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THE CALIBRATION OF LANDSAT MSS DATA AS AN ANALYSIS TOOL

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I. ABSTRACT

The primary aim of an analysis of Landsat data is to obtain as much useful and reliable information as possible about the various earth-surface materials present in a scene. To assist the analyst in accomplishing this objective, quantitative data analysis techniques have been developed and successfully applied in computer-aided mapping, inventorying, and monitoring of earth resources.[9] To increase the effectiveness of these techniques, the analyst must have a thorough understanding of the spectral behavior of earth-surface features, the radiometric characteristics of the digital Landsat MSS data, and the fundamental concepts supporting each numerical analysis function used.

The purpose of this paper is to show how calibration of Landsat data can be a useful analysis tool, particularly when adequate reference data are not available. In the approach described, the Landsat digital counts, along with the minimum and maximum radiance values from the internal calibration lamp, are used to derive calibrated in-band radiance values which, when plotted, are similar in shape to spectral reflectance curves, such as those obtained by spectroradiometers. Included in this paper for comparison is a series of examples of calibrated Landsat mean plots for a variety of earth-surface materials over different geographic locations at different time periods. Data used includes examples from all four Landsat MSS systems.

II. SPECTRAL CHARACTERISTICS OF EARTH-SURFACE MATERIALS

It is widely recognized that the inherent spectral variability of earth-surface materials precludes the description of a particular material by means of a unique spectral signature. It is possible, nevertheless, to categorize the major types of ground covers, i.e., vegetation, soil and water, into distinct "families" of spectral responses with variations that can be considered characteristic of each basic type. Furthermore, combinations of these materials, referred to as mixture classes, result in spectral data patterns that are linear combinations of the spectral responses of the major ground cover types.[1]

The general spectral responses for vegetation, soil, and water can be illustrated with reflectance curves for corn, silt loam, and clear and turbid water, as shown in Figure 1. These spectral measurements were obtained in the field using an Exotech Model 20C spectroradiometer, an instrument for measuring reflectance nearly continuously through the range of its sensitivity at increments of .01-.30 μm. The gaps in the curves, such as those between .7 and .8 μm and between 1.2 and 1.3 μm, are wavelengths at which the instrument is unable to obtain measurements.

For comparison, the location and width of the four reflective wavelength bands of the Landsat 1, 2, 3, and 4 multispectral scanner systems are also shown. As will be further discussed in Section III, the data from Landsat are measurements of in-band radiance; that is, the response of a material is integrated over the bandwidth of each discrete wavelength band.

III. RADIOMETRIC CALIBRATION OF LANDSAT DATA

The oscillating scanner mirror of the Landsat MSS system collects radiation across the ground scene during the west-

to-east, or active, scan movements. During the retrace scan cycles, the mirror collects radiation from an internal incandescent tungsten lamp and from the black cavity of the interior of the scanner body. These two measurements from the retrace scan establish the maximum and minimum radiation signals.[3] The output signal from a single detector of the Landsat MSS system can be exemplified by the continuous rise and fall of the measurements obtained from the active and passive cycles. Figure 2 represents the response during four scan and three retrace movements of a sensor.

The minimum radiation value for each band is obtained during the retrace motion and corresponds to the digital count level of zero in the digital data; the maximum radiation value, which is obtained during the same retrace, corresponds to the highest digital count, 127 or 63. These minimum and maximum radiances, expressed in mWatts/cm^2-sr, are different for different periods of operation of the Landsat 1, 2, 3, and 4 MSS systems.[4,5,6,8] These values are summarized in Table 1 for all Landsat MSS systems.

The spectral irradiance characteristics of the calibration lamp are similar to solar spectral irradiance, but at a lower level. Because of this, the minimum and maximum in-band radiances can be used to convert the relative spectral response values recorded by the sensors into in-band radiance values which, when plotted, have shapes that approximate reflectance curves of corresponding earth surface materials.

Transforming the Landsat digital counts into absolute radiance units relies on the linear relationship that exists between the digital counts and the radiance measurements, x and y respectively in Figure 3. For Landsat 1 data, represented here, the radiance range lies between 0.0 and 1.76 mWatts/cm^2-sr. This radiance range is used to calculate in-band radiance according to the following formula:

$$y = mx + b$$

where y = the in-band radiance (mWatts/cm^2-sr)
    m = ratio of the maximum in-band radiance for the scanner to maximum digital count
    x = a digital count
    b = the minimum radiance (mWatts/cm^2-sr) for the scanner.

As shown on Table 1, for Landsat 1 MSS

data, b is equal to zero; for data from Landsat 2, 3, and 4, b is not zero. Using this equation and the values in Table 1, we can, for example, calculate that a digital count of 32 in Band 4 data from Landsat 1 would be equivalent to an in-band radiance value of 0.63mWatts/cm^2-sr.

It must be emphasized again that calibration of Landsat data provides in-band radiance values, i.e., data values that represent the average response integrated across each bandwidth of the scanner. The plot of the in-band radiance values, therefore, only approximates in shape the curve of the continuous spectral measurements obtained by spectroradiometers, but the similarity is close enough for the analyst to use the plots to derive information about the nature of the earth-surface materials present.

IV. USE OF CALIBRATED DATA AS AN ANALYSIS TOOL

In general, analysts using Landsat data tend to assume consistency in the responses from the Landsat MSS sensors. While this assumption is generally correct, it is not precisely true. An awareness of these inconsistencies and knowledge about how to use them may enable the analyst to derive more information from the data.

To our knowledge, most software packages for the analysis of remote sensing data provide no way for the analyst to make effective use of the calibration information. One approach that has been used is exemplified by the LARSYS-format tapes,[7] where the minimum and maximum in-band radiance in mWatts/cm^2-sr for each spectral band is included in the ID record, and the corresponding minimum and maximum digital count for every line of data and for each spectral band is recorded as the last six samples of every line of data.

In order to perform the calibration of the Landsat MSS data using LARSYS, a calibration code of 4 is used in the CHANNELS control parameter:

CHANNELS 4(3/0,1.76/)

where 4 = calibration code specific to this software
    3 = channel number (Landsat Band 6)
    0 = minimum radiation level for Band 6, Landsat 1
    1.76 = maximum radiation level for Band 6, Landsat 1 (mWatts/cm^2-sr)

Calibration can be performed in LARSYS by any of the processors that include a CHANNELS control parameter.

While calibrated values from single pixels can be plotted, a more useful approach is to plot the calibrated radiance values of groups of pixels representing similar ground materials, such as the four mean values for each spectral class derived from clustering. The plots that are produced are similar in shape to spectral curves obtained by spectroradiometers. Although these plots of calibrated data cannot be compared in absolute terms with spectral reflectance curves, the general shapes of the plots provide an indication of the identity and purity of the spectral classes. When ground reference data are not available, these plots are especially useful for making decisions about the validity of pooling or deleting classes that are not separable. This comparison of in-band radiance plots with spectral response curves cannot be made using uncalibrated data.

Interpretation of the plots depends on the analyst's familiarity with the general spectral characteristics of earth-surface materials and with the specific conditions that would contribute to the radiance characteristics of the scene being analyzed. The relatively pure classes, i.e., those that represent a single, fairly homogeneous material, are easily associated with the right general category of earth surface material. For example, the "agricultural crop" and "forest" plots illustrated in Figure 4 have the same general shape as the green vegetation curve in Figure 1; the "water" plot decreases in spectral response from the visible wavelengths (Band 4) toward the infrared (Band 7), as in Figure 1. On the other hand, when mixtures of cover materials are present, the calibrated in-band radiance plots appear as combinations of the two materials. For example, in Figure 4, the class identified as "edge" is a weighted average (linear combination) of the spectral responses of pure forest and pure water. In some situations the analyst can use these plots to determine the proportions of "pure" cover materials that compose a "mixture" class.

Figures 5 through 15 are a collection of in-band radiance plots derived from data collected over many parts of the world by all four Landsat satellites. In making comparisons among the plots, note that the y-axis is not at the same scale in all plots; the x-axis scale is consistent, with the in-band radiance for

Channel 1 (MSS 4) falling at the 0 tick mark; the radiance for Channel 2 (MSS 5) at the tick mark for 1; the radiance for Channel 3 (MSS 6) at the tick mark for 2; and Channel 4 (MSS 7) at mark 5. The channels were distributed along the x-axis in this manner to emulate the relative widths of the wavelength bands. The plots are arranged chronologically with respect to the data collection date. The labels appearing on the individual plots were assigned by analysts using available reference data.

Several comments need to be made about the shapes of the plots in order to emphasize their usefulness in analysis. First, one of the most revealing features of the plots is the "V" that is centered at Channel 2 whenever there is vegetation present. For example, in Figure 5, that shape clearly sets Classes 5 and 6, the two vegetation classes, apart from the three non-vegetation classes, Soils 1, Soils 2, and Water. One may assume from the plots that there is virtually no vegetation in these other classes.

Second, whenever vegetation occurs in combination with other materials, the "V" pattern still occurs, but it is more shallow. For example, in Figure 7, the "V" of the two strong vegetation classes, deciduous forest and emerging crop, stands out clearly, but Class 15, named "Water edge," also shows evidence of vegetation in its composition, though to a lesser degree. The Class 15 plot appears to be the combination of a water class and a deciduous forest class, a combination which occurs frequently in Indiana.

Third, the sharpness or shallowness of the "V" pattern is an indication of the relative amount of vegetation present. An interesting example of this occurs in Figure 11 with respect to the two mixture classes of soil and vegetation. Class 6, with the sharper "V" of the two, has been labeled "Vegetation/Soils" by the analyst; Class 5, with a very shallow "V" has been labeled "Soils/Vegetation," an indication that while vegetation is present, soils predominate. The two plots labeled "Soils 1" and "Soils 2" contain no vegetation.

Fourth, frequently two different vegetation classes have very similar responses in Channels 1 and 2, as can be seen on Figure 5. The plots emphasize the fact that regardless of this similarity, the two classes can be separated spectrally. There are large differences between the classes in Channels 3 and 4, and, in fact, the plots cross over one another.

Fifth, again it must be emphasized that the plots aid in analysis only because of their shapes and not because of the absolute radiance values that have been calculated. Compare the plots labeled "Water" on Figures 5 and 8. While both appear from their shape to be clear water, the radiance values in the former are considerably smaller than those plotted in Figure 9. Many environmental factors contribute to that difference, factors such as the altitude and latitude of the scene and the time of year the data were collected. The significant factor is that the shapes of the two plots are nearly identical and compare favorably with the plots of clear water from other examples.

V. CONCLUSION

Calibration of Landsat MSS data allows the analyst to convert the digital counts on the CCT's into absolute radiance measurements which can be plotted so as to emulate the response curves obtained from spectoradiometers. Calibration values for Landsat MSS data, which vary from one period of satellite operation to another, may be recorded directly on the image tapes allowing analysts easy access to this information. The shapes of the resulting plots suggest the predominant types of materials present, as well as mixtures of materials. Often analysts are seriously hampered by a lack of reliable reference data; in these instances especially, calibrated in-band radiance plots can provide extremely important information for identification of the earth-surface materials present.

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9. Swain, P.H. and S.M. Davis (1978), Remote Sensing: The Quantitative Approach, McGraw-Hill International Book Company, New York.

AUTHOR BIOGRAPHICAL DATA

Luis A. Bartolucci, B.S., M.S. and Ph.D. in Geophysics from Purdue University, has been involved in Remote Sensing Research since 1969. He has played an active role in the development of remote sensing technology for applications in the area of water resources and has also made outstanding contributions in the field of thermal infrared radiation for remote sensing applications. In addition, Dr. Bartolucci has served as consultant to the U.S. Information Agency, the U.S. Agency for International Development, the Inter-American Development Bank and to several Latin American development agencies. He has been Principal Investigator and Project Director of several domestic and international research and training programs involving computer-aided processing and analysis of remotely sensed data for earth resources inventories.

Shirley M. Davis is Senior Education and Training Specialist at Purdue University's Laboratory for Applications of Remote Sensing and Director of Independent Study, Continuing Education Administration. Mrs. Davis received the

A.B. degree with honors in English in 1958 from Sweet Briar College and the M.A. degree in English from Case-Western Reserve University in 1962. Her major contributions to remote sensing education have been as co-author and editor of the LARSYS Educational Package; co-editor and contributing author of the textbook Remote Sensing: The Quantitative Apprach; Chairman of the 1981 Conference on Remote Sensing Education; and creator/coordinator of the videotape series Introduction to Quantitative Analysis of Remote Sensing Data. Her recent work has involved the development of educational materials for digital image processing.

Table 1. Calibration Information for Different Periods of Operation of Landsat 1, 2, 3 and 4 MSS Systems

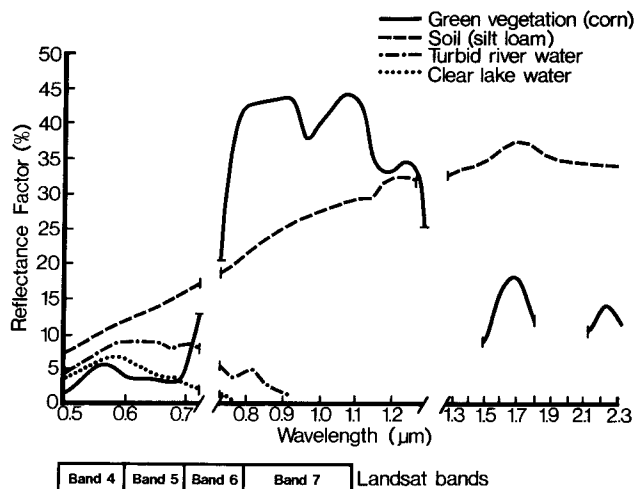| System and Performance Period	Wavelength Band (in μm)	Minimum CCT Digital Count	Maximum CCT Digital Count	Minimum Radiance (in mwatts/cm^2 sr)	Maximum Radiance (in mwatts/cm^2 sr)
Landsat 1	0.5 - 0.6	0	127	0	2.48
	0.6 - 0.7	0	127	0	2.00
	0.7 - 0.8	0	127	0	1.76
	0.8 - 1.1	0	63	0	4.60
Landsat 2 1/22/75 - 7/16/75	0.5 - 0.6	0	127	0.10	2.10
	0.6 - 0.7	0	127	0.07	1.56
	0.7 - 0.8	0	127	0.07	1.40
	0.8 - 1.1	0	63	0.14	4.15
Landsat 2 after 7/16/75	0.5 - 0.6	0	127	0.08	2.63
	0.6 - 0.7	0	127	0.06	1.76
	0.7 - 0.8	0	127	0.06	1.52
	0.8 - 1.1	0	63	0.11	3.91
Landsat 3 3/5/78 - 5/31/78	0.5 - 0.6	0	127	0.04	2.20
	0.6 - 0.7	0	127	0.03	1.75
	0.7 - 0.8	0	127	0.03	1.45
	0.8 - 1.1	0	63	0.03	4.41
Landsat 3 after 5/31/78	0.5 - 0.6	0	127	0.04	2.59
	0.6 - 0.7	0	127	0.03	1.79
	0.7 - 0.8	0	127	0.03	1.49
	0.8 - 1.1	0	63	0.03	3.83
Landsat 4	0.5 - 0.6	0	127	0.02	2.30
	0.6 - 0.7	0	127	0.04	1.80
	0.7 - 0.8	0	127	0.04	1.30
	0.8 - 1.1	0	63	0.10	4.00

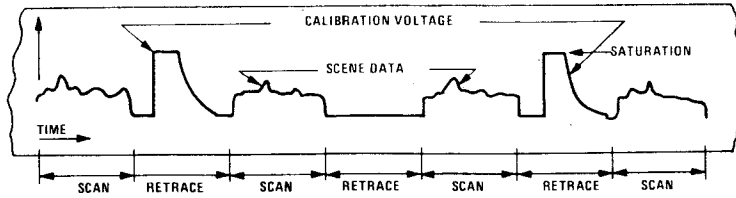Figure 1. Spectral Reflectance Characteristics of Major Earth-Surface Materials.

Figure 2. Representation of Output Signal from Landsat MSS System. Response curves show four scan and three retrace movements, the latter including the maximum (saturation) and minimum calibration signals.
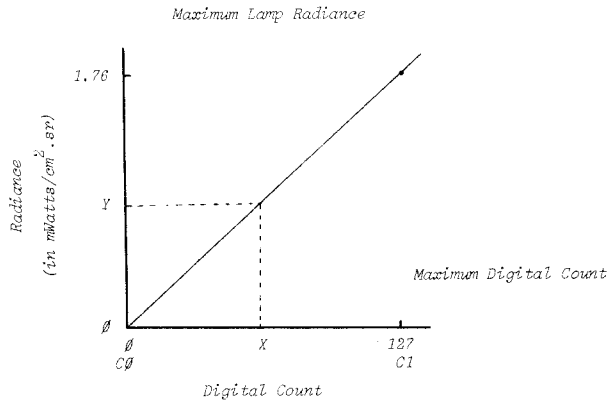

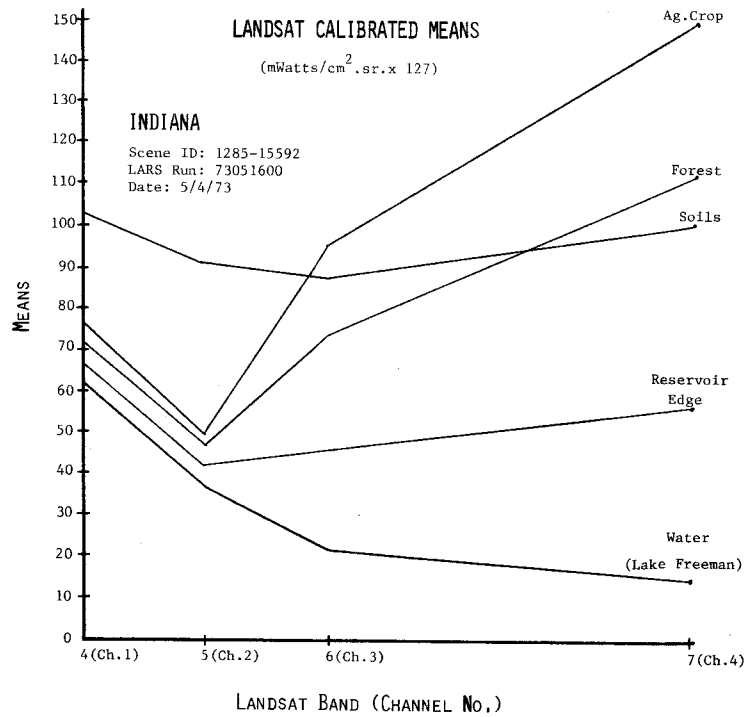Figure 3. Graphic Representation of the "Linear Calibration" of Landsat 1, Band 6 data.

Figure 4. Plot of Calibrated Landsat Data Corresponding to the Mean Spectral Response of Major Classes.
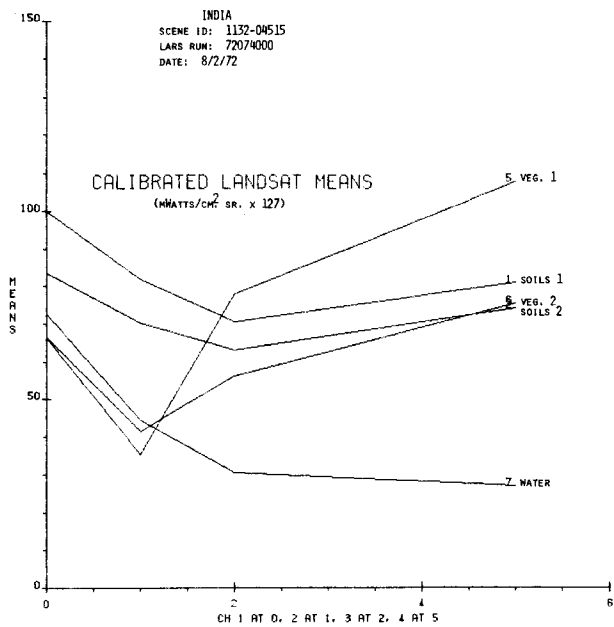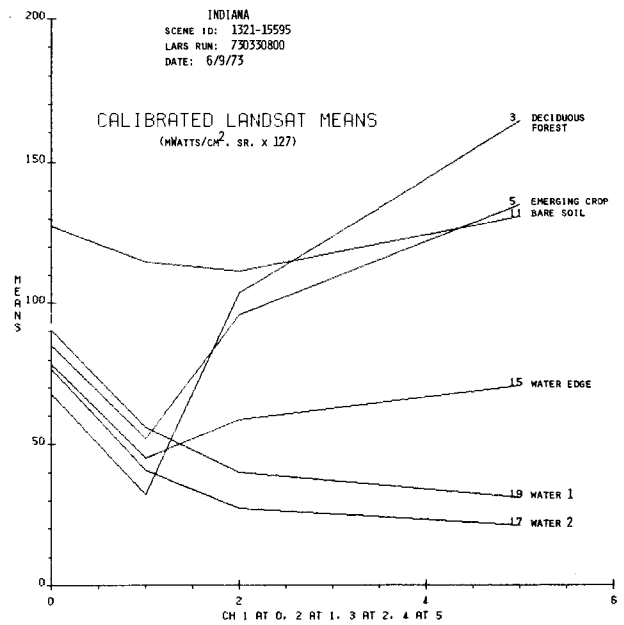
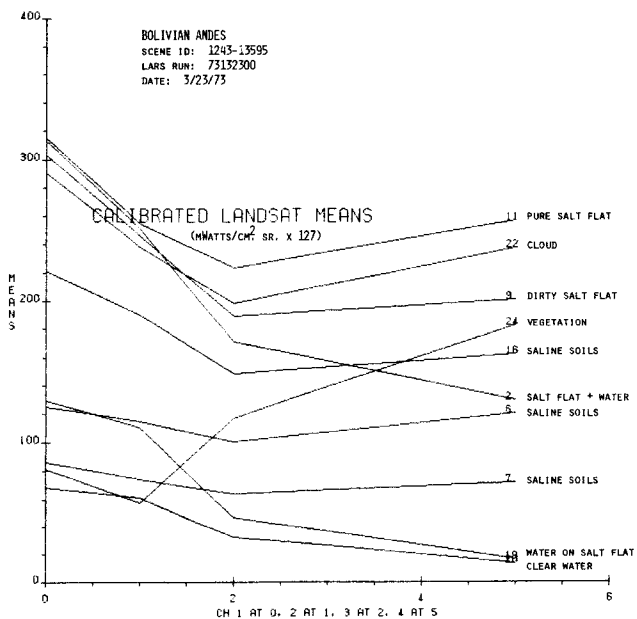Figure 5.   Sample Plots.
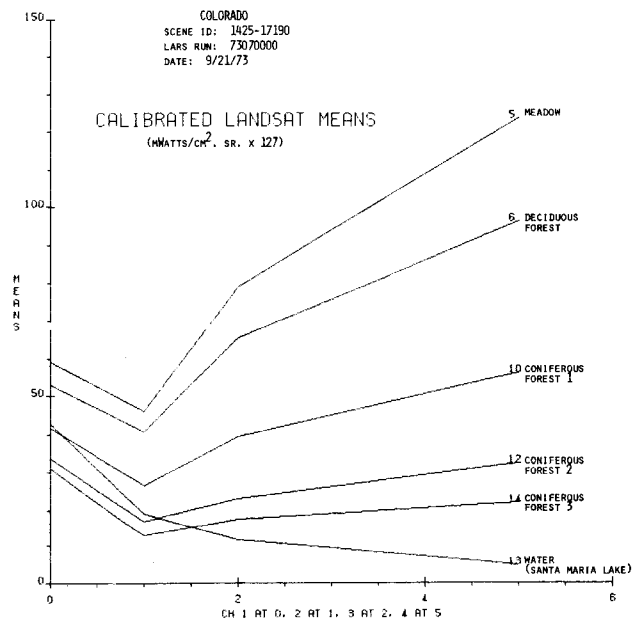

Figure 7.   Sample Plots.
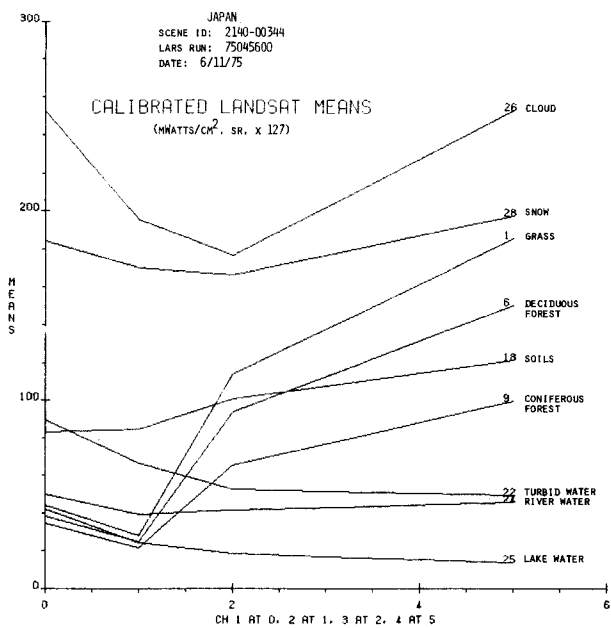

Figure 6.   Sample Plots.

Figure 8.   Sample Plots.

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Figure 9 (JAPAN)

JAPAN
SCENE ID: 2140-00344
LARS RUN: 75045600
DATE: 6/11/75

CALIBRATED LANDSAT MEANS
(MWATTS/CM^2, SR, x 127)

MEANS

300
200
100
0

26 CLOUD
28 SNOW
1 GRASS
6 DECIDUOUS FOREST
18 SOILS
9 CONIFEROUS FOREST
22 TURBID WATER
21 RIVER WATER
25 LAKE WATER

0   2   4   6
CH 1 AT 0, 2 AT 1, 3 AT 2, 4 AT 5

Figure 9.   Sample Plots.

Figure 11 (SPAIN)

SPAIN
SCENE ID: 2187-10143
LARS RUN: 75022500
DATE: 7/28/75

CALIBRATED LANDSAT MEANS
(MWATTS/CM^2, SR, x 127)

MEANS

150
100
50
0

1 SOILS 1
2 SOILS 2
4 SOILS/VEG.
6 VEG./SOILS
9 VEG. 1
10 VEG. 2
11 WATER EDGE
12 WATER

0   2   4   6
CH 1 AT 0, 2 AT 1, 3 AT 2, 4 AT 5

Figure 11.   Sample Plots.

Figure 10 (POLAND)

POLAND
SCENE ID: 2155-08512
LARS RUN: 75044900
DATE: 6/26/75

CALIBRATED LANDSAT MEANS
(MWATTS/CM^2, SR, x 127)

MEANS

200
150
100
50
0

8 POTATO FIELDS
9 ALFALFA
11 FOREST 1
6 WHEAT
12 FOREST 2
16 WATER 1
15 WATER 2

0   2   4   6
CH 1 AT 0, 2 AT 1, 3 AT 2, 4 AT 5

Figure 10.   Sample Plots.

Figure 12 (EL SALVADOR)

EL SALVADOR
SCENE ID: 2331-15303
LARS RUN: 75045000
DATE: 12/19/75

CALIBRATED LANDSAT MEANS
(MWATTS/CM^2, SR, x 127)

MEANS

200
150
100
50
0

10 CLOUD
7 COTTON FIELD
12 SAND
1 COCONUT TREES
13 TURBID WATER
4 CLEAR OCEAN WATER

0   2   4   6
CH 1 AT 0, 2 AT 1, 3 AT 2, 4 AT 5
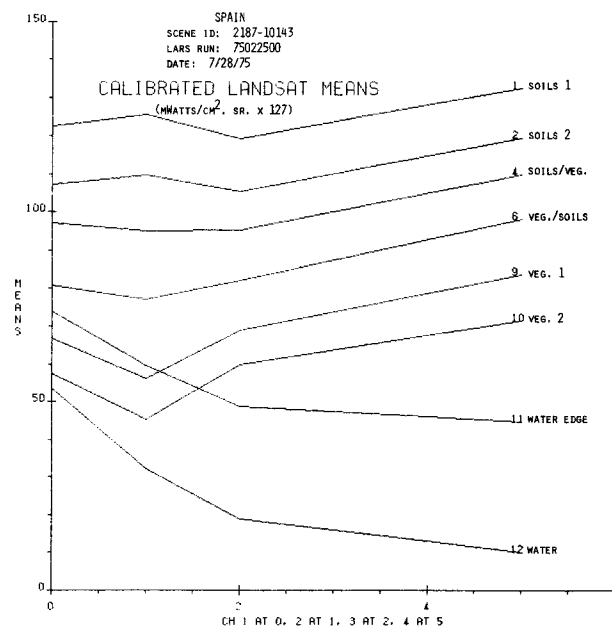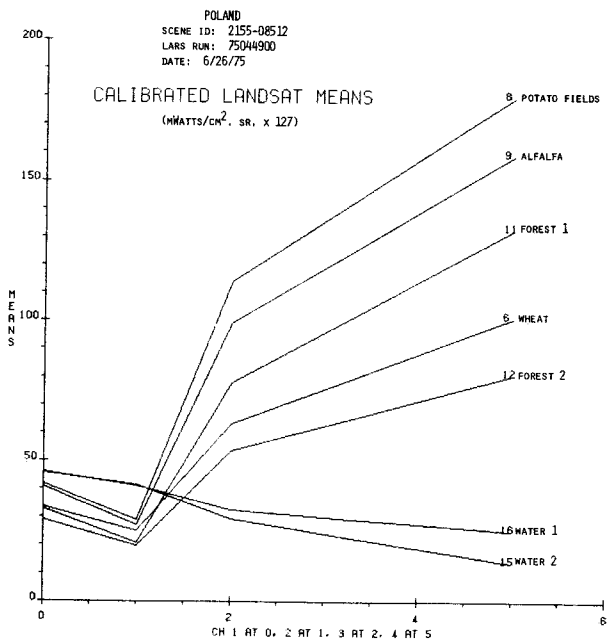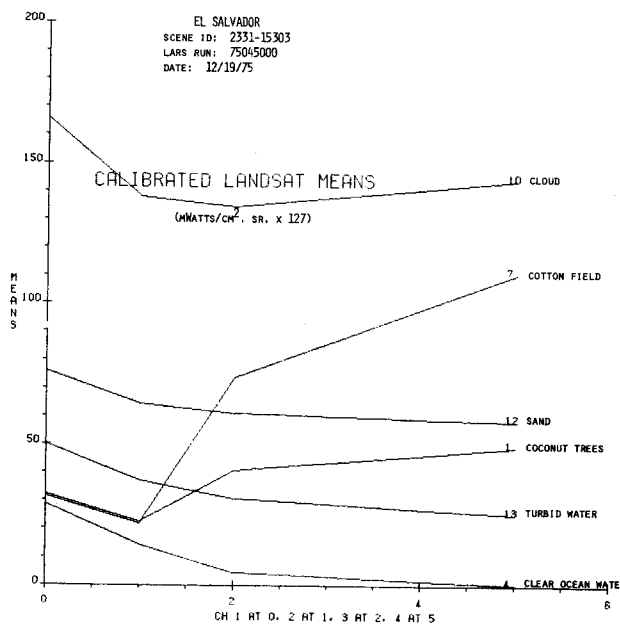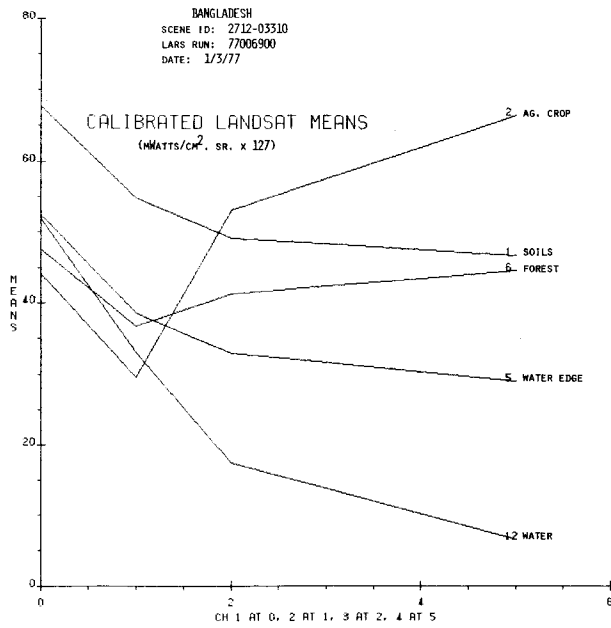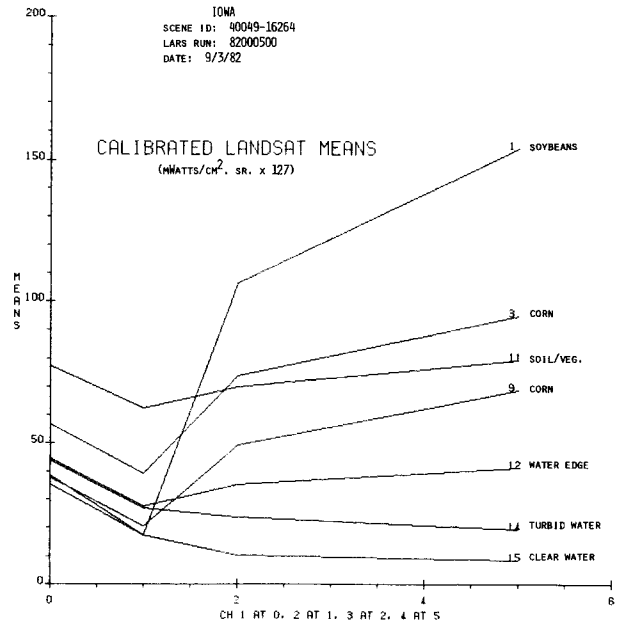
Figure 12.   Sample Plots.
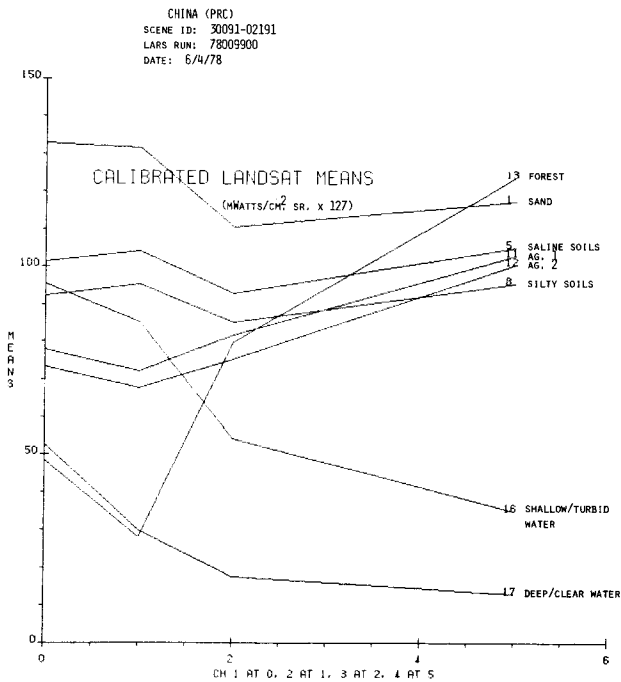
Figure 13. Sample Plots.

Figure 15. Sample Plots.

Figure 14. Sample Plots.