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THE USE OF THEMATIC MAPPER SIMULATOR CALIBRATION DATA FOR ASSESSMENT OF DATA QUALITY

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ABSTRACT

In-flight calibration data collected from the Thematic Mapper Simulator (TMS) may be used to assess the quality of acquired earth scan data. The following results are indicated by analysis of first and second order statistics taken over one second intervals:

1. Based on limited samples, individual TMS channels have noise which varies from channel to channel, but remains constant within a channel. The noisiest channel, number 7, is good to about 5 significant bits. Channels 2-6 are good to better than 7 bits while channels 1 and 8 are good to 6 and 7 bits, respectively.

2. Short term variations of more than 5% in the average values of calibration source responses are likely to be indicative of problems. Earth scan data taken at the same time as these variations occur should be examined carefully for abnormal behavior.

3. Absolute radiometric calibration is unlikely to be meaningful in a temporal (flight to flight) sense due to single point calibration methods used.

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INTRODUCTION

If one considers the status of the Landsat-D Thematic Mapper, it becomes clear that for the next year or so, the primary source of comparable data will be produced by the aircraft version of it, the Thematic Mapper Simulator (TMS). In preparation for a complete analysis, some users of TMS data have requested that a radiometric calibration be performed on the data acquired for them over particular flight lines. In the course of pursuing this, it was found that the available calibration data were insufficient for an accurate radiometric calibration. This appears to be a manifestation of the non availability of funds devoted to calibration facilities and techniques.

However, it was determined that the calibration data which is a part of the data stream produced by the TMS served a useful purpose other than that for which it was originally intended; namely, it could be used to assess instrumental stability and data channel noise. This was accomplished by computing and plotting one second averages and standard deviations of calibration data acquired during the backscan portion of the sweep. During the backscan, a nonvarying calibration lamp and two thermal black bodies are observed by all spectral channels of the TMS. The response of the visible and near IR channels to the thermal black bodies acts as a zero level for these channels.

The use of this data is straightforward, for if there is little or no variation in the plots of the averages of the data obtained from the calibration sources, the behavior of the TMS Earth scan data during this time should be stable. If variations in the plots are observed for all channels, and these variations are similar in magnitude, time of occurrence, and trend, either the calibration source is fluctuating or the electronics is unstable. In the latter case, standard calibration methods will transfer these characteristics to the observed earth scan data. The third situation and perhaps the most dangerous occurs when two adjacent channels, or nearly adjacent channels appear stable and a third channel, spectrally close to the other two has irregular calibration data variations. These conditions can lead to erroneous conclusions about the relationship of the channels and observations based on the corresponding earth scan data.

Section 1 briefly discusses general calibration procedures applicable to TMS data. Section 2 shows some examples of observed varying calibration data and the associated effects obtained from flights flown for Dr. D. W. Deering of GSFC. The final section discusses conclusions and makes suggestions regarding the use of the calibration data if calibration is required. Appendix 1 discusses the output and its interpretation based on computer programs written by the author to display the calibration data.

Throughout the dicusssion, the author assumes the reader has some familiarity with the TMS with regard to spectral bands, spatial resolution, operation and data acquisition. Background can be found in references 1, 2, and 3. References relating to Landsat-D (4-5) provide other useful information.

1. Standard Calibration Procedures

Materials used for detectors in scanning radiometers such as the TMS usually respond to emitted or reflected energy in a linear fashion. Assuming sufficient care in the electronics design of the instrument so that linearity is maintained, the major problem in calibrating an instrument is in defining a known source. For the purposes of this paper it is assumed that well defined calibration sources do exist in the spectral range of interest.

a. Reflective Calibration

The spectral region for reflective measurements range from about .35 micrometers to about 3.5 micrometers. Calibration lamps with known characteristics have been developed by the National Bureau of Standards for use in this region. Thus, the output of a given detector and associated spectral filter can be measured and will define a point on a straight line for a plot of output voltage versus energy.

The procedure utilized by Johnson Spacecraft Center (JSC) for calibration of the TMS in this spectral region utilizes a one lamp integrating sphere as a standard. The output of the visible and near IR channels is recorded using the integrating sphere as a source. Electronic gains in the TMS are set so that each channel will give a full scale response if illuminated by the incoming solar radiance in the associated spectral interval. An expected albedo factor is also included in this setting, so as to allow reasonable response from expected terrain. The internal calibration lamp is then set at a level which gives about a 50% to 75% output in all channels by controlling the voltage and current to it. Provided that the lamp output remains constant, the instrumental (TMS) output can then be compared to the sphere data and hence, may be "calibrated".

The instrument is then flown, with the lamp voltage and current values supposedly being kept at the same levels as in the calibration lab.

There are some disadvantages associated with this method of calibration which are as follows:

1. It is assumed that detector and amplifier responses are linear. This needs to be proven utilizing multilevel sources.
2. Calibration lamp radiance as a function of voltage and current to the lamp should be tabulated. The assumption that voltage and current remain constant even if properly set at the beginning is risky. Along with this, lamp stability for the duration of the flights needs to be demonstrated. As the lamp is run well below rated values, radiometric changes are probably not severe.
3. Instrument response in the lab may differ from that in flight due to differing ambient conditions.
4. Complete system stability as a function of time needs to be determined.

Until these points are satisfactorily resolved, valid temporal comparisons are unlikely to be meaningful. The single point calibration raises severe doubts as to the accuracy of the data in an absolute sense even in regions of stable calibration data.

b. Thermal Calibration

The TMS has one spectral band centered at about 11 microns which responds to thermally emitted energy from which an effective blackbody temperature may be estimated. This latter quantity assumes unity emissivity. The observed radiance, W, is related to the temperature of the blackbody and the spectral bandpass of the observing instrument by the Planck function

$$W(\lambda,T) = \Delta\lambda \cdot C_1 \cdot \lambda^{-5} \cdot \exp[(C_2/\lambda T) - 1]^{-1}$$ where

λ is the wavelength in micrometers

$\Delta\lambda$ is the spectral bandwidth

T is the temperature in degrees Kelvin, and

C_1, C_2 are constants which have values that depend on the ultimately desired units

As long as $\Delta\lambda$ is fairly small we can estimate $W(\lambda,T)$ with this differential form rather than the formal integral.

Since the sensor output is linear with respect to energy and there are two calibration blackbodies, we can obtain a two point calibration for the thermal data. Each sensor data point can be converted to energy, and then to temperature by solving for T in the Planck function. This scheme allows temporal comparisons of temperature as the calibration is in flight and updated each scan line. The main concern is the accuracy of the determined temperature of the blackbodies. The linearity of the thermal channel has been demonstrated at JSC. (6)

2. Calibration Data Usage

Calibration data recorded on the JSC Universal Tape appears to be more useful for monitoring instrument performance rather than as a vehicle for computing radiometric values. The reason for this statement is that seven of the eight channels require a linear transformation based on physical values which are imperfectly known (see section 1a). If one thinks in terms of energy, the thermal channel is also linear. For many applications, namely classification, a transformation of the form aX+b applied on a channel by channel basis should not alter the final results significantly, although decision rules may be altered due to changes in variance.

Prior to attempting an absolute radiometric calibration, the behavior of supposedly non-changing calibration sources and associated parameters such as voltage, current, and temperature was observed for all channels. This was accomplished by computing one second averages and standard deviations of the instrument response to the two blackbodies and the internal calibration lamp and plotting them. Stability of these outputs as a function of time should indicate that the TMS instrument is stable and relative comparisons between channels can be made with some degree of confidence. Deviations from the condition of long term stability are likely to indicate instrument problems and data collected from Earth areas at the time of the deviation should be avoided or examined for abnormal behavior. Parameters which control the output of the calibration sources such as blackbody temperature and visible lamp current were observed and plotted as a check for cause of variation when it was encountered.

The following figures were made from data flights flown for Dr. W. W. Deering of Code 923 and illustrate the above points.

a. Data Quality Analysis

Figure 1a-1d are typical outputs from the TMS. The heavy line represents the average value of the calibration lamp over a 1 second interval; the standard deviation is added and subtracted from this average and is indicated by the lighter lines. For this case the TMS was running at 15 scans per second, though this is a variable which depends on the height and speed of the aircraft.

It can be seen that the noise varies from channel to channel. This observation, with regard to channel noise, is fairly consistent for the available data sets. Utilizing the results of these plots, table 1 can be estimated and indicates the accuracy of each channel with respect to eight bits. This is nearly equivalent to dividing 255, the maximum available count, by the average standard deviation for such channel.

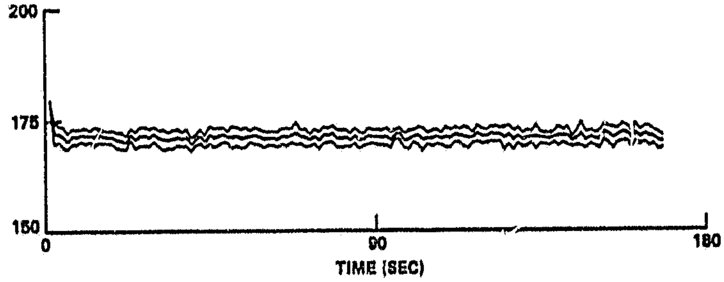

Figure 1a - Typical of TMS Channel 1

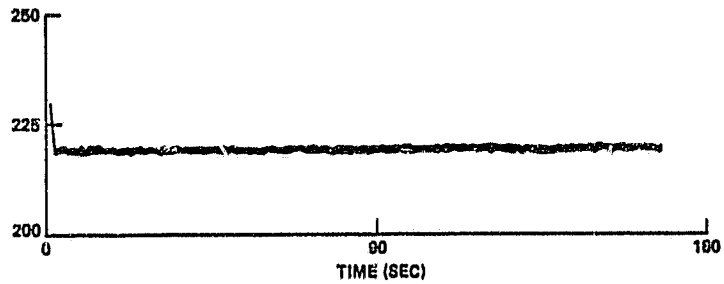

Figure 1b - Typical of TMS Channels 2 - 6

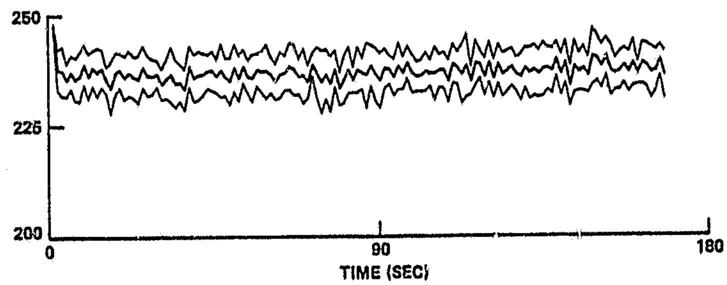

Figure 1c - Typical of TMS Channel 7

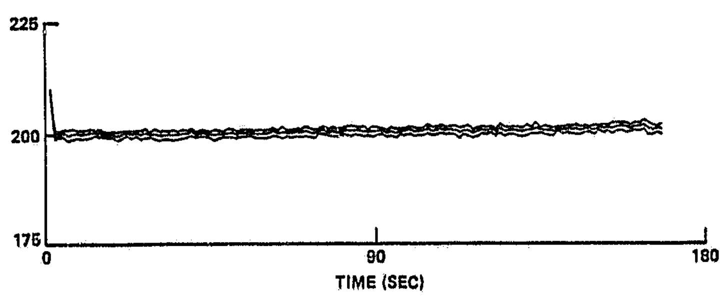

Figure 1d - Typical of TMS Channel 8

Table 1
Estimated Significant Bits for TMS Data

Channel	1	2	3	4	5	6	7	8
Significant Bits	6	7+	7+	7+	7+	7+	5	7

b. A Data Anomaly

Figure 2a and 2b show data from two adjacent channels (5 and 6) of a particular flight line. Scaling locates the disturbance in channel 6 as occurring at near line 75. Utilizing a routine which plots average grey value as a function of distance along a line defined by two points (Fig. 3), we note a disturbance in the region of line 75 in both value and standard deviation at point a. The increase in standard deviation shown at point b is associated with a light to dark or dark to light transversal such as when going from land to water. A close examination of the images revealed an occurrence which appears to be a bit slip (Fig. 4), and hence, may be due to a temporary malfunction of some part of the data system.

Note that on Figure 2, the zero level response in channel 5 or 6 is different for each observed blackbody. In practice the difference is small (about 3 counts or less) but has been emphasized in the plots. This effect may be caused by a small light leak but this has not been verified. The effect seems small enough to be ignored.

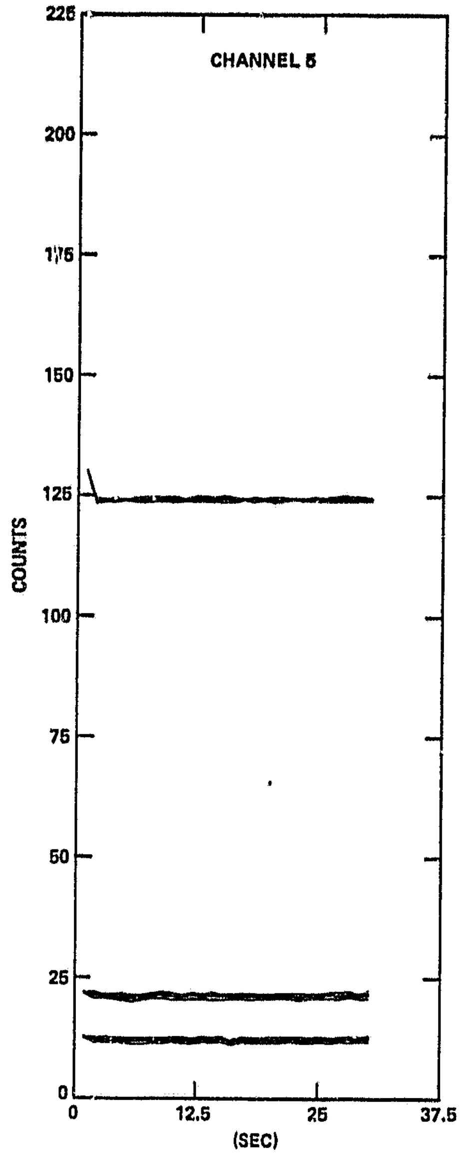

Figure 2a

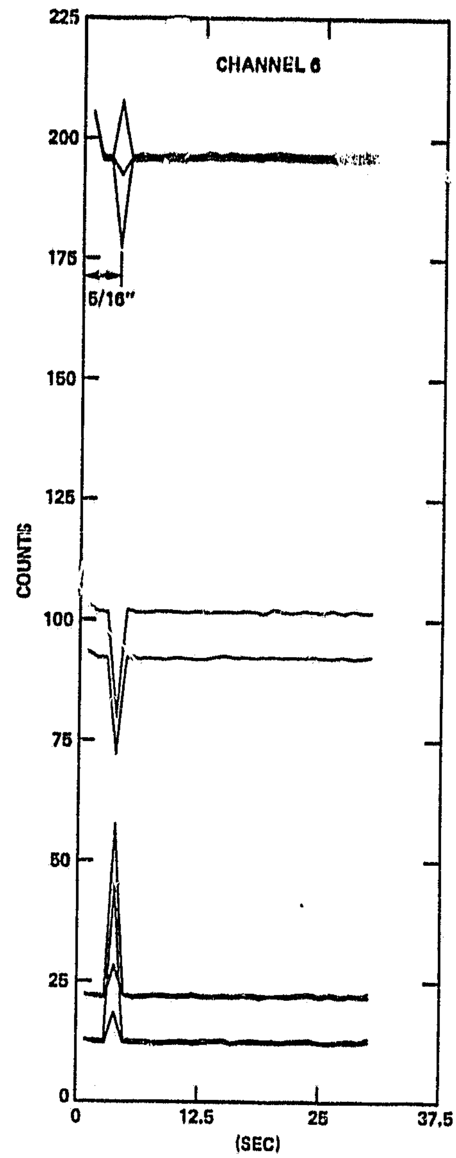

Figure 2b

Figure 2 - Response of channels 5 and 6 to the visible calibration lamp and blackbodies. The perturbation in channel 6 occurs at about 3.9 seconds into the flight segment which corresponds to line 75 as there were 19 scans per second for this segment.

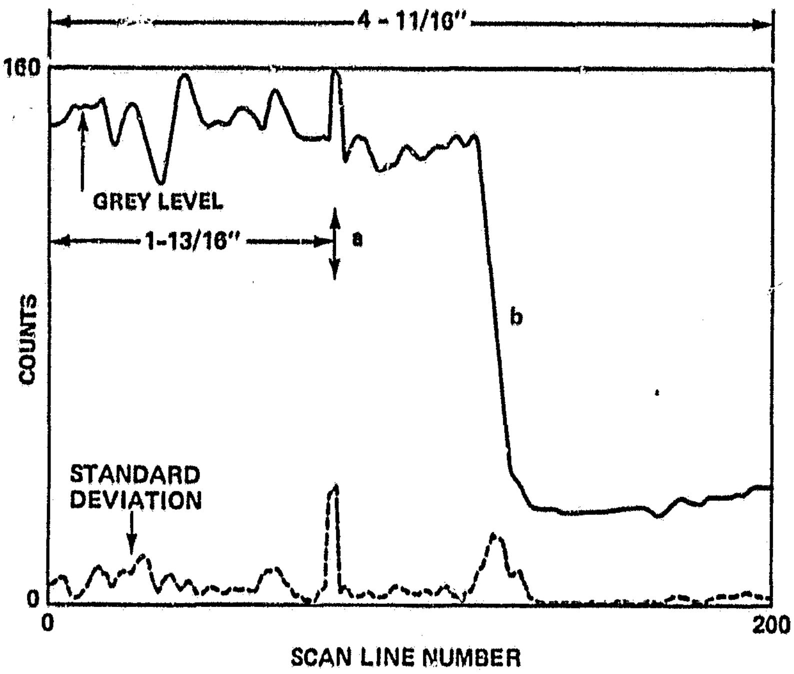

Figure 3 - This plot represents the average value (solid) and standard deviation of real image data for channel 6 of the TMS. Statistics are computed within a moving 3x3 box about a point located on a line defined by two image points.

c. Changes Between Channels

The next set of figures (5a, b, c) show calibration data from channel 1, 2, and 3, (short wavelength, reflected). Channels 1 and 3 are stable while channel 2 has a varying zero level. Utilizing the routine referenced in the above paragraph it is seen that grey level data from channel 1 and 3 exhibit similar behavior (an increase with time), while data from channel 2 exhibits a trend in the opposite direction (Figs. 6a, b, c). These data were obtained from cloud shadow regions of the scene. Data acquired from well illuminated regions do not show any noticeable differences (see Figs. 7a, b, c). So far a reasonable explanation for this has eluded the author.

The question should be asked, "Does a variation in the zero calibration levels indicate a real data variation?" The preceding data indicate this possibility in an equivocal sense. Data with a constant zero level and varying lamp response have not been found so far in the existing data sets.

Figure 4a

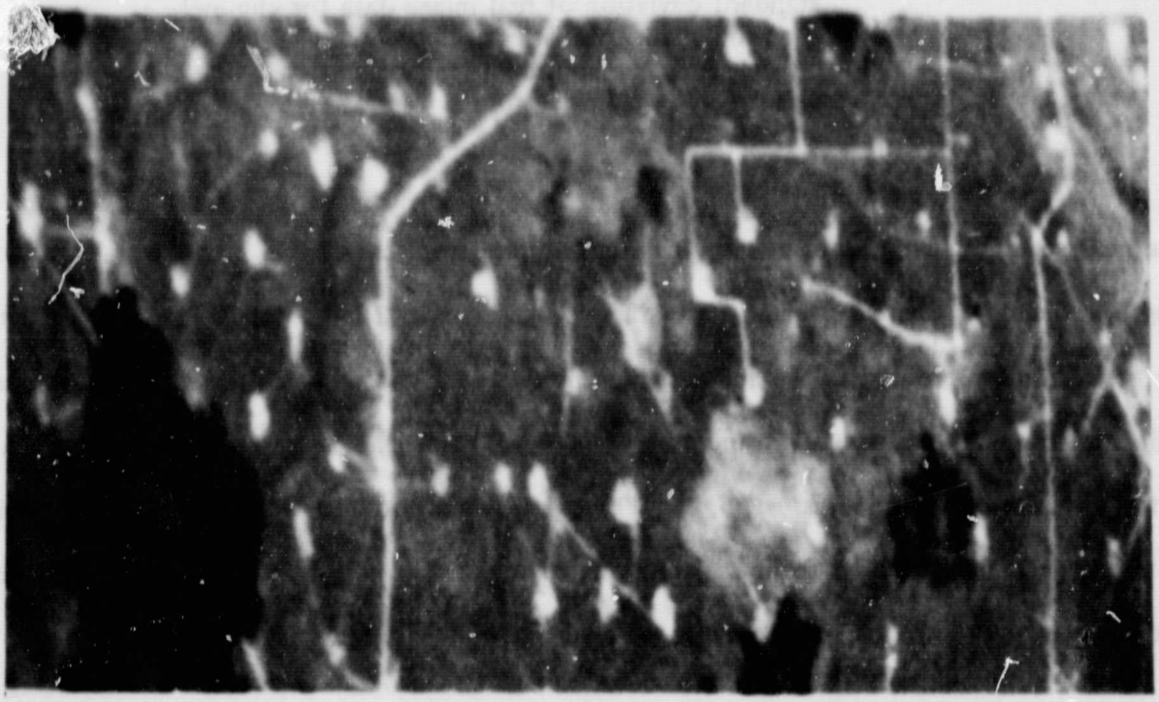

Figure 4b

Figure 4 - This is the image formed from the data acquired from channel 6 (Fig. 4a). The data in the scanlines designated by the arrow shows abnormal behavior. The cause of this is unknown, but appears to be due to a temporary malfunction in the data recording system as the recovery is fairly rapid. Channel 5 is also shown in Fig. 4b for comparison purposes and does not exhibit this anomaly.

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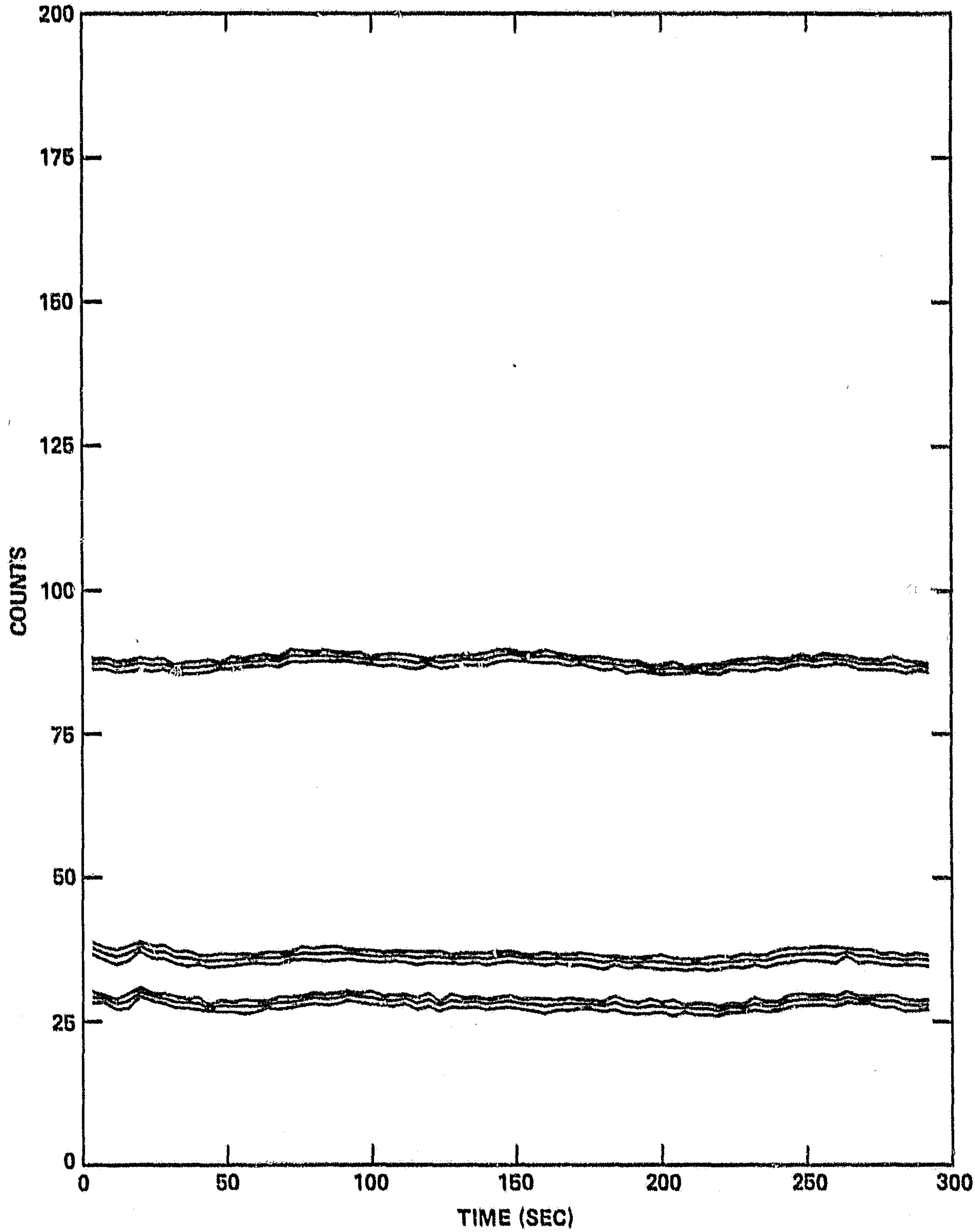

Figure 5a - TMS Calibration Data for Channel 1 - Fairly Stable

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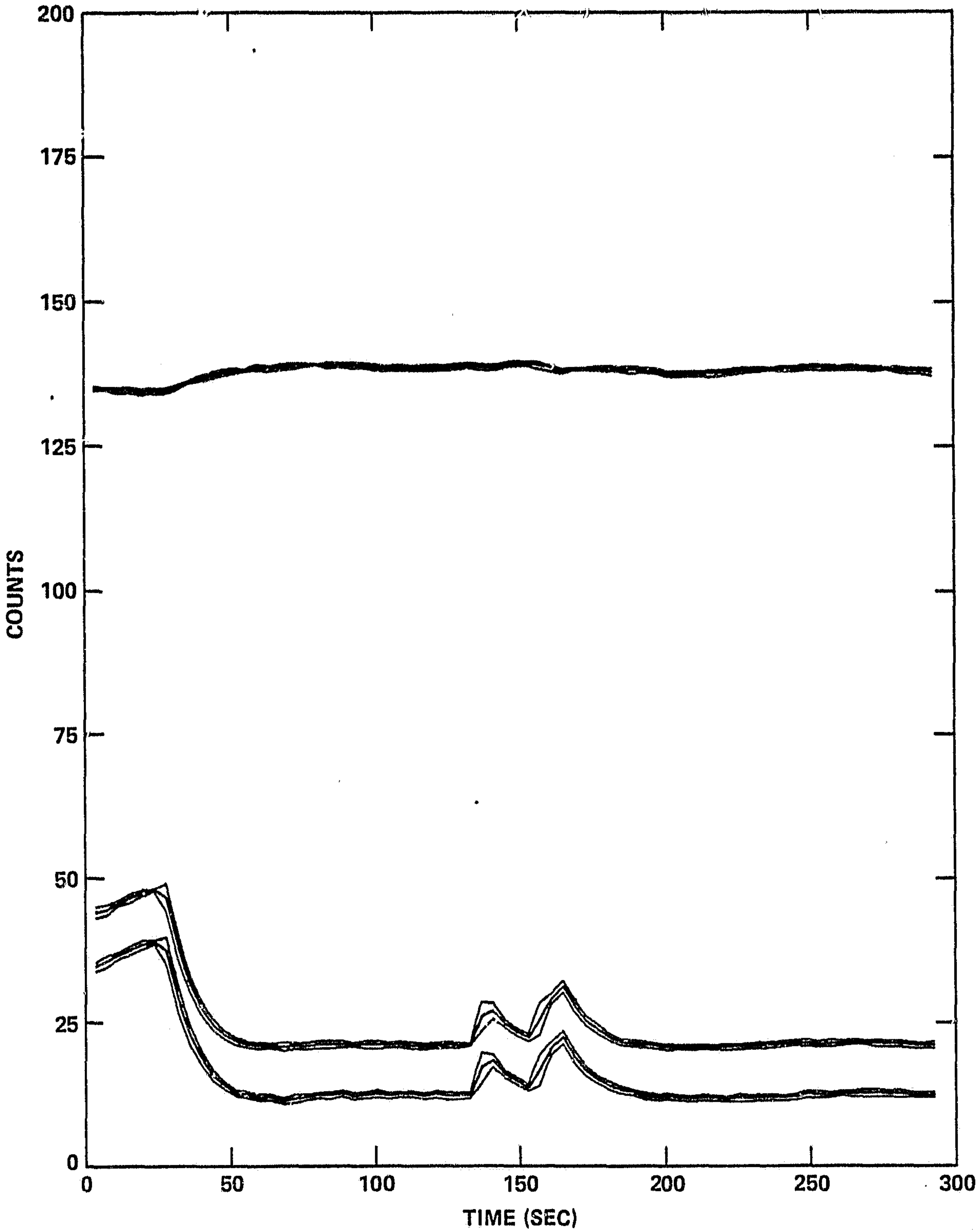

Figure 5b - TMS Calibration Data for Channel 2 - Unstable Zero Level

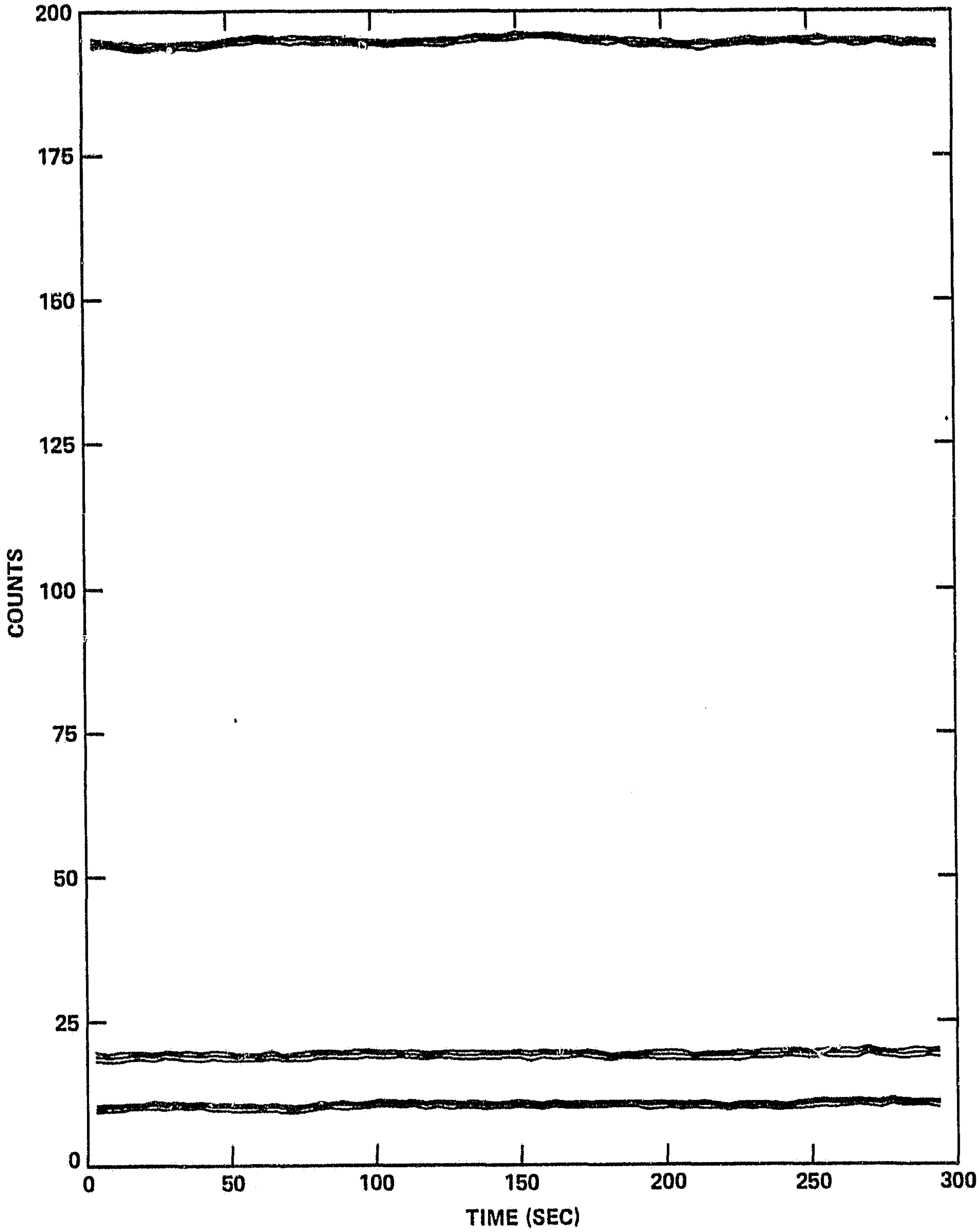

Figure 5c - TMS Calibration Data for Channel 3 - Fairly Stable

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6a

6b

6c

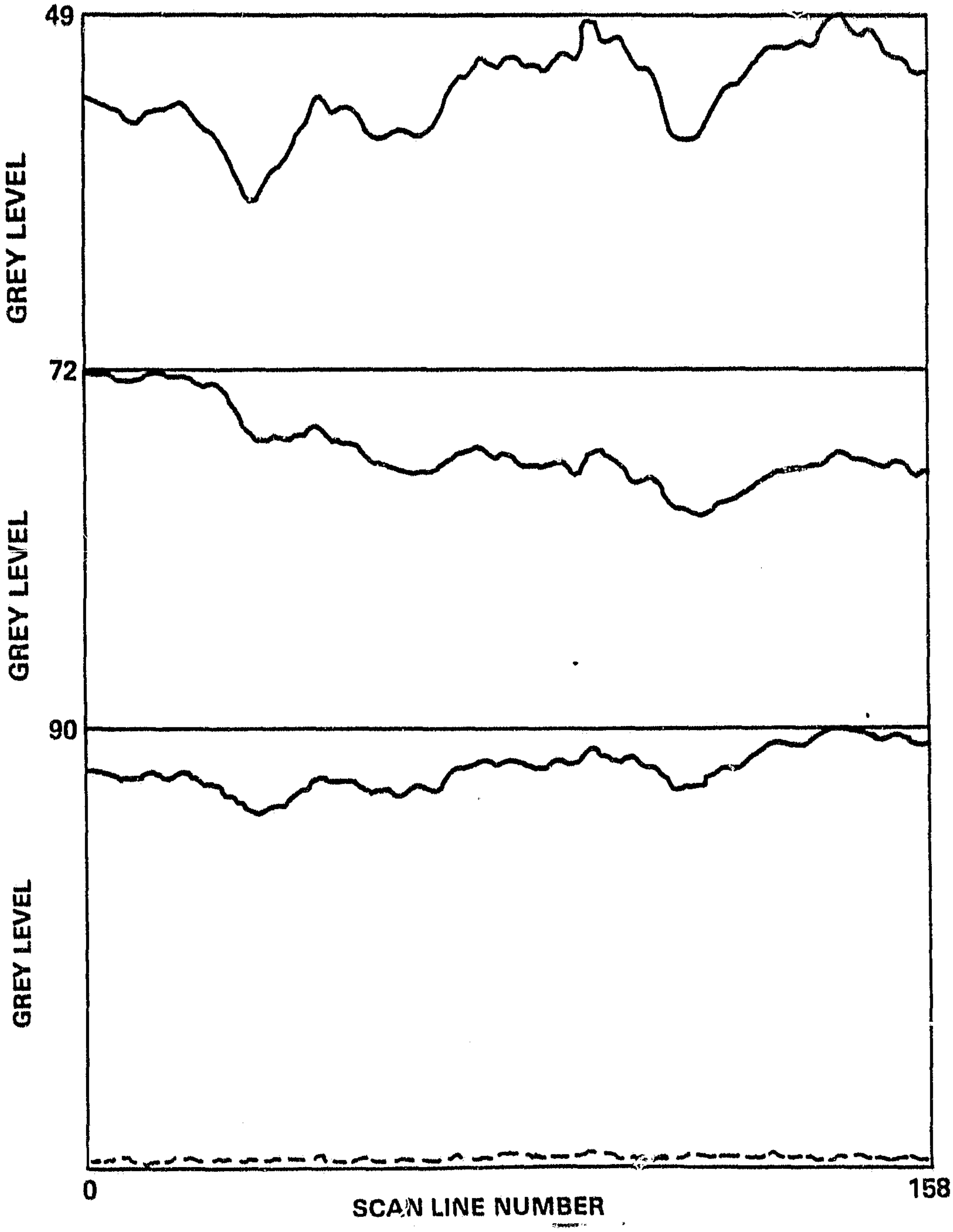

Figure 6 - These plots, similar to those in Fig. 3 are the grey values of channels 1, 2, and 3 for pixel 87 of the first 160 lines of data. The image data appeared uniform to the eye but the area was in a cloud shadow. The trend of Figure 6a and 6c is similar (increasing as a function of time.) Figure 6b shows a trend in the opposite direction. Without the calibration data, this might be considered significant.

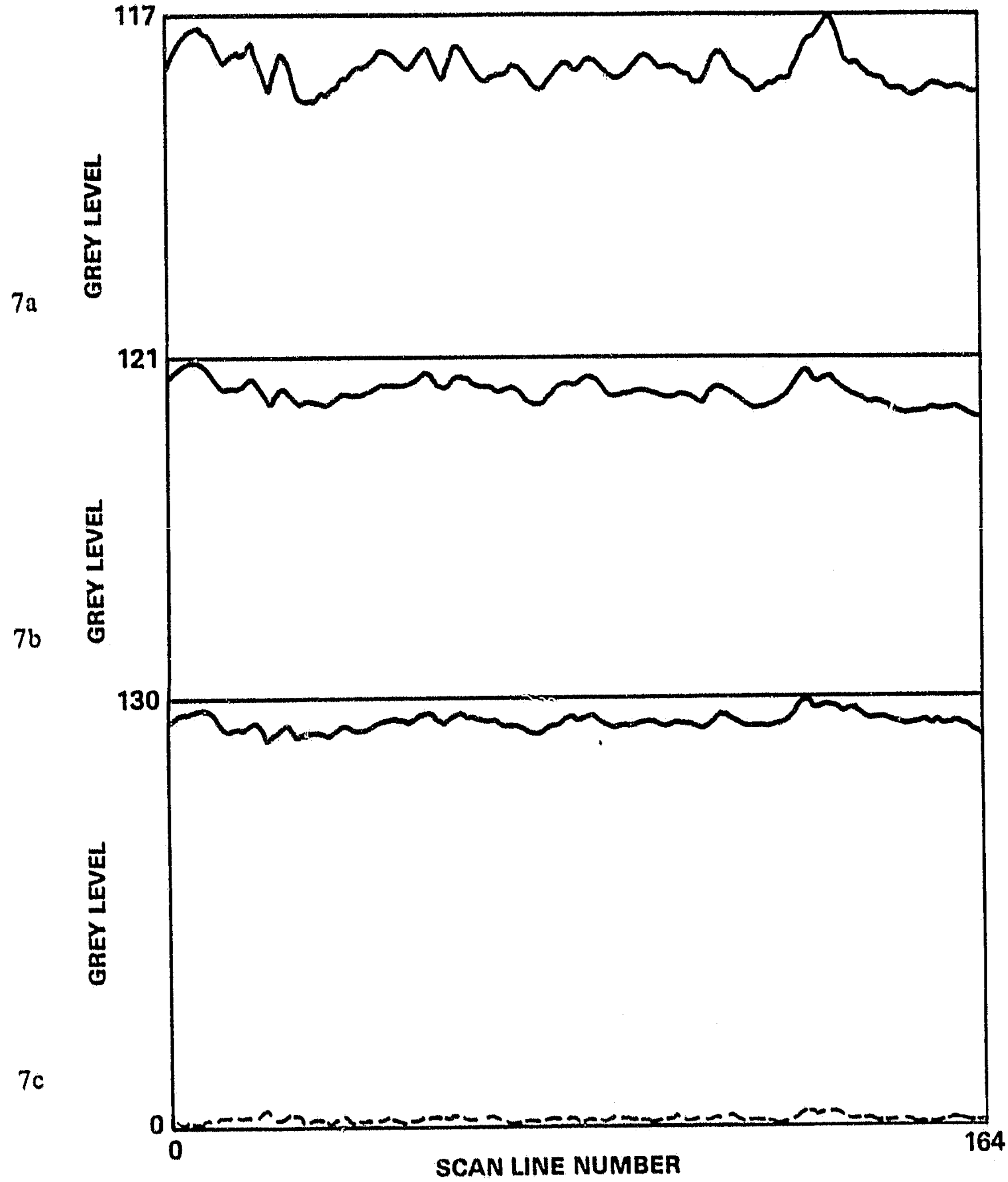

Figure 7 - These plots are for the first 164 lines and are located at pixel 409. The data are from an open (no cloud shadow) visually uniform area. There is no readily observable difference in the behavior of channels 1, 2 or 3 for this situation.

3. Conclusions

Plots of one second averaged data which are calculated from observations of the calibration sources of the TMS, appear to be a reasonable tool for assessing data quality. Conclusions drawn from observations corresponding to regions where variations occur in the steady source calibration data should be examined carefully as the effect may be instrumental and not data dependent.

Absolute calibration in the reflective channels is unlikely to be accurate. The thermal channel appears to have the potential for fairly accurate calibration.

The radiometric utility of the calibration information provided with TMS data seems to be limited in the visible and near infrared regions. Fluctuations in what should be constant levels are not fully understood at this time, and these characteristics would be transmitted to the earth scan data if standard calibration methods are applied.

The calibration of TMS data is a difficult problem. The methods currently in use fall short of allowing a good absolute calibration in the visible and near infrared regions. The primary use of the calibration data is found in assessing instrument stability.

The examples used in section 2 are typical of the variations encountered, but not typical of overall TMS data quality. Variations of the type discussed occured in less than 10% of the flight segments processed by the author.

4. Acknowledgement

The author would like to thank Drs. Ken Meehan and D. W. Deering for providing study input data and providing the initial impetus for this project. Computer work was carried out on the AOIPS 11/70 and the Image 100 and many thanks are due Code 930 for computer support. Several discussions with Ray Stokes of JSC proved illuminating.

APPENDIX 1

To obtain the output shown in Figure A1 from a TMS tape, it is necessary to utilize two programs. These programs are resident on the AOIPS 11/70 system. It is suggested that the author be contacted regarding the specifics of running these programs. It is quite likely that by the time this is read, that responsibility for the running of this job will be in Code 930 and all that will be required is an operator request.

The plots in Figure A1 are typical of the output expected. The Y axis represents output levels (voltage or counts) and the X axis corresponds to elapsed time from the start time given in the label. For true elapsed time, divide the X axis by the T EXP factor.

The total number of plots expected of this type is the number of operating channels plus 1. When all eight channels are operating, the first seven plots represent outputs from channels one through seven. The eighth plot is channel 8 (thermal) and the ninth plot displays calibration lamp voltage and current and blackbody temperatures. The heavy line in each group of plots is the average value with the ± standard deviation shown by the fine line. The bottom two plots for the visible channels are responses to the blackbodies (theoretically zero). An offset of 10 units is introduced for plotting purposes, as the real difference between responses is usually less than three counts. Output for the thermal channel is similar except that the third set of plots represents energy detected from the calibration lamp.

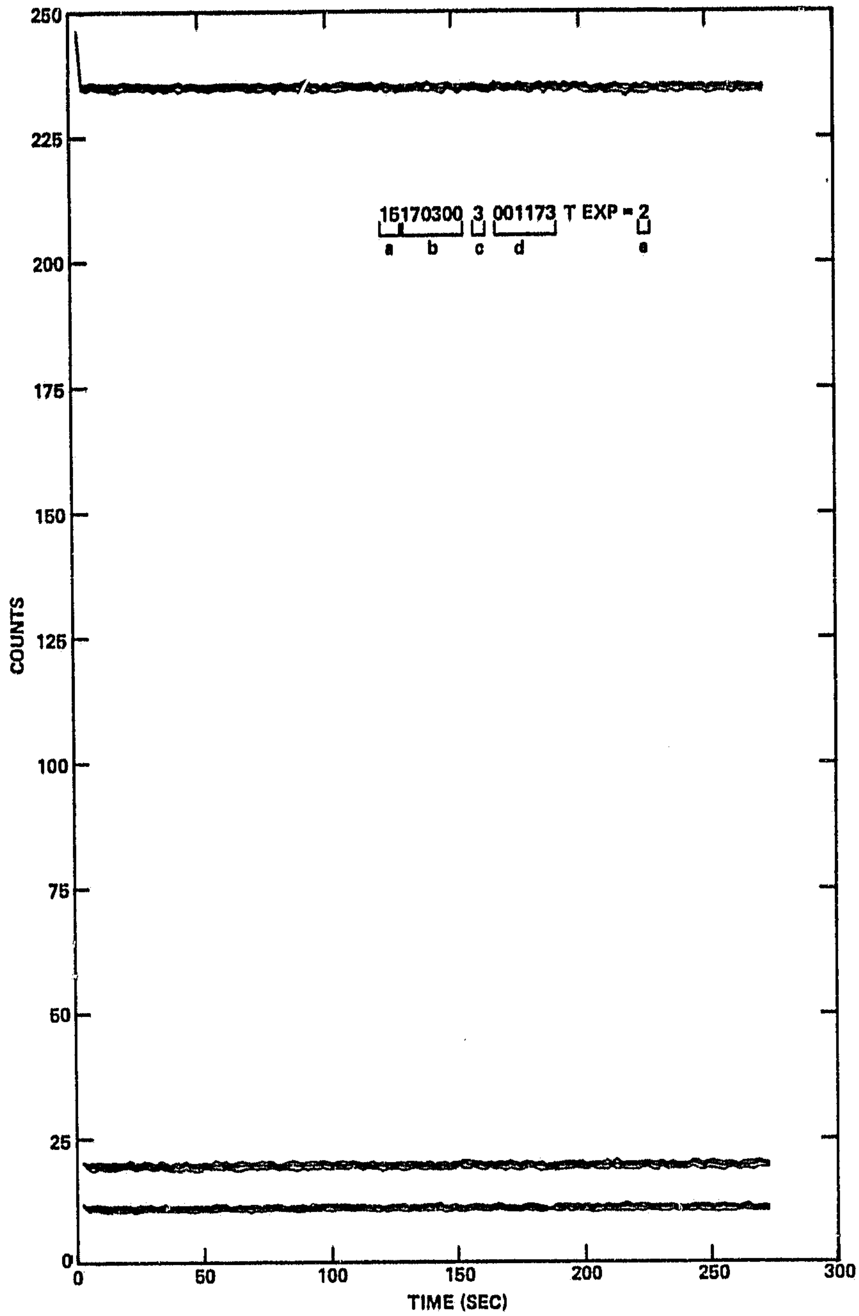

Figure A-1 - Typical output with explanation of notation:
a = number of scans/sec
b = Start Time (HHMMSS)
c = Data Channel
d = Tape number corresponding to segment
e = X axis scale divider (100.00 = 50)

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