Aug−1997, 02:49 pm

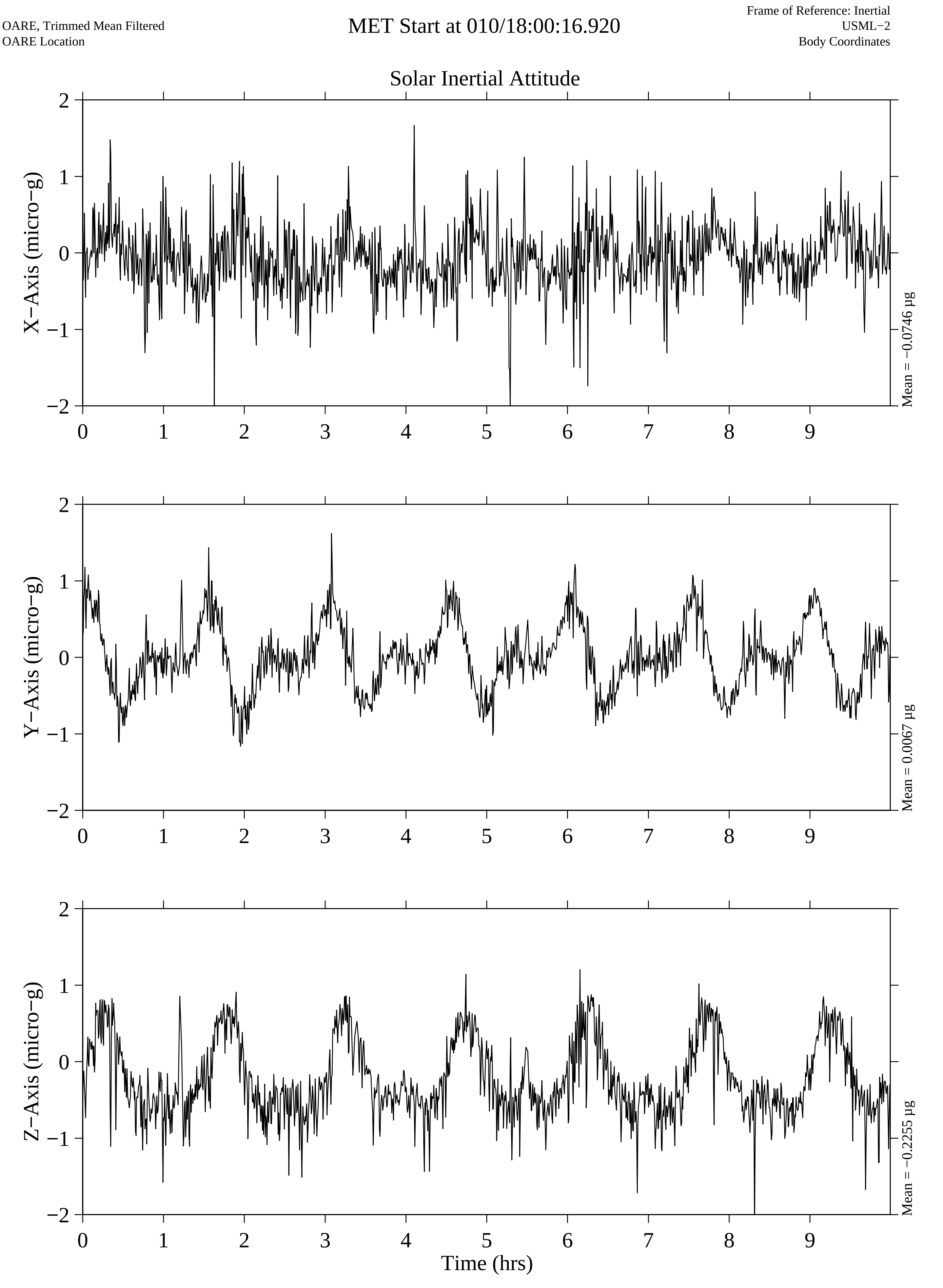


MEIT 1999 Figure 6-4: OARE TMF Data During Water Dump and Attitude Change from STS-78 (LMS)

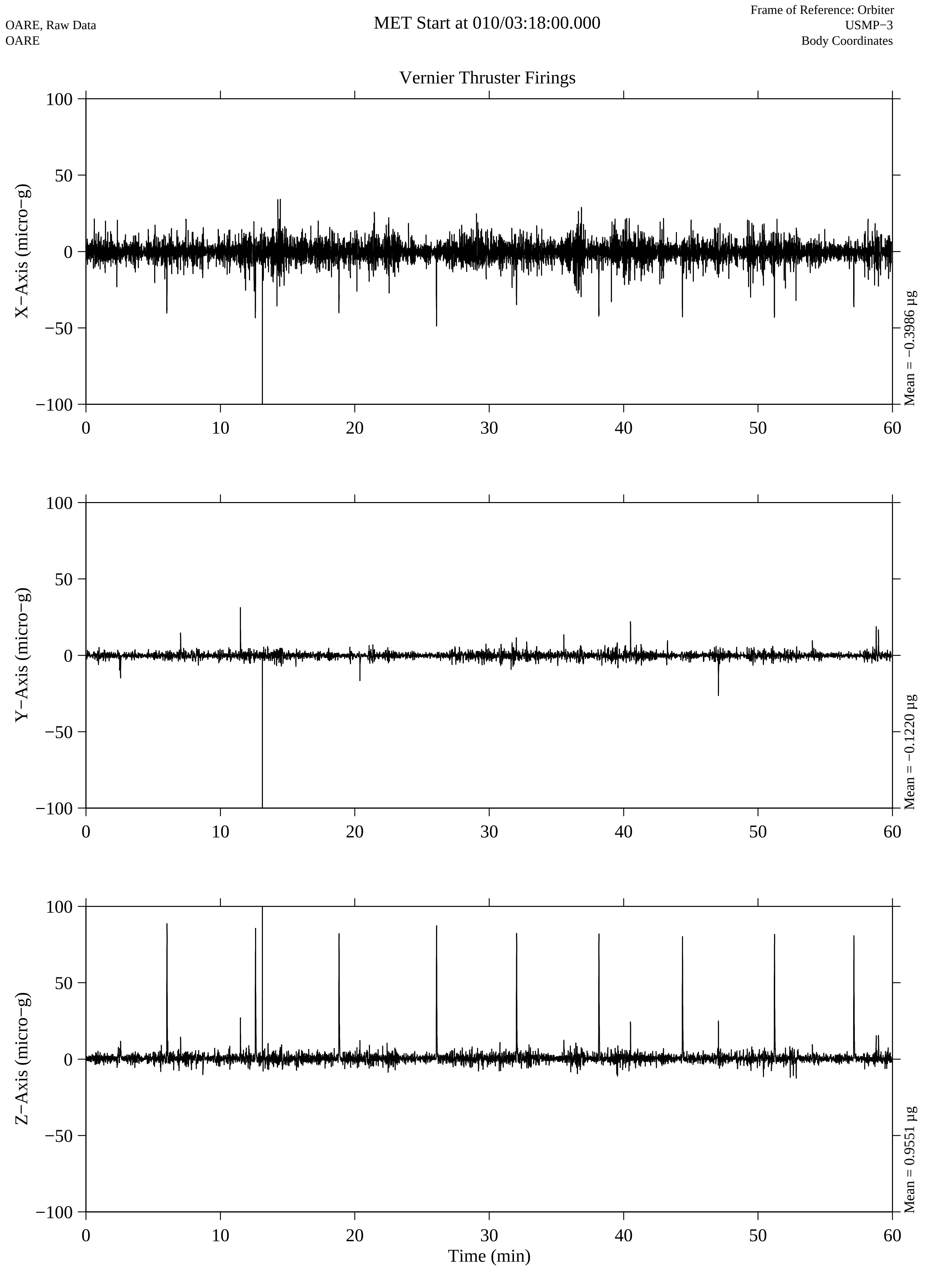
Solar Inertial Attitude



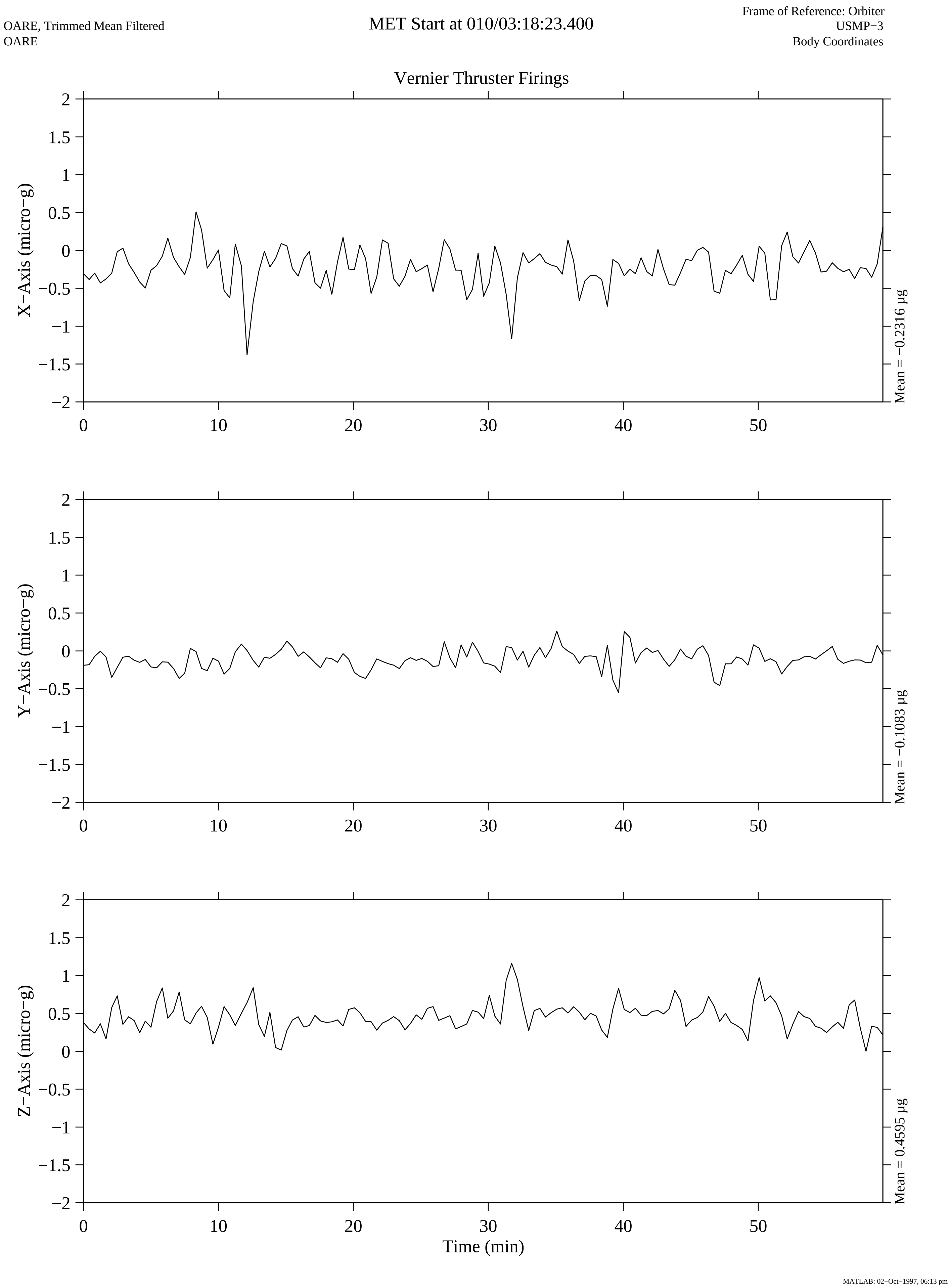
MATLAB: 02−Oct−1997, 05:44 pm



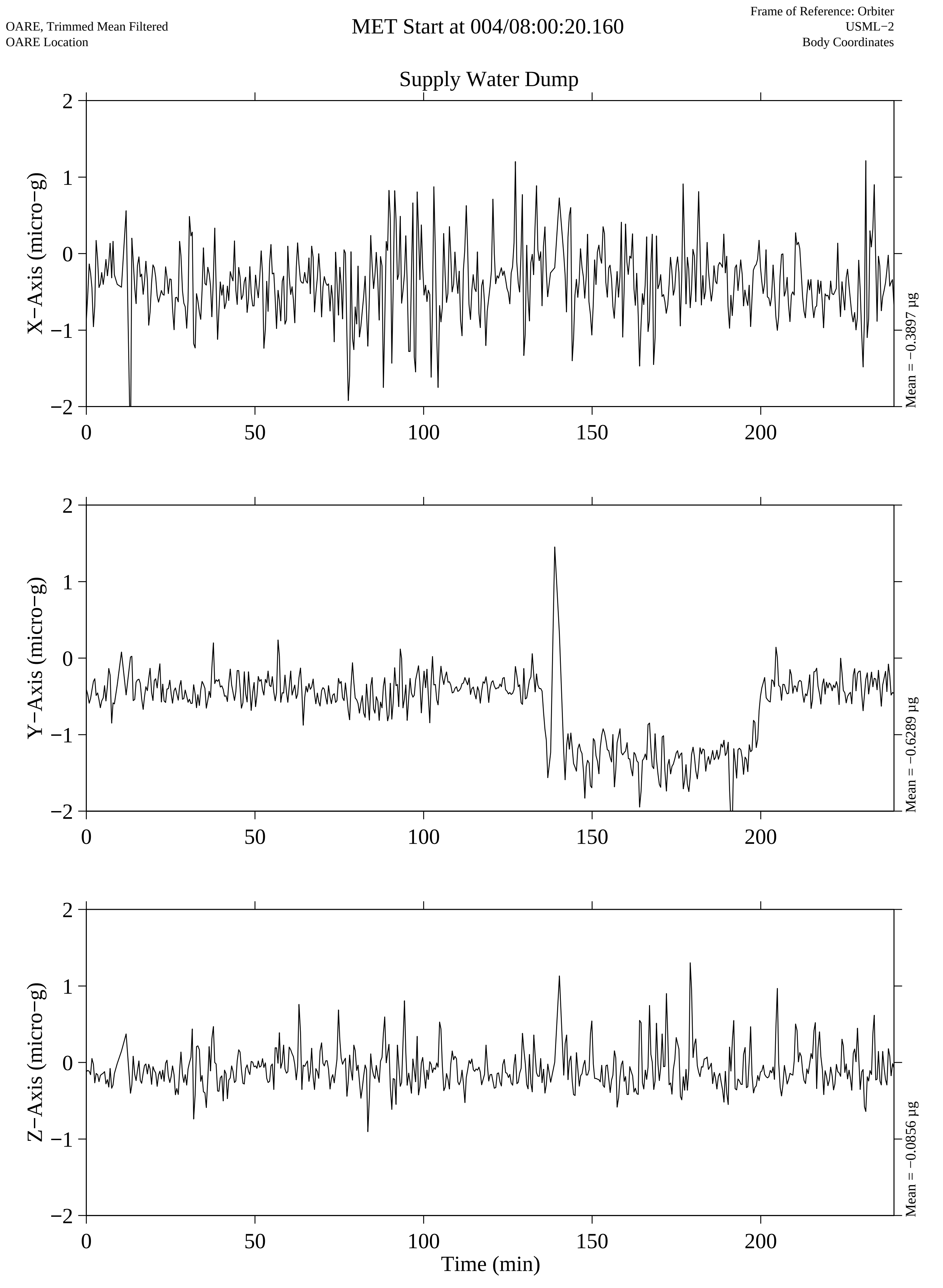
MEIT 1999 Figure 6-6: OARE TMF Data During Solar Inertial Attitude from STS-73 (USML-2)



MEIT 1999 Figure 6-7: Raw OARE Data Showing Vernier Thruster Firings from STS-75 (USMP-3)



MEIT 1999 Figure 6-8: OARE TMF Data Showing Vernier Thruster Firings from STS-75 (USMP-3)



MEIT 1999 Figure 6-9: OARE TMF Data Showing Water Dump from STS-73 (USML-2)

OARE, Trimmed Mean Filtered

OARE Location

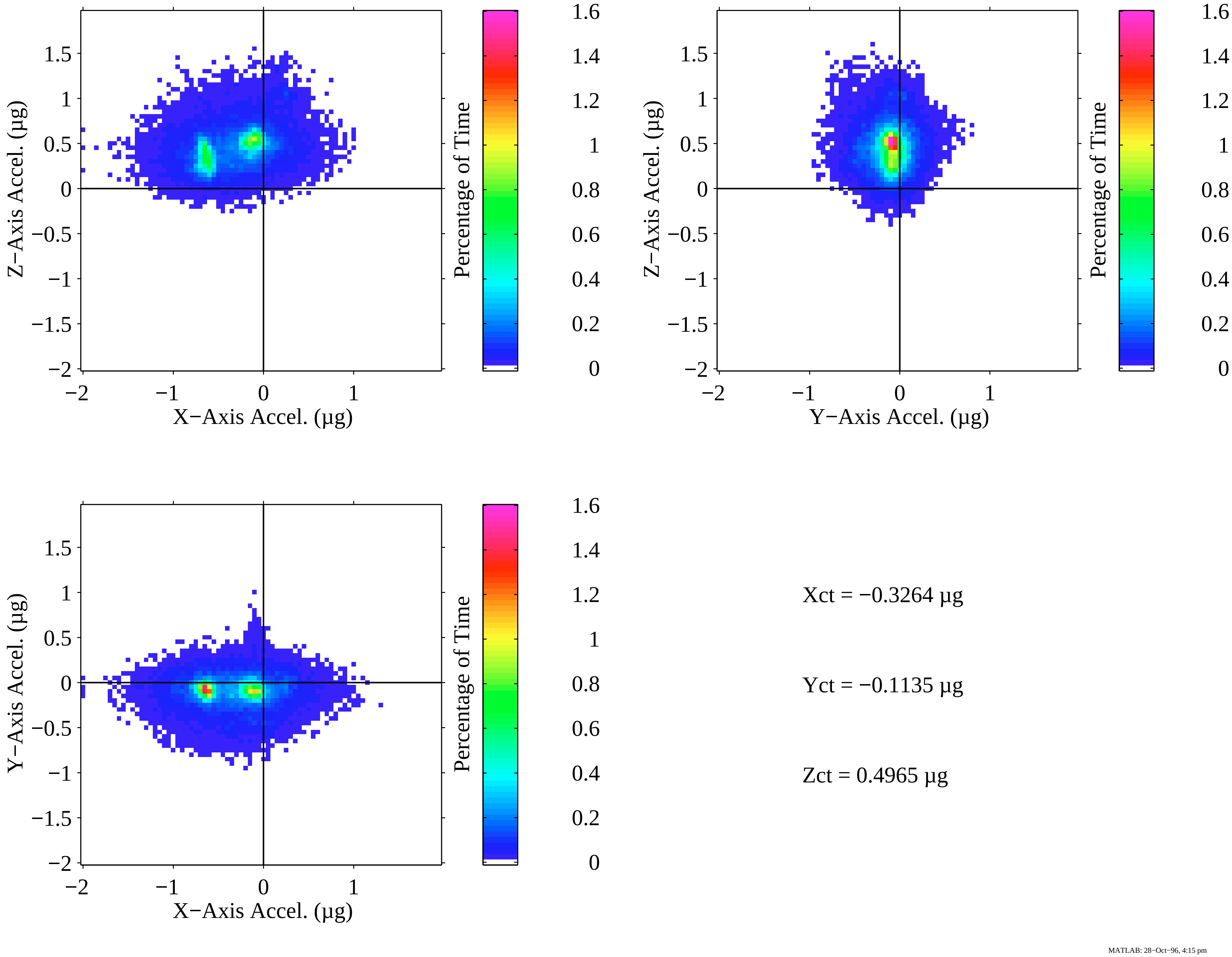
MET Start at 000/00:13:17.040

LMS Quasi−Steady Acceleration Environment

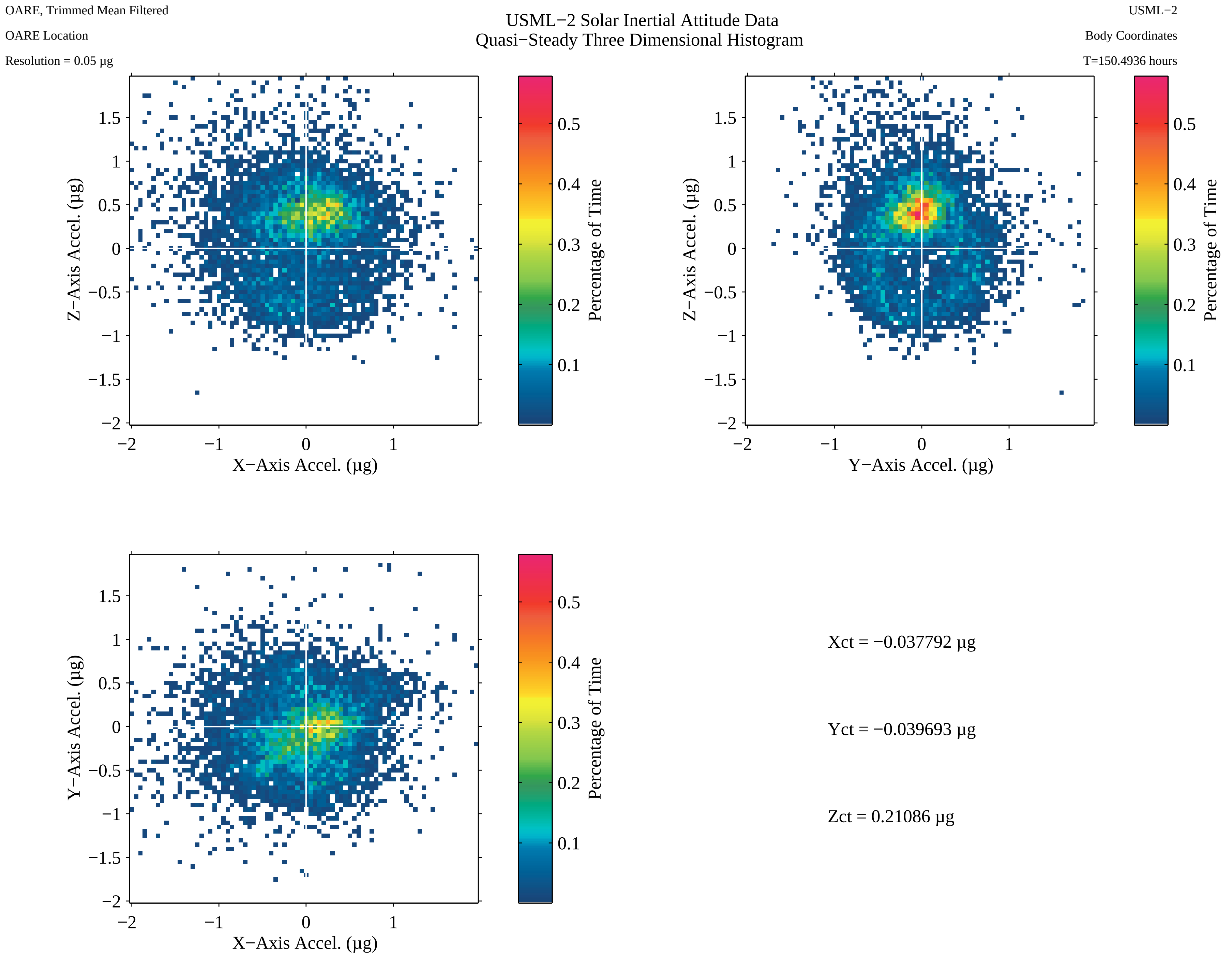
LMS

Body Coordinates

T=404.9 hours



MEIT 1999 Figure 6-10: Quasi-Steady Three-Dimensional Histogram Plot for Entire STS-78 (LMS) Mission



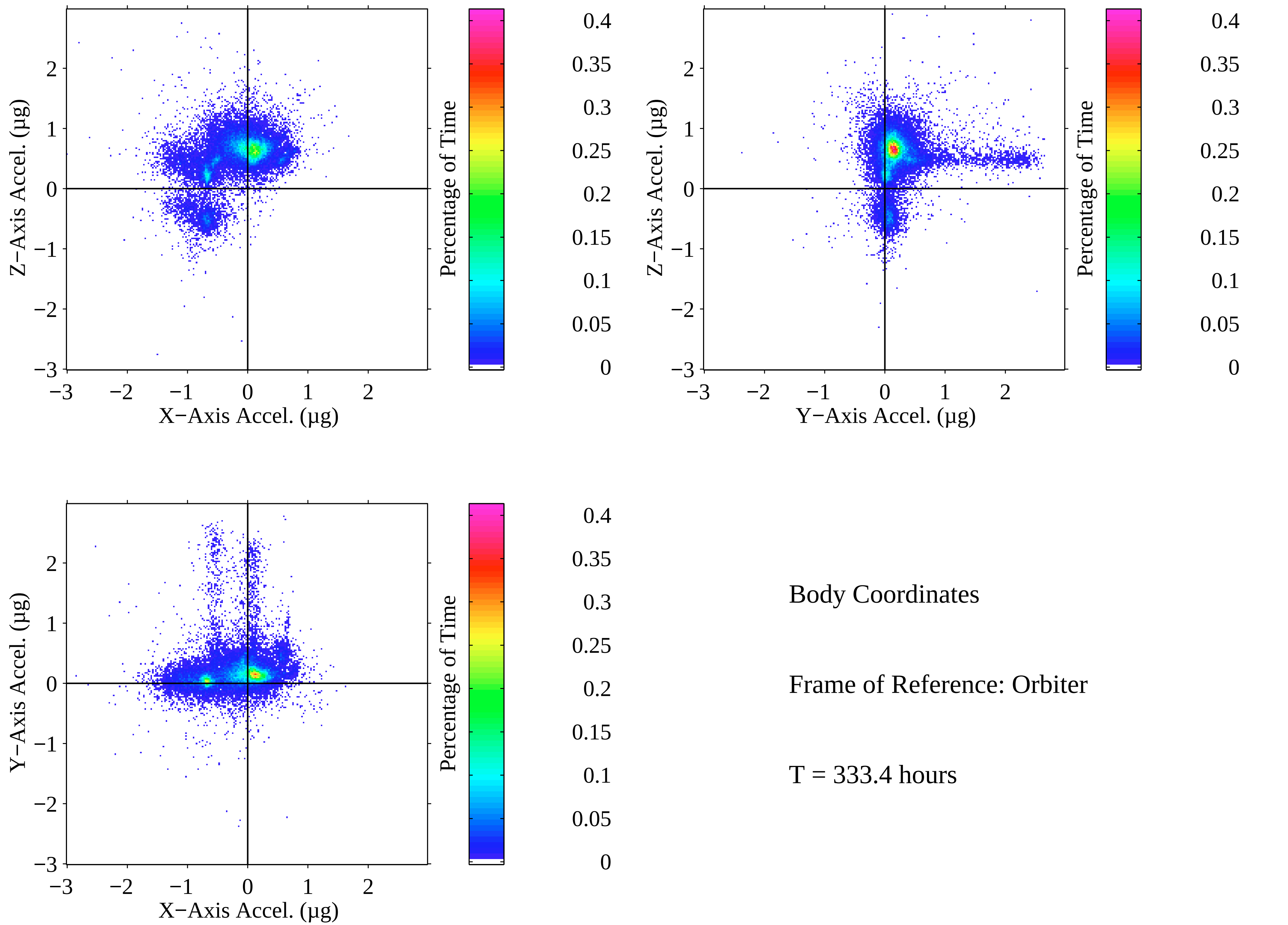
MEIT 1999 Figure 6-11: Quasi-Steady Three-Dimensional Histogram Plot for Solar Inertial Attitude from STS-73 (USML-2)

OARE, Trimmed Mean Filtered

OARE Location

MET Start at 000/00:12:16.920

USMP−2 (STS−62) Mission Plot



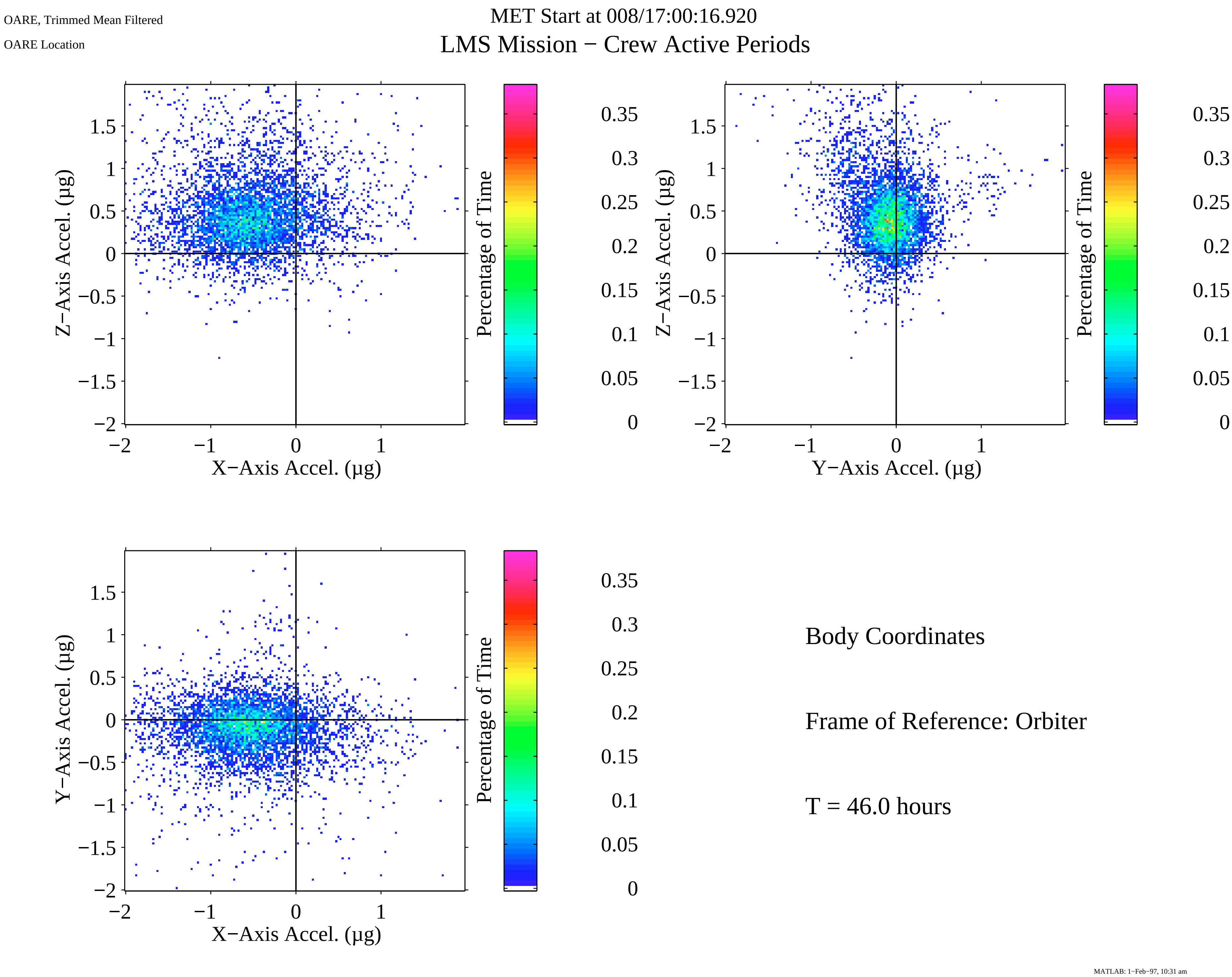
Body Coordinates

Frame of Reference: Orbiter

T = 333.4 hours

MATLAB: 1−Feb−97, 10:45 am

MEIT 1999 Figure 6-12: Quasi-Steady Three-Dimensional Histogram Plot for Entire STS-62 (USMP-2) Mission



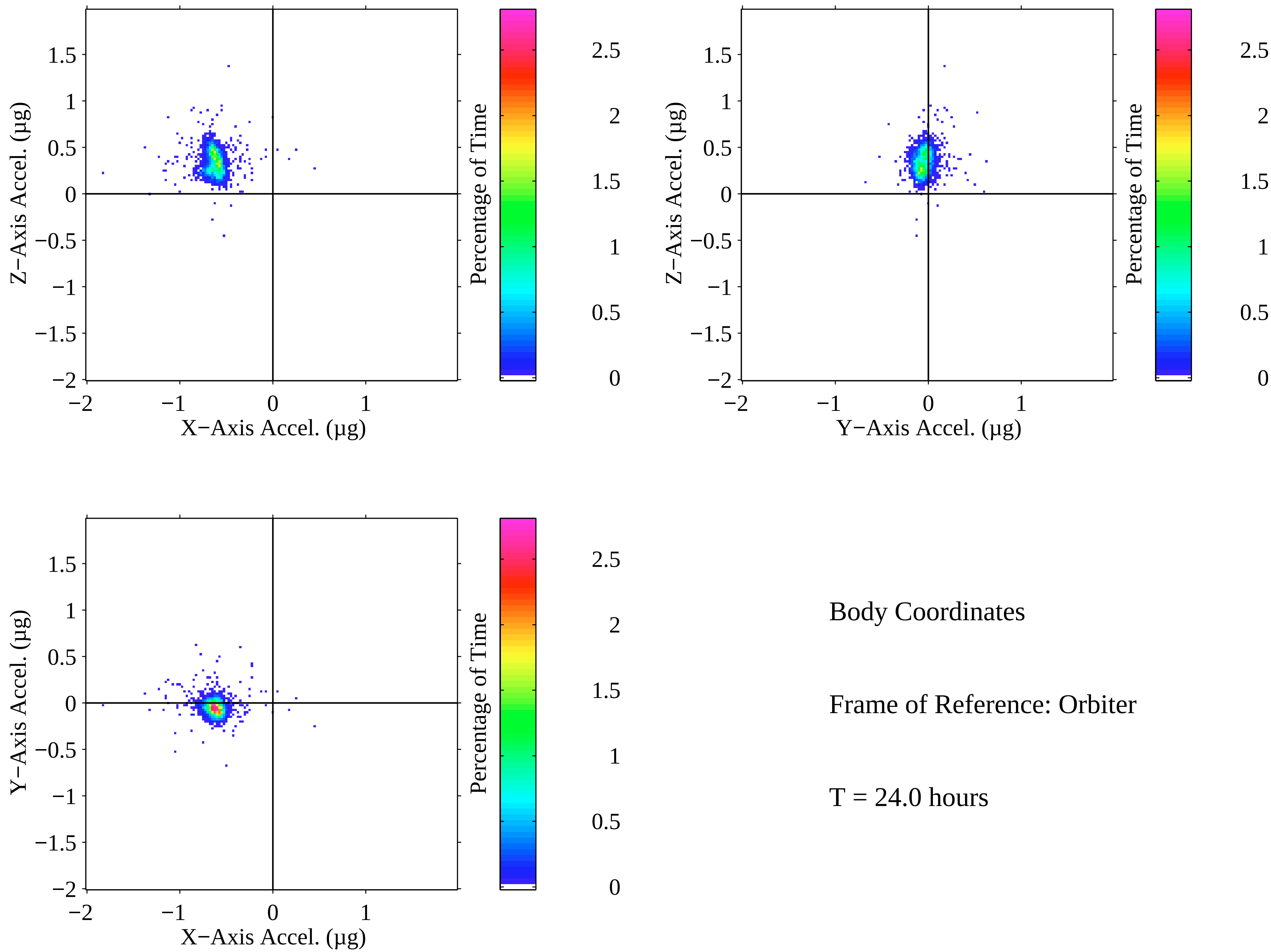
MEIT 1999 Figure 6-13: Quasi-Steady Three-Dimensional Histogram Plot Crew Active Period STS-78 (LMS)

OARE, Trimmed Mean Filtered

OARE Location

MET Start at 009/09:00:07.920

LMS Mission − Sleep Cycles



MATLAB: 1−Feb−97, 10:21 am

MEIT 1999 Figure 6-14: Quasi-Steady Three-Dimensional Histogram Plot Crew Sleep Period STS-78 (LMS)