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A Joint Program for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing



Early Warning and Crop Condition Assessment

APRIL 1983

# LANDSAT DATA PREPROCESSING

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W. W. Austin

Lockheed Engineering and Management Services Company, Inc.

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Lyndon B. Johnson Space Center
Houston, Texas 77058

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16. Abstract

The purpose of this task was to evaluate the effect on Landsat data of a sun-angle correction, an intersatellite Landsat-2 and Landsat-3 data range adjustment, and the atmospheric correction algorithm. Fourteen 1978 crop year LACIE sites were used as the site data set. The preprocessing techniques were applied to multispectral scanner channel data and transformed data were plotted and used to analyze the effectiveness of the preprocessing techniques. Ratio transformations effectively reduce the need for preprocessing techniques to be applied directly to the data. Subtractive transformations are more sensitive to sun-angle and atmospheric corrections than ratios. Preprocessing techniques, other than those applied at the Goddard Space Flight Center, should only be applied as an option of the user. The results of this study, while performed on Landsat data are also applicable to meteorological satellite data.

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# LANDSAT DATA PREPROCESSING

Job Order 72-457

This report describes the Spectral Analysis activities of the Early Warning project of the AgRISTARS program.

PREPARED BY

W. W. Austin

APPROVED BY

G. O. Boatwright, Manager
Early Warning/Crop Condition
Assessment project
AgRISTARS Program

R. F. Hansen, Project Manager
Early Warning/Crop Condition
Assessment project
Renewable Resources Department

LOCKHEED ENGINEERING AND MANAGEMENT SERVICES COMPANY, INC.

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For

Earth Resources Applications Division

Space and Life Sciences Directorate

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
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# PREFACE

The Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing is a multiyear program of research, development, evaluation, and application of aerospace remote sensing for agricultural resources, which began in fiscal year 1980. This program is a cooperative effort of the U.S. Department of Agriculture, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration (U.S. Department of Commerce), the Agency for International Development (U.S. Department of State), and the U.S. Department of the Interior.

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# 1. INTRODUCTION

The purpose of this task was the evaluation of the effect on Landsat data of a sun-angle correction, an intersatellite Landsat-2-to-Landsat-3 data range adjustment, and the atmospheric correction (ATCOR) algorithm. Graphs of reflectivity versus time are used to illustrate these effects. The preprocessing techniques are applied to multispectral scanner (MSS) channel data and to data transformed by the Ashburn vegetative index (AVI), by Kauth Greeness, and by two-channel ratio transformations. Analysis of results determined recommendations for use of these techniques in the Early Warning project of the Agriculture and Resources Inventory Surveys through Aerospace Remote Sensing (AgRISTARS) program. Fourteen 1978 crop year Large Area Crop Inventory Experiment (LACIE) sites are used as the site data set.

The preprocessing techniques examined in this study are in use for Landsat data. However, the results of the study are also applicable to meteorological satellite (metsat) data. The same sources of data distortion in Landsat data will have a greater effect in metsat data; hence, effective methods of minimizing these distortions will be more crucial in the use of metsat data. An effective treatment developed on Landsat data should be directly transferable to metsat data.

An overview of the Landsat data collection system is presented in section 2 as background for this study. The technical approach of this study is given in section 3; the site data set and the set of transformations used on the MSS channel data are listed in section 4. Section 5 describes the preprocessing techniques examined in the study. Section 6 describes the software programs and the procedures used to implement these. Results of applying the preprocessing techniques are given in in section 7. Discussion of results, evaluation of the techniques, and recommendations for future work in this area are given in section 8. The conclusion based on the results of the study appears in section 9.

The appendices included in this report provide some of the reference material used to implement the task objective. Appendix A is a discussion of the sunlight-to-digital-counts conversion of Landsat data. The preprocessing of Landsat data done at Goddard Space Flight Center (GSFC) is presented in appendix B. The Earth Resources Observations Systems (EROS) assessment of the quality of the full frame imagery associated with the data set is given in appendix C.

The author would like to express sincerest thanks to Gautam Badhwar for his aid and assistance. At the onset of this task it was suggested that the crop trajectories be curve fit using the Badhwar BSTAGE model. Therefore, some lines of code in LPLOT and RAWPLT are taken directly from BSTAGE even though the ides of modeling was eventually dropped. The Landsat correction and sun-angle corrections are from BSTAGE, except that the sine of 39° and 51° (instead of 40° as in BSTAGE) are divided by the sine of the sun-elevation angle.

# 2. BACKGROUND

Sunlight is reflected off the surface of the Earth, received by sensors in the Landsat, translated to digital values, and transmitted to ground receiving stations for use in remote sensing analysis.

Remote sensing analysis of the scene, then, is based on identification of the reflected signal transmitted to Earth by Landsat. Use of the Landsat data requires understanding of the sources of data distortion inherent in the acquisition and transmission of the data and of the preprocessing techniques which have been applied at GSFC to the LACIE/AgRISTARS segment data for the purpose of reducing some of this distortion. The intended use of the Landsat data may require further preprocessing to support a specific application.

A number of factors affect the Landsat data (figure 2-1):

- o Sunlight passes through the atmosphere and immuminates a target on the Earth. The amount of light received by the target is affected by the elevation of the Sun and the atmospheric conditions: some light will be scattered by particles in the atmosphere, some will be absorbed by the atmosphere, and some will be transmitted to the target.
- o The geometric configuration of the target affects the dispersion of the reflected light, and the nature of the target determines the amount of light reflected at each wavelength. Forward scatter radiance from the area surrounding the target alters the signal.
- o The atmosphere modulates the reflected signal by scatter and absorption.
- o The satellite sensor scan angle, the geometry of the scanning system, and the sampling method affect the magnitude of the recorded signal.
- o Spectral sensitivity varies between the sensors on different satellites and between the detectors within a sensor: equal values may not be recorded for the same input.
- o The method of translating the analog signal, generated from the reflected radiance, into digital counts for transmittal to the Earth further affects the correlation between the recorded signal and the ground features.

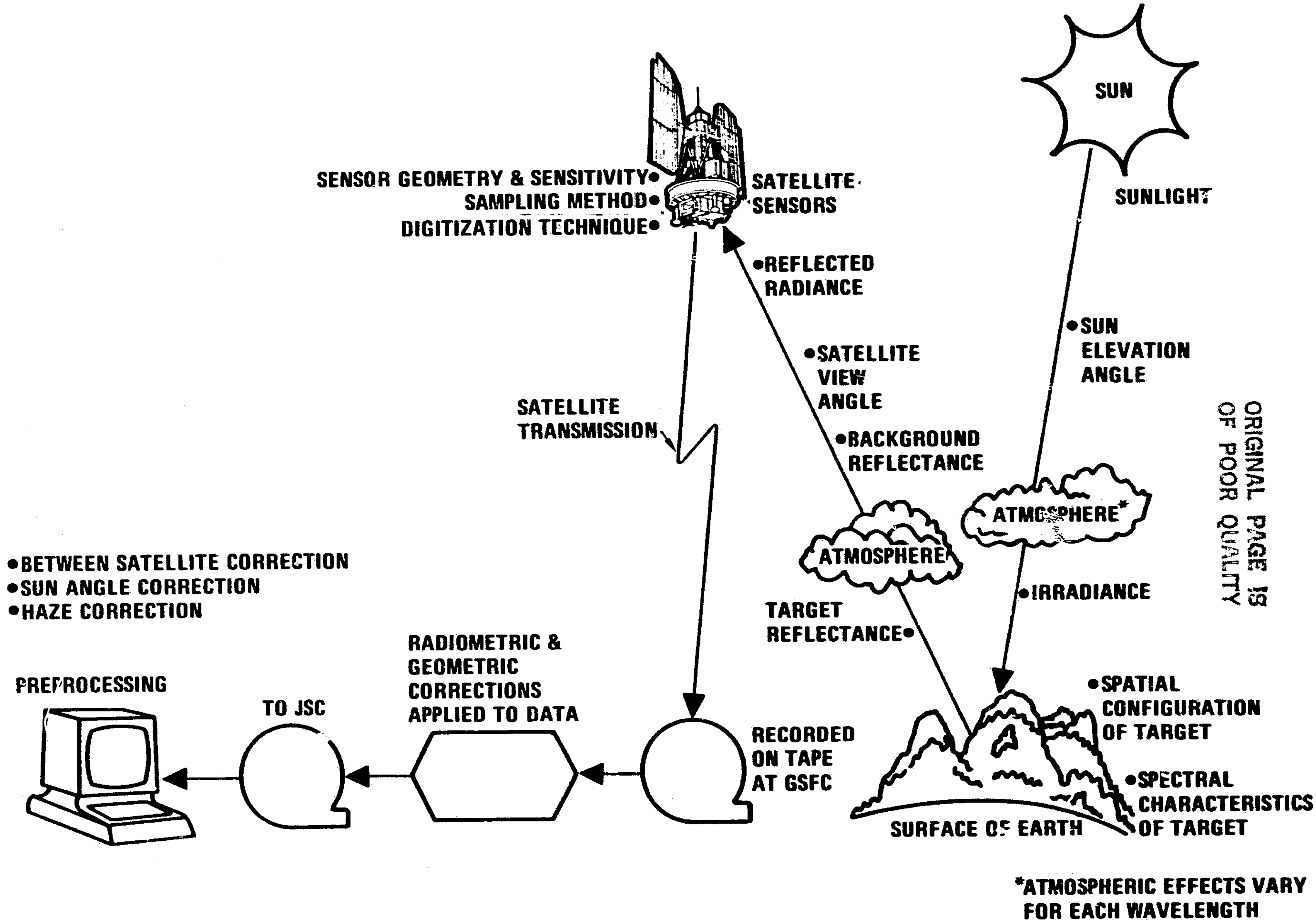




Figure 2-1.- Factors affecting Landsat data.

Appropriate use of preprocessing techniques can minimize some of the problems which arise during the acquisition process. However, if applied inappropriately, preprocessing can increase data distortion and itself become a source of error.

A limited amount of preprocessing was applied to the Landsat data used in LACIE and in the AgRISTARS program. Some geometric and radiometric corrections are routinely applied at GSFC before the data are sent to JSC. These corrections, based on measurements made onboard the satellite, are intended to calibrate for variations in the spacecraft and scanner geometrics and for variations in detector response.

Further data manipulations may be applied as preprocessing techniques at the option of the user. A data range adjustment may be applied to MSS channel-4 data before multichannel use with data from other MSS channels. A between-satellite calibration is usually applied when acquisitions from different satellites are used together. Sun elevation angle correction and atmospheric preprocessing techniques are used in an attempt to standardize acquisition conditions for some research purposes. Evaluation of the effect of these optional preprocessing techniques, the implementation method most commmonly used at JSC, is the purpose of this study.

Appendix A is a more detailed discussion of the target radiance-to-digital counts conversion, with emphasis on potential error sources. In the appendix this conversion is examined in two parts: (1) irradiance and target reflectance (what the target receives and what the target reflects) and (2) reflected radiance and satellite transmission (what the satellite receives and what the satellite transmits). The preprocessing techniques applied to LACIE/AgRISTARS data at GSFC are examined in appendix B.

# 3. TECHNICAL DESIGN

This task is designed to illustrate the effect of applying selected preprocessing techniques to Landsat data. Graphs of spectral response versus time are used to display the effect of applying sun-angle, satellite, and atmospheric corrections on time trajectories established by the mean values of pure pixels of a crop and by the mean values of a LACIE segment. The graphs are evaluated for the effect, and for the importance and feasibility, of implementing each technique.

The purpose of applying preprocessing techniques to Landsat data is to reduce the distortion effect on the data by atmospheric and veiwing geometry factors, i.e., to reduce the effect of sources of error, so that scene content can be identified as accurately as possible. Currently, two approaches are feasible:

1. Correction factors applied directly to the data. Measurable differences in acquisition circumstances (such as data acquisition with different sun-elevation angles) can be standardized to a reference circumstance (to a reference sun angle, for example). This is the method of the preprocessing techniques illustrated in this study.

   - The data range of MSS channel 4 is standardized to that of MSS channels 1, 2, and 3.
   - The sun-angle correction standardizes to a reference sun-elevation angle of 39°.
   - The data range of Landsat-3 acquisitions is adjusted to that of the Landsat-2 acquisitions.
   - The atmospheric correction standardizes to a reference haze level, sun-elevation angle, and background reflectance.

2. Use of transformed data. The data can be transformed by methods which reduce the need for preprocessing, especially with the use of ratio type transformations. For example, in a given acquisition, the data for each MSS channel are all obtained with the same sun elevation angle, hence the use of a ratio of two channels will tend to cancel the sun angle effect.

Other transformations may also tend to reduce the need for the direct application type of preprocessing.

Both these approaches are incorporated in this task. Parameters developed for direct application to the data are tested both on the MSS channel data, where a maximum effect is expected, and on the transformed data, where a smaller effect is expected, especially with the ratioed data.

Neither of these methods can be assumed to eliminate the effect of the factors addressed. These factors are wavelength and atmospherically dependent (see appendix A), hence a reduction of effect is all that can be assumed.

To implement the design the following steps were taken:

1. Factors which affect the data and were used as a basleine for this task were researched.
2. A data set was established from the 1978 corn/soybean and wheat/barley sites from the LACIE sample segments.
3. Software was designed to extract segment mean values and the mean values of a field of 'pure crop' for all available acquisitions. This created a crop signature trajectory in time against the effect of applying preprocessing techniques which could be tested.
4. Software was written to produce graphs of "raw" and transformed data, with and without preprocessing techniques.
5. Graphs of the field and segment mean values were generated for each channel for both raw and transformed data. These were generated with and without the application of preprocessing techniques.
6. Graphs were analyzed to determine the effect of applying preprocessing techniques, and evaluated for the necessity and feasibility of implementing the preprocessing technique in the early warning project.

Figure 3.1 illustrated the implementation plan for this task. While the principle objective of the task was to examine the effect of applying sun angle, satellite, and atmospheric correction of Landsat data, this study will also apply to corrections on metsat data. Sun angle, view angle, and atmospheric effects are expected to be greater on metsat data than on Landsat data due to a larger satellite scan angle and a larger solar zenith angle. An effective treatment of the effects developed on Landsat should apply directly to metsat data due to the correlation of MSS channels with the AVHRR channels (ref. 1).

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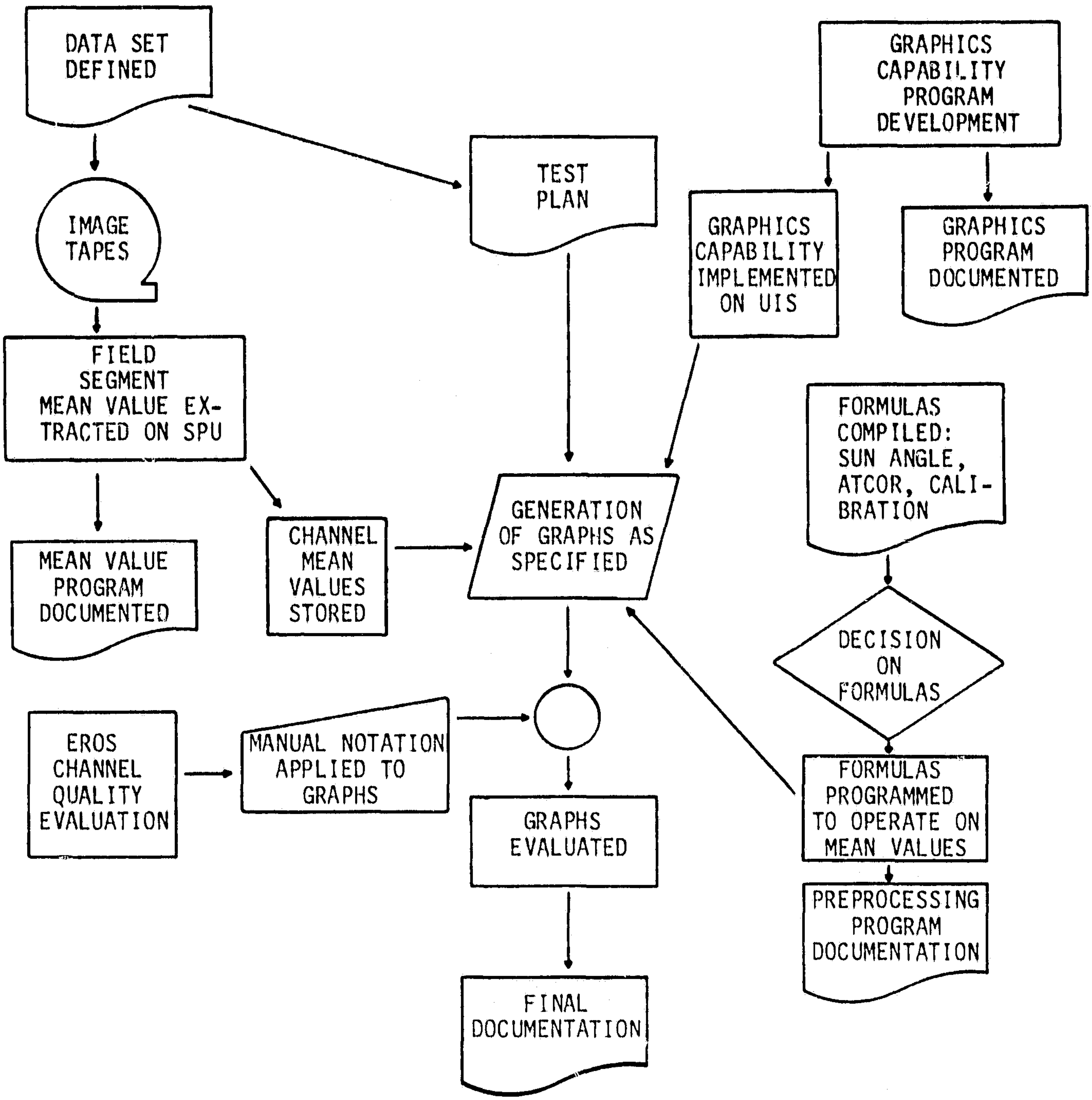



Figure 3.1- Landsat preprocessing implementation plan.

# 4. DATA SET SELECTION

## 4.1 SITE SELECTION

The data set consists of 1978 crop year data from 14 LACIE sites. Site selection was as geographically dispersed as possible within the following constraints:

1. A multitemporal sequence of Landsat-2 and Landsat-3 acquisitions was required for the site in order to illustrate the effect of applying an intersatellite data calibration.

2. Consecutive day coverage was emphasized. Choice of the data set was limited by the LACIE practice of deleting consecutive day acquisitions to conserve disc space on the computer system (the Earth Resources Interactive Processing System). Consecutive day acquisitions are useful for comparing the effects of variations in both the satellite view angle and the atmospheric conditions on data taken over the same geographic area with the same sun angle.

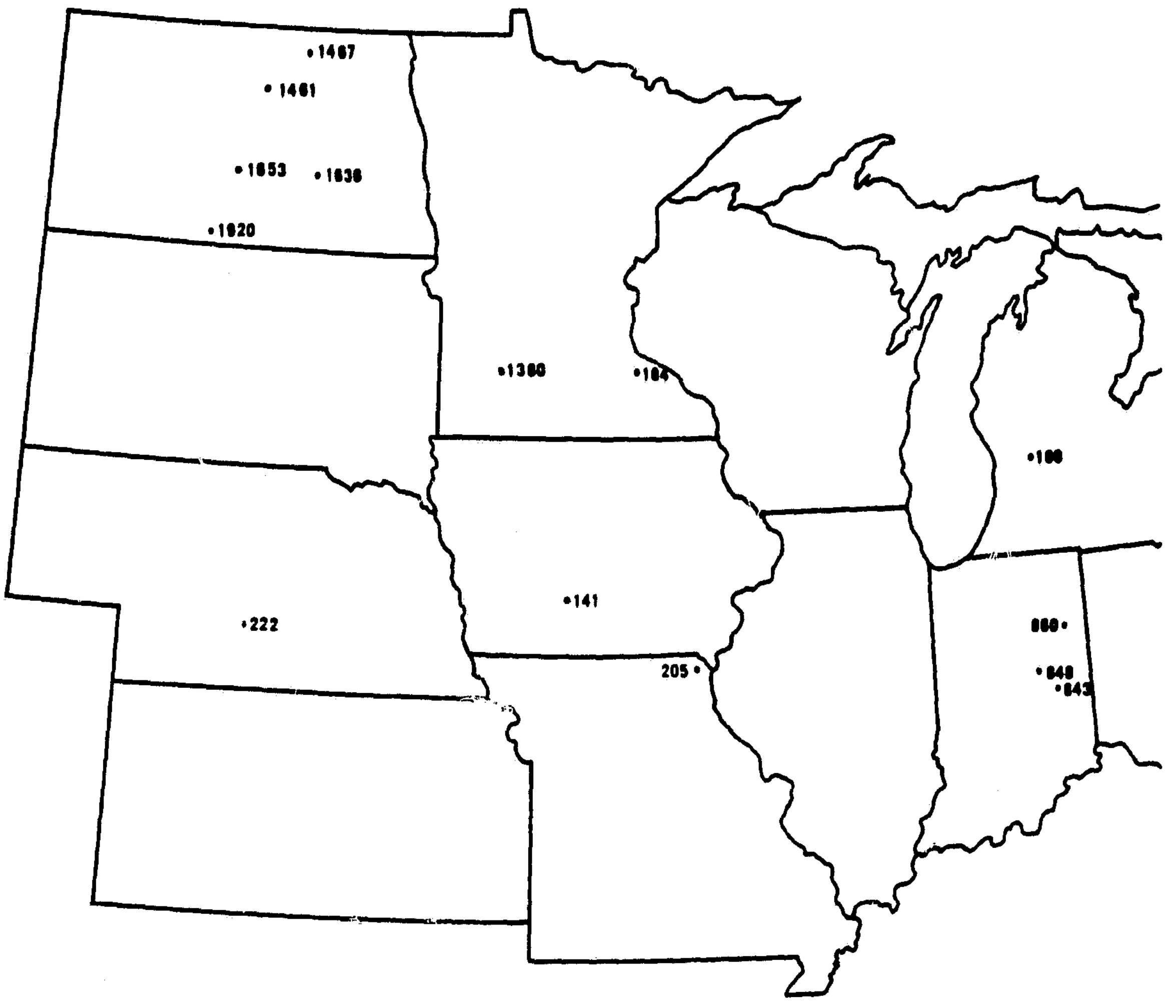
3. A minimum of four data acquisitions for the site, taken during the growing season of corn or spring wheat, was required in order to establish a crop time trajectory against which preprocessing effects could be tested.

4. Digitized ground truth was available for all sites. A minimum of 5 percent of the scene, as identified by ground-truth data, was composed of corn or spring wheat. This assured that a field of reasonable crop purity was available for establishing a signature trajectory.

5. Figure 4.1 illustrates the geographical location of the 14-site data set and lists the sites.

## 4.2 DATA TRANSFORM SELECTION

As described in section 3, the technical approach required the use of channel values and transformed data values as the basic data set for assessing the effect of preprocessing techniques.




| | | | |
|---|---|---|---|
| S.S. 141 | Madison, Iowa | S.S. 860 | Wells, Indiana |
| S.S. 180 | Kent, Michigan | S.S. 1380 | Redwood, Minnesota |
| S.S. 184 | Goodhue, Minnesota | S.S. 146. | Pierce, North Dakota |
| S.S. 205 | Clark, Missouri | S.S. 1467 | Towner, North Dakota |
| S.S. 222 | Dawson, Nebraska | S.S. 1636 | Stutsman, North Dakota |
| S.S. 843 | Henry, Indiana | S.S. 1653 | Burleigh, North Dakota |
| S.S. 848 | Madison, Indiana | S.S. 1920 | Sioux, North Dakota |

Figure 4.1 - Name and location of the 14 sites comprising the data set.

These transforms included a subtraction, rotation, and ratio of channel data. Graphs of spectral response versus time were generated for:

a. Raw single channel values for each MSS channel.

b. The Ashburn vegetative index (AVI), a subtractive transform (ref. 2)
   AVI = 2(Ch 4) - (Ch 2)

c. The Kauth-Thomas transformation, greenness value (GRN) (ref. 24)
   Greenness = -.290 (Ch 1) - .562 (Ch 2) + .600 (Ch 3) + .441 (Ch 4) + 15.0

d. Ratioed data, the RVI
   RVI = (Ch 4)/(Ch 2)

e. Data transformed by the vegetative index (VI)
   VI = [2 (Ch 4) - (Ch 2)]/[2 (Ch 4) + (Ch 2)]

Data transformed by the AVI and the greenness transformations have been used successfully for classification of agricultural cropland. The RVI and VI also have been used for this purpose, but these specific ratios were chosen because they have been used in research of atmospheric effects on Landsat data. This selection of data transforms was motivated by a desire to make this study as relevant as possible to current research and to current use of satellite data.

# 5. PREPROCESSING TECHNIQUES

## 5.1 DATA RANGE ADJUSTMENT FOR MSS CHANNEL-4 DATA

A difference in sensor sensitivity between channel 4 and channels 1, 2, and 3 results in channel 4 data being transmitted in a linear uncompressed mode in contrast to the quasi-logarithmic compressed mode of channels 1, 2, and 3. Consequently after decompression ag GSFC, the data range of channel 4 data remains 0 to 63, while channel 1, 2, and 3 data is in the range 0 to 127. The ERTS and LACIE processors scaled the data in this fashion; the all digital system, the Multi Data Processor (MDP), installed after the launch of Landsat 3, scales all channels to the 0-127 range. For multi-channel use of data produced on the LACIE processor, channel 4 data is usually scaled to the same range as channels 1, 2, and 3 by doubling the data values.

For this study, doubling of channel 4 values is incorporated in the algorithm for AVI, RVI, and VI; however, greenness does not require doubling of the channel-4 input.

## 5.2 SUN ANGLE STANDARDIZATION FACTOR

A sun angle "correction" has been proposed to remove what has been considered a major source of scene-to-scene variation: the variation of solar elevation, which is the lighting condition under which the data is generated. Changes in sun elevation angle affect the data range and the variation of the data; radiance data taken with a low sun angle will generally have a lower digital value over the same target than that taken with a larger angle. The sun-elevation angle is known for each acquisition and appears in the header of the image tape. It is assumed that natural surfaces are approximately diffuse reflectors; thus, multiplication of the data values by a factor determined by the sine, or the cosine, of either the sun elevation angle or its compliment, the sun zenith angle, can be used to bring the data to a standard reference angle, i.e. to appear as if the data were all taken under the same lighting conditions. The sun angle standardization facor, $X_{io}$, is:

$$X_{io} = \frac{\sin \theta_o X_i}{\sin \theta}$$

where $\theta$ is the sun-elevation angle of the acquisition, $\theta_o$ is the reference solar angle and $X_i$ is the data in MSS channel i.

While this type of correction is justified by the system geometry, it cannot be considered a complete correction since natural surfaces are not proper diffuse reflectors and the effect of solar elevation angle is wavelength and target dependent. "If the Earth atmosphere system is truly a Lambertian reflector, this normalization completely takes out the sun angle effect" (ref. 3). The system cannot realistically be assumed to be Lambertian, but some of the effects, the amount varying with wave length, are decreased by the use of such a factor. Sun-angle standardization is useful in the following situations:

1. Use of multisatellite data. When acquisitions from different Landsats are used together, a sun-angle normalization may be desirable. Landsat-1 through Landsat-3 were planned for sun-synchronous orbits at 18-day intervals with a 9-day interval between operating satellites. Nominal equatorial crossing, descending mode, for all Landsats is 09:30 a.m., local solar time; acceptable tolerance permits an equatorial time crossing variance of as much as 30 minutes between satellites, which results in recorded sun-elevation variance between satellites of up to 5° on the same day.

2. Use of multitemporal data. Multitemporal use of acquisitions over, for example, a crop growth cycle probably gains in comparability if data is adjusted by a sun-angle correction. This would lessen the effect of the change in sun-angle on the multitemporal changes in crop signature. (There is a change of up to 45° in solar elevation angle in a year for a specific location).

3. Use of data from different geographical areas. Comparison of crop signatures for the same growth stage, different geographical areas (hence different solar elevation angles) may be more valid if some compensation is made for the different solar angles.

For this study, sun-elevation angles were standardized to 39°. Most of the acquisitions used in the study have sun-elevation angles of about 50°; hence the graphs presented in this study illustrate a relatively large sun-angle correction.

## 5.3 SATELLITE CALIBRATION FACTORS

Comparison of the spectral data ranges from Landsat-2 and Landsat-3 defined a consistently lower range for the values of Landsat-3 acquisitions. For analysis of images from both satellites, it is desirable to standardize the data range so that interpretation can be done in a consistent manner. For LACIE/AgRISTARS data, Landsat-2 data with prelaunch calibration (LACIE segment data) is taken as the standard, and Landsat-3 data is adjusted to this by application of the appropriate multiplicative and additive factors. A discussion of sensor performance and calibration techniques is given in appendix A. For this study, the data for each channel of the Landsat-3 acquisitions are adjusted into the range of the Landsat-2 acquisitions by use of these multiplicative factors.

Channel 1: Landsat-3 data values multiplied by 1.161
Channel 2: Landsat-3 data values multiplied by 1.230
Channel 3: Landsat-3 data values multiplied by 1.062.

These factors, which were developed to adapt Landsat-3 data for use with Landsat-2 data in LACIE operations, have proven satisfactory.

## 5.4 ATMOSPHERIC CORRECTION (ATCOR) PROGRAM

The ATCOR algorithm was developed to standardize Landsat data for acquisition-to-acquisition variations that are due to the effect of haze, sun angle, and background reflectance (ref. 4). ATCOR is based on the assumption that the darkest channel-1 pixels in the scene can be used to estimate a haze level; this MSS channel has the bandwidth which is most sensitive to haze. With an estimated haze level for a scene at each acquisition, ATCOR computes coefficients to transform MSS data in all four channels as would be recorded at a selected reference level of haze, of sun angle, and of background reflectance. Figure 5.1 illustrates the ATCOR program. The program operates internally in two steps: Step 1 calculates the haze level for each acquisition for the segment, and step 2 calculates the per acquisition ATCOR coefficient which will adjust the data to standard sun angle, haze, and backgound refectance conditions. Figure 5.2 relates optical depth to visibility.

Target reflectance, $P_i$, is computed as a function of changes in the three variables sun zenith angle ($\Theta_o$), acquisition haze level ($\tau_h$), and average scene radiance outside the target ($\bar{\rho}_i$).

$L_i = a_i\ (\bar{\rho}_i, \Theta_o, \tau_h)\ \rho_i + b_i\ (\rho_i, \Theta_o, \tau_h)$, where $L_i$ is the output corresponding to target radiance $\rho_i$. The quantity $\Theta$ is obtained from acquisition reader information; $L_i$ is a known quantity; and the haze level $\tau_h$ (assumed homogeneous for the segment) is computed from the data. A set of "darkest pixels" is defined by taking the minimum value of all the channel-1 pixels in each line of the Landsat image. These 117 pixel values are averaged; the reflectance value corresponding to this average is assumed to be 0.03 (i.e., 3 percent of incident radiation is reflected). The ATCOR tables are used to determine the amount of haze present, the haze level for the segment, $\tau_h$. From this derived $\tau_h$, background reflectance values can be computed for all four channels. This permits the defining of ATCOR coefficients which will adjust the data to standard values for sun angle, haze, and background reflectance.

Haze added to a scene increases data values and decreases contrast (compresses data values). Haze removal, conversely, will decrease data values and increase contrast. Channel 1 is most sensitive to haze effects, while data from channel 4 are the least affected. In vegetation areas, channels 1 and 2 are considerably more sensitive than channels 3 and 4.

Haze levels can significantly alter crop profiles and lead to misidentification of scene content. The production film converter (PFC) film products produced from Landsat images for use in LACIE and in the AgRISTARS program are not reliable indicators of haze and optical depth since these transparency

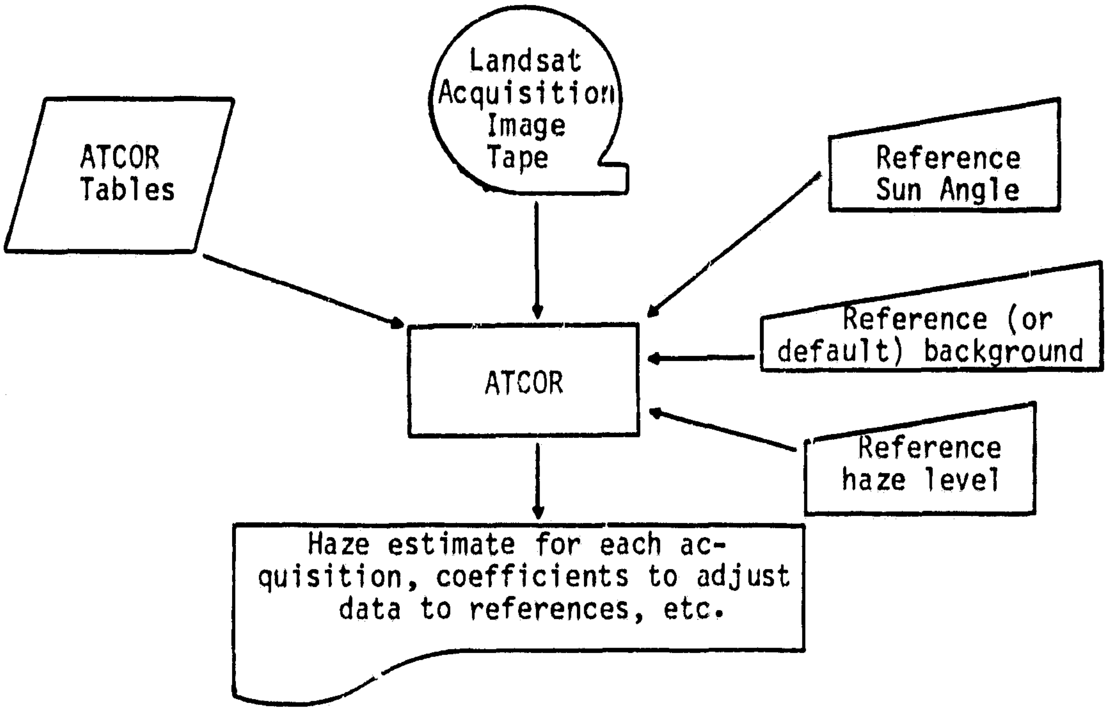



Figure 5.1 - an illustration of the ATCOR program.

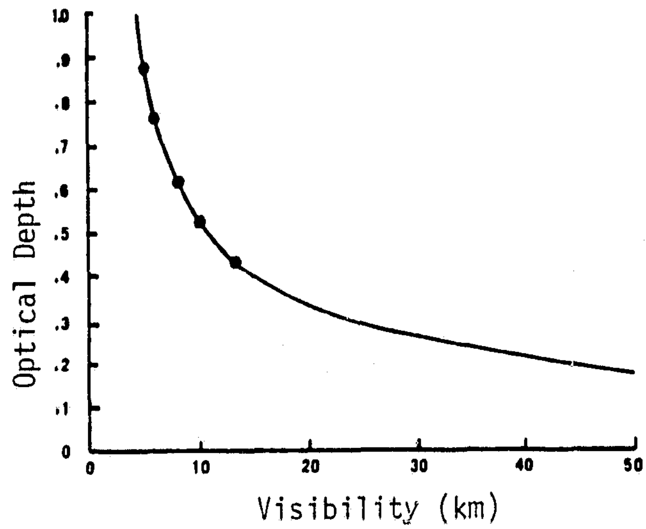



Figure 5.2 - Haze optical depth as a function of visibility.

products, produced as aids for agricultural analysis, maximize contrast in a scene. Haze is subjectively estimated from visual examination of the PFC products. In LACIE/AgRISTARS, acquisitions with light haze tend to be used, with any haze effects being considered part of data "noise"; heavy haze- or cloud-affected acquisitions are generally not useful for analysis. Standardization of scene haze level would be very beneficial in multitemporal scene analysis.

In this study the haze level, expressed as optical depth $\tau$, was calculated for each acquisition. The ATCOR coefficients adjust each acquisition to a 0.2 optical depth (minimal haze) and a 30° sun-elevation angle. A program default value of 0.05 was used for channel-1 background reflectance, a value suitable for agricultural scenes.

The usefulness of ATCOR decreases when clouds and cloud shadows are in the scene. The ATCOR tables were derived to represent a Rayleigh modular scattering atmosphere with a layer of Mie scattering haze (a continental type haze) of three different concentrations: 0.0, 0.424, and 0.848 optical depths.

# 6. PROCEDURE FOR GENERATION OF GRAPHS

For this study, graphs of reflectivity versus time were used to illustrate the effect of applying preprocessing techniques to Landsat data. The following procedure was used to generate these graphs.

1. Tape input. The data for this study were brought in as JSC universal format Landsat acquisition image tapes. Using the Crop Condition Assessment (CCA) computer at the U.S. Department of Agriculture Foreign Agricultural Service (USDA/FAS) facility, up to six acquisitions, each with data from four channels, could be merged into one 24-channel image. These merged images were then loaded into image files using the Integrated Multivariant Data Analysis and Classification System (IMDACS) load processor on the PDP 11/45 computer.

2. Field/segment boundary definition. Using the IMDACS field definition processor, field boundaries were entered in line, pixel format (with four coordinates per field). One field of either corn or spring wheat was defined for each of the 14 segments used in this study. A standard "whole segment" set of coordinates was also entered for each site.

3. Field/segment mean values calculation. Field and segment means were calculated for each channel and each acquisition using the IMDACS statistics processor. The IMDACS statistics processor outputs a statistics file which had to be read using the READ utility sub-program AREAD. The program REFORM used AREAD to read the output of the statistics processor and outputs a file of field and segment means ordered by segment and acquisition. Four files were generated:

   - LYCFLD.SPT was the corn field data: mean value, standard deviation for each acquisition.
   - LYCSEG.SPT was the corresponding data for the segment.
   - LYWFLD.SPT was wheat field data for those segments where this was the crop field defined.
   - LYWSEG.SPT was the corresponding segment data.

These files were placed in the scene processing unit (SPU) computer to await plotting. Transfer was accomplished using DECNET.

4. Generation of ATCOR coefficients. Generation of ATCOR coefficients required special processing on the National Advanced Systems AS-3000 computer in JSC building 17. The program ATCOR was run on each acquisition of the universal format tape used as original input; coefficients were generated for three optical depths ($t = 0.2$, $0.3$, and $0.4$). The line printer output was then collected and brought to the FAS computer facility. The ATCOR coefficients were input manually to data file ATCOEF. DAT on the SPU to await graphing.

5. Display of data files. When generation of the data files was complete on the SPU, the program LSTAGE was run to display the files and verify contents prior to graphing.

6. Generation of graphs. The graphs for this study were produced on the FAS Calcomp plotter attached to the SPU Computer. Two software programs were used to generate the graphs.

   The first program, RAWPLT, graphed field mean values and segment mean values versus acquisition dates for each channel.

For each channel, the program (a) plotted the channel data, (b) plotted the data with the data from Landsat-3 acquisitions adjusted to the Landsat-2 acquisition data range and with a correction factor applied to standardize the sun-elevation angle, and (c) plotted the ATCOR corrected data. RAWPLT generates eight plots (four MSS channels, full and segment mean values) with three graphs per plot. Up to 14 acquisition dates per segment can be graphed.

The formulas used to calculate the satellite and sun-angle adjustment are these:

| Adjusted Landsat-3 data | Landsat-3 data |
|---|---|
| Channel 1 = 1.161 | Channel 1 |
| Channel 2 = 1.230 | Channel 2 |
| Channel 3 = 1.246 | Channel 3 |
| Channel 4 = 1.062 | Channel 4 |

Data standardized to a sun-elevation angle of 30° were be multiplied by the following factor, $\frac{\sin 39^0}{\sin \Theta}$ where $\Theta$ is the sun angle given in the header information. The ATCOR coefficients corrected to a 39° sun-elevation angle, an optical depth (haze level) of 0.2, and the default background reflectance of 0.05. Internally the program adjusted data from Landsat-2 and Landsat-3 to the range of Landsat-1. ATCOR corrected data:

$$X_i' = a_i X_i + b_i$$

where i = 1, 2, 3, or 4, denoting the MSS channel. The second software program, LPLOT, graphed field mean values and segment mean values versus acquisition dates for data transformed by four formulas. As with RAWPLT, each graph had three plots: channel data, satellite and sun-angle-adjusted data, and ATCOR corrected data. Adjustments as above were applied to the individual channels; eight graphs were plotted using RAWPLT and then transformations were applied and plotted using LPLOT which plots eight additional formulas for transformations for AVI., RVI, VI, and greenness formulas.

Figure 6.1 illustrates the functional flow described above. A total of 16 graphs per segment were generated as above, 3 plots on each graph. These 672 trajectories are the basis for the conclusions, recommendations and evaluations of the preprocessing techniques.

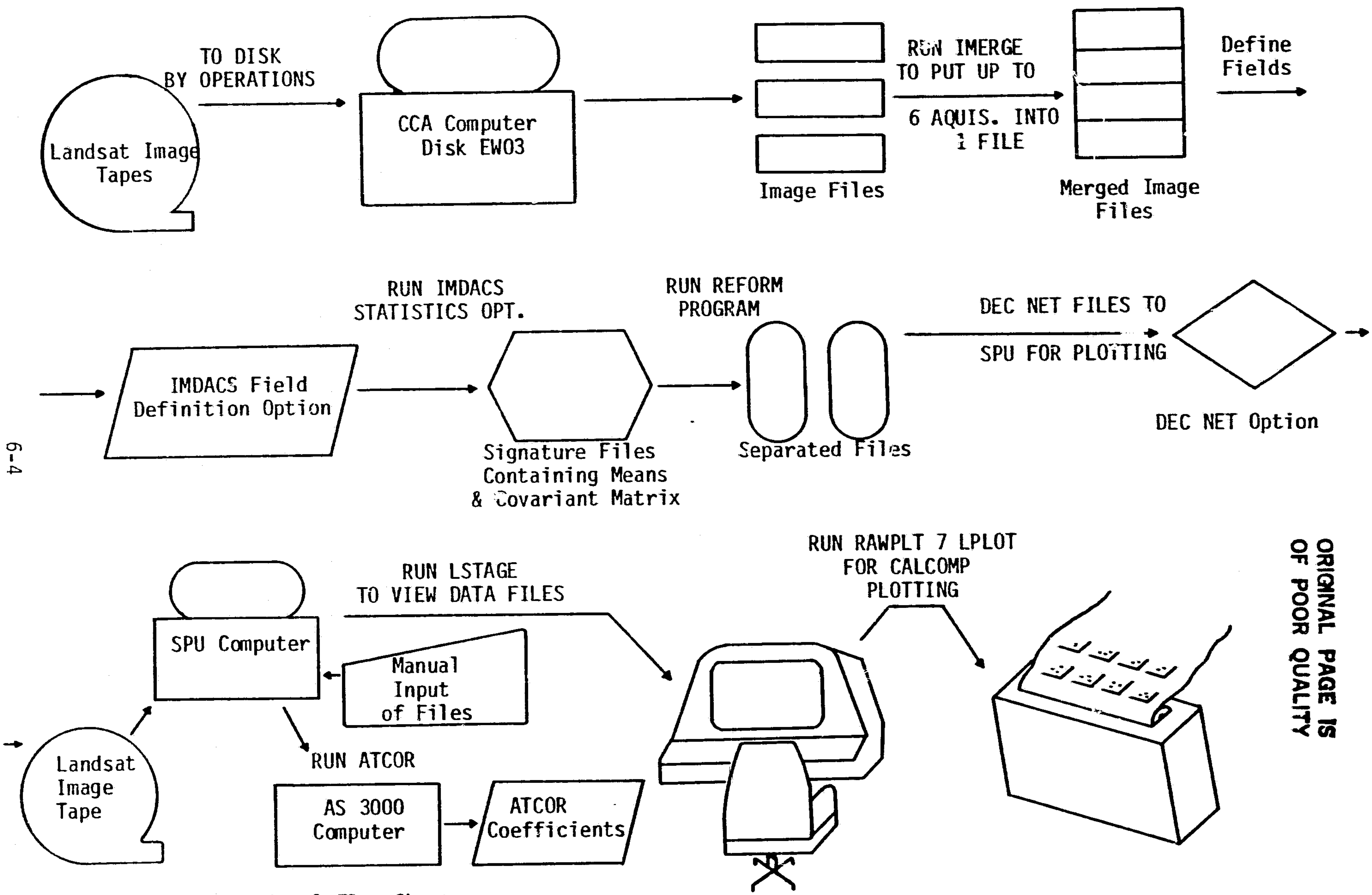



Figure 6.1 - Functional Flow Chart

# 7. RESULTS

Table 7-1 is the site data set used for this study. For the 14 sites, the following information is listed:

- o Segment number and location
- o A sample field, corn or spring wheat, (line, pixel) coordinates
- o Sun-elevation angle from the acquisition image header
- o The ATCOR haze estimation for each acquisition ([illegible]); this indicates increasing haze with increasing value
- o All available acquisitions, 1978 dates prior to Julian day 310, with comments on data quality (assessed from the LACIE/AgRISTARS film products), an (L-3) identification if data were acquired by Landsat-3, and some agronomic observations.
- o A commentary which includes identification of scene components which comprise more than 10 percent of the scene.

Examples of graphs of the segments are presented in figures 7.1 and 7.2. The first figure illustrates sun-angle and satellite corrections along with ATCOR correction applied to MSS channels 1, 2, 3, and 4 and to data transformed by the AVI, RVI, VI, and Kauth greenness using the mean values of selected fields, AA pure corn or spring wheat; the second figure presents the same graphs based on segment mean values. Graphs of raw data are marked with a cross, graphs of Landsat and sun-angle-adjusted data are plain, and the ATCOR corrected graphs are marked with circles.

Graphs for each site were plotted and used to analyze the effects of all the preprocessing techniques on both the MSS channel data and transformed data. These plots were made for the mean values from selected fields of corn or wheat as well as the mean values for entire segments.

Full-frame imagery from Sioux Falls, South Dakota, was screened for cloud cover and data quality. This information applies to the area measuring 100 n.m. square, the area from which is extracted the 5- by 6-n.m. LACIE/AgRISTARS sample segment. While this information is not exactly applicable to the information presented in this section, it is included as appendix C for correlation with the material presented in table 7-1.

TABLE 7-1.- SITE DATA SET

| Sample segment number and location, sample field (line, pixel) | Sun-elevation angle | ATCOR haze estimate | Acquisitions available (Julian day-78XXX) | Comments |
|---|---|---|---|---|
| S.S. 1380 | | | | |
| Redwood, Minnesota | 47 | .155 | 115 | This segment has good acquisition coverage and nice sized fields. Segment is considered a spring wheat segment (7% of the scene)* but is predominately corn (32%) and soybeans (39%). |
| | 55 | .216 | 169 (Emergence | |
| Wheat field #1 | 56 | .063 | 196 (L-3) | |
| (110, 130), (110, 134) | 52 | .174 | 204 | |
| (113, 134), (113, 130) | 52 | .193 | 205 | |
| | 49 | .227 | 222 Oats in harvest | |
| | 49 | .007 | 231 (L-3) Harvest | |
| | 49 | .052 | 232 (L-3) | |
| | 44 | .167 | 241 | |
| | 44 | .184 | 249 (L-3) | |
| | 39 | .048 | 268 (L-3) clouds | |
| S.S. 1461 | | | | |
| Pierce, North Dakota | 46 | .411 | 118 Clouds | This segment has been analyzed extensively. A severe hail storm between acquisitions 190 and 199 damaged fields in a triangular area (line 40, pixel 0) to (line 0, pixel 150) as well as some fields ourside this area. Acquisition history is good; scene components of comprising more than 10% of the scene are spring wheat (32%) and idle crop-land (22%). |
| | 50 | .522 | 136 Haze | |
| Wheat field #2 | 51 | .264 | 137 Early emergence | |
| (7,159), (7,166), | 53 | .267 | 154 | |
| (11,166), (11,159) | 53 | .214 | 155 | |
| | 52 | .173 | 190 | |
| | 54 | .137 | 199 (L-3) 3 small clouds | |
| | 50 | .277 | 208 Slight haze | |
| | 49 | .168 | 209 Clouds | |
| | 50 | .353 | 217 (L-3) | |
| | 46 | .236 | 236 (L-3) harvest of wheat | |
| | 36 | .314 | 263 | |

*Scene percentages are accuracy assessment proportions computed at the subpixel level. For ground-truth identification, each pixel is divided into six components and the components are identified. This provides a "majority rule" pixel label plus a capability for using pixels of varying "purity." There are 22,932 pixels in a LACIE segment; the proportions above are computed based on the identification of 137,592 subpixels per segment.

TABLE 7-1.- Continued

| Sample segment number and location, sample field (line, pixel) | Sun-elevation angle | Atcor haze estimate | Acquisitions available (Julian day-78XXX) | Comments |
|---|---|---|---|---|
| S.S. 1467 | | | | |
| Towner, North Dakota | 50 | .379 | 136 | Acquisition coverage for this segment includes some consecutive days of poor data quality. In addition, days 154 and 155 exhibit unusually large variations in the individual channels for visually "clear" days. Segment is 40% spring wheat, 11% barley, and 30% idle cropland. |
| | 51 | .298 | 137 | |
| Wheat Field #3 | 53 | .303 | 154 Emergence | |
| | 53 | .292 | 155 | |
| (82,60), (82,65), | 52 | .039 | 190 Clouds | |
| (89,65), (89,60) | 52 | -.005 | 191 Clouds | |
| | 54 | .146 | 199 (L-3) 2 small clouds | |
| | 54 | .039 | 200 (L-3) clouds | |
| | 50 | .335 | 208 Haze | |
| | 50 | .214 | 217 (L-3) | |
| | 50 | .173 | 218 (L-3) Barley harvest | |
| S.S. 1636 | | | | |
| Stutsman, North Dakota | 46 | .742 | 117 Haze | Segment is in an area dotted with small lakes; acquisition coverage is good. Scene includes 37% spring wheat, 11% sunflowers, 11% pasture, and 19% idle cropland. |
| | 51 | .214 | 135 | |
| Wheat Field #4 | 51 | .277 | 136 Some emergence | |
| | 53 | .250 | 154 3 clouds with shadows | |
| (27,90), (26,96), | 53 | -.055 | 190 6 clouds with shadows | |
| (30,96), (30,90) | 50 | .223 | 207 | |
| | 50 | .131 | 208 Harvest of barley | |
| | 51 | .080 | 216 (L-3) | |
| | 51 | .373 | 217 (L-3) | |
| | 47 | .303 | 226 Haze, harvest of wheat | |
| | 42 | .360 | 243 | |
| | 36 | .080 | 270 (L-3) | |

TABLE 7-1.- Continued

| Sample segment number and location, sample field (line, pixel) | Sun-elevation angle | Atcor haze estimate | Acquisitions available (Julian day-78XXX) | Comments |
|---|---|---|---|---|
| S.S 1653 | | | | |
| Burleigh, North Dakota | 41 | .399 | 101 Haze | This segment is in a strip field area and wheat fields of adequate size are difficult to define. |
| | 47 | .435 | 119 | |
| Wheat Field #5 | 51 | .281 | 136 Early emergence | |
| | 51 | .189 | 137 Clouds | |
| (93,48), (93,55), | 53 | .241 | 154 | |
| (98,57), (98,49) | 54 | .191 | 155 | |
| | 53 | .047 | 190 Clouds | |
| | 53 | .146 | 191 some small clouds | |
| | 54 | -.055 | 199 (L-3) clouds | |
| | 50 | .227 | 208 Barley in harvest | |
| | 50 | .166 | 209 | |
| | 51 | .198 | 217 (L-3) some harvest of wheat | |
| S.S. 1920 | | | | |
| Sioux, North Dakota | 42 | .192 | 101 | This segment has strip fields. Acquisition history is not especially good related to crop growth cycle, but does not include consecutive day coverage. Scene includes 17% spring wheat, 12% hay, and 45% pasture. |
| | 52 | .402 | 136 Emergence | |
| Wheat Field #6 | 52 | .370 | 137 | |
| | 55 | .114 | 199 (L-3) some small clouds | |
| (78,28), (78,37), | 51 | .004 | | |
| (82,37), (82,28) | 51 | .304 | 209 | |
| | 52 | .169 | 217 (L-3) | |
| | 52 | .155 | 218 (L-3) | |
| | 47 | .210 | 236 (L-3) some harvest | |
| | 37 | .031 | 271 (L-3) clouds | |

TABLE 7-1.- Continued.

| Sample segment number and location, sample field (line, pixel) | Sun elevation angle | Atcor haze estimate | Acquisitions available (Julian day-78XXX) | Comments |
|---|---|---|---|---|
| S.S. 141 | 42 | .069 | 086 (L-3) | Good acquisition coverage. Scene includes 24% corn, 19% soybeans, and 26% pasture. |
| | 48 | .257 | 103 (L-3) | |
| Madison, Iowa | 52 | .364 | 130 | |
| | 55 | .355 | 166 | |
| Corn Field #1 | 55 | .520 | 167 Emergence | |
| | 55 | .113 | 212 (L-3) 3 small clouds | |
| (46,148), (46,154), | 50 | .331 | 221 Haze | |
| (53,157), (53,152) | 42 | .333 | 256 Clouds, haze | |
| | 41 | .088 | 265 (L-3) harvest beginning | |
| | 41 | .037 | 266 (L-3) | |
| | 37 | .209 | 274 | |
| | 31 | .219 | 292 | |
| S.S. 180 | | | | |
| Kent, Michigan | 45 | .201 | 107 | Scene includes 15% corn, 11% alfalfa, 32% Trees, and 14% orchards. |
| | 51 | .117 | 116 (L-3) | |
| Corn Field #2 | 52 | .073 | 117 (L-3) clouds | |
| | 53 | .109 | 197 | |
| (102,122), (102,129), | 53 | .209 | 198 | |
| (105,129), (105,122) | 50 | .172 | 215 Clouds | |
| | 47 | .143 | 233 | |
| | 47 | .302 | 234 | |
| | 47 | -.019 | 243 (L-3) | |
| | 37 | .130 | 269 | |
| | 26 | .099 | 305 Harvest | |
| | 26 | .246 | 306 | |

TABLE 7-1.- Continued

| Sample segment number and location, sample field (line, pixel) | Sun-elevation angle | Atcor haze estimate | Acquisitions available (Julian day-78XXX) | Comments |
|---|---|---|---|---|
| S.S. 184 | | | | |
| Goodhue, Minnesota | 47 | .270 | 104 (L-3) Haze | Scene includes 20% corn, 31% trees; 13% of the segment has not been identified by ground truth. |
| | 51 | .566 | 130 | |
| Corn Field #3 | 51 | .458 | 131 | |
| | 58 | .087 | 157 (L-3) emergence | |
| (36,171), (36,176) | 49 | .161 | 220 | |
| (40,176), (40,171) | 49 | .074 | 221 Small cloud | |
| | 50 | .062 | 229 (L-3) | |
| | 45 | .098 | 247 (L-3) | |
| | 40 | -.045 | 265 (L-3) | |
| | 39 | -.061 | 266 (L-3) | |
| | 35 | .134 | 274 Cloud, shadow | |
| S.S. 205 | 42 | .451 | 093 | |
| | 48 | .140 | 101 (L-3) | |
| Clark, Missouri | 57 | .316 | 137 (L-3) | Scene includes 17% corn, 47% soybeans, and 10% trees. |
| | 57 | .298 | 138 (L-3) | |
| Corn Field #4 | 59 | .186 | 155 (L-3) emergence | |
| | 59 | .239 | 156 (L-3) | |
| (48,169), (48,173), | 56 | .217 | 209 (L-3) clouds | |
| (55,175), (56,172) | 51 | .244 | 218 | |
| | 51 | .269 | 219 | |
| | 48 | .104 | 246 (L-3) | |
| | 38 | .364 | 272 Haze, harvest | |
| | 37 | .228 | 282 (L-3) | |
| | 33 | .283 | 290 | |

TABLE 7-1.- Continued

| Sample segment number and location, sample field (line, pixel) | Sun elevation angle | Atcor haze estimate | Acquisitions available (Julian day-78XXX) | Comments |
|---|---|---|---|---|
| S.S. 222 | | | | |
| Dawson, Nebraska | 44 | .344 | 089 (L-3) | Acquisition coverage is good. Scene includes 49% corn and 39% alfalfa |
| | 44 | .246 | 090 (L-3) | |
| Corn Field #5 | 53 | .625 | 135 | |
| | 55 | .316 | 171 Clouds, emergence | |
| (4,142), (4,150), (8,150), (8,142) | 57 | .075 | 198 (L-3) | |
| | 52 | .155 | 206 | |
| | 50 | .294 | 224 | |
| | 51 | .033 | 234 (L-3) | |
| | 45 | .343 | 243 | |
| | 46 | .266 | 251 (L-3) | |
| | 46 | .047 | 252 (L-3) | |
| | 40 | .110 | 270 (L-3) | |
| | 36 | .231 | 278 | |
| | 34 | .148 | 288 (L-3) harvest | |
| S.S. 843 | 40 | .394 | 088 | Good acquisition history. Scene includes 32% corn, 31% soybeans and 10% pasture. |
| | 47 | .233 | 097 (L-3) | |
| Henry, Indiana | 59 | .256 | 151 (L-3) | |
| | 59 | .234 | 152 (L-3) | |
| Corn Field #6 | 56 | .254 | 160 | |
| | 55 | .299 | 178 Emergence | |
| (13,121), (13,123) (22,127), (22,125) | 54 | .085 | 197 | |
| | 48 | .115 | 232 | |
| | 48 | .086 | 233 | |
| | 44 | .364 | 251 | |
| | 39 | .166 | 268 Harvest | |
| | 39 | .083 | 269 | |
| | 29 | .548 | 304 | |

TABLE 7-1.- Concluded

| Sample segment number and location, sample field (line, pixel) | Sun-elevation angle | Atcor haze estimate | Acquisitions available (Julian day-78XXX) | Comments |
|---|---|---|---|---|
| S.S. 848 | 40 | .298 | 089 | Acquisition coverage is good. |
| | 47 | .214 | 097 (L-3) | corn (32%), soybeans (30%), and |
| Madison, Indiana | 46 | .333 | 107 | trees (13%). PFC film products |
| | 53 | .206 | 116 | were not available to check |
| Corn Field #7 | 59 | .224 | 152 (L-3) | acquisitions 107 and 116. |
| | 56 | .269 | 160 Emergence | |
| (3,12), (3,15), | 56 | .262 | 161 | |
| (10,15), (10,12) | 55 | .411 | 178 | |
| | 54 | .106 | 197 | |
| | 48 | .137 | 232 2 small clouds | |
| | 48 | .136 | 233 | |
| | 44 | .350 | 251 | |
| | 39 | .110 | 269 Harvest beginning | |
| | 28 | .296 | 305 | |
| S.S. 860 | 47 | .224 | 097 (L-3) | Scene includes 28% corn, |
| | 46 | .353 | 107 | 31% soybeans, and |
| Wells, Indiana | 53 | .216 | 116 (L-3) | 13% nonagricultural area. |
| | 59 | .213 | 151 (L-3) | |
| Corn Field #8 | 59 | .244 | 152 (L-3) | |
| | 56 | .291 | 160 Emergence | |
| (91,61), (91,66), | 56 | .284 | 161 | |
| (95,67), (95,62) | 55 | .670 | 178 Clouds | |
| | 54 | .104 | 197 | |
| | 48 | .123 | 232 | |
| | 47 | .132 | 233 | |
| | 43 | .316 | 251 | |
| | 39 | .154 | 268 | |
| | 39 | .137 | 269 Corn still vigorous | |

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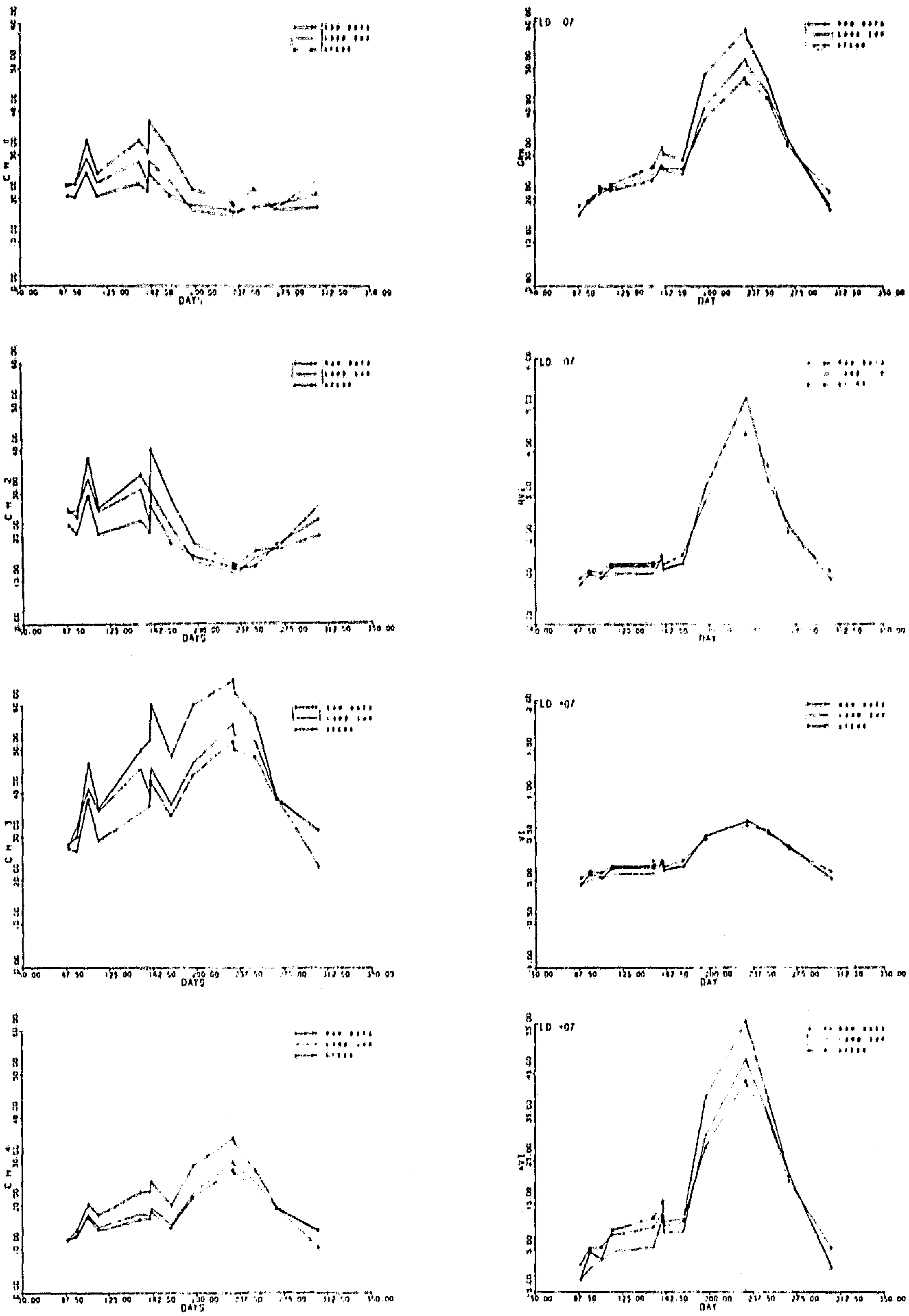


Figure 7-1 - Mean values from field #7 for AA pure corn in Madison, Indiana.

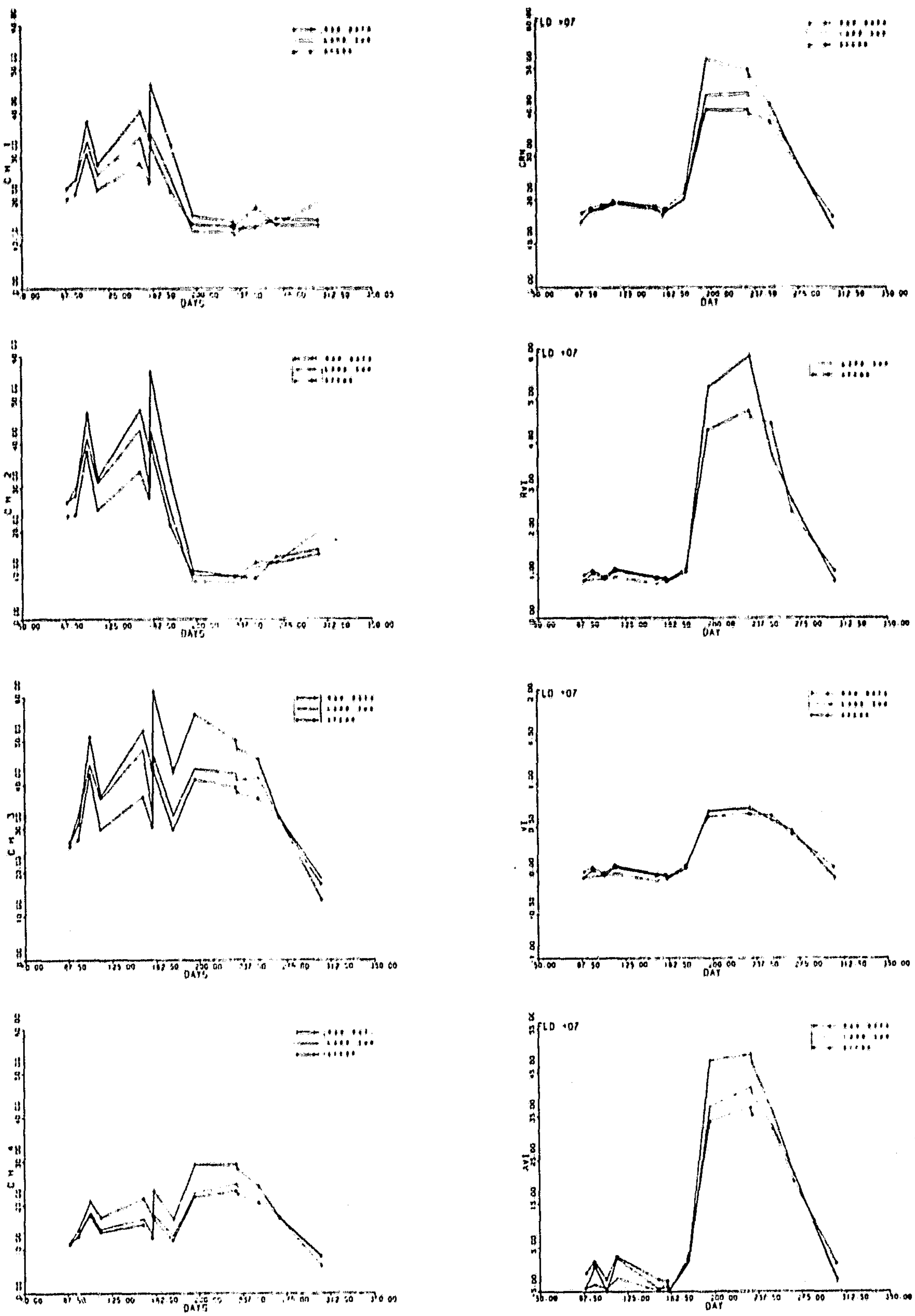



Figure 7-2 - Mean values from segment 848 for AA pure corn in Madison, Indiana.

# 8. DISCUSSION AND EVALUATION OF RESULTS: RECOMMENDATIONS FOR THE FUTURE

## 8.1 SUMMARY OF RESULTS

This task addressed the question of whether the use of data transformations and the use of preprocessing techniques are beneficial in the use of Landsat data. Information content of the MSS channel data cannot be increased by transforming the data, but the use of transforms which screen out unwanted information can result in increased clarity of presentation of the information of value. For identification of agricultural land use in the Landsat scene, the information of value is the target radiance. When presented for interpretation, this information should be as free as possible from confusion factors such as sun angle, satellite viewing geometry effects and atmospheric variations - the data distortions addressed by the preprocessing techniques evaluated in this study. Ratio type transformations, RVI and VI, do effectively reduce the need for preprocessing techniques applied directly to the data. Use of this type of transformation would be preferred for evaluation of crop profiles in time, such as crop condition assessment and episodic events. The subtractive type vegetative indexes, like the AVI, are more sensitive to use of a sun-angle correction and to ATCOR than are the ratios. The Kauth greenness transformation also exhibits this sensitivity. These transformations, unlike the ratios, appear to benefit from use of direct application preprocessing techniques.

Data transformations, which have been selected to clarify information relevant to the use of the Landsat data, are beneficial. However, it is also recommended that MSS channel values be available for use with transformed data. The wavelengths of the MSS channels were chosen to exhibit features of plant physiology such as chlorophyll absorption and leaf structure. A loss of either (or both) of these may be reflected in the transformed data, but the untransformed channel data must be used to determine which is reflected. Channel values, then, provide a reference from the profiles of the transformed data back to the input MSS channel, which has a direct meaning in plant phenology. Use of channel values in a study such as this is beneficial also because it shows the magnitude of the data variability.

Data range adjustment for MSS channel 4 was not assessed as a separate preprocessing technique for this study since doubling of the channel 4 values was either incorporated in the data transformations or unnecessary.

The sun-angle correction factor (ratio of sines) had a predictable effect on the data: since a reference angle of 30° was used and most acquisitions for these segments had angles of about 50°, most acquisitions were adjusted to approximately 20 percent lower values. Adjusting to a standard of 30° produced an exaggerated effect; a reference angle of 50° would be more suitable for this data set. Sun-angle adjustment does have an effect on the data profile: presence of the sun-angle effect enhances the data for crop-profile-in-time work because of the correlation between growth cycle and the sun-elevation pattern. Removal of this effect will tend to flatten the profile.

Sun-angle standardization will increase the validity of a temporal crop profile using the MSS channels or the data transformed by the AVI and Kauth greenness. Standardization is unnecessary if VI or RVI transformed data are used. A sine correction factor is simple to implement. Implementation should remain the option of the user with current knowledge.

The satellite data-range adjustment of Landsat-3 data to Landsat-2 was plotted with sun-angle standardization for this study, creating some confusion. The Landsat-3 calibration factors for the study have been thoroughly tested, and the factors are easy to implement. A statistical study should be done, however, to determine if a satellite adjustment makes a significant difference in the Landsat data crop profile; the adjustment may be insignificant.

The ATCOR correction tends to smooth the data. The sun-elevation angle used as reference, 39°, induced a large correction similar to that noted for the sun-angle correction factor discussed in the previous paragraph. There is no external standard for comparison of the ATCOR correction. The LACIE/AgRISTARS film products do not exhibit haze well. However, for the consecutive days 136 (haze) and 137 (clear), using data from sample segment (s.s.) 1461, the ATCOR program estimated haze values of 0.55 and 0.26 respectively.

ATCOR lowered the data value for day 136 with a large adjustment, but lowered the value for day 137 very little. This is the desired correction similarly, on s.s. 1636, a haze estimate of 0.74 corresponded to a visually hazy acquisition on day 117; the data values were lowered markedly by ATCOR. Negative haze estimations may have occurred in segments where there are clouds (for example, s.s. 1467, days 190 and 191; s.s. 1653, day 199; s.s 1920, day 271). These negative values may have indicated that the darkest pixels in the segment were pixels of cloud shadow - emitted energy only. Since the haze estimation was formulated for reflected radiance, the estimate would have been invalid in this case. Negative haze estimates also appeared on the imagery for s.s. 184, acquisitions 265 and 266, where there were no visible clouds. The application of ATCOR affected the MSS channel crop profiles most markedly; the AVI and the greenness profiles were affected less; the ratioed profiles were changed the least; occassionally, a peak greenness value of RVI would be lowered by ATCOR, perhaps because of the method of calculating background reflectance.

More investigation of the ATCOR correction should be done before implementation of the technique; it appears to be beneficial to crop profile work unless use of a ratio transformation renders it unnecessary.

## 8.2 RECOMMENDATIONS

Based on this study the following recommendations are presented:

1. Understanding the data collection system is essential for effective use of satellite data. Sources of data distortion, as well as the preprocessing techniques proposed for reducing the effects of these sources, should be researched prior to the definition of suitable applications of satellite data.

   RECOMMENDATION: A study similar to this should be done on the advanced very high resolution radiometer (AVHRR) system of data collection used by the National Oceanic and Atmospheric Administration (NOAA) satellites, the NOAA-6 and NOAA-7.

2. This study illustrates the sensitivity of different data transformations to specific applications. The raw channel values retain reference to the defined physical significance of the MSS channel values.

RECOMMENDATION: In archiving data, raw MSS channel values, untransformed and without preprocessing additional to that done at GSFC, should be saved in order to preserve maximum flexibility of data use.

3. The preprocessing techniques routinely applied to Landsat data for LACIE/AgRISTARS are designed to compensate for known conditions of data collection and are correlated to measurements made onboard the satellite. Further preprocessing to emphasize specific features of the data, or to reduce "confusion" factors, should remain the option of the user. Data distortion is defined by the use of the data; wide spectrum usefulness of the data could be limited by increased preprocessing.

   RECOMMENDATIONS: No addition should be made to the preprocessing techniques routinely applied to Landsat data at GSFC. Additional techniques, defined as desirable for a specific purpose, should remain the option of the user.

4. Based upon the evidence from this study, use of a ratio-type data transformation lessens the need for application of currently proposed preprocessing techniques. Specifically, the potential for error caused by omission of preprocessing is less when using data transformed by transforms such as the VI or RVI.

   RECOMMENDATION: A ratio-type data transformation is preferred for generation of crop profiles of reflectivity versus time to be used in agricultural research with satellite data.

5. The ATCOR program developed at the Johnson Space Center (JSC) by Lockheed Engineering and Management Services Company, Inc. and the XSTAR program developed by the Environmental Research Institute of Michigan (ERIM) are two of the most significant methods now in use for defining multiplicative and additive preprocessing algorithms by using a few characteristics of the Landsat data to drive a mathematical model (ref. 2). The XSTAR algorithm is based on the premise that haze will cause data transformed by the Kauth-Thomas rotation to be shifted in the negative "yellow" direction, away from its haze-free position in data space. The XSTAR algorithm is used with a sun-angle correction (cosine of the solar zenith angle reference to a solar zenith angle of 39°) and a screening process

which removes garbled data, clouds, water, and cloud shadow. The original intent of this study was to examine the results of an XSTAR correction as was done with ATCOR. However, a research version of the most current implementation of this method was not available at the time of the study.

RECOMMENDATION: When available, graphs should be generated to illustrate the effect of the XSTAR haze correction algorithm on the data set used in this study.

6. The sequence of acquisitions used for this study indicates a view-angle-dependent difference in data range; i.e., the second day of consecutive dates tends to be lower.

RECOMMENDATION: The effect of satellite view angle on Landsat data should be quantified and evaluated statistically using the consecutive-day data set defined for this project.

7. This study indicates that sun-angle effects contribute significantly to the apparent crop profile when the MSS channels, a subtractive transform, or Kauth greenness is graphed versus time. Graphs standardized to 51° sun elevation were created for this task as well as the 39° reference presented in the study.

RECOMMENDATION: The effect of applying a sine correction factor to standardize sun-elevation angle in the use of crop profiles should be quantified and evaluated statistically using data generated for this study.

8. ATCOR coefficients are available to standardize the data set used in this study to optical depths of 0.2, 0.3, and 0.4. This material should be analyzed for consistency of the ATCOR standardization method.

RECOMMENDATION: The effect of standardizing data to varying haze levels using the ATCOR program should be quantified and evaluated statistically, using data generated for this study.

9. The benefits of applying an intersatellite adjustment factor to the MSS channels, and to data transformed by the AVI or the Kauth greenness, are uncertain. The factors used in this study have been used extensively with acceptable results. More rigid statistical evaluation should be done on the necessity for applying this adjustment, however.

   RECOMMENDATION: A statistical study should be done to assess the significance of the difference in the data ranges of Landsat-2 and Landsat-3; an adjustment may not be necessary.

10. This study focused on evaluation of methods of alleviating the effects of some types of data distortion on channel data and on data transformed by selected methods. Results were definitive enough to support conclusions on useful methods to reduce data distortion, which is a source of confusion in the interpretation of crop profiles. The techniques used for this study could be applied to examining the effects of, for example, plant phenology on MSS channel and selectively transformed data with analogous results.

    RECOMMENDATION: Channel and transformed data should be used, in a manner similar to that used in this study, to graph a data set affected by known agrometeorological episodic events, and the results subsequently should be evaluated.

11. Global standards (i.e., ground observations) should be defined for various land uses. This would benefit research in the area of atmospheric effects.

    RECOMMENDATION: Accurate ground-level measurements taken at the same date, the same target, and the same view angle as those of the satellite should be made for comparison with both Landsat and Metsat data and for validation of the ATCOR model.

12. The effect of background reflectance on reflectance from the target and the effect of target-dependent differences in detector response may possibly be reduced by using the RVI or VI of a field divided by that of the segment. This use of ratio is analogous to the reduction of the effect of difference in sun-angle, satellite, and some atmospheric effects by use of channel ratio. In this case, the background reflec-

tance of the scene and the field would have some overlap as would the geometry of the target (terrain elevation similarity, for example). Hence ratio of field mean to segment mean might reduce these effects.

RECOMMENDATION: The effects of spatial division should be assessed in much the same way that spectral division has been assessed in this study.

# 9. CONCLUSION

The effectiveness of using transformed data to reduce the need for preprocessing techniques is encouraging. The results of this study indicate that, with current knowledge, use of transformed data - especially ratioed data - is the most practical method of reducing the effects of the sources of error, hence increasing the signal-to-noise ratio, in Landsat data to be used for identification of agricultural scene components.

# 10. REFERENCES


1. Austin W. W., and Ryland W. G.: Simulation of METSAT Data Using Landsat Data. LEMSCO 16978, 4/83.

2. The LACIE Symposium. Proceedings of the Technical Sessions, vols. 1 and II, July 1979.

3. Dave, J. V.: Influence of Illumination and Viewing Geometry on the Tasselled Cap Transformation of Landsat MSS Data. Remote Sensing of the Environment, pp. 1137-55, 1981.

4. Potter, J. F.: The Atmospheric Correction Program ATCOR. LEC 8645, August 1976.

5. Landsat Data Users Handbook. Goddard Space Flight Center, NASA September 1976.

6. Duggin, M. J.: The Effect of Angular Factors on Popularly Used Indicators of Vegetative Vigor. Proceedings of ASP, 46th Annual Meeting St. Louis, Missouri, pp. 239-241.

7. Duggin, M. J., and Slater, P. N.: The Effect of Sensor Bandpass and Spectral Response in Crop Stress Detection. ASP Fall Technology Meeting, Niagara Falls, 1980.

8. Slater, P. N.: A Re-Examination of the Landsat MSS. Photogrammetric Engineering and Remote Sensing, vol. 45, no. 11, Nov. 1979.

9. Landsat Data Users Handbook. Revised edition. U.S. Geological Survey, 1979.

10. Holkenbrink, P. F.: Manual on Characteristics of Landsat Computer Compatible Tapes Produced by the EROS Data Center Digital Image Processing System. 1979.

11. Austin, W. W.: Radiometric Calibration of Landsat 2 MSS Data. ref. 644-1871, IDC to J. K. Oney.

12. Landsat Data Users Notes #8. Sept. 1979.

13. Ahern, F. J., et al.: Using Clear Lakes as Standard Reflectors for Atmospheric Measurements. Proceedings of the 11th International Symposium on Remote Sensing of the Environment, vol. 1, pp. 731-755.

14. Austin, W. W., et al.: Landsat 3 Data Compatibility Study. March 1979.

15. Dozier, J. and Frew, J.: Atmospheric Corrections to Satellite Radiometric Data over Rugged Terrain Remote Sensing of the Environment. 11:191-205 (1981).

16. Duggin, M. J., and Ellis, P. J.: Limitations on the Spectral Descrimination of the Landsat MSS. Proceedings of the ACSM - ASP Convention, March 9-14 St. Louis, p.p. 329-334.

17. Duggin, M. J., et al.: A Method for Calibrating Multispectral Scanner to Allow for the Spectral Dependence of the Instrument Response. American Institute of Aeronautics and Astronautics, Dec. 1980.

18. Duggin, M. J., et al.: Calibration Problems in the MSS: A Discussion and Some Suggestions. To be published in Photogrammetric Engineering and Remote Sensing.

19. Earth Resources Technology Satellite. General Electric Co.

20. Holmes, Q., et al.: Development of Landsat-Based Technology for Crop Inventories: Appendices. SR-E9-004042, NAS9-15476.

21. Horan, J. J., et al: Partial Performance Degradiation of a Remote Sensor in a Space Environment, and Some Probable Causes. Applied Optics, vol. 13, p. 1230, May 1974.

22. Johnson, W. R., and Sestak, M. L.: An Analysis of Haze Effects on Landsat MSS Data. SR-L1-04071, TSC-17127, March 1981.

23. Kaneko, T.: View Angle Effect in Landsat Imagery. Proceedings of the 11th International Symposium, vol. II, April 1977.

24. Kauth, R. J., and Thomas, G. A.: The Tasselled Cap - A Graphic Description of the Spectral-Temporal Development of Agricultural Crops as seen by Landsat. Proceedings of the Symposium on Machine Processing of Remotely Sensed Data. LARS, Purdue University, 1976.

25. Lambeck, P. F.: Signature Extension Preprocessing for Landsat MSS Data. ERIM 122700-32, Nov. 1977.

26. Landsat Newsletter No. 15. June 1, 1977.

27. MSS Standard Interface Document. General Electric Co., July 1978, GE-BO-78-034.

28. Potter, J. F.: The Correction of Landsat Data for the Effects of Haze, Sun Angle, and Background Reflectance. Proceedings of the 4th Symposium on Machine Processing of Remotely Sensed Data, LARS, June 21-23, 1977.

29. Potter, J. F. and Mendlowitz, M. A.: The ATCOR-A Sun Angle Correction Program. LEC 9695, May, 1977.

30. Potter, J. and Shelton, M: Effect of Atmospheric Haze and Sun Angle on Automatic Classificaiton of ERTS-1 Data. Proceedings of the Ninth International Symposium on Remote Sensing of Environment, 1974.

31. Ryland, W. G.: Program RAWPLT Users Guide. LEMSCO-17331, AgRISTARS, Oct. 1981.

32. Ryland, W. G.: Program LPLOT User Guide. Oct. 1981.

33. Wehmanen, O. A.: Landsat-3 Calibration Factors. Letter to R. O. Hill (NASA/JSC), ref. 644-1044, Sept. 13, 1978.

# APPENDIX A:

# DISCUSSION OF THE SUNLIGHT-TO-DIGITAL-COUNTS CONVERSION OF LANDSAT DATA

## APPENDIX A

## DISCUSSION OF THE SUNLIGHT-TO-DIGITAL-COUNTS CONVERSION OF LANDSAT DATA

The intent of applying preprocessing techniques to Landsat data is to minimize the detrimental effects on the data which occur in the conversion of sunlight to digital counts. Definition and application of effective preprocessing techniques require examination of the potential sources of error (or data distortion) in this conversion. Error sources can be divided into two categories: atmospheric conditions and viewing geometry. These categories are interdependent as well as wavelength dependent, so neither category can be treated separately with precision. Atmospheric conditions affect the entire data path and confound any precise measurement of geometric effects. Similarly, viewing geometry is a factor in the effect of the atmosphere on the data. Atmospheric factors have a different effect in the different MSS channels, and geometric factors also tend to produce different effects in each MSS channel. This wavelength dependent difference is, however, an integral part of the scene identification process; it is mentioned here to emphasize that a channel-consistent correction factor cannot be assumed to be adequate for complete error removal. Atmospherically based sources of error have not been effectively quantified to date; potential error sources based on the geometry of the viewing system are examined in this appendix.

Figure 2.1 illustrates the data flow. The resultant Landsat data contains significant, but largely undeterminable, alterations to the data from both known and unknown sources. Error characterization and reduction is important to assure that detected radiation differences exceed system noise, and hence that terrain classification can be unambiguous. It is important to remember that the application of the Landsat data determines the definition of the term "error". The terms "data distortion," "source of error," "error," and "noise" are viewed as equivalent and all refer to "results of the conditions under which Landsat data are collected." In the following discussion, the presence of atmospheric and wavelength dependent differences as confusion factors is assumed, and these are not mentioned in the path of sun radiance through the system geometry illustrated in figure 2,1.

Within each subsection below, the potential source of error is described, and relevant known information is presented. Possibilities of reducing the error are discussed. Discussion of the sunlight-to-counts conversion is divided into two sections: (1) target reception and reflection and (2) satellite reception and transmission.

## IRRADIANCE AND TARGET REFLECTANCE

Incoming solar radiation to the target depends upon wavelength, atmospheric conditions, and solar elevation; outgoing radiation reflected from the target is, in addition, dependent upon the spatial and spectral reflectance properties of the target.

## SUN-ELEVATION ANGLE

Changes in solar elevation angle cause variations in the lighting conditions under which imagery is obtained. These changes are due primarily to the north/south seasonal motion of the Sun. At certain times of the year, imagery is not obtained in the high latitude regions of the earth because of inadequate scene illumination. "At solar elevation angles greater than 30°, it is expected that all scenes can be satisfactorily imaged; normally, no attempt is made to obtain imagery for solar elevation angles less than 10°" (ref. 5).

The actual effect of changing the solar elevation angle on a given scene is very dependent on the scene itself. For example, the intrinsic reflectance of sand is significantly more sensitive to changing solar elevation angle than are most types of vegetation.

Sun elevation angle is listed in the header information supplied with each acquisition image. With current knowledge, some estimations of sun angle correction factors for direct application to the data are possible. Multiplying by a sine, or cosine, factor can be used to normalize the data to a fixed solar angle.

The ERIM atmospheric correction program XSTAR has been suggested more as a correction for the sun-angle normalization procedure than as a complete atmospheric correction. ATCOR, a Lockheed-developed haze correction algorithm, is proposed as an improvement over the cosine sun-angle standardization and has been applied for this purpose. Use of a ratio-type data transformation reduces the effect of sun angle on the data.

## TARGET REFLECTANCE

Target reflectance is a function of sun/atmosphere irradiance with the spatial and spectral properties of the target. Geometrical variation of the target will affect the reflectance and absorption of sunlight and the signal dispersion, and this geometry-dependent variation is different for each of the spectral wavelengths. Spectral characteristics of the target material also affect the reflectance and absorption of the sunlight. These spatial and spectral characteristics are central to the target identification process. Background reflectance contributes an unknown amount to the target reflectance, and for the unknown mixture of reflectance properties over most of the Earth's surface, too little is known to attempt definitive correction. Use of ATCOR may reduce the effects of background reflectance, as may use of data ratioing.

## REFLECTED RADIANCE AND SATELLITE TRANSMISSION

Reflectance from the target is altered by the reflectance of the surrounding background scene and by atmospheric effects. The reflected irradiance is then affected by (1) the satellite view angle, (2) the sensor configuration and sensitivities, (3) the resolution of the sampling method, and (4) the digitization required for transmittal to ground receiving stations.

The satellite sensor characteristics: The multispectral scanner (MSS), that produces a continuous strip image of the Earth in various spectral bands as it continually scans the earth in a swath perpendicular to the Landsat orbital track. Scanning is accomplished in the crosstrack direction by an oscillating mirror; satellite motion along the orbit provides the along-track scan.

Landsat-1 through Landsat-3 were planned for sun synchronous orbits, 570 miles above the earth, 14 orbits per day, and 18-day coverage cycle. Repetitive image centers are maintained to within 20 n.m.; planned orbit overlap varies from 14 percent at the equator to 85 percent at 80° latitude. In the overlap regions, coverage is on consecutive days, 14 satellite revolutions apart.

SATELLITE VIEW ANGLE

Satellite view angle - variation across the flight path - is the means by which radiance reflected from the Earth is measured. Sensor outputs are dependent upon the instantaneous view angle corresponding to each output. Coverage in the overlap regions described above is taken with different satellite view angles.

Since the Landsat MSS scans a swath of 100 n.m. width on the ground from a height of 570 n.m., the view angle varies between -5.78 and 5.78 degrees. The view angle change for consecutive day coverage, same geographical area, at a latitude of 35° to 45° is 7° to 8°. Using consecutive day data, ground conditions are very similar and the sun angle has changed very little, while the change in viewing angle is the maximum possible. Sensor outputs are generally smaller on the second day. Average sensor response for agricultural areas is approximately 5 percent lower on the second day acquisitions as compared with the first. On the first day, Sun and sensor will be on the same side of the target, the sunny side; on the second day, the sensor will be on the opposite side of the target from the Sun, i.e., the shady side: this may cause some of the reduction. The reduction is scene content dependent and wavelength dependent, and it will depend also on the nature of the target and on target geometry. For example, reflectance off lakes may increase on the second day because of mirror-image reflectance off the water.

Experimentation with ground based measurements (ref. 6) indicates that the largest variations with satellite view angle will occur outside the sun elevation range of 30° to 50°.

Normalization of the satellite view angle could be done directly (in a manner similar to the sun angle approach), although appropriate parameters have not been defined for doing this. Response variation due to change in view angle is apparently small; use of data ratioing will decrease the effect.

## SENSOR CONFIGURATION AND SENSITIVITIES

The Landsat MSS responds to Earth reflected sunlight in four spectral bands:

| Landsat band | MSS channel | Wavelength ( m) | Spectrum |
|---|---|---|---|
| 4 | 1 | 0.5 to 0.6 | visible green |
| 5 | 2 | 0.6 to 0.7 | visible red |
| 6 | 3 | 0.7 to 0.8 | infrared |
| 7 | 4 | 0.8 to 1.1 | infrared |

Relative reflectance in these bands is an indication of scene content. Scanning is accomplished by means of an oscillating mirror between the ground scene and a double reflector telescoping type of optical chain. The mirror scans the crosstrack field of view as it oscillates about its nominal position. Potential error sources in sensor performance include (a) the difference in sensor sensitivity for the different channels, (b) the inconsistency in data acquisition caused by sensor configuration and (c) the variations in detector response within a sensor. The technique used to calibrate the sensor is also a potential source of error.

Each MSS spectral band utilizes six detectors. Photomultipliers are used in channels 1, 2, and 3; channel 4 uses silicon photodiodes. This difference in receptor defines a difference in the subsequent treatment of data acquired by MSS channel 4 from that acquired by MSS channels 1, 2, and 3. Detectors are coupled to the focal plane of the MSS optical system by means of square optical light pipes. These pipes conduct the radiance at the focal plane to optical filters immediately preceding each detector; the filters are identical for all detectors in a given spectral band, but unique for each spectral band.

Six scan lines are scanned at once with a slight sequential effect for each sensor. That is, the data in the various spectral bands (MSS channels) are acquired sequentially and not instantaneously, although data acquisition is within 65 microseconds (Landsat-1 and Landsat-2). Compensation for such differences as scan line length (variable due to mirror motion variation) are made in the GSFC geometric corrections (appendix B). The spectral effects of sequential acquisition (i.e., the data from each MSS channel may not be based on exactly the same ground area) are unavoidable.

Each of the 24 light pipes conducts a square area of image radiance at the focal plane onto an individual detector. Within-channel equality of detector response to equal input is maintained by the calibration-data-based radiometric corrections applied at GSFC. However, although the detectors within a channel are calibrated to a standard response, the consistency of detector response within an MSS channel seems to be dependent upon the variation of the target (ref. 7); a spectrally flat target such as white sand will cause uniform detector response; a vegetative target will cause more variation in the response of the six detectors within each channel. There can be significant differences between the six detectors for a single channel; however, the instrument response functions are assumed equal for the detectors within an MSS channel.

The average response curves for the MSS channels are different on different Landsats. To select the worst case: At a wavelength of 0.52 m, the responses for the Landsat 1 MSS are about 0.87 and 0.94 for channels 1 and 3. The corresponding values for the Landsat 2 MSS are 1.0 and 0.76. Detector-to-detector variations in the spectral response within a given band can produce as instrascan line striping, i.e., "an error in spectroradiometric response between detectors as high as 16 percent for images of vegetation" (ref. 8).

More accurate definition of the detector response curves, or calibration to a vegetation-simulation rather than barium sulphate, have been proposed to reduce target-dependent striping effects. Removal of any target-dependent differences in detector response is not really feasible since each scene consists of a variety of targets. The effect of target-dependent differences in detector response may limit classification accuracy.

## SENSOR CALIBRATION

Calibration of the MSS is done onboard using a continuously variable neutral density filter and a calibrated light source. During the mirror retrace period, the radiance from the Earth scene is blanked out by a mechanical shutter. The sensors are then exposed to a rotating variable neutral density wedge optical filter illuminated by an internal light source. The Sun is used to calibrate the internal lamp when the spacecraft is at a nearly polar position. As the spacecraft orbits the earth, coming from the dark side, the spacecraft is illuminated by the sun before sunlight reaches the surface of the Earth. Thus the sun calibration can be done with dark Earth as a background. Detector calibration then, is done on every other retrace interval of the scan; calibration information for the light source is collected once each orbit. Since calibration information is obtained on the detector level, there is a check on the relative detector radiometric response, and it is possible to equalize gain changes which may occur in the six detectors of a spectral band. Adjustment for changes in calibration lamp radiance can also be made. Calibration data is encoded and transmitted with the reflectance data. Radiometric corrections based on the calibration data are applied as part of the preprocessing techniques done at GSFC (appendix B).

## SPATIAL AND SPECTRAL RESOLUTION OF THE SAMPLING METHOD

The analog signals produced as output by the 24 detectors are sampled, digitized, and formatted into a serial digital data stream by a multiplexer. The sampling interval is constant (9.95 sec). However, the output is not exactly consistent due to several perturbations: variations in spacecraft attitude and motion, Earth rotation effects, and variations in mirror motion. The spatial sampling variations are reflected in the spectral resolution of the sampling.

"The nominal instantaneous field of view (IFOV) of each detector is 79 meters square as determined by the focal length of the telescope, the nominal altitude of the spacecraft and the dimensions of the light pipes at the focal plane" (ref. 5). For Landsats 1, 2, and 3, because of slight differences in focal length and fiber core sections, actual IFOV's are 76.1 ±.4 for Landsat-1, 76.3 ±.4 for Landsat-2, and 76.2 ±.7 for Landsat-3. Effective IFOV, instead of the nominal 79 meters, is approximately 56 by 79 meters: 56 meters of new information and 23 of overlap. The spatial resolution is often given as 79 by 57 meters, or 1.1 acre in size, but this does not mean the area of the ground instantaneously sampled by a single detector. According to the system geometry, at any instant the ground projected IFOV is more nearly 76 x 76 meters, or 1.43 acres. These nominal spatial resolution figures are necessarily approximate since the variable spacecraft altitude and motion and the mirror velocity affect the physical arrangement of the sensor and the sampling process. Neglecting the atmosphere, the output signal from the detector is proportional to the radiance of the IFOV plus the surrounding area included by the spread function of the optics. This is a circular area about 30 meters in diameter, so each area sampled on the ground will contain some flux from at least 30 meters beyond the ground projected IFOV of 76 by 76 meters.

The perturbations causing the nonconstant effects are neither predictable nor avoidable, so the consequent errors are probably unavoidable. These errors simply reflect the fact that the MSS is not ideal.

ANALOG TO DIGITAL CONVERSION AND DATA TRANSMITTAL TO EARTH

The digitization process preparatory to data transmission to Earth converts the analog signal from the detectors to digital values in the range 0.5 to 63. All values between $_i$ - 0.5 and $_i$ + 0.5 are mapped to $_i$, where $_i$ is an integer in this range. From this point on, the integer values are the level of sensitivity available in the data.

The analog output from each of the 24 detectors in the MSS is sampled and multiplexed into a pulse amplitude modulated (PAM) stream. The samples can be transmitted directly to the analog-to-digital (A/D) converter for encoding or, for MSS channels 1, 2, and 3, can be directed to a quasi-logarithmic signal compression amplifier. A high-gain option can be selected for scenes producing low sensor irradiance. The analog processing options are selected by ground command. Landsat/AgRISTARS data use low-gain mode; signal compression is chosen for channels 1, 2, and 3, linear quantization for channel 4. The photomultiplier detector signal-to-noise performance is improved by compression; the signals in channel 4, derived from silicon photo diodes, are never compressed.

After analog processing, all data are encoded into six-bit digital words; six-bit encoding is used regardless of whether the data is linearly processed or compressed. There are two signal compression amplifiers in the spacecraft: one is used to process sensor data from MSS channels 1 and 3, and the other is used for channel 2 data. Sensor signal amplitudes are represented in 64 discrete steps, integer values 0, 1, 2, 3, ..., 63.

If the satellite is within transmitting range of one of the U.S. reception facilities (in Maryland, California, and Alaska) at the time of acquisition, the data are transmitted immediately over Domsat. Otherwise, the data are recorded onboard for later transmittal when a station is within range.

# APPENDIX B

# PREPROCESSING OF LACIE/AgRISTARS LANDSAT DATA AT GODDARD SPACE FLIGHT CENTER

# APPENDIX B

# PREPROCESSING OF LACIE/AgRISTARS LANDSAT DATA AT GSFC

## PREPROCESSING AT GSFC FOR THE LACIE/AgRISTARS PROJECTS

At GSFC, the data is reprocessed, framed as individual scenes, and encoded on tapes for delivery to JSC. The MSS data, digitized onboard the satellite and transmitted and recorded in digital form, are (1) decompressed (if compressed), (2) corrected radiometrically to reduce the effects of non-uniform responses of the scanner sensors, and (3) geometrically corrected for distortions caused by the sensor and spacecraft, and subsequently registered. The images are then framed to be spatially coincident with Return Beam Vidicom (RBV) camera system data, and the LACIE sample segments are extracted.

## DECOMPRESSION OF DIGITIZED VALUES

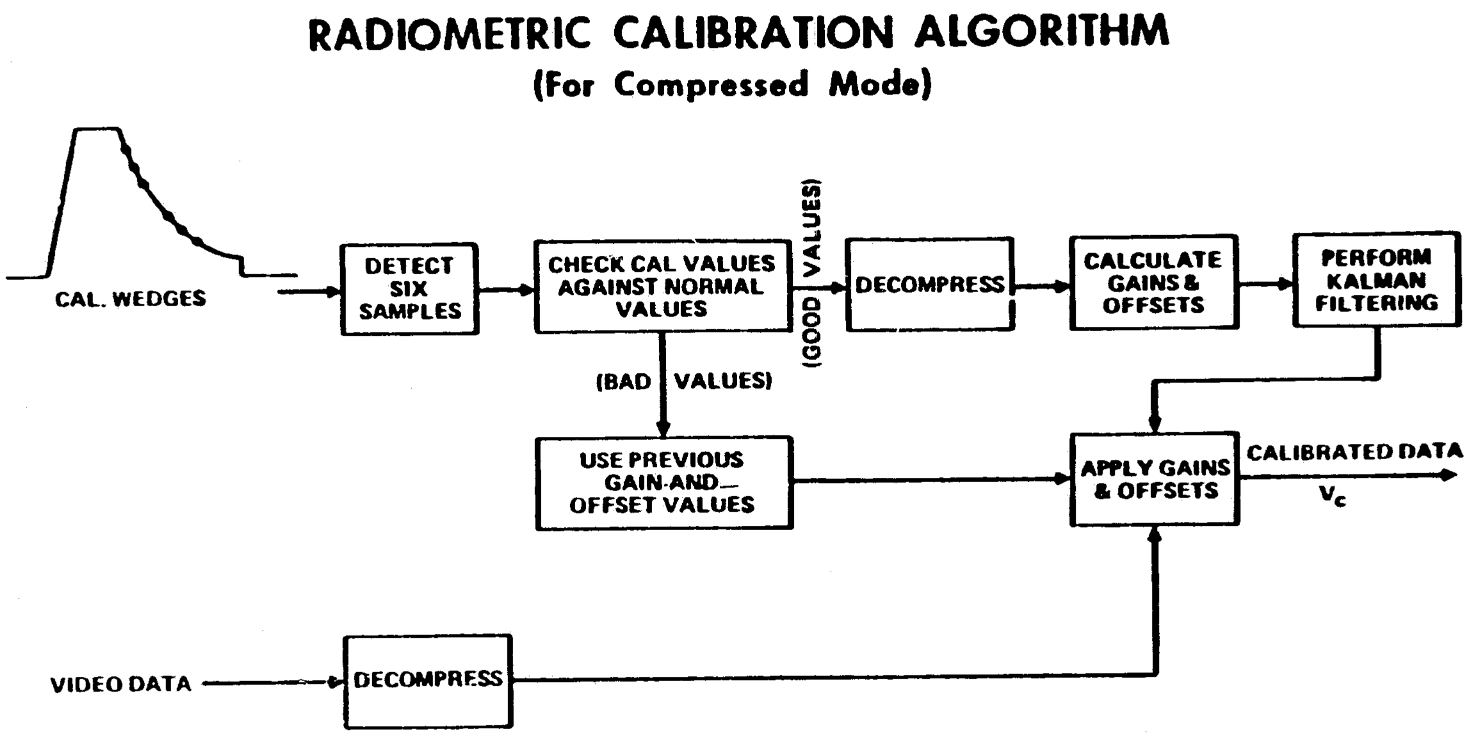
If data are acquired in the compressed mode, decompression is done before calibration. Each image is annotated to indicate the setting of compression and mode. LACIE/AgRISTARS data are recorded compressed for MSS channels 1, 2, and 3, and linear for channel 4; low-gain mode is used for all channels. Decompression is done by a table look-up routine. Input values of 0 to 63 are output as 0 to 127; the 6-bit encoding used for transmission is decompressed into 7-bit. Since compression for channels 1 and 3 is different from that for channel 2, two decompression tables are given for each of the Landsats. Before calibration, omitted values are not used; after calibration, different values may be used. For example, a comressed value of 53 for channel 2 Landsat-3 data will be decompressed into the value 98. Calibration data (decompressed also using these tables) determine gains and offsets which are applied to the decompressed values and may change 98 to a different number. Over the entire Landsat image, for all MSS channels, all the values from 0 through 127 may be used.

## RADIOMETRIC CORRECTIONS

From an internal calibrated light source, the response characteristics of the individual detectors are obtained and compared with an internally generated calibration wedge. The calibration wedge radiance versus word count responses are then derived for each detector in each spectral band. The calibration wedge is used to define any change (gain and offset) in detector response. The radiance level of the Sun is used to calibrate the light source (ref. 9). Radiometric calibrations (gains and offsets) are computed and applied to bring the responses of the six individual detectors in a spectral band to a common model (mismatching is evidenced as striping on the image). "It should be noted that the radiometric correction process is not uniquely reversible because of computational round-offs and dual entries in the decompression tables" (ref. 10) even if the gain and offset values are known.

Figure B-1 (ref. 9) illustrates the algorithm for MSS radiometric calibration. In the algorithm, a and b are determined from the calibration data collected for each scan line (i.e., for each detector). From preflight calibration tests, the radiance at selected word counts and the maximum radiance to be assigned to each spectral band were determined. There is a tendency toward long-term drift in the MSS detector response and in the calibration lamp radiance; m and A in the algorithm are detector-dependent parameters used to control long-term drifts in detector response. At launch, M is equal to 1 and A is equal to 0 in the algorithm. $R_{max}$ is the maximum radiance assigned to a specific spectral band, and that value produces a digital count of 63 for linearly acquired data and a digital count of 127 for decompressed data. (In a similar manner, $R_{min}$ is the minimum radiance and produces a count of 0.) For Landsat 2 and Landsat-3, the prelaunch calibration did not fully utilize the dynamic range capabilities of the sensor; hence the amount of input allowed for constant output of 0 to 127 or 0 to 63 was changed. Postlaunch radiometric calibrations were defined.

During the period January 22 to July 15, 1975, all CCT's (Landsat-2 data) were produced using the prelaunch analog to digital calibration. Effective July 16, 1975, all CCT's except those processed for LACIE were calibrated using the postlaunch calibration (ref 17). LACIE segment imagery continued to use the prelaunch calibration. During the period 1977 to 1978, an intent was expressed to switch the LACIE processor to the postlaunch calibration (ref. 11). However, no reference has been found to confirm that the postlaunch calibrations were ever used on the LACIE data. Consequently,




$$V_c = \left[\frac{K}{M \cdot b}\,(V-a)\right] - A$$

WHERE:

- $V_c$ = CALIBRATED IMAGE DATA (0-127)
- A = OFFSET MODIFIER
- K = MAXIMUM IMAGE COUNT (e.g., 127)
- M = GAIN MODIFIER
- V = DECOMPRESSED INPUT IMAGE DATA (0-127)
- a = FILTERED OFFSET VALUE
- b = FILTERED GAIN VALUE .

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Figure B-1.- MSS radiometric calibration algorithm.

algorithms in use at JSC are based on an assumption of prelaunch calibration only on AgRISTARS Landsat-2 data.

The film products produced from Landsat data are relatively insensitive to these radiometric calibrations; however, it is imperative that calibration information be available for numerical work. Currently, the full-frame CCT's from EROS, Landsat-2 acquisitions, require calibration adjustment to be compatible with the Landsat-2 segment data extracted from the full frames for LACIE.

GEOMETRIC CORRECTIONS

The attitude control system (ACS) of the satellite provides spacecraft alignment to a very close tolerance. However, variations do occur, and these, along with the effects of Earth rotation, cause a slight distortion in the MSS images. Data for "MSS geometric calibrations are derived from three sources: (1) preflight measurements of the time/displacement characteristics of the scanning mirror assembly, (2) preflight measurement of the spatial relationship of the individual detector fiber optics in the focus plan of the scanner, and (3) line length data codes contained in the MSS data after each mirror sweep" (ref. 9). Based on this information, data can be corrected for:

- line length variations due to variation in the size and number of pixels per line (a function of the mirror velocity)
- channel-to-channel offset in the along-scan line direction resulting from the physical layout of the detectors
- Earth rotation
- detector-to-detector sampling delay caused by mirror motion

The raw image data are also transformed to a standard map projection, either the Space Oblique Mercator (SOM) or the Hotline Oblique Mercator (HOM); or (as options) to the Polar Stereographic (PS) or Universal Transverse Mercator (UTM), based on a correction grid. This produces "an output image with known pixel locations. The analogy of stretching a sheet of rubber over a gridwork of pins describes the result quite well, although the process is entirely mathematical" (ref. 12).

The MSS is a continuous scanning device, which produces a continuous record. Full-frame images are constructed by cutting this record into pieces corresponding to an RBV camera system frame; that is, the RBV time is used as a reference. Overlap is provided and is made possible by writing MSS scan lines twice (once on each of two adjacent frames) and corresponds to an area of nautical miles 8.8 on the ground.

The MSS sensor operates at a rate that produces pixel overlap within scan lines. This pixel overlap, like the actual number of pixels per scan line (tolerance about 7 pixels), varies because of variation in mirror motion. The scanner samples pixels whose centers are approximately 57 meters apart; these are subsequently treated as independent pixels measuring 57 by 79 meters. The correlation from the overlap is ignored.

LACIE specified sample segments are extracted from the full frame data; correlations are performed to ensure registration to within 1 pixel between successive data acquisitions.

# APPENDIX C

# EROS DATA QUALITY ASSESSMENT

## APPENDIX C

## EROS DATA QUALITY ASSESSMENT

Full-frame imagery (100 nautical miles square) is screened for cloud cover and data quality at EROS. These assessments for the full frames associated geographically with the site data set are presented in table C-1. For each sample segment, the EROS cloud cover assessment and the channel quality estimates are given for each acquisition. Path/row designations for the full-frame images are noted.

EROS quality estimates are given in code for individual channel images. An "8" code refers to an image in which there are some very minor digital defects; a "5" code refers to an image which has minor defects, some of which may affect the usability of the image. A "2" code indicates an image that has major defects, or possibly an array of minor errors that compound each other. A rating of "0" indicates that data discontinuity and shifting have occurred in large areas of the scene. The defects referred to in the quality codes, it should be noted, are digital and electronic but do not necessarily refer to the spectral quality.

TABLE C-1.- EROS FULL-FRAME DATA ASSESSMENT

| Segment/ location | Acquisition date | ERPS cloud cover assess- ment, % | EROS quality estimate Channel 1 | 2 | 3 | 4 | 5 | Path/row |
|---|---|---|---|---|---|---|---|---|
| 1830 | 115 | 10 | 8 | 8 | 8 | 8 | * | 31/29 |
| | 169 | 0 | 8 | 8 | 8 | 8 | * | 31/29 |
| Kimball, | 196 | 10 | 8 | 8 | 8 | 8 | * | 31/29 |
| Nebraska | 204 | 0 | 8 | 8 | 8 | 8 | * | 30/29 |
| | 205 | 10 | 5 | 5 | 8 | 8 | * | 31/29 |
| | 222 | 10 | 8 | 8 | 8 | 8 | * | 30/29 |
| | 231 | 0 | 8 | 8 | 8 | 8 | * | 30/29 |
| | 232 | 10 | 8 | 8 | 8 | 8 | * | 31/29 |
| | 241 | 10 | 8 | 8 | 8 | 8 | * | 31/29 |
| | 249 | 10 | 8 | 8 | 2 | 8 | * | 30/29 |
| | 268 | 10 | 5 | 8 | 8 | 8 | * | 30/29 |
| | 118 | 50 | 8 | 8 | 8 | 8 | * | 34/26 |
| | 136 | 10 | 8 | 8 | 8 | 8 | * | 34/26 |
| | 137 | 10 | 8 | 5 | 8 | 8 | * | 35/26 |
| | 154 | 20 | 5 | 8 | 8 | 8 | * | 34/26 |
| 1461 | 155 | 10 | 0 | 8 | 0 | 8 | * | 35/26 |
| | 190 | 40 | 5 | 8 | 8 | 8 | * | 34/26 |
| Pierce, | 199 | | | | | | | |
| North | 208 | 30 | 8 | 2 | 8 | 8 | * | 34/26 |
| Dakota | 209 | 50 | 8 | 8 | 8 | 8 | * | 35/26 |
| | 217 | 0 | 5 | 5 | 2 | 8 | * | 34/26 |
| | 218 | 10 | 5 | 8 | 8 | 8 | * | 35/26 |
| | 236 | 10 | 0 | 8 | 8 | 8 | * | 35/26 |
| | 263 | 60 | 8 | 8 | 8 | 8 | * | 35/26 |
| 1467 | 136 | 10 | 8 | 8 | 8 | 8 | * | 34/36 |
| | 137 | 10 | 8 | 5 | 8 | 8 | * | 35/26 |
| Towner, | 154 | 20 | 5 | 8 | 8 | 8 | * | 34/26 |
| North | 155 | 10 | 0 | 8 | 0 | 8 | * | 35/26 |
| Dakota | 190 | 40 | 5 | 8 | 8 | 8 | * | 34/26 |
| | 191 | 20 | 8 | 8 | 8 | 8 | * | 35/26 |
| | 199 | 40 | 5 | 8 | 8 | 8 | * | 34/27 |
| | 200 | 30 | 8 | 8 | 5 | 8 | * | 35/26 |
| | 208 | 30 | 8 | 2 | 8 | 8 | * | 34/26 |
| | 217 | 0 | 5 | 5 | 2 | 8 | * | 34/26 |
| | 218 | 10 | 5 | 8 | 8 | 8 | * | 35/26 |
| 1636 | 117 | 30 | 8 | 8 | 8 | 8 | * | 33/27 |
| | 135 | 0 | 8 | 8 | 8 | 8 | * | 33/27 |
| Stutsman, | 136 | 0 | 8 | 8 | 8 | 8 | * | 34/27 |
| North | 154 | 10 | 5 | 8 | 5 | 8 | * | 34/27 |
| Dakota | 190 | 20 | 5 | 8 | 8 | 8 | * | 34/27 |
| | 207 | 10 | 8 | 5 | 8 | 8 | * | 33/27 |
| | 208 | 10 | 8 | 2 | 8 | 8 | * | 34/27 |
| | 216 | 0 | 5 | 8 | 8 | 8 | * | 33/27 |
| | 217 | 0 | 5 | 5 | 5 | 5 | * | 34/27 |
| | 226 | 70 | 8 | 8 | 8 | 8 | * | 34/27 |
| | 243 | 10 | 5 | 5 | 8 | 8 | * | 33/27 |
| | 270 | 10 | 8 | 8 | 8 | 8 | * | 33/27 |

| Segment/ location | Acquisition date | ERPS cloud cover assessment, % | EROS quality estimate Channel 1 | 2 | 3 | 4 | 5 | Path/row |
|---|---|---|---|---|---|---|---|---|
| 1653 | 101 | 70 | 8 | 8 | 8 | 8 | * | 35/27 |
| | 119 | 40 | 8 | 8 | 8 | 8 | * | 35/27 |
| Henry, | 136 | 0 | 8 | 8 | 8 | 8 | * | 34/27 |
| Indiana | 137 | 10 | 8 | 8 | 8 | 8 | * | 35/27 |
| | 154 | 10 | 5 | 8 | 8 | 8 | * | 34/27 |
| | 155 | 10 | 0 | 8 | 8 | 8 | * | 35/27 |
| | 190 | 20 | 5 | 8 | 8 | 8 | * | 34/27 |
| | 191 | 30 | 8 | 8 | 8 | 8 | * | 35/27 |
| | 199 | 40 | 5 | 8 | 8 | 8 | * | 34/27 |
| | 208 | 10 | 8 | 2 | 8 | 8 | * | 34/27 |
| | 209 | 10 | 8 | 8 | 8 | 8 | * | 35/27 |
| | 217 | 0 | 5 | 5 | 5 | 5 | * | 34/27 |
| 1920 | 101 | 50 | 8 | 8 | 8 | 8 | * | 35/28 |
| | 136 | 10 | 8 | 8 | 8 | 8 | * | 34/28 |
| Sioux, | 137 | 30 | 8 | 8 | 8 | 8 | * | 35/28 |
| North | 199 | 30 | 8 | 8 | 8 | 8 | * | 34/28 |
| Dakota | 209 | 0 | 8 | 8 | 8 | 8 | * | 35/28 |
| | 217 | 0 | 5 | 5 | 2 | 5 | * | 34/28 |
| | 218 | 0 | 5 | 8 | 8 | 8 | * | 35/28 |
| | 236 | 40 | 5 | 8 | 8 | 8 | * | 35/28 |
| | 271 | 70 | 8 | 8 | 8 | 8 | * | 34/28 |
| 141 | 086 | 0 | 8 | 8 | 8 | 8 | * | 29/31 |
| | 103 | 10 | 8 | 8 | 8 | 5 | * | 28/31 |
| Madison, | 130 | 10 | 8 | 8 | 8 | 8 | * | 28/31 |
| Iowa | 166 | 40 | 8 | 8 | 8 | 8 | * | 28/31 |
| | 167 | 20 | 5 | 8 | 8 | 8 | * | 29/31 |
| | 212 | 40 | 5 | 8 | 5 | 8 | * | 29/31 |
| | 220 | 30 | 5 | 5 | 5 | 5 | * | 28/31 |
| | 221 | 10 | 5 | 8 | 8 | 8 | * | 29/31 |
| | 256 | 90 | 8 | 8 | 8 | 8 | * | 28/31 |
| | 265 | 10 | 5 | 8 | 8 | 8 | * | 28/31 |
| | 266 | 0 | 8 | 8 | 8 | 8 | * | 29/31 |
| | 274 | 0 | 8 | 8 | 8 | 8 | * | 28/31 |
| | 292 | 0 | 8 | 8 | 2 | 8 | * | 28/31 |
| 180 | 107 | 0 | 8 | 8 | 8 | 5 | * | 23/30 |
| | 116 | 10 | 5 | 8 | 8 | 8 | 5 | 23/30 |
| Kent, | 117 | 0 | 5 | 8 | 8 | 8 | * | 24/30 |
| Michigan | 180 | 10 | 5 | 8 | 8 | 8 | * | 24/30 |
| | 197 | 20 | 5 | 8 | 8 | 5 | * | 23/30 |
| | 198 | 50 | 5 | 8 | 5 | 8 | * | 24/30 |
| | 215 | 40 | 5 | 8 | 8 | 8 | * | 23/30 |
| | 225 | 30 | 5 | 5 | 8 | 5 | * | 24/30 |
| | 233 | 10 | 5 | 8 | 8 | 8 | * | 23/30 |
| | 234 | 10 | 8 | 8 | 8 | 8 | * | 24/30 |
| | 243 | 10 | 5 | 8 | 8 | 8 | * | 24/30 |
| | 269 | 10 | 8 | 8 | 8 | 8 | * | 23/30 |
| | 305 | 0 | 8 | 8 | 8 | 8 | * | 23/30 |
| | 306 | 0 | 8 | 8 | 8 | 8 | * | 24/30 |

| Segment/ location | Acquisition date | ERPS cloud cover assessment, % | EROS quality estimate Channel 1 | 2 | 3 | 4 | 5 | Path/row |
|---|---|---|---|---|---|---|---|---|
| 184 | 104 | 10 | 8 | 5 | 8 | 8 | * | 29/29 |
| | 130 | 10 | 8 | 8 | 8 | 8 | * | 28/29 |
| Goodhue, | 131 | 10 | 8 | 8 | 8 | 8 | * | 29/29 |
| Minnesota | 157 | 10 | 8 | 8 | 8 | 8 | 2 | 28/29 |
| | 220 | 40 | 8 | 8 | 8 | 5 | * | 28/29 |
| | 221 | 10 | 8 | 8 | 8 | 8 | * | 29/29 |
| | 229 | 10 | 5 | 8 | 8 | 8 | * | 28/29 |
| | 247 | 10 | 8 | 8 | 8 | 8 | * | 28/29 |
| | 265 | 10 | 5 | 8 | 8 | 8 | * | 28/29 |
| | 266 | 0 | 5 | 8 | 8 | 8 | * | 29/29 |
| | 274 | 10 | 8 | 8 | 8 | 8 | * | 29/29 |
| 205 | 093 | 20 | 2 | 2 | 2 | 2 | * | 27/32 |
| | 101 | 10 | 8 | 8 | 8 | 8 | * | 26/32 |
| Clark, | 137 | 40 | 5 | 8 | 8 | 8 | * | 26/32 |
| Missouri | 138 | 10 | 8 | 8 | 8 | 8 | 5 | 27/32 |
| | 155 | 10 | 5 | 8 | 8 | 8 | * | 26/32 |
| | 156 | 10 | 5 | 5 | 5 | 8 | 5 | 27/32 |
| | 209 | 50 | 8 | 8 | 8 | 8 | * | 26/32 |
| | 218 | 10 | 8 | 5 | 8 | 8 | * | 26/32 |
| | 219 | 10 | 8 | 8 | 5 | 8 | * | 27/32 |
| | 246 | 10 | 8 | 5 | 8 | 8 | * | 27/32 |
| | 272 | 30 | 5 | 8 | 8 | 8 | * | 26/32 |
| | 282 | | | | | | | |
| | 290 | 10 | 8 | 8 | 8 | 8 | * | 26/32 |
| | 308 | 0 | 8 | 8 | 5 | 8 | * | 26/32 |
| 222 | 080 | 0 | 5 | 8 | 8 | 8 | * | 32/32 |
| Dawson, | 089 | 0 | 8 | 8 | 8 | 8 | * | 32/31 |
| Nebraska | 090 | 10 | 8 | 8 | 8 | 5 | * | 33/31 |
| | 165 | | | | | | | |
| | 171 | 20 | 8 | 8 | 8 | 8 | * | 33/31 |
| | 198 | 30 | 5 | 8 | 8 | 8 | * | 33/31 |
| | 206 | 10 | 8 | 5 | 5 | 8 | * | 32/31 |
| | 207 | 0 | 8 | 8 | 8 | 8 | * | 33/31 |
| | 224 | 10 | 8 | 8 | 8 | 8 | * | 32/31 |
| | 225 | 50 | 8 | 8 | 8 | 8 | * | 33/31 |
| | 234 | 10 | 8 | 8 | 8 | 8 | * | 33/31 |
| | 243 | 0 | 5 | 8 | 5 | 8 | * | 33/31 |
| | 251 | 10 | 5 | 8 | 2 | 8 | * | 32/31 |
| | 252 | 10 | 8 | 5 | 5 | 8 | * | 33/31 |
| | 270 | 0 | 8 | 8 | 8 | 8 | * | 33/31 |
| | 278 | 40 | 8 | 8 | 8 | 8 | * | 32/31 |
| | 288 | 10 | 8 | 8 | 8 | 8 | * | 33/31 |

| Segment/ location | Acquisition date | ERPS cloud cover assessment, % | EROS quality estimate | | | | | Path/row |
|---|---|---|---|---|---|---|---|---|
| | | | Channel | | | | | |
| | | | 1 | 2 | 3 | 4 | 5 | |
| 843 | 088 | 10 | 5 | 5 | 8 | 8 | * | 22/32 |
| | 097 | 0 | 8 | 8 | 8 | 8 | * | 22/32 |
| Henry, | 151 | 10 | 8 | 8 | 8 | 8 | 5 | 22/32 |
| Indiana | 152 | 20 | 8 | 8 | 8 | 8 | * | 23/32 |
| | 160 | 10 | 8 | 8 | 8 | 8 | * | 22/32 |
| | 178 | 10 | 8 | 8 | 8 | 8 | * | 22/32 |
| | 197 | 10 | 8 | 8 | 8 | 8 | * | 23/32 |
| | 232 | 10 | 8 | 8 | 8 | 8 | * | 22/32 |
| | 233 | 10 | 5 | 5 | 8 | 8 | * | 23/32 |
| | 251 | 0 | 8 | 5 | 8 | 8 | * | 23/32 |
| | 268 | 0 | 8 | 8 | 8 | 8 | * | 22/32 |
| | 269 | 0 | 8 | 8 | 8 | 8 | * | 23/32 |
| | 304 | 10 | 8 | 5 | 8 | 8 | * | 22/32 |
| 848 | 089 | 10 | 8 | 8 | 8 | 8 | * | 23/32 |
| Madison, | 097 | 0 | 8 | 8 | 8 | 8 | * | 22/32 |
| Indiana | 107 | 0 | 8 | 8 | 8 | 8 | * | 23/32 |
| | 116 | 0 | 5 | 8 | 8 | 8 | 5 | 23/32 |
| | 152 | 20 | 8 | 8 | 8 | 8 | * | 23/32 |
| | 160 | 10 | 8 | 8 | 8 | 8 | * | 22/32 |
| | 161 | 0 | 8 | 8 | 8 | 8 | * | 23/32 |
| | 179 | 20 | 8 | 8 | 8 | 8 | * | 23/32 |
| | 197 | 10 | 8 | 8 | 8 | 8 | * | 23/32 |
| | 232 | 10 | 8 | 8 | 8 | 8 | * | 22/32 |
| | 233 | 10 | 5 | 5 | 8 | 8 | * | 23/32 |
| | 251 | 0 | 8 | 5 | 8 | 8 | * | 23/32 |
| | 269 | 0 | 8 | 8 | 8 | 8 | * | 23/32 |
| | 305 | 10 | 8 | 8 | 8 | 8 | * | 23/32 |
| 860 | 088 | 10 | 5 | 5 | 8 | 8 | * | 22/32 |
| Wells, | 097 | 0 | 8 | 8 | 8 | 8 | * | 22/32 |
| Indiana | 107 | 0 | 8 | 8 | 8 | 8 | * | 23/32 |
| | 116 | 0 | 5 | 8 | 8 | 8 | 5 | 23/32 |
| | 151 | 10 | 8 | 8 | 8 | 8 | 5 | 22/32 |
| | 152 | 20 | 8 | 8 | 8 | 8 | * | 23/32 |
| | 160 | 10 | 8 | 8 | 8 | 8 | * | 22/32 |
| | 161 | 10 | 8 | 8 | 8 | 8 | * | 23/32 |
| | 178 | 10 | 8 | 8 | 8 | 8 | * | 22/32 |
| | 197 | 10 | 8 | 8 | 8 | 8 | * | 23/32 |
| | 232 | 10 | 8 | 8 | 8 | 8 | * | 22/32 |
| | 233 | 10 | 5 | 5 | 8 | 8 | * | 23/32 |
| | 251 | 0 | 8 | 5 | 8 | 8 | * | 23/32 |
| | 268 | 0 | 8 | 8 | 8 | 8 | * | 22/32 |
| | 269 | 0 | 8 | 8 | 8 | 8 | * | 23/32 |
| | 304 | 10 | 8 | 5 | 8 | 8 | * | 22/32 |

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