Section 6:

Analysis Techniques for Quasi-Steady Data

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Topics for discussion

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

OARE and MAMS Data

- **OARE and MAMS data are recorded and stored in an inertial frame of reference**
  - **an acceleration of the vehicle in the positive x-axis direction is reported as a positive x-axis acceleration even though a free particle may appear to move in the negative x-axis relative to the accelerating vehicle**
- **MAMS OSS (OARE Sensor Subsystem) is located onboard the International Space Station, inside the US Module.**
  - **Since Flight 6A (April 2001), EXPRESS Rack 1, LAB1O2**
- **OARE stored in Orbiter body coordinates and MAMS OSS data are currently OSS sensor coordinates. In the future, the data will be stored in Space Station Analysis Coordinate System.**
- **Sensor Coordinate systems**

OARE vs. Orbiter Body

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

MAMS OSS vs. SSA

$$\begin{bmatrix} X_A \\ Y_A \\ Z_A \end{bmatrix} = \begin{bmatrix} X_{OSS} \\ -Z_{OSS} \\ Y_{OSS} \end{bmatrix}$$

Trimmean Filter (TMF) Description

- **The trimmed mean filter (TMF) is an adaptive, robust[1] estimator designed to compute a "good" estimate of the quasi-steady acceleration signal by rejecting higher-frequency transients (thruster firings, crew activity, etc.)**
- **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 (Figure 6-1)**

1. Hogg, Robert V., "Adaptive Robust Procedures: A Partial Review and Some Suggestions for Future Applications and Theory", Journal of the American Statistical Association, Vol. 69 (December 1974).

Trimmean Filter (TMF) Description

- **Most PIMS implementations of the TMF operate on 500 sample window every 25 seconds (OARE) or on 480 sample window every 16 seconds (MAMS).**
- **Other parameter pairs used in the past include:**
  - **3000 sample window every 8 seconds**
  - **3000 sample window every 30 seconds**
- **TMF parameters example (Figure 6-2)**

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, similar to kurtosis

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 - The quasi-steady acceleration signal is computed to be the arithmetic mean of the trimmed data set.**

Trimmean Filter (TMF) Description

- **The TMF assumes the signal distribution is symmetric, but not necessarily Gaussian. 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 rejected for a nominal shuttle mission**
- **Amount rejected is expected to be less for ISS during microgravity periods since attitude control is performed by control moment gyros (CMG), not thrusters as on STS. No analysis yet performed.**

OARE/MAMS Bias Operations

- **Initial transient in OARE bias is caused primarily by dielectric charging of the ceramic insulator material that surrounds the cylindrical axis electrodes**
- **Dielectric charging effects not seen in MAMS. However there is a transient effect in bias due to temperature during warm up period of 4 to 6 hours.**
- **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/MAMS Bias Operations

- **Bias calibration sequence of steps for a given axis**
  - **50 seconds of data collected (Measurement 1)**
  - **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	Notes
Acceleration versus Time	• precise accounting of measured data with respect to time; best temporal resolution
Interval Min/Max Acceleration versus Time	• 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	• provides a measure of net acceleration of duration greater than or equal to interval parameter
Trimmed Mean Filtered Acceleration versus Time	• removes infrequent, large amplitude outlier data
Quasi-Steady Mapped Acceleration versus Time	• use rigid body assumption and vehicle rates and angles to compute acceleration at any point in the vehicle
Quasi-Steady Three-Dimensional Histogram (QTH)	• 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 transform applied to quasi-steady acceleration data; looking at time series plot and noting orbital rate is frequency domain analysis.**
- **Data recorded at a rate of 10 samples per second**
- **Time domain plot types available**
  - **Raw acceleration data – Not recommended for general consumption (use with caution)**
    - 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
  - **Interval average acceleration data**

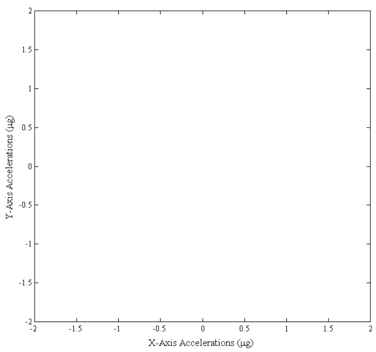
$$x_{avgk} = \frac{1}{M} \sum_{i=1}^{M} x_{[(k-1)*M+i]} \qquad k = 1,2,\ldots,\left\lfloor \frac{N}{M} \right\rfloor$$

- 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

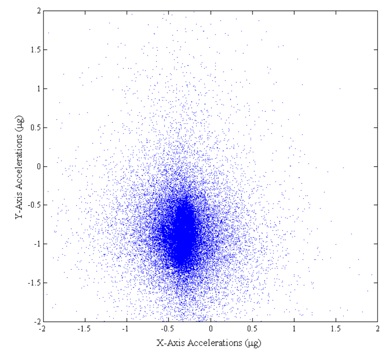
Analysis and Display of Quasi-steady Data

- **Acceleration domain plot types available**
  - **Quasi-steady Three-dimensional Histograms (QTH)**
    - displays a summary of acceleration vector magnitude and alignment projected on three orthogonal planes
    - uses 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 to normalize the results
      - gives a percentage of time representative of the magnitude and orientation of the quasi-steady acceleration vector
      - Makes meaningful comparisons of quasi-steady data between STS missions, ISS increments, or other periods of interest.

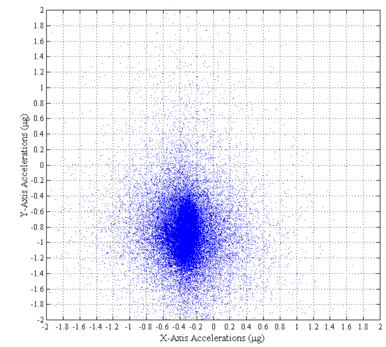
Analysis and Display of Quasi-steady Data



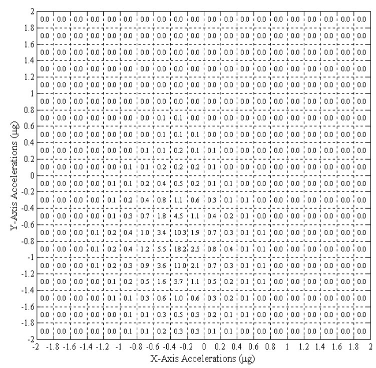
For the XY plane, choose area of interest by selecting limits.



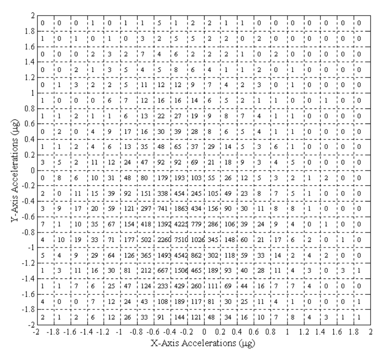
Plot X and Y components of quasi-steady vector.



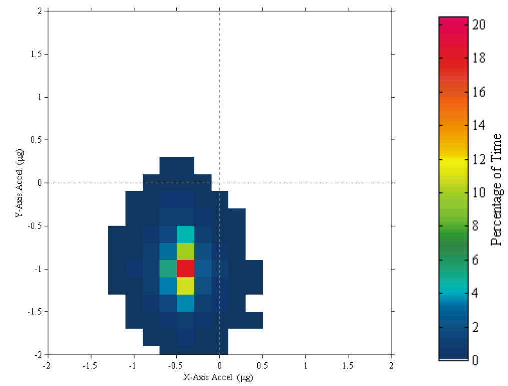
Divide area into equal size bins.



Count the number of "hits" in each bin.



Calculate the percentage of total number of data points for each bin.



Assign a color gradient to percentage points.

Analysis and Display of Quasi-steady Data

- **Additional options for quasi-steady plot types**
  - **Mapping is an estimate of the quasi-steady vector at a location other than measurement location. (e.g. the vehicle center of mass (CM) or to an experiment location)**
    - Rigid body assumptions, no relative motion of “vehicle parts”
    - requires use of the vehicle (Orbiter or ISS) telemetry data
    - mapping is accomplished via the following equations

$$A^{EL} = A^{ML} - A_{gg}^{ML} - A_{rot}^{ML} + A_{rot}^{EL} + A_{gg}^{EL}$$

$$A^{CM} = A^{ML} - A_{gg}^{ML} - A_{rot}^{ML}$$

    - Where
      - ML = measurement location
      - EL = experiment location
      - A_{gg} = gravity gradient component of acceleration
      - A_{rot} = rotational components of acceleration

    - A_{gg} and A_{rot} for experiment location are zero when mapping to CM

Analysis and Display of Quasi-steady Data

- **gravity gradient component**
  - **The gravity gradient component are accelerations from forces acting on a particle that is away from the center of gravity.**
- **An independent particle will tend to accelerate towards the CM if it is in front or behind the CM or to the left or right of the vehicle. The gravity gradient will tend to accelerate a particle away from the CM if it is above or below the CM.[2]**
  - A_{gg} at any location is given by the equation (in μg):

$$A_{gg} = \left(\frac{g_e \cdot r_e^2}{r_O^3} \right) \cdot \begin{bmatrix} rx \\ ry \\ -2 \cdot rz \end{bmatrix} \cdot \left(\frac{1x10^6}{g_e} \right)$$

  - Where
    - r_e is the radius of the Earth
    - r_0 is the distance of the vehicle to center of the Earth
    - [x,y,z] is the distance from the CM
    - $g_e = 9.81$ m/s^2

2. Matisak, B.P., Rogers M.J.B, Alexander J.I.D., "Analysis of the Passive Accelerometer System (PAS) Measurements During USML-1", AIAA 94-0434 (January 1994).

Analysis and Display of Quasi-steady Data

- **For LVLH attitudes, the vehicle is rotating about a single axis and an approximation can be used[2]:**

$$\left(\frac{g_e \cdot r_e^2}{r_O^3}\right) = \omega_O^2$$

  - Where
    - ω_o is the angular velocity of the vehicle
    - [x,y,z] is the distance from the CM

- **For Shuttle flights, this approximation was frequently used.**
- **For ISS, extensive XPOP attitude in early flights will limit it's usefulness.**

Analysis and Display of Quasi-steady Data

- **rotational component**
  - **The rotational acceleration effects are comprised of tangential and radial components.**
    - The tangential acceleration components contribute mainly during thruster firings and are not part of the quasi-steady domain. Therefore they are assumed negligible.
    - The radial components are given:

$$A_{rot} = \begin{bmatrix} -(\omega_y^2 + \omega_z^2) & \omega_x\omega_y & \omega_x\omega_z \\ \omega_x\omega_y & -(\omega_x^2 + \omega_z^2) & \omega_y\omega_z \\ \omega_x\omega_z & \omega_y\omega_z & -(\omega_x^2 + \omega_y^2) \end{bmatrix} \mathrm{x} \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

    - Where
      - $\omega_{x,}\ \omega_{y,}\ \omega_z$ are the rotational velocities about the x,y,z axes
      - [x,y,z] is the distance from the CM

Analysis and Display of Quasi-steady Data

- **Additional options for quasi-steady plot types**
  - **Select frame of reference as either inertial or science**
  - **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.grc.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
  - **Microgravity Analysis Workstation (MAWS) data**
    - stored in ASCII format
    - contains analytical prediction data for the STS 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

- **MAMS data is stored on NASA GRC file server *tsccrusader.grc.nasa.gov***
    - ftp and automated web server to generate MATLAB plots and distribute data on an as-needed basis
    - ossbtmf (TMF and bias compensation applied
    - ossraw – 10 samples per second data + temperature + bias status

Analysis and Display of Quasi-steady Data

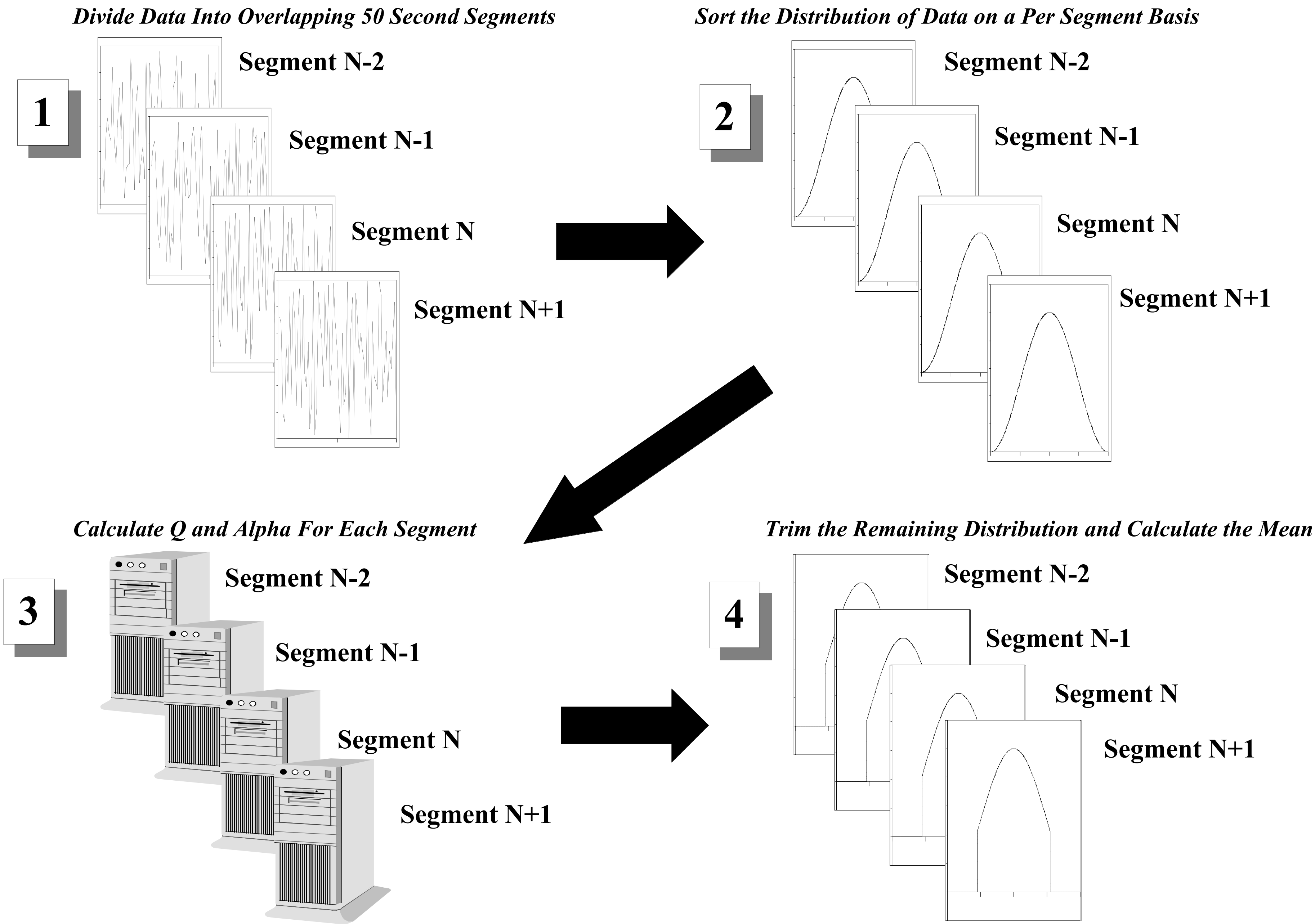
- **Raw OARE acceleration data**
  - **Figure 6-3 LMS Water Dump and Attitude Change**
  - **Figure 6-5 USML-2 Solar Inertial Attitude**
  - **Figure 6-7 USMP-3 Vernier Thruster Firings**

- **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**

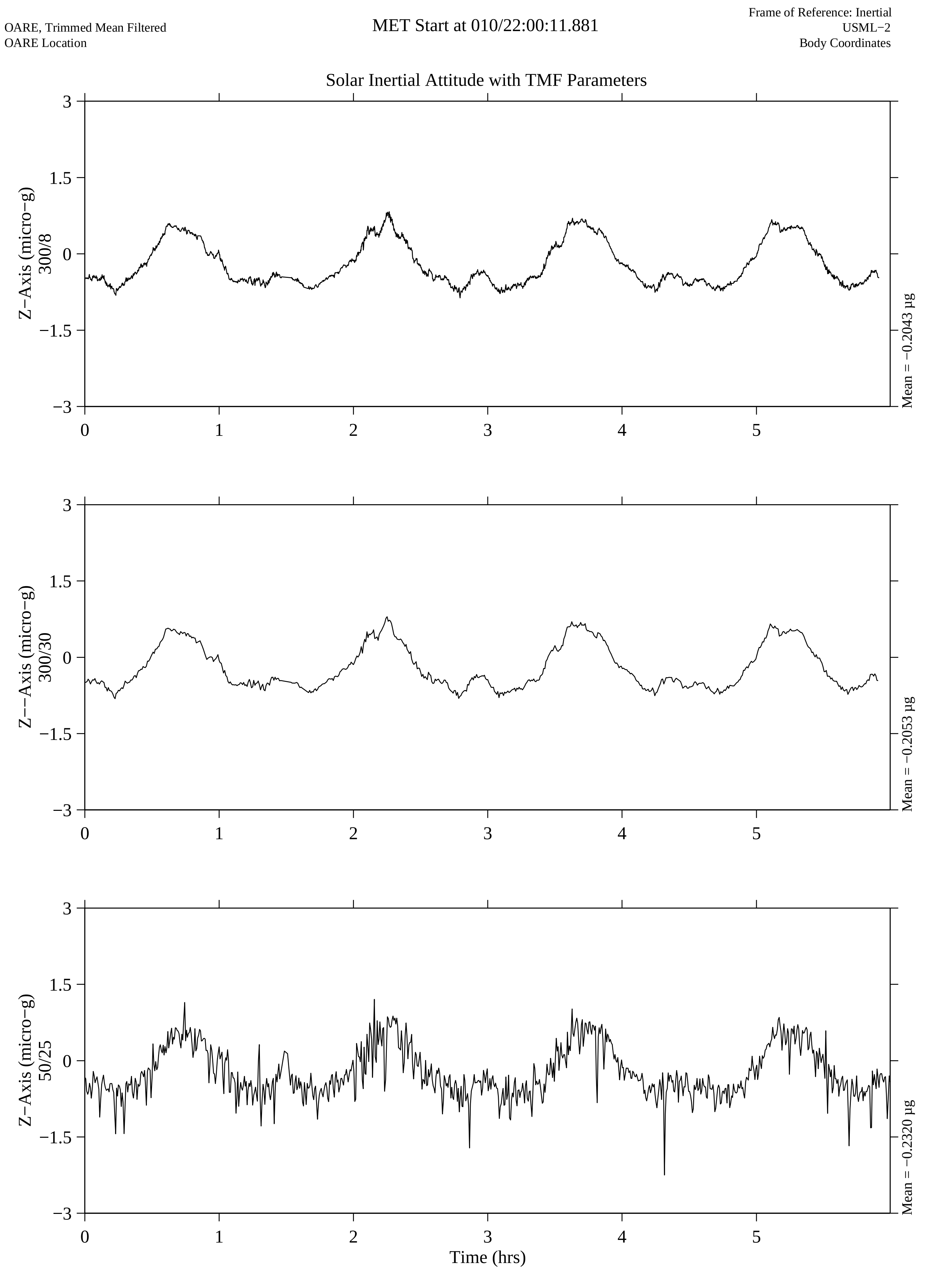
Analysis and Display of Quasi-steady Data

- **QTH plots**
  - **Figure 8-10 LMS Mission Plot**
  - **Figure 8-11 USML-2 Solar Inertial Attitude**
  - **Figure 8-12 USMP-2 Mission Plot**
  - **Figure 8-13 LMS Crew Active Period**
  - **Figure 8-14 LMS Crew Sleep Period**

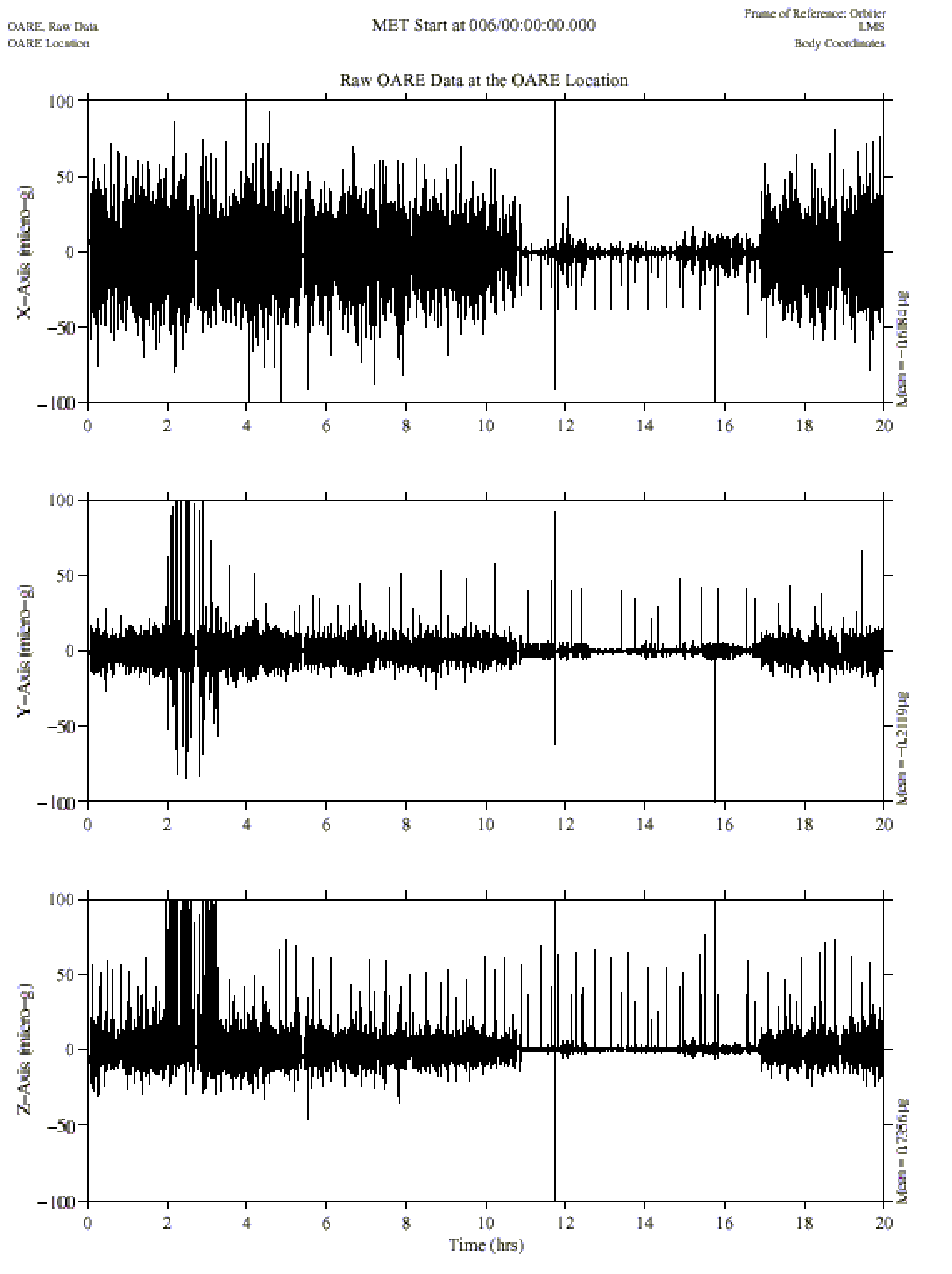
TMF Process



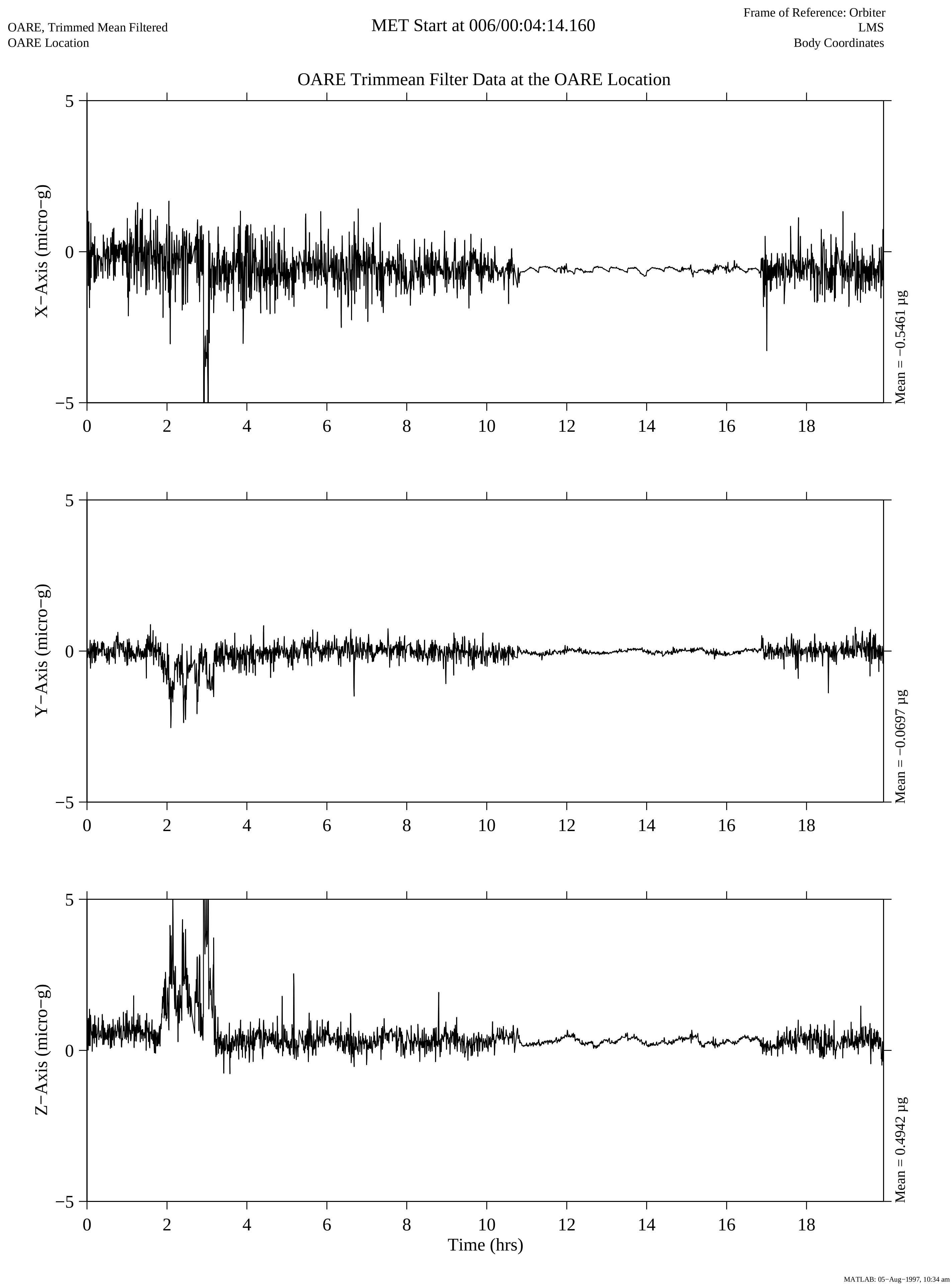
MEIT 2002 Figure 6-1



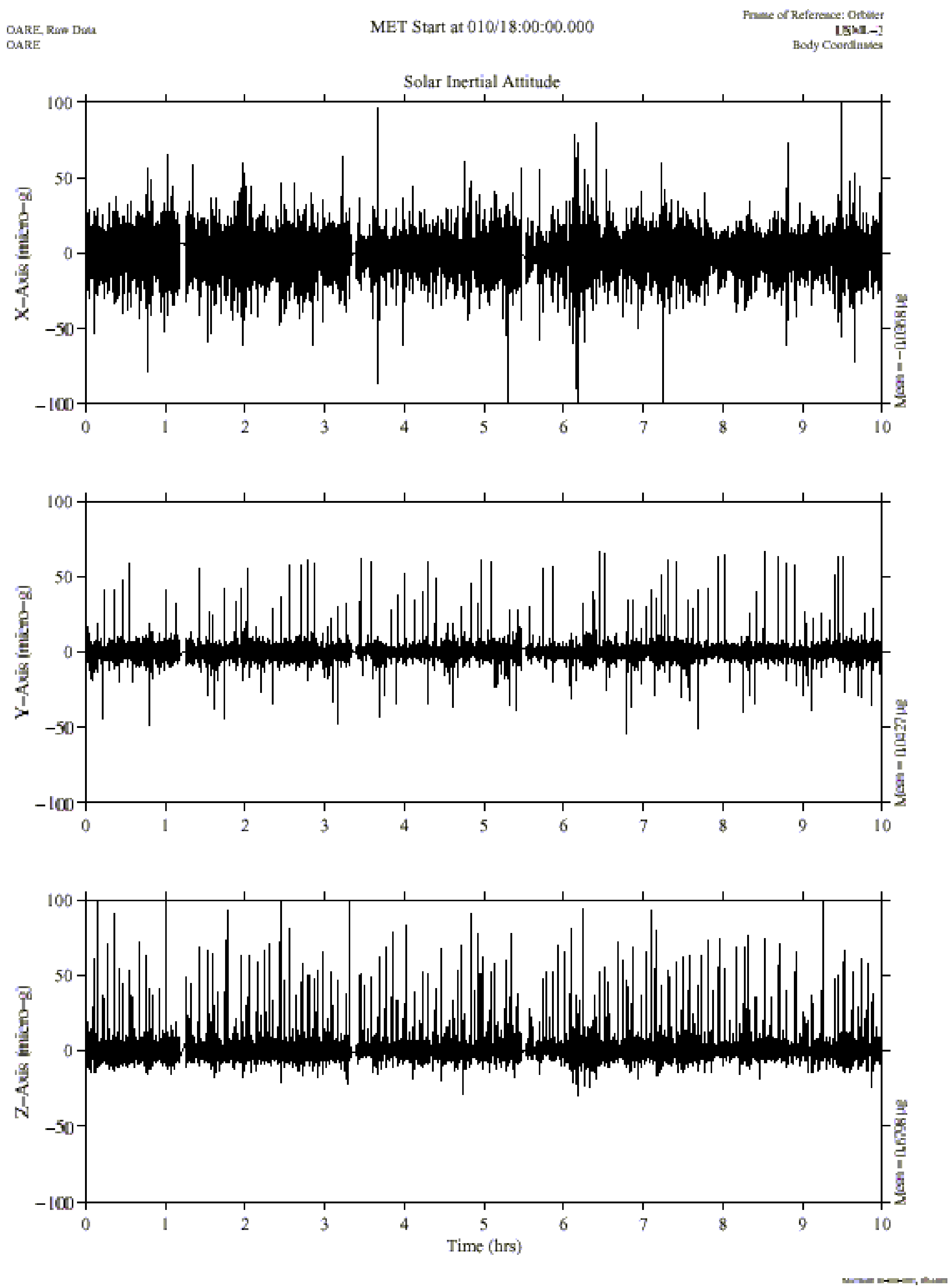
MEIT-2002 Figure 6-2: OARE TMF Data Showing TMF Parameter Comparison from STS-73 (USML-2)



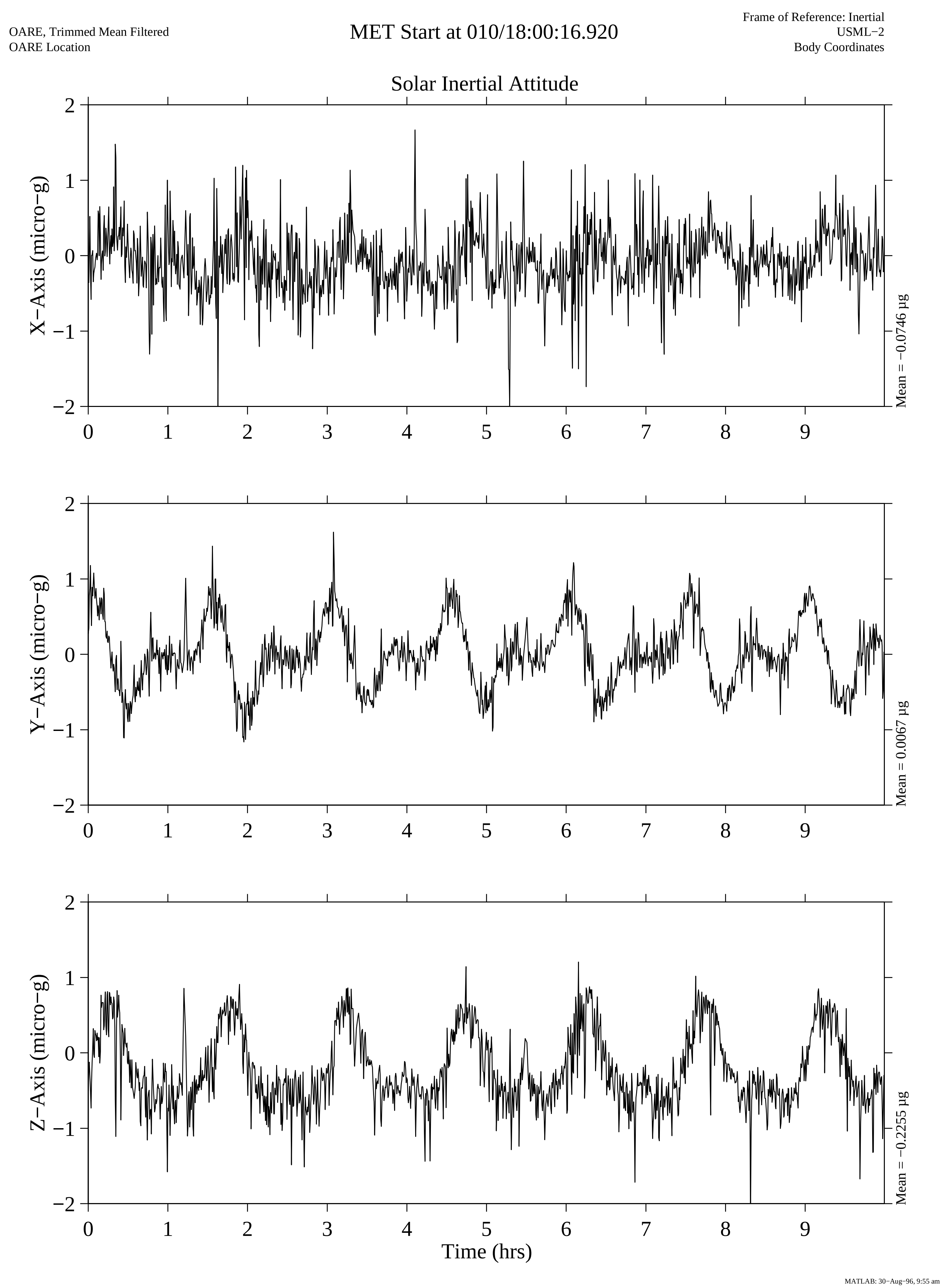
MEIT-2002 Figure 6-3: OARE Raw Data During Water Dump and Attitude Change from STS-78 (LMS)



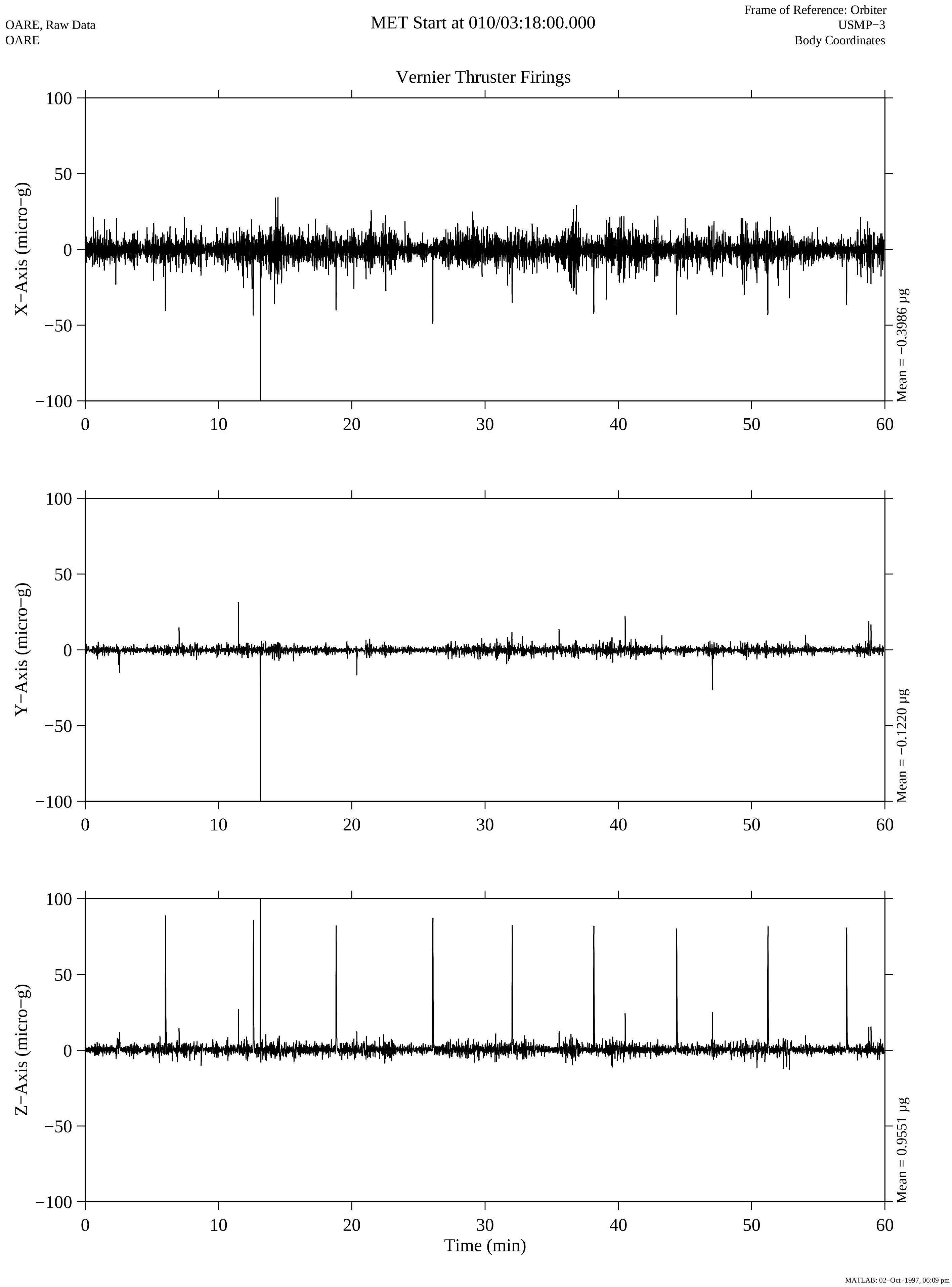
MEIT-2002 Figure 6-4: OARE TMF Data During Water Dump and Attitude Change from STS-78 (LMS)



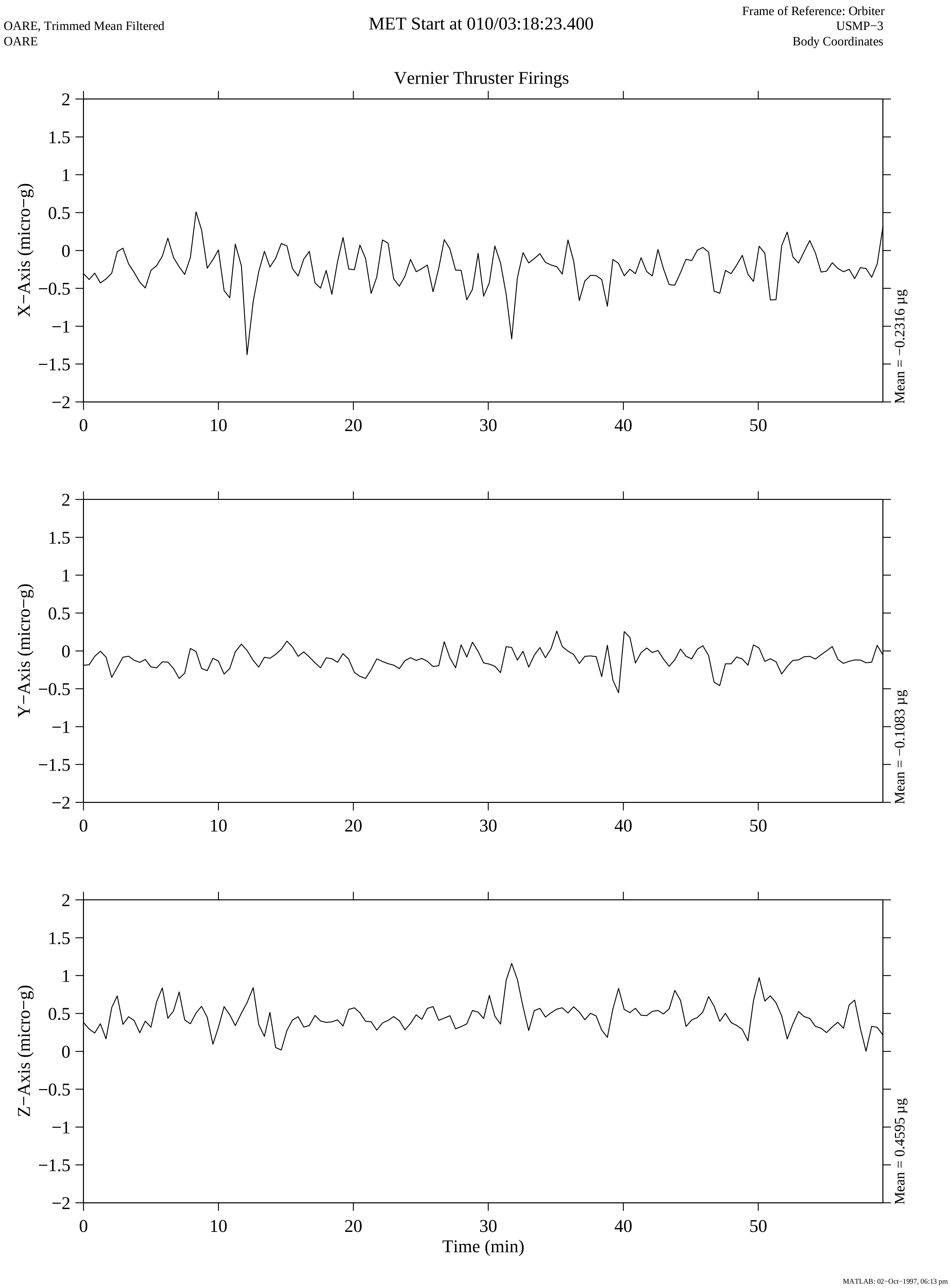
MEIT-2002 Figure 6-5: OARE Raw Data During Solar Inertial Attitude from STS-73 (USML-2)



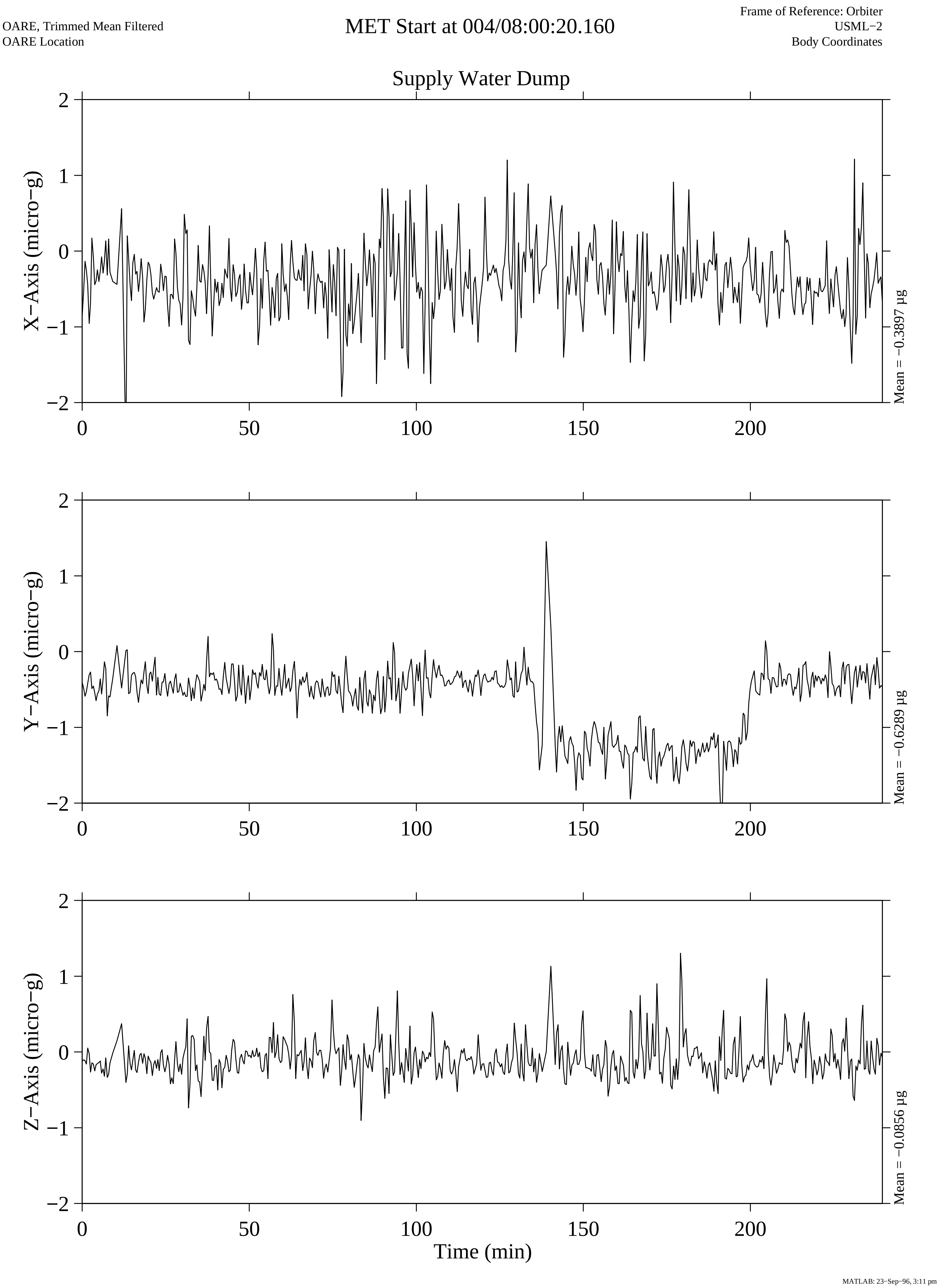
MEIT-2002 Figure 6-6: OARE TMF Data During Solar Inertial Attitude from STS-73 (USML-2)



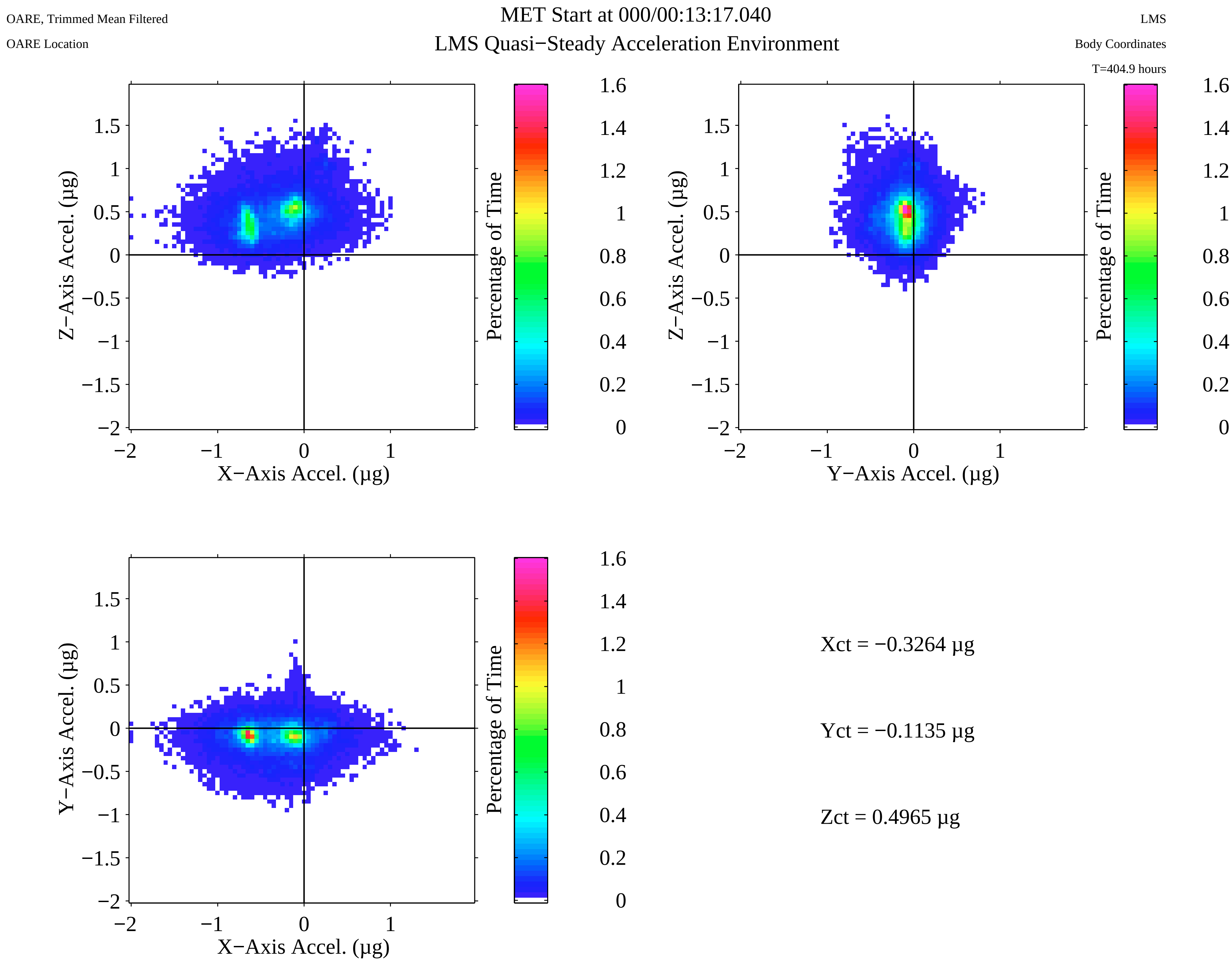
MEIT-2002 Figure 6-7: Raw OARE Data Showing Vernier Thruster Firings from STS-75 (USMP-3)



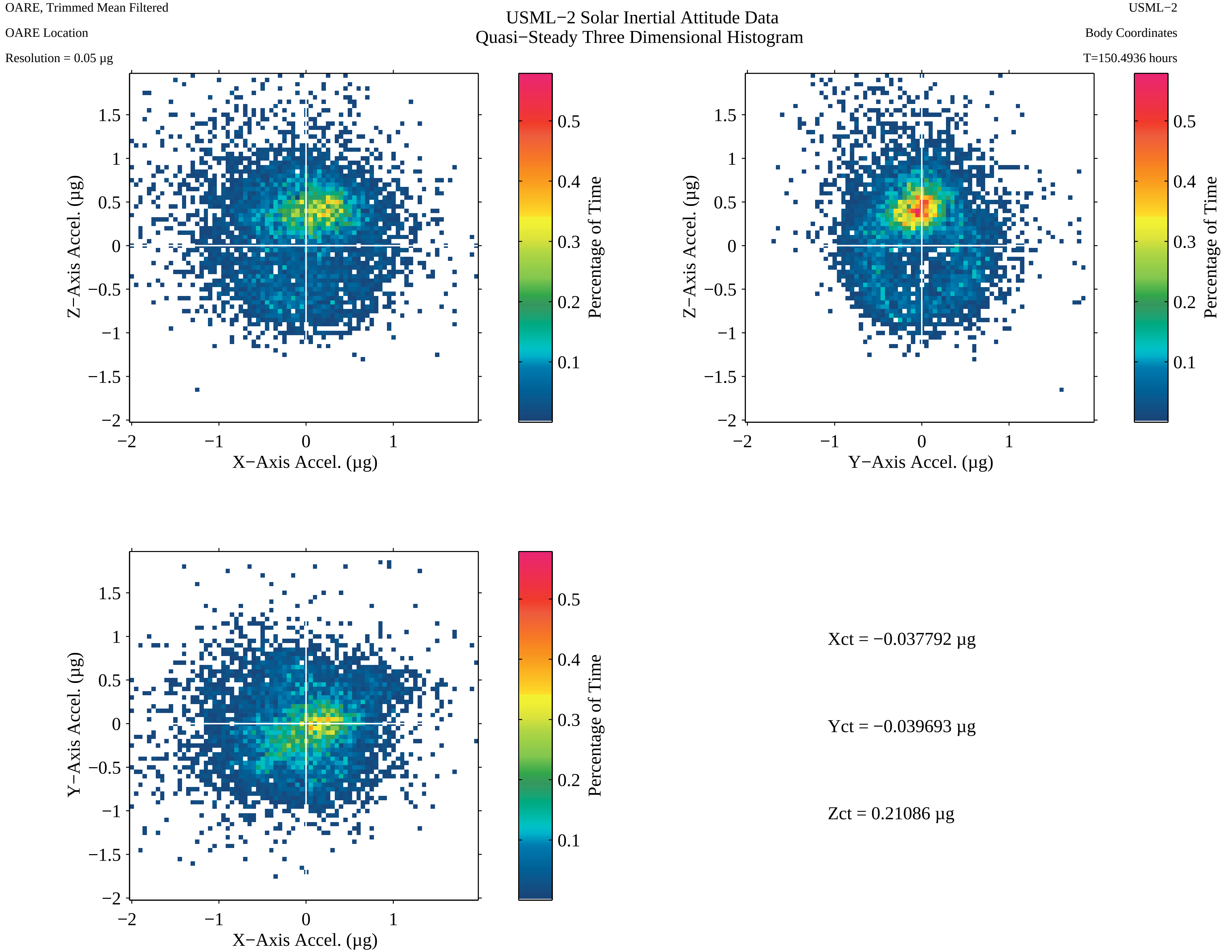
MEIT-2002 Figure 6-8: OARE TMF Data Showing Vernier Thruster Firings from STS-75 (USMP-3)



MEIT-2002 Figure 6-9: OARE TMF Data Showing Water Dump from STS-73 (USML-2)



MEIT-2002 Figure 6-10: Quasi-Steady Three-Dimensional Histogram Plot for Entire STS-78 (LMS) Mission



MEIT-2002 Figure 6-11: Quasi-Steady Three-Dimensional Histogram Plot for Solar Inertial Attitude from STS-73 (USML-2)

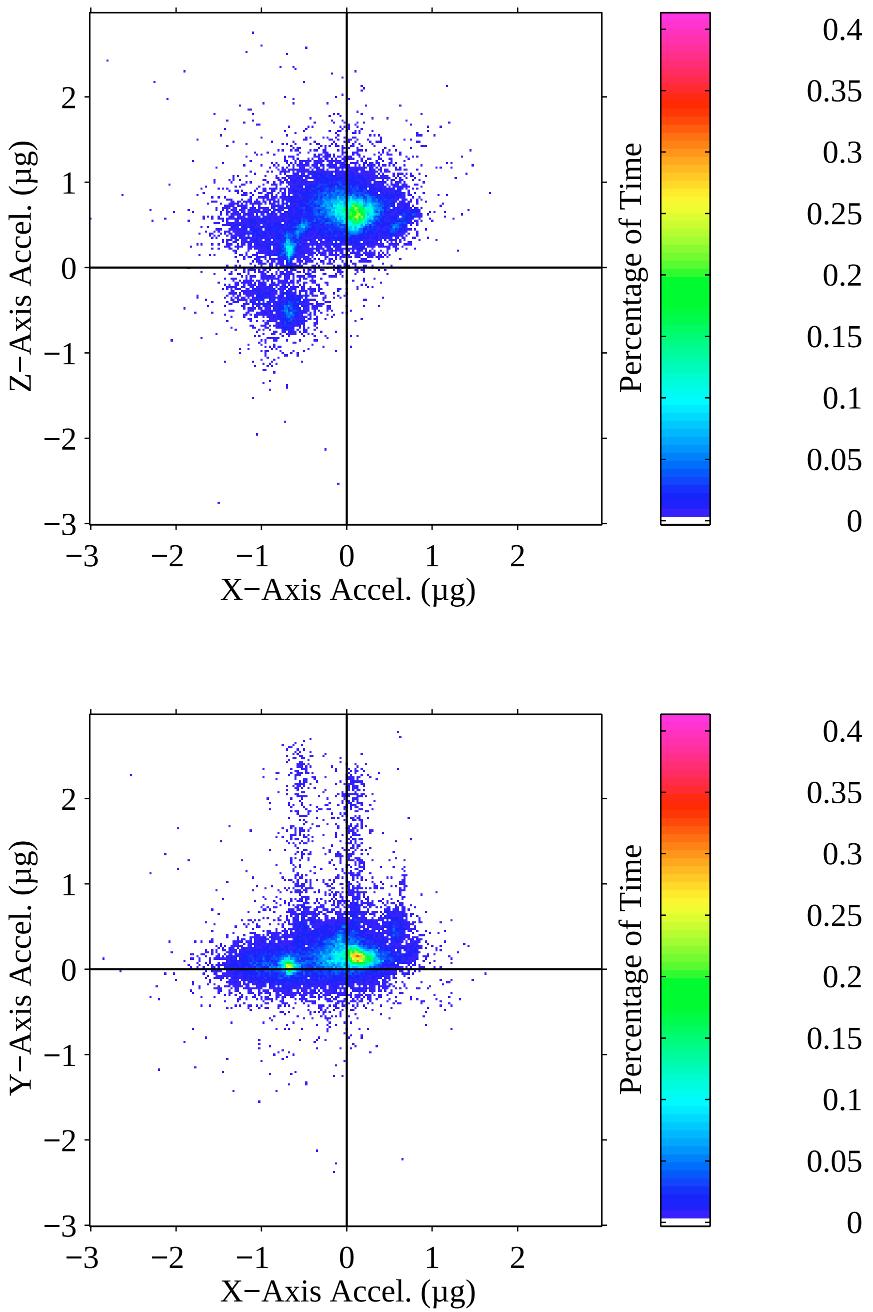
MATLAB: 03−Feb−2000, 02:27 pm

OARE, Trimmed Mean Filtered

OARE Location

MET Start at 000/00:12:16.920

USMP−2 (STS−62) Mission Plot



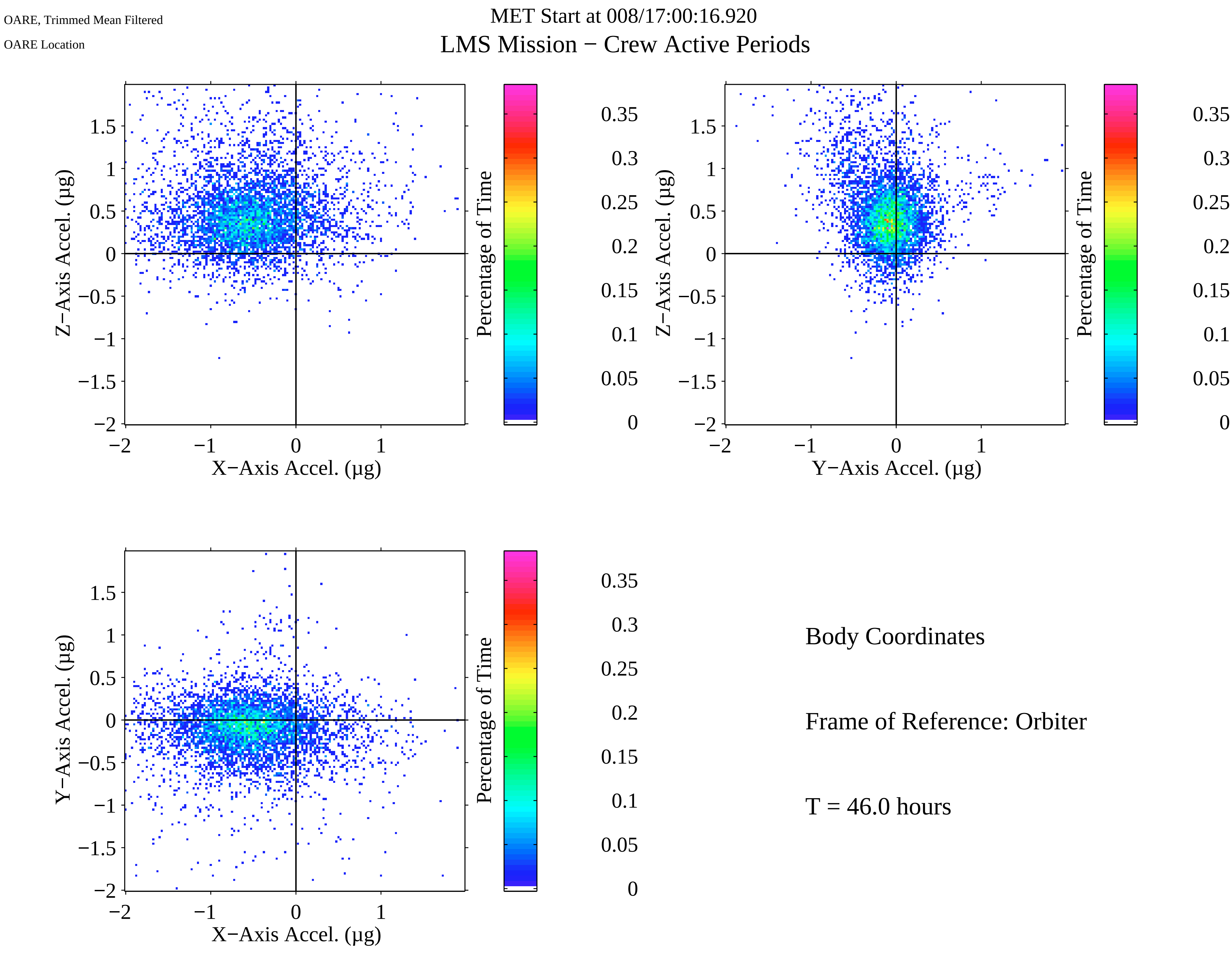
Body Coordinates

Frame of Reference: Orbiter

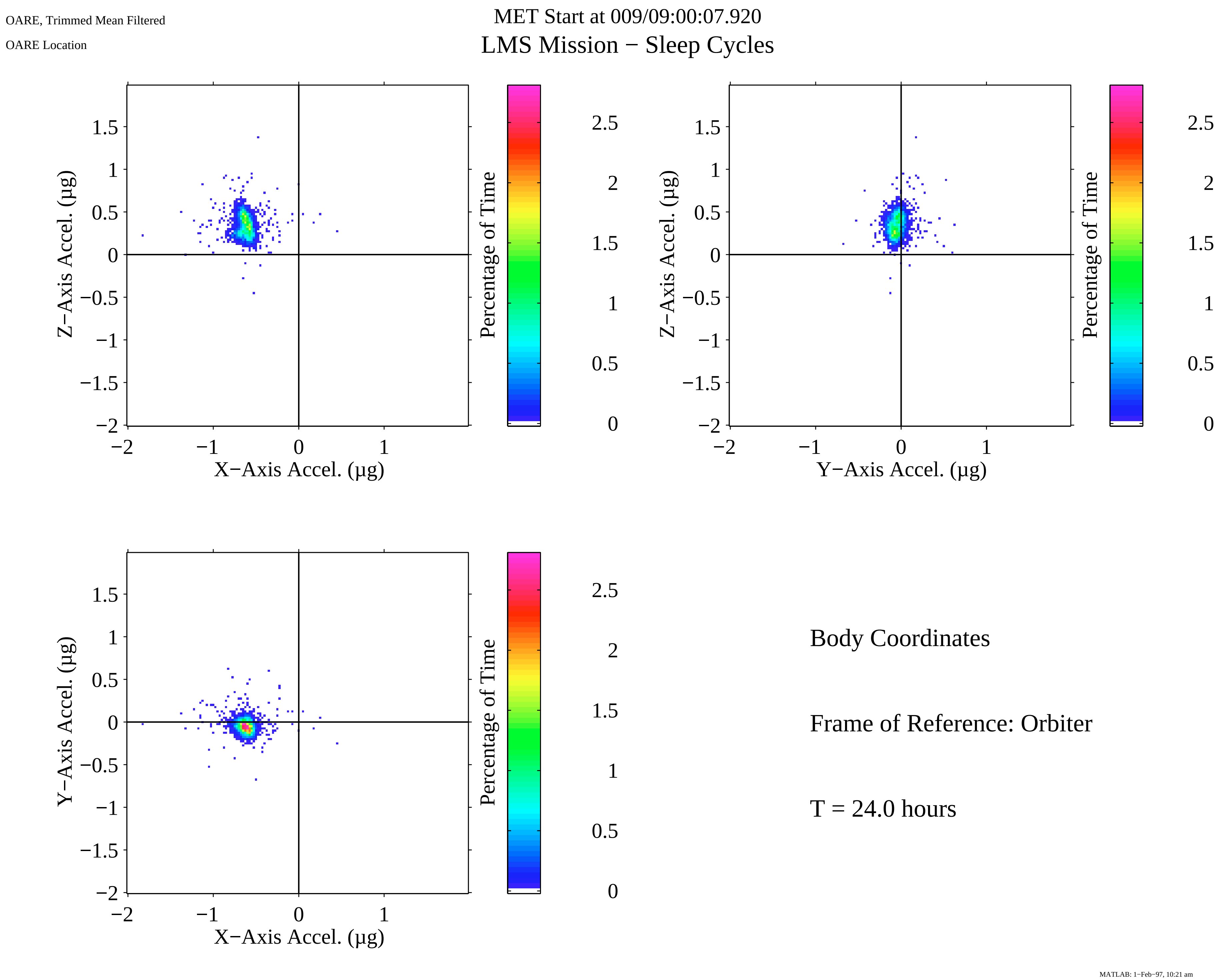
T = 333.4 hours

MATLAB: 1−Feb−97, 10:45 am

MEIT-2002 Figure 6-12: Quasi-Steady Three-Dimensional Histogram Plot for Entire STS-62 (USMP-2) Mission



MEIT-2002 Figure 6-13: Quasi-Steady Three-Dimensional Histogram Plot Crew Active Period STS-78 (LMS)



MEIT-2002 Figure 6-14: Quasi-Steady Three-Dimensional Histogram Plot Crew Sleep Period STS-78 (LMS)