132860

INVESTIGATION OF TECHNIQUES FOR CORRECTING ERTS DATA FOR SOLAR AND ATMOSPHERIC EFFECTS

(NASA-CR-132860) INVESTIGATION OF TECHNIQUES FOR CORRECTION ERTS DATA FOR SOLAR AND ATMOSPHERIC EFFECTS Interim Report, Feb - Jul. 1973 (Bendix Corp.) ~~53~~ 54 p HC $4.75 CSCL 05B G3/13

N74-10380

Unclas 21946

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August 1973
Interim Report for Period February 1973 - July 1973

Prepared for

GODDARD SPACE FLIGHT CENTER

Greenbelt, Maryland 20771

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Investigation of Techniques for Correcting ERTS Data for Solar and Atmospheric Effects		5. Report Date September 1973
		6. Performing Organization Code
7. Author(s) Dr. Robert H. Rogers		8. Performing Organization Report No.
9. Performing Organization Name and Address Bendix Aerospace Systems Division 3300 Plymouth Road Ann Arbor, Michigan 48107		10. Work Unit No.
		11. Contract or Grant No. NAS 5-21863
12. Sponsoring Agency Name and Address Goddard Space Flight Center Greenbelt, Maryland, 20771		13. Type of Report and Period Covered Interim February 1973 through July 1973
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Significant findings during this report period are: (1) the feasibility of using techniques for obtaining and using atmospheric parameters to transform ERTS data into absolute target reflectance was demonstrated. (2) Ground-truth instrumentation must have a dynamic range of 1 x 10^5 for obtaining the full set of atmospheric parameters encountered in the field. (3) Atmospheric transmittance for January through May 1973 varied from 13 to 18 percent in the ERTS bands. (4) Energy scattered to the spacecraft from the atmosphere for the March overflight was equivalent to that produced by a target having a reflectance of 11% in Band 4, 5% in Band 5, 3% in Band 6, and 1% in Band 7. (5) This atmospheric radiance varies as a function of Sun zenith angle (scatter angle) and is predicted to change by 30% for sun angles at the latitude of the Michigan test site. (6) If not removed from spacecraft measurements before computing reflectance of surface targets, this radiance is a major source of error. (7) ERTS CCT data, transformed into reflectance and displayed on color-coded TV and gray-scaled computer printouts, show the average deep water areas in inland lakes to have a reflectance of 4% in Band 4, 1% in Band 5, 0.25% in Band 6, and 0.15% in Band 7.

17. Key Words (Selected by Author(s))	18. Distribution Statement		
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*

PREFACE

OBJECTIVE OF THE PROGRAM

The objective of this experiment is to establish a radiometric calibration technique that will permit the absolute reflectance characteristics of ground targets to be determined from ERTS spacecraft data.

The accomplishment of this objective entails the pursuit and accomplishment of intermediate goals that include:

a. Development and evaluation of techniques to determine absolute target reflectance from ERTS data by the measurement and removal of the solar and atmospheric parameters derived from ground-based radiant power measurements.

b. Development and evaluation of techniques to determine absolute reflectance of large natural and man-made targets from ground-based spot sampling.

c. Development and evaluation of computer software, techniques, and procedures for transforming ERTS computer-compatible tapes (CCTs) into a new set of tapes and images which have been corrected for solar and atmospheric effects.

d. Inter-comparison of the capabilities of correcting the ERTS data for solar and atmospheric parameters and effects by candidate radiometric calibration techniques that include (1) transfer calibration, (2) ground-based radiant power measurements, (3) use of spacecraft data alone (little or no auxiliary inputs), and (4) radiation transfer models.

SCOPE OF WORK

The scope of this work is to provide the personnel and equipment necessary to develop radiant power measuring instruments (RPMIs), deploy RPMIs to obtain solar and atmospheric parameters in concert with aircraft and ERTS overflights, and to test and evaluate procedures for using these parameters in transforming ERTC CCTs into a new set of tapes and images corrected for atmosphere. Using the performance achieved by the RPMI technique as a baseline, the scope of the work also includes comparing the effectiveness of alternative techniques in correcting ERTS data for effects of atmosphere that degrade radiometric fidelity of ERTS data.

CONCLUSIONS

The significant results accomplished during this reporting period include:

a. Computer processing of ERTS CCTs and atmospheric parameters established the feasibility of the techniques for obtaining and using atmospheric parameters in transforming spacecraft measurements into absolute target reflectance signatures.

b. The RPMI's wide dynamic range (1×10^5) was found to be essential for field measurements, which varied from 25 mW/cm^2 in Band 7 when viewing direct beam solar irradiance to 0.02 mW/cm^2-Sr when viewing water in Band 7.

c. Solar irradiance outside the atmosphere, when derived from RPMI measurements, was determined to be within 5 percent in Band 4, 1 percent in Bands 5 and 6, and 1.2 percent in Band 7 of the NASA-published data.

d. Atmospheric transmittance was found to vary from 13 to 18% in the ERTS bands during the January through May time period.

e. Energy scattered to the spacecraft from the atmosphere during 27 March was determined to be equivalent to that produced by a target having a reflectance of approximately 11 percent in Band 4, 5 percent in Band 5, 3 percent in Band 3, and 1 percent in Band 7.

f. Analysis of ground-measured data acquired during the January through May time period shows that this atmospheric radiance, which is a function of sun angle (scattering angle), will vary in the order of 30 percent at the ERTS Sun angles existing at Michigan latitudes.

g. This atmospheric parameter was determined to be the largest source of error, if not properly determined and removed from ERTS measurements, when computing the reflectance of surface targets.

h. Reflectance from six inland lakes, derived from ERTS CCTs, show that the deep water areas have an average reflectance of 4 percent in Band 4, 1 percent in Band 5, 0.25 percent in Band 6, and 0.15 percent in Band 7.

i. Direct measurement of the reflectance of the lakes with the RPMI indicates that the average reflectance was 2 percent in Band 4, 1 percent in Band 5, 0.25 percent in Band 6, and 0.04 percent in Band 7. In summary, the ground measurements of reflectance are in close agreement with those derived from ERTS data except for the value obtained from Band 4.

j. Absolute reflectance of target within an ERTS scene was viewed by transforming CCT data to reflectance units and, then, showing specified reflectance levels as a color on a TV display and as a computer symbol on gray-scaled printouts.

RECOMMENDATIONS

On the basis of the work performed to date, the following tasks are recommended:

a. Continue to use the RPMI technique as a basis from which to develop and inter-compare candidate techniques for correcting spacecraft data for atmospheric effects. The additional RPMI field and rooftop measurements are essential to the development of an understanding of the effects of seasonal variations on atmospheric parameters. They are also required to complete development of correlations between measured atmospheric parameters and other environmental factors, i.e., visual range, cloud cover, etc.

b. Continue the analysis of other calibration techniques in order to identify the elements of the most cost-effective calibration procedures. Special emphasis should be given to techniques such as (1) procedures which use little or no concurrent ground-truth measurements, i.e., use historical atmospheric parameters and computer look-up tables to determine parameters which may be a function of time, location, visibility etc., (2) radiation transfer models, such as Dr. R.S. Fraser's model at GSFC, and (3) transfer calibration which uses reflectance determined from ground-based spot sampling of large natural and man-made targets.

c. Undertake a concurrent program to determine the cost-effectiveness of providing atmospheric corrections to a broad range of ERTS data applications, i.e., air and water quality monitoring, detection and monitoring of strip mining operations, land use mapping, crop and soil surveys, etc.

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ILLUSTRATIONS

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1. INTRODUCTION

This report summarizes the results of the second 6 months of activity to establish a radiometric calibration technique that will permit the absolute reflectance characteristics of ground targets to be determined from ERTS spacecraft data.

Previous reports have described the technical details of the Radiant Power Measuring Instrument (RPMI), calibration of the RPMI, and procedures for using the RPMI for obtaining the needed solar and atmospheric parameters. In this report, the emphasis is on the procedures used and the results achieved in processing ERTS computer compatible tapes (CCTs) and atmospheric parameters to obtain the reflectances of test sites.

1.1 BACKGROUND

The need for target reflectance signatures evolves from the needs of individual Principal Investigators, NASA's requirements to correlate results of a large number of investigators, and the pre-conditions of wide-area extrapolations of ground truth data for automatic data processing techniques. Target reflectance data are needed by all-man and machine systems to obtain the unambiguous interpretation of ERTS data. In response to the need for absolute target reflectance signatures, this ERTS-1 Experiment, PR303, is evaluating the capabilities of a wide range of techniques for determining and removing solar and atmospheric parameters and effects from ERTS data. Techniques being evaluated include (1) transferring known ground reflectance to spacecraft measurements, (2) using the ground-based RPMI to measure, directly, the needed solar and atmospheric parameters, (3) using spacecraft data alone (no auxiliary inputs), and (4) using radiation transfer models employing inputs such as surface pressure, ground visibility, temperature, relative humidity, etc.

The approach taken has been to develop and deploy RPMIs to obtain solar and atmospheric parameters in concert with ERTS overflights and to evaluate the procedures for using these parameters to transform ERTS CCTs into absolute target reflectance signatures. The capability of the RPMI and procedures for obtaining and using the atmospheric parameters are being determined by comparing reflectance computed from ERTS data with known values obtained from ground truth measurements. Reflectance of the truth sites; located near Ann Arbor, Michigan; are established by ground-based spot sampling with the hand-held RPMI.

Using the performance achieved by the RPMI technique as a basis, the effectiveness of the alternative calibration techniques (radiation transfer models, etc.) to correct ERTS data for effects of atmosphere are being compared and determined.

Results of this experiment include a knowledge of the accuracy achievable by the various calibration techniques, specifications for RPMIs optimized for ERTS that permit direct measurement of atmospheric parameters and truth site reflectance, and computer techniques for transforming ERTS CCTs into a new set of tapes and images, corrected for atmospheric effects.

1.2 ATMOSPHERIC PROBLEM

The reflectivity, ρ, of a diffusely reflecting target, is given by

$$\rho = \frac{L_T \pi}{H} , \qquad (1)$$

in which L_T is the radiance and H is the total (global) irradiance at the target surface. When radiance is measured at a remote distance, the detected value, L, has two components; a target value $L_T \tau$, where τ is the atmospheric transmission from target to sensor, and a component caused by the atmospheric radiance, L_A. The desired target reflectance in terms of the remote radiance measurement, L, is then

$$\rho = \frac{L - L_A}{\tau} \cdot \frac{\pi}{H} . \qquad (2)$$

The target irradiance, H, also has two components; one caused by the direct sun, denoted $H_{sun} \cos Z$ (in which H_{sun} is the irradiance on a surface normal to the sun's rays and Z is the solar zenith angle) and a component caused by the sky, denoted H_{sky}. Expanding H of Equation 2 in terms of the direct sun and sky components result in

$$\rho = \frac{(L - L_A) \cdot \pi}{\tau (H_{sun} \cos Z + H_{sky})} . \qquad (3)$$

For a remote sensing system looking vertically downward, τ is the atmospheric transmission of one air mass. If m is the number of air masses referenced to the zenith air mass (for which m = 1), the atmospheric transmission through some other value of m is given by τ^m. The direct sun component of target irradiance, H_{sun} in Equation 3, can be subdivided as

$$H_{sun} = H_o \tau^m , \qquad (4)$$

in terms of the solar irradiance normal to the sun's rays outside the atmosphere, H_o. Combining Equations 3 and 4, the desired target reflectance, ρ, in terms of ERTS radiance, L, measurements is

$$\rho = \frac{(L - L_A) \cdot \pi}{\tau (H_o \tau^m \cos Z + H_{sky})} , \tag{5}$$

where L_A, τ, H_o, m, cos Z, and H_{sky} are the solar and atmospheric parameters that must be known to accurately compute target reflectance.

In computer processing of ERTS CCTs, the parameters L, H_o, m, and Z of Equation 5 are easily and quickly determined. Target counts, c_i, are recorded on ERTS CCTs and, when the tape data has been decompressed and radiometrically corrected (which it normally is), the counts are easily transformed to the desired target radiance, L of Equation 5, by

$$L_i = c_i K_i \text{ mw/cm}^2 \text{ - Sr} , \tag{6}$$

where i indicates MSS band number and constants K_i are determined as described on Page G-14 of the ERTS Data User Handbook. The constants K_i are equal to:

$$K_4 = \frac{2.48}{127} , \quad K_5 = \frac{2.00}{127} , \quad K_6 = \frac{1.76}{127} , \quad \text{and} \quad K_7 = \frac{4.6}{64} ,$$

where the numerators are the maximum specified radiance (in mW/cm^2 -Sr) as given in Table G.2-2 of the handbook and the denominators specify the corresponding maximum counts in each band.

The sun zenith angle, Z, is computed from $Z = 90 - \theta_E$, in which the sun elevation angle, θ_E, is also extracted from the ERTS CCT. For sun zenith angles less than 60 degrees, the air mass, m of Equation 5, is given to an accuracy better than 0.25 percent by m = sec Z. For larger sun angles, a more accurate value is given by Bemporad's formula

$$m = \sec Z - 0.001867 (\sec Z - 1) - 0.002875 (\sec Z - 1)^2 - 0.0008083 (\sec Z - 1)^3 . \tag{7}$$

The solar irradiance, H_o, outside the Earth's atmosphere is well known and can be determined from the published data (Thekaekara, 1971) or derived from RPMI measurements by the procedure described in Section 2.1.2. Values obtained from RPMI and Dr. Thekaekara's data for a mean Earth-Sun distance of 1 astronomical unit (AU), equal to 1.496×10^{13} cm, follow in Table 1.

Table 1. Solar Irradiance, H_o, (1 AU)

MSS Band	RPMI (mW/cm^2-Sr)	Thekaekara (mW/cm^2-Sr)
4	18.65	17.7
5	15.11	15.15
6	12.33	12.37
7	25.17	24.88

The solar irradiance specified in the table will vary with changes in Earth-Sun distance by less than six percent over a 12-month period. If desired, the values specified (for 1 AU) can be corrected for the precise Earth-Sun distance at the time of ERTS overflight by factors also given in Dr. Thekaekara's report.

If accurate spectral reflectance of the surface targets are to be derived, the remaining solar and atmospheric parameters needed for Equation 5, namely L_A, τ, and H_{sky}, depend on the specific atmosphere within the scene and must be determined for the specific atmosphere existing at the time of ERTS overflight.

2. RESULTS AND DISCUSSION

To facilitate comparison between the four major intermediate goals of this program, listed in the preface of this report, and the work performed, the discussions in each of Sections 2.1 through 2.4 correspond, in order, with each of the four goals.

2.1 GOAL 1, DETERMINING ATMOSPHERIC PARAMETERS FROM GROUND-BASED RADIANT POWER MEASUREMENTS

2.1.1 RADIANT POWER MEASURING INSTRUMENT

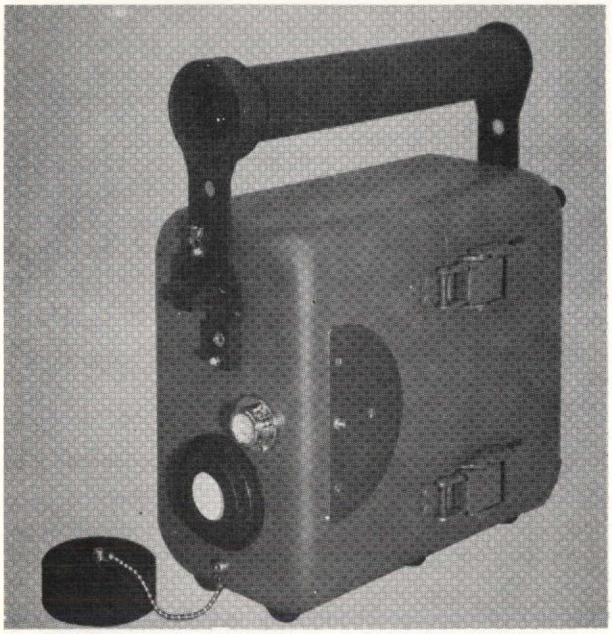
The Radiant Power Measuring Instrument (RPMI) shown in Figure 1 was developed specifically for this investigation to obtain the complete set of solar and atmospheric measurements needed to determine target reflectance from the ERTS radiance data. The design and fabrication of one engineering model and four prototype models was completed in January of 1973. A new technology report was also submitted at that time. The RPMI and its characteristics have been well documented in previous reports so only a brief summary is included here.

The RPMI is a rugged, hand-carried, portable instrument calibrated to measure both down-welling and reflected radiation within each ERTS MSS band. A foldover handle permits a quick change from wide-angle global or sky irradiance measurements to narrow angle (7.0° circular) radiance measurements from sky and ground targets.

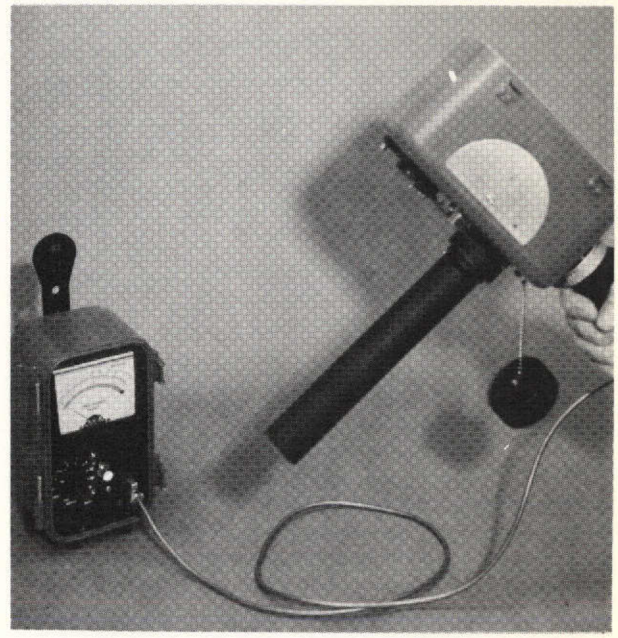
The RPMI's wide dynamic range (1 to 10^6) was tailored to permit measurements to be made over the full range of solar and atmospheric parameters encountered by ERTS investigators. These extremes have been found to include direct beam solar irradiance up to 25 mw/cm^2 in Band 7, sky radiance as low as 0.077 mw/cm^2-Sr in Band 6, and radiance reflected from water surfaces in Bands 6 and 7 as low as 0.02 mw/cm^2-Sr. The RPMI measurements are traceable to a National Bureau of Standards source to an accuracy of 5 percent absolute and 2 percent relative from band to band. The RPMI calibration is also checked, from time to time, against the NASA Goddard calibration source to ensure uniformity between RPMI and ERTS MSS measurements.

2.1.2 ATMOSPHERIC PARAMETERS FROM RPMI TECHNIQUE

To develop an understanding of the magnitude of the solar and atmospheric parameters that degrade the radiometric fidelity of ERTS data, a measurement program was established to perform field measurements with an RPMI on every suitable ERTS overpass. The initial measurement procedures developed from



RPMI assembled



Reflected Radiation — Used with small calibration panels and cards, to obtain direct measurement of truth site reflectance. Reflectance also immediately derived from ratio of reflected radiance and global irradiance.

Global Irradiance (H) — 2π steradian field of view for measuring downwelling (incident) radiation ERTS MSS bands. Bubble level aids this measurement.

Sky Irradiance (H_{SKY}) — Block sun to measure global irradiance minus direct sun component, in every ERTS MSS band. Angle from zenith to sun is also measured in this mode by reading sun's shadow cast on sun dial.

Radiance from Narrow Solid Angles of Sky — Handle serving as field stop permits direct measurements through a 7.0° circular field of view. This mode is also used to measure direct beam irradiance.

Figure 1. Radiant Power Measuring Instrument

this experience were reported at the NASA symposium on significant results, held in March of 1973 (See NASA SP-327, Volume I). This report expands upon these earlier findings.

The RPMI is deployed in concert with ERTS overflights as shown in Figure 1 to obtain the direct measurements, within the four ERTS MSS bands, of (1) global irradiance, H, (2) sky irradiance, H_{sky} (i.e., by shadowing sun and reading global minus direct beam-solar), (3) radiance from a narrow solid angle of sky L_{MEAS} (ϕ), and (4) direct beam solar irradiance, $H_{sun}(m)$. From these measurements, additional solar and atmospheric parameters, such as beam transmittance, τ; path radiance, L_A; and direct beam solar irradiance above the atmosphere, H_o, are determined. With these parameters, Equation 5 may be applied to transform the ERTS radiance measurements, L, into absolute target reflectance units. A summary of the techniques being evaluated for obtaining the needed atmospheric parameters with an RPMI follows.

2.1.2.1 Global Irradiance

Global irradiance, H, is measured directly in each ERTS MSS band as shown in Figure 1. Additional accuracy in H can be obtained by measuring the direct beam solar irradiation, $H_{sun}(m)$, and sky irradiance, H_{sky} (direct Sun shadowed out), and then computing the total target irradiance, using

$$H = H_{sun}(m) \cos Z + H_{sky} \quad . \tag{8}$$

The sun angle, Z, may be read from the sun dial on the side of the RPMI after leveling the instrument with its bubble level.

2.1.2.2 Direct Beam Solar Irradiance

Direct beam solar irradiance, H_{sun}, is measured by pointing the instrument directly at the Sun with the telescope in place and recording the irradiance at each wavelength.

2.1.2.3 Beam Transmittance

Beam transmittance, τ, per unit air mass is determined directly from

$$\tau = \left(\frac{H_{sun}}{H_o} \right)^{\frac{1}{m}} \tag{9}$$

when the solar irradiance outside the atmosphere, H_o, is known. The air mass is calculated from the solar zenith angle, using Equation 7.

2.1.2.4 Beam Transmittance and Solar Irradiance Outside the Atmosphere

Beam transmittance, τ, and solar irradiance outside the atmosphere, H_o, can be determined by making a series of H_{sun} measurements and then plotting an "extinction" curve as shown in Figure 2. For this case, H_{sun} is plotted on a logarithmic scale as a function of air mass. The intercepts of the lines with the vertical axis (i.e., at m = 0) gives H_o in each ERTS MSS band. The beam transmittance per unit air mass, τ, is then computed from either Equation 9 or from

$$\tau = \left(\frac{H_{sun}(m_1)}{H_{sun}(m_2)} \right)^{\frac{1}{m_1 - m_2}}, \tag{10}$$

where

$H_{sun}(m_1)$ = direct beam solar irradiance at air mass m_1.

$H_{sun}(m_2)$ = direct beam solar irradiance at another air mass, m_2.

It can be shown that the slope of the extinction curve is log τ, and Equation 10 follows directly.

The value of H_o (i.e., H_{sun} at m = 0), once determined for each RPMI band, may be used to test and/or recalibrate the RPMI, using the Sun as a source, at any location in the world.

Results of field measurements for January through May of 1973 are recorded in Table 2. The results show that the beam transmittance (per unit air mass) varies from 13 to 19 percent.

Table 2. Beam Transmittance per Unit Air Mass

MSS Band	Measured Transmittance Range
4	0.697 to 0.856
5	0.770 to 0.902
6	0.812 to 0.940
7	0.843 to 0.975

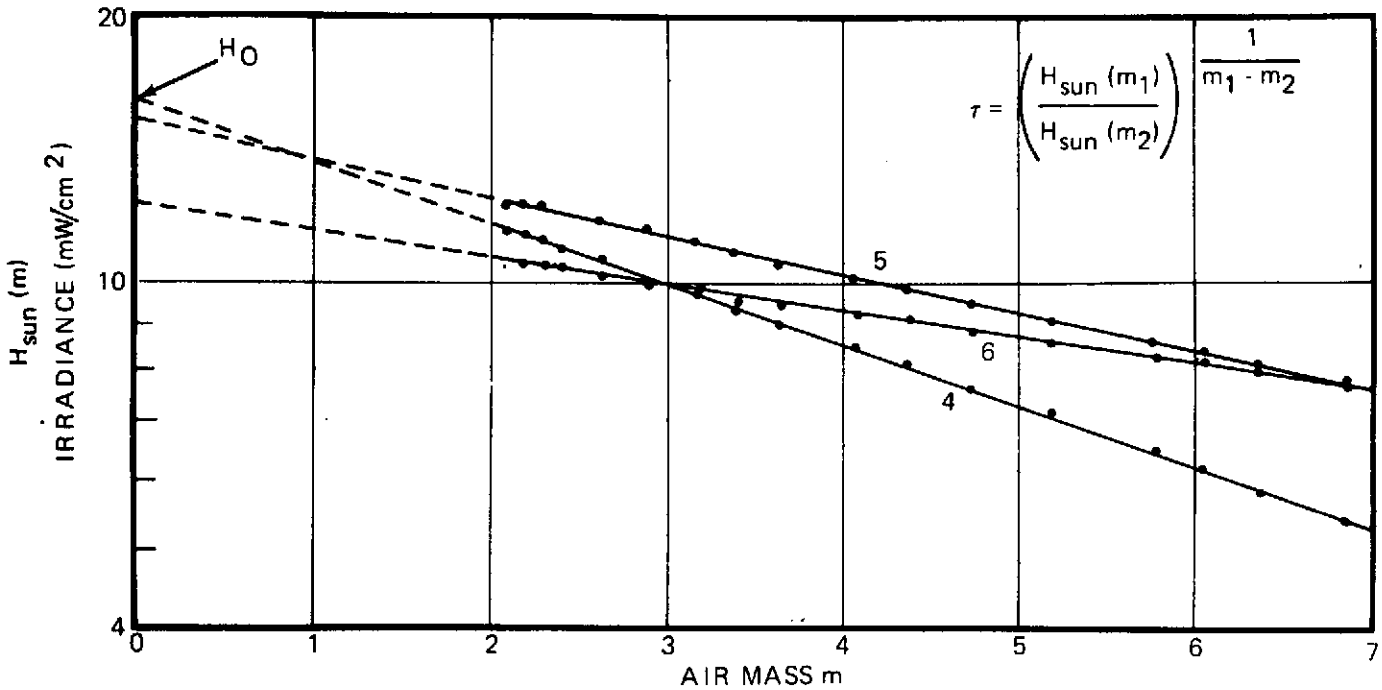


Figure 2. Atmospheric Extinction Curves

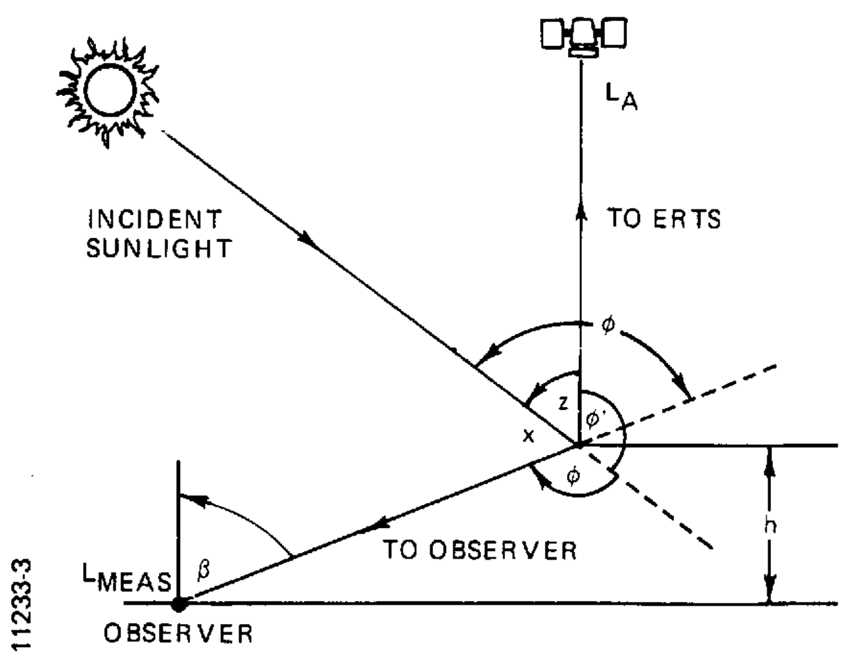


Figure 3. Sky Radiance Measurements

2.1.2.5 Sky Irradiance

Sky irradiance, H_{sky}, is measured by leveling the RPMI with the built-in bubble level so that the diffuser is horizontal with the target surface and can receive irradiation from 2π steradians. H_{sky} is the irradiance recorded when the direct beam Sun is shadowed out using an opaque object.

2.1.2.6 Path Radiance

Path radiance, L_A, is the energy reaching the spacecraft from Rayleigh and aerosol scattering by the atmosphere. As path radiance cannot be measured directly, it must be derived from ground-based sky radiance measurements of the backscatter. The simplest technique is to use the RPMI to measure the sky radiance, $L_{MEAS}(\phi)$, scattered at angle ϕ, as shown in Figure 3, such that ϕ is identical to ϕ', the angle through which radiation is scattered to the spacecraft, and then to correct this measurement for the difference in air masses between the direction of observation and the direction of the spacecraft. This technique provides a straightforward measurement procedure when $Z > 45$ degrees. If $Z < 45$ degrees, atmospheric modeling is necessary to extrapolate from the available measurement angles to the desired scattering angle. When L_{MEAS} is recorded at an angle equal to the scattering angle to the ERTS, the path radiance, L_A, seen by ERTS is

$$L_A = L_{MEAS}\left(\frac{1 - \tau}{1 - \tau^{m_o}}\right), \qquad (11)$$

in which m_o is the air mass in the direction of observation (in this case $m_o = \frac{1}{\cos\beta}$) and τ, as previously defined, is the atmospheric transmission per unit air mass. The validity of this formula has been demonstrated by Peacock and Rogers (1973) and discussed by Duntley, Gordon, and Harris (1973). Equation 11 is adequate when the atmospheric measurements are made concurrent with the ERTS overflight (i.e., at a sun angle close to the one at the time of the ERTS flyover).

A correction factor, T_{ERTS}/T_Z, must be applied to Equation 11 to derive the path radiance, L_A, viewed by the spacecraft if the time between the ERTS overpass of the test site and the sky radiance observations is significant. An approach for determining this correction factor is also shown in Figure 3.

Sunlight entering the atmosphere at an angle Z, as shown in Figure 3, is scattered at altitude h into the direction of the observer at point 0. The energy available for scattering depends on the atmospheric extinction coefficient, $\tau_{\infty}h$, measured from outside the atmosphere to altitude h. The attenuation is given by $\exp(-\tau_{\infty}h \cdot m)$. The energy scattered is a function of the scattering coefficient, α_h, at altitude h. Thus, the energy scattered in the direction of the observer from altitude h is proportional to

$$\exp(-\tau_{h\infty} \cdot m) \cdot \alpha_h . \qquad (12)$$

The average attenuation, for all altitudes, suffered by the energy in passing from the sun to point x is given by

$$T = \frac{\sum_N \exp(-\tau_{h\infty} \cdot m) \cdot \alpha_h}{N \sum_N \alpha_h} , \qquad (13)$$

in which N defines each atmospheric altitude used in the summation. Use of the value α_h in the equation expresses the importance of h in contributing energy at the observer location point, 0. A normalizing factor is included in the denominator. Values of $\tau_{h\infty}$ and α_h have been tabulated (Valley, 1965). To adjust $\tau_{\infty h}$ from a standard atmosphere to the actual atmospheric conditions at the observer's location, $\tau_{\infty h}$ is multiplied by $\exp(-\tau_{\infty o})/\tau$, in which τ is the measured atmospheric transmission and $\tau_{\infty o}$ is the extinction coefficient for a beam traversing one atmospheric air mass of a standard atmosphere. This is also given by Valley (1965). Variations in T are small, so the error in using a corrected standard rather than a real atmosphere is small.

Thus, a complete formula which gives the sky radiance, L_A, at the time of the ERTS overpass from L_{MEAS} made at another solar zenith angle and air mass is

$$L_A = L_{MEAS}(\phi) \left[\frac{1 - \tau}{1 - \tau^{m_o}} \right] \frac{T_{ERTS}}{T_Z} , \qquad (14)$$

in which ϕ, the scattering angle to the observer, equals the scattering angle to ERTS, and T_{ERTS} and T_Z are given by Equation 13 for the zenith angles at the time of the ERTS passage and the time of the L_{MEAS} readings.

The validity of this equation is demonstrated in Figures 4 and 5. Figure 4 shows ground-based sky radiance measurements as a function of the scattering angle for a range of solar air masses. Each of the curves was obtained by pointing the RPMI at the Sun and then sweeping the RPMI in azimuth and in elevation, taking sky radiance readings at 10-degree intervals. Alongside each curve, the solar air mass at the time of the observations is given. The curve defined by the open squares, which falls steeply, is for a range of solar air masses, and was produced by recording the zenith sky radiance over a period of several hours. Application of Equation 14 to these data in Figure 4, assuming $T_{ERTS} = 1$, gives the results shown in Figure 5. Except for about ± 5 percent of scatter, all the points now

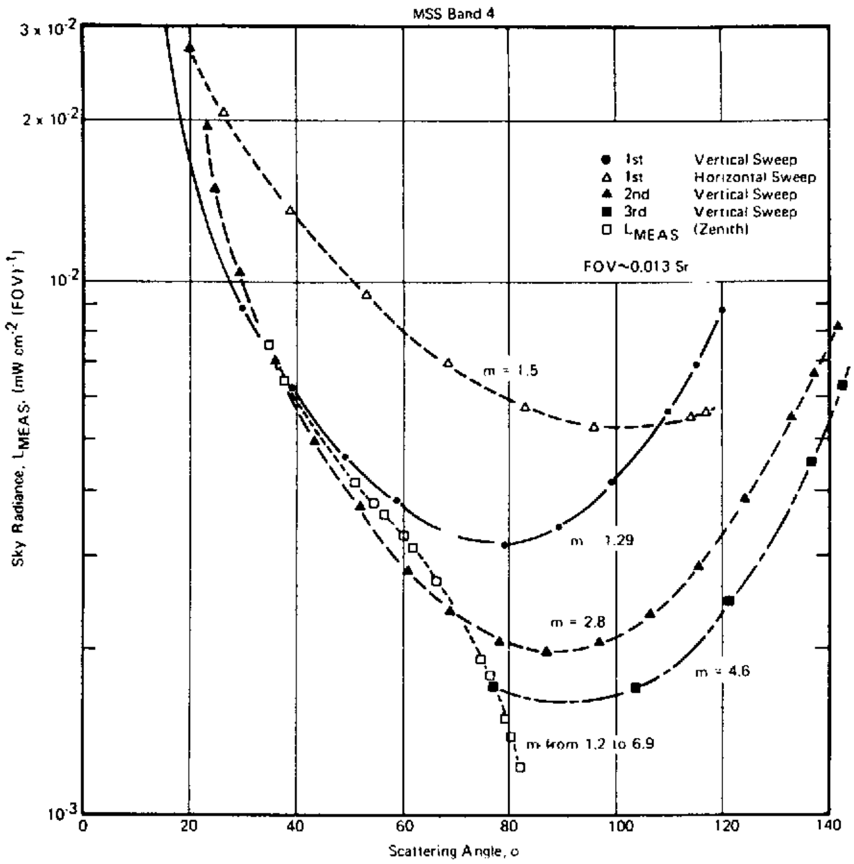


Figure 4. RPMI Sky Radiance Measurements

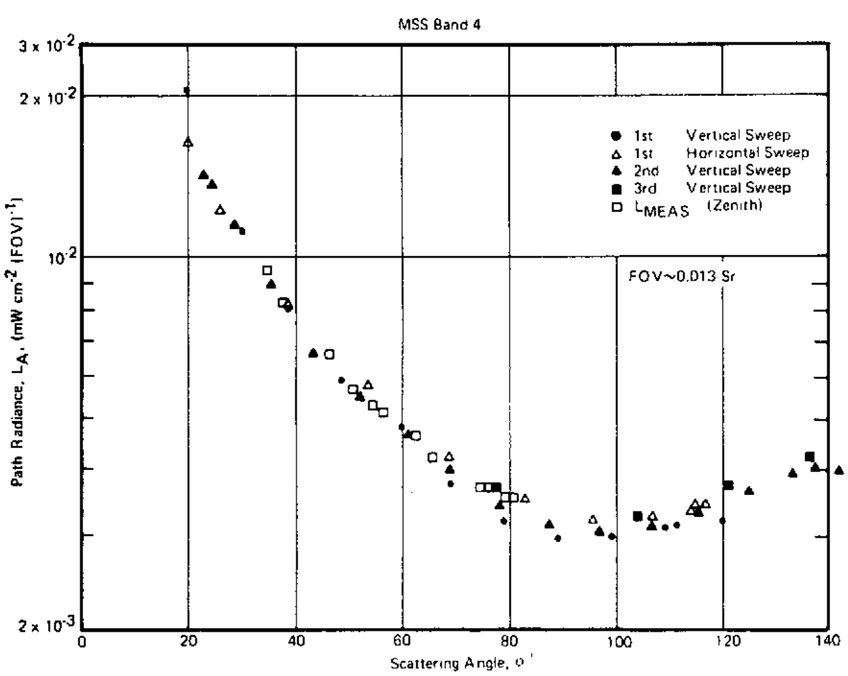


Figure 5. Path Radiance Viewed by ERTS Band 4

follow the same line. By selecting L_A from the curve at the scattering angle which exists at the time of ERTS overflight, and multiplying this value by T_{ERTS}, the desired value of L_A at the time of the ERTS overflight is determined.

Analysis of plots, such as the one shown in Figure 5 for the January through May time-period, show that, for scattering angles (110 to 150°) expected at the Michigan test site latitudes, path radiance can be anticipated to vary from about 25 to 30 percent.

These observations are continuing in order to establish the repeatability and the accuracy of the derived L_A when measurements at only one or two angles are used.

2.2 GOAL 2, DETERMINING TARGET REFLECTANCE BY GROUND-BASED SPOT SAMPLING TECHNIQUE

Techniques for determining absolute reflectance of large natural and man-made targets from ground-based spot sampling have been developed. One technique is to measure radiance from the target and to ratio this measurement within direct sun and sky irradiance measurements. The other technique, transfer calibration, makes use of panels of known reflectance.

2.2.1 USING SOLAR AND ATMOSPHERIC PARAMETERS

Section 2.1 describes the procedures for determining the solar and atmospheric parameters needed to transform, by Equation 5, ERTS radiance measurements, L, into reflectance units. This same procedure is also applicable to transforming target radiance measured by aircraft or from ground sensors into absolute target reflectance.

When determining reflectance from ground-based radiance measurements, L_T, it is usually sufficient, because of the short path length between the target and sensor, to assume that the atmospheric attenuation is unity ($\tau = 1$) and that the backscatter from the atmosphere is zero ($L_A = 0$). In this case, Equation 5 reduces to

$$\rho = \frac{\pi L}{H_{sun} \cos Z + H_{sky}} \qquad (15)$$

where:

L = RPMI radiance measurement (W/m^2 - Sr) made by aiming the RPMI telescope at the target.

H_{sun} = direct sun irradiance (W/m^2) made by aiming the RPMI telescope directly at the sun (this is also $H_o \tau^m$).

Z = sun angle in degrees, measured from the zenith.

H_{sky} = sky irradiance (W/m^2) made with the telescope off and the RPMI level and viewing the total sky with the direct sun blocked out.

Details for implementing this procedure with the prototype RPMI units are discussed in Appendix A.

2.2.2 APPLYING TRANSFER CALIBRATION

If the procedure described in Section 2.2.1 is used to establish the reflectance of test panels in each ERTS band, the calibrated test panels can, in turn, be used as points of reference to determine, by "transfer calibration", the reflectance of unknown surfaces. Since the RPMI provides an output that is linear with target reflectance, the procedure is, simply, to aim the RPMI at the calibration panel(s), note the meter indication, aim the RPMI at the target of unknown reflectance, and again note the meter indication. A straight-line extrapolation transforms the meter indication obtained from the unknown target to a reflectance value.

For example, Figure 6 is a plot of the RPMI meter indication versus the reflectance of four cardboard panels, denoted A, B, C, and D. The absolute reflectance of the panels was determined for each of the ERTS bands as described in Section 2.2.1. The panels have a matte finish and are approximately these colors:

- Panel A - medium brown.
- Panel B - white.
- Panel C - black.
- Panel D - medium green.

The relationship of RPMI indications to percent reflectance in each band is noted to be a linear function. The reflectance calibrations of these panels are checked periodically by the procedure described in Section 2.2.1 to test for any change in reflectance that might be caused by fading or other pigment changes.

On 13 July 1973, the reflectance of Forest Lake water was estimated from a boat using this method, as illustrated in Figure 7. RPMI readings were made with the instrument held one meter above each panel. Immediately afterward, readings were taken with the instrument held one meter above the lake surface and just below the surface. The resulting reflectance values are shown in Table 3.

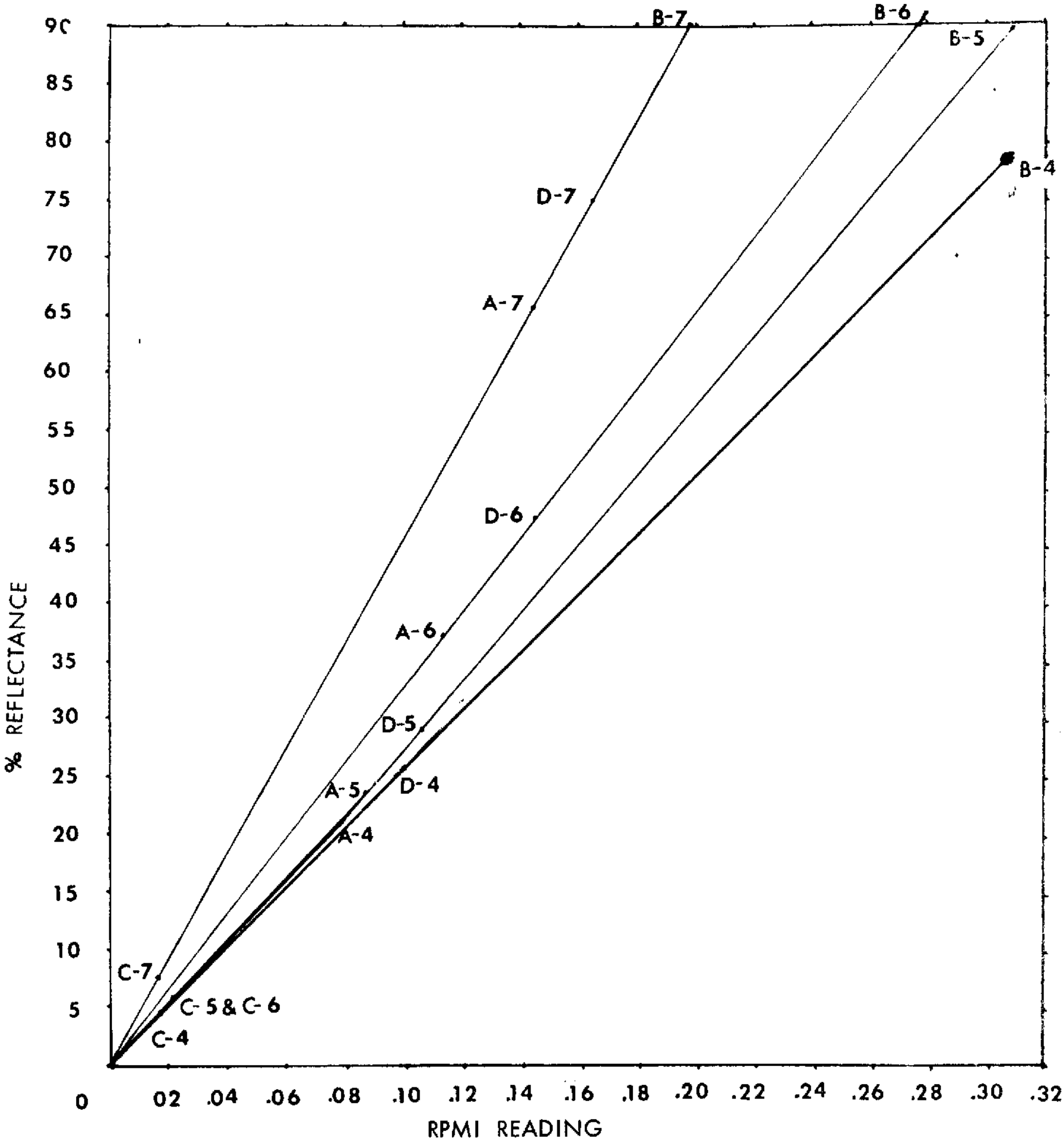


Figure 6. Percent Reflectance versus RPMI Indications for Reflectance Panels A through D

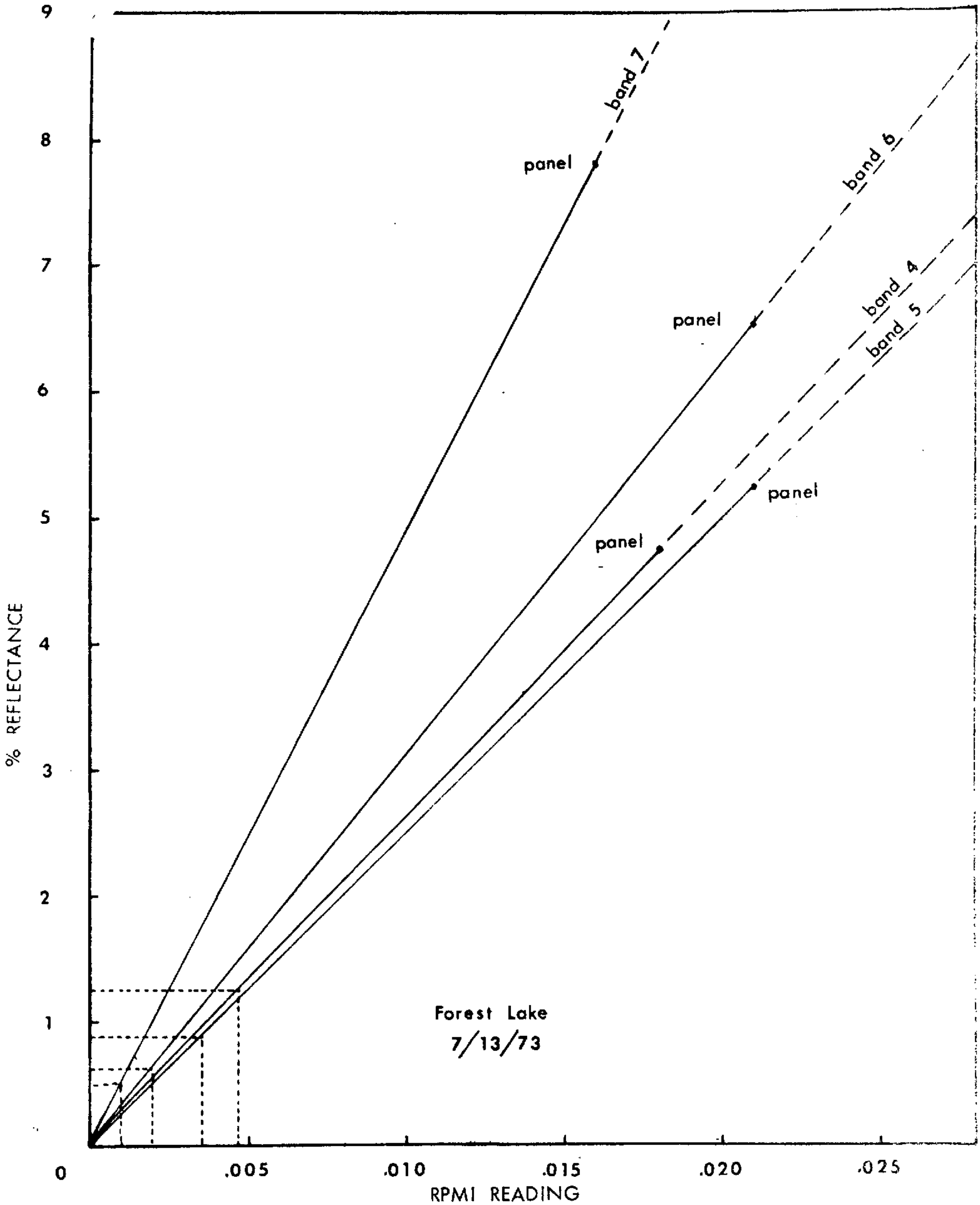


Figure 7. Transfer Calibration Method of Determining Unknown Reflectance of Water Based on Reflectance of Reference Panels

Table 3. Percent Reflectance of Forest Lake Water on 13 July 1972

RPMI Position	ERTS Spectral Band				Band Ratios	
	4	5	6	7	4 to 5	4 to 6
Above Water	1.225	0.850	0.575	0.425	1.44	2.13
Below Water	0.730	0.485	0.210	0.075	1.51	3.48

Notably, readings taken above water are greater than those taken below water because of some specular reflectance from surface wavelets. However, as expected, the band ratio (Band 4 to Band 5) of upwelling light is smaller above water because of a selective loss of shorter wavelengths reflected back downward from the undersurface (Hutchinson, 1957). Of these, the above-water measurements should be more like those recorded by ERTS.

2.3 GOAL 3, DEVELOPING PROCESSING TECHNIQUES TO CORRECT ERTS CCT FOR ATMOSPHERIC EFFECTS

Computer software, techniques, and procedures for transforming ERTS CCTs into data and images corrected for atmosphere are being developed in the Bendix Earth Resources Data Center (ERDC) pictured in Figure 8. The nucleus of this center is a Digital Equipment Corporation PDP-11/15 computer with 32 K words of core memory, two 1.5 M-word disc packs, two 9-track 800 bpi tape transports, a line printer, a card reader, and a teletype unit. Other units are an Ampex FR-2000 14-track tape recorder; a bit synchronizer and tape deskew drawers which can reproduce up to 13 tape channels of multispectral data from high density tape recordings; a high-speed hard-wired special-purpose computer for processing multispectral data; a 70-mm laser film recorder for recording imagery on film; and a color moving-window computer-refreshed display.

Computer software and techniques for handling ERTS CCTs have been developed to perform functions that include:

a. Reading and printing out housekeeping data. Data of specific interest includes scene number, tape number, whether data is compressed or decompressed, date, latitude and longitude of scene center point, sun elevation angle, and whether data is radiometrically correct.

b. Transforming ERTS data into reflectance of surface targets. This process includes reading atmospheric parameters τ, H_o, H_{sky}, and L_A, as defined by Equation 5, from punched cards. Sun zenith angle, Z, and air mass, m, are computed from the sun elevation angle on tape. Target counts on tape are transformed into radiance (as specified in Section 1.2) and into target reflectance by Equation 5.

c. Displaying color-coded TV images of target reflectance. After computing target reflectance as indicated in b above, the reflectance level is assigned one of 16 colors on the TV monitor. The reflectance range of interest and color combination is easily changed to optimize viewing of the desired target characteristics. This is a very fast procedure, and permits viewing of a complete ERTS tape in several minutes.

d. Producing reflectance gray scale printouts. Similar to c above, except reflectance is assigned to one of 12 computer symbols.

e. Generating statistical edit. The TV monitor or gray scale printout is used to locate coordinates (by resolution element number and scan line number) of the areas of specific interest, such as deep water areas in lakes, etc. These coordinates, input to the computer on punched cards, specify areas on the ERTS tape which are used to compute on a per band basis; average target count, standard deviation, average radiance, and average reflectance.

Examples of these processing techniques and others follow in Section 2.4.

2.4 GOAL 4, EVALUATING CANDIDATE CALIBRATION TECHNIQUES

Different approaches for computing target reflectance from ERTS data are being investigated in the ERDC. Some of these are summarized in the block diagram of Figure 9. The approach illustrated in the figure that leads to the most accurate transformation of ERTS data to reflectance is the application of Equation 5 and the full set of solar and atmospheric parameters, L_A, H_o, τ, and H_{sky}, as defined in Section 1.2.

Another approach, also illustrated in Figure 9, operates on the assumption that RPMI measurements concurrent with the spacecraft overflight are unavailable. In this case, the objective is to make best use of atmospheric parameters determined from previous RPMI missions; i.e., historic values which have been stored in the computer data base. The accuracy of computational strategies, such as assuming that some of the atmospheric parameters can be neglected (i.e., $L_A = 0$), assuming that some are the same as those derived from a standard atmosphere, etc. are also being explored.

Figure 6. Earth Resources Data Center

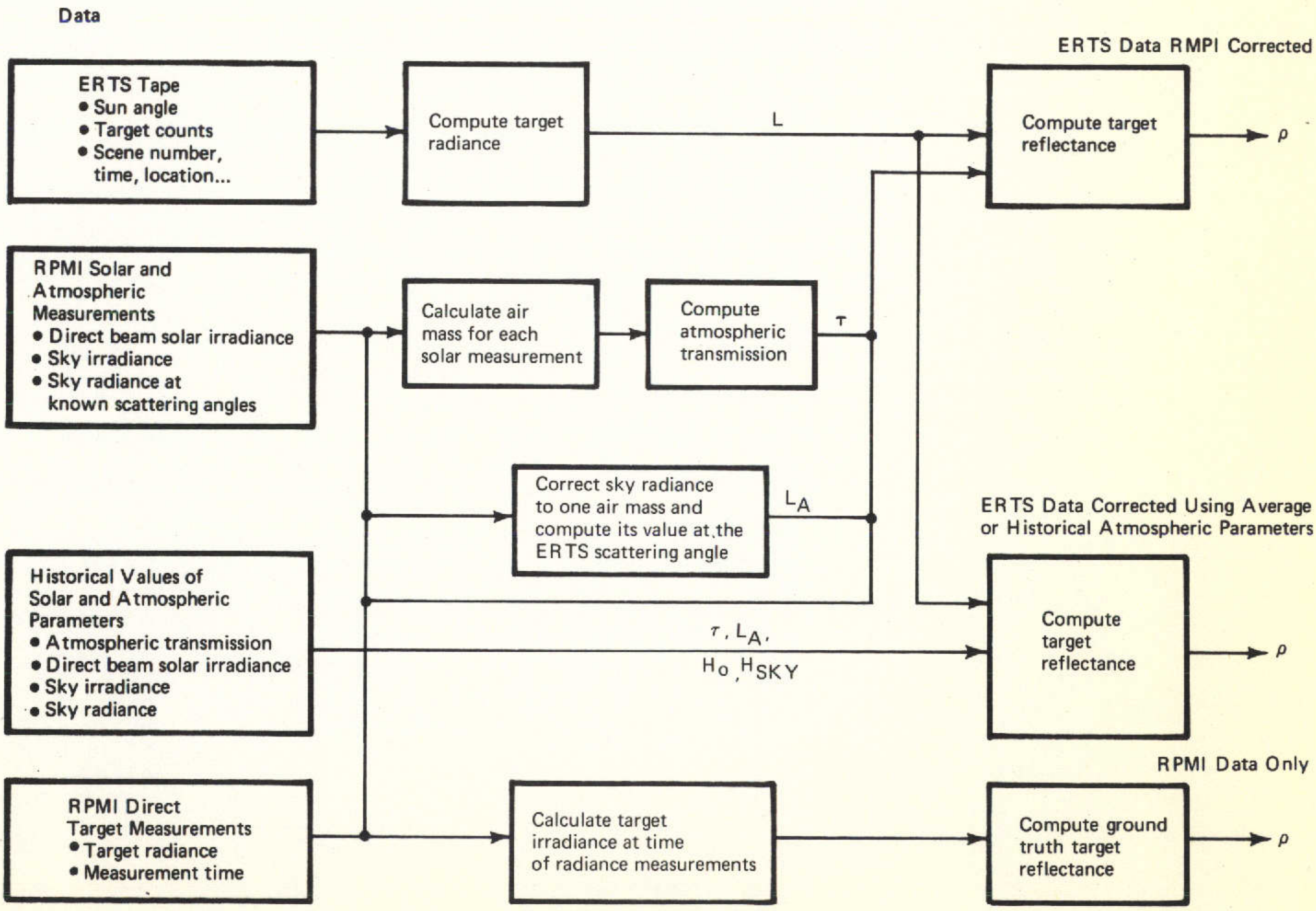


Figure 9. Machine Processing of ERTS and RPMI Data

The accuracy of each approach is being carefully determined by comparing reflectance generated from ERTS tapes to reflectance of ground truth targets whose reflectance is measured directly with the RPMI. This step is also shown in Figure 9.

These approaches to computer processing of ERTS CCTs are illustrated below, using ERTS data acquired on 27 March, 14 April, and 21 May over Lake Huron and four small lakes, Orchard, Lower Long, Forest, and Island, located in Oakland County, Michigan. The locations of the lakes are shown in Figure 10. Personnel from Bendix, Cranbrook Institute, and Oakland University deployed (1) RPMIs to measure atmospheric parameters and spot reflectance of the lakes, (2) a Secchi Disk to determine the depth of light penetration into the water, and (3) Forel-Ule instrumentation to determine water color. The NASA C-130 aircraft provided photographic and scanner coverage of the lakes and panels of known reflectance that were deployed at Willow Run Airport.

One of the first data reduction steps is to transform RPMI measurements into a complete set (H_o, τ, H_{sky}, and L_A) of solar and atmospheric parameters. These parameters, derived from RPMI measurements by the procedures described in Section 2. 1. 2, are recorded in Table 4.

Table 4. Atmospheric Parameters on 27 March 1973

Parameter	Band Number			
	4	5	6	7
Solar Irradiance outside Atmosphere, H_o (mW/cm^2)	18.62	15.2	12.55	25.58
Beam Transmittance, τ	0.752	0.824	0.852	0.877
Sky Irradiance, H_{sky} (mW/cm^2)	1.9	1.25	0.9	1.46
Path Radiance, L_A (mW/cm^2 - Sr)	0.268	0.127	0.081	0.103
Sun Zenith Angle, Z	48.0°			

Scale 1:48,000

Figure 10. Test Lakes

Two methods of utilizing the atmospheric parameters to produce ERTS images corrected for atmospheric effects have been evaluated. Both methods utilize Equation 5 to first transform ERTS data to absolute target reflectance, thereby removing the solar and atmospheric parameters in the process. For one method, the reflectance level is used to produce a color-coded image in which the color designates a specific reflectance level. For the other method, the reflectance level is used to produce a "gray-scaled" computer printout in which a symbol designates a specified reflectance range.

Figure 11 shows the color-coded TV display of reflectance patterns in Orchard and Cass Lakes in ERTS channels 4, 5, and 7. Orchard Lake is approximately three miles on a side, and the scene shown is approximately five miles on a side. Interferences caused by a "banding effect" are apparent as horizontal lines, particularly in Bands 5 and 7. A gray-scaled reflectance printout of Band 4 of Orchard Lake is shown in Figure 12 for comparison with an aerial photograph taken on the same date. Figure 13 shows Orchard Lake in the aerial photograph, on TV display, and in a gray-scaled printout.

Within the gray-scale printouts of Orchard Lake, shown in Figures 12 and 13, six discrete levels of reflectance can be observed in Band 4. Over the six test lakes, up to seven levels were observed in this same band. The distribution of computer symbols indicating a reflectance ranging from 3.1 to 5.5 percent corresponds, generally, with the known deep-water areas. Shallow waters in this same band (bottom visible in the aerial photograph) correspond to a reflectance distribution in the order of 5.5 to 8.7 percent. The progressively more reflective areas within that range compare fairly well with shallower and shallower water. Reflectance levels from 8.7 percent upward correspond to land.

To obtain statistical information (i.e., average counts, average radiance, average reflectance, standard deviations, etc.) on specific target areas, such as the deep water in Orchard Lake, the gray-scale print-out is used as a map to establish the coordinates of the target, using scan-line count and resolution element numbers. These coordinates, input to the computer, define data areas (edits) where the desired statistical computations are performed. The deep water areas denoted by the dashed boxes in Figure 14 were chosen to demonstrate this process. To obtain the average reflectance of each specified area of interest, the solar and atmospheric parameters, as defined by Equation 5, are also, of course, a necessary input to the computer. The computation steps for each specified area and each ERTS band include:

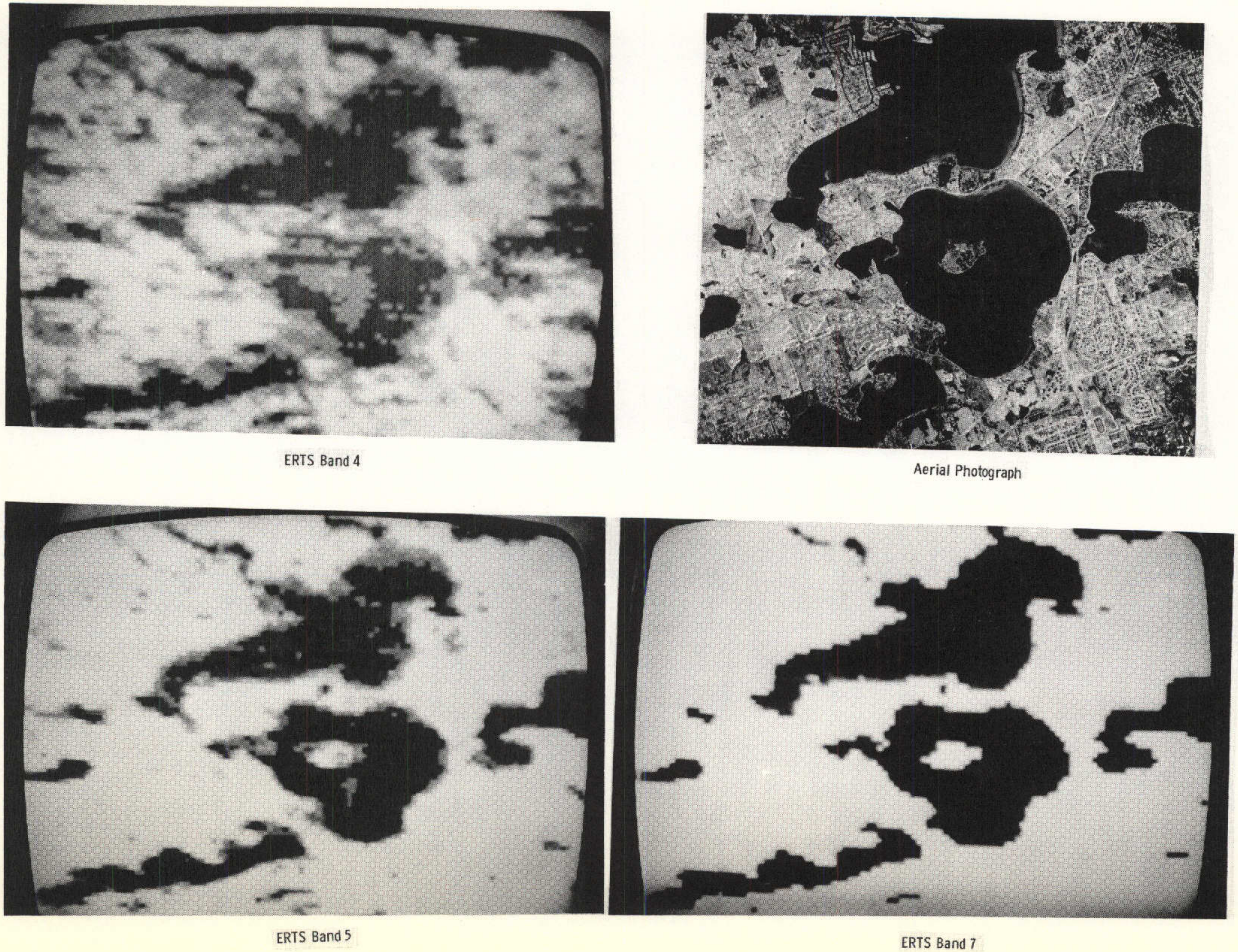
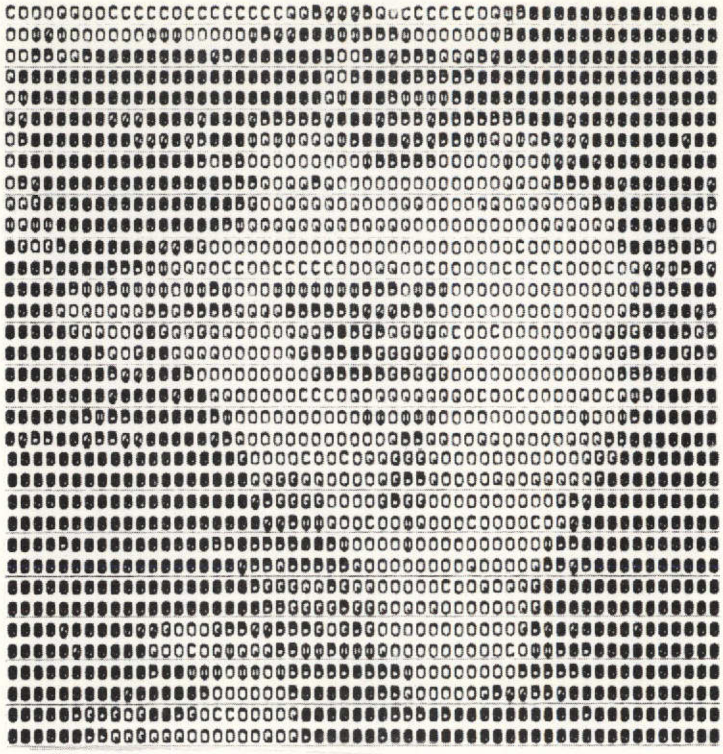


Figure 11. Comparison of Orchard and Cass Lakes Using Color Reflectance Displays and an Aerial Photograph



CHARACTER	REFLECTANCE RANGE		
	0.000	-	0.006
.	0.010	-	0.014
/	0.018	-	0.027
C	0.031	-	0.035
O	0.039	-	0.047
Q	0.051	-	0.055
Φ	0.059	-	0.067
G	0.071	-	0.075
B	0.079	-	0.087
Ø	0.091	-	0.095
●	0.099	-	0.100

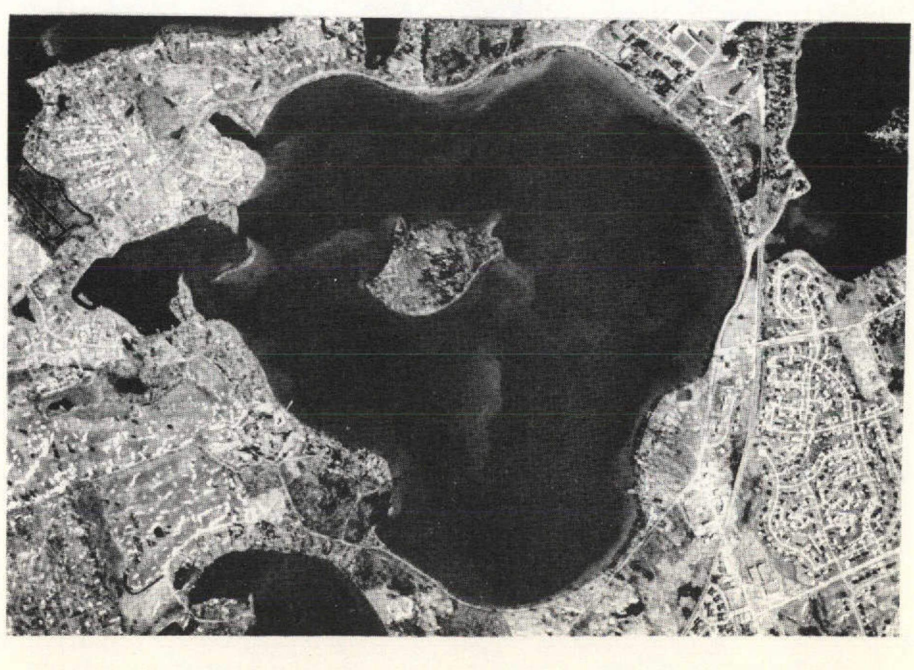
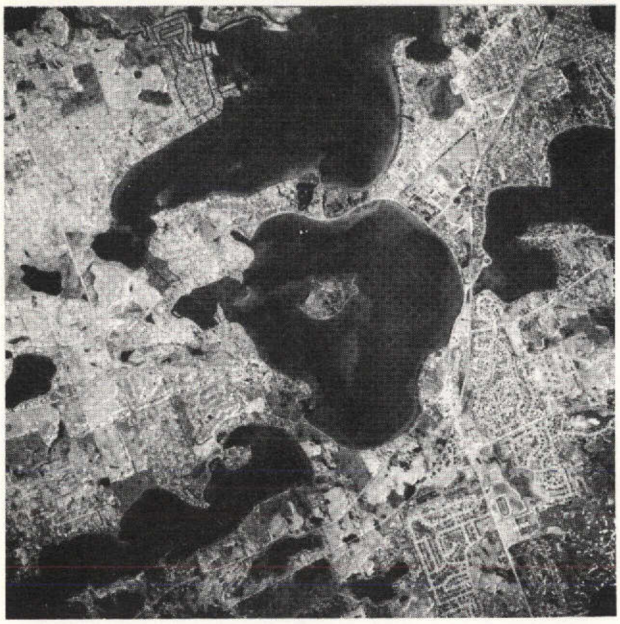
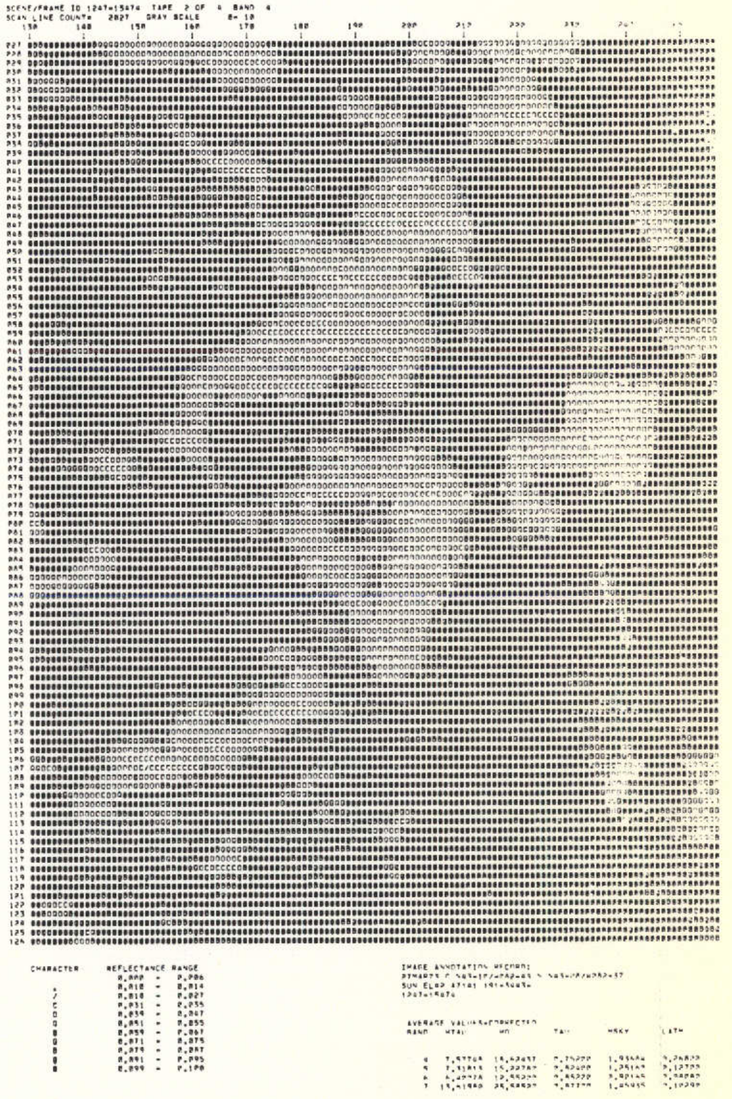


Figure 12. Comparison of ERTS Reflectance Printout and Aerial Photograph



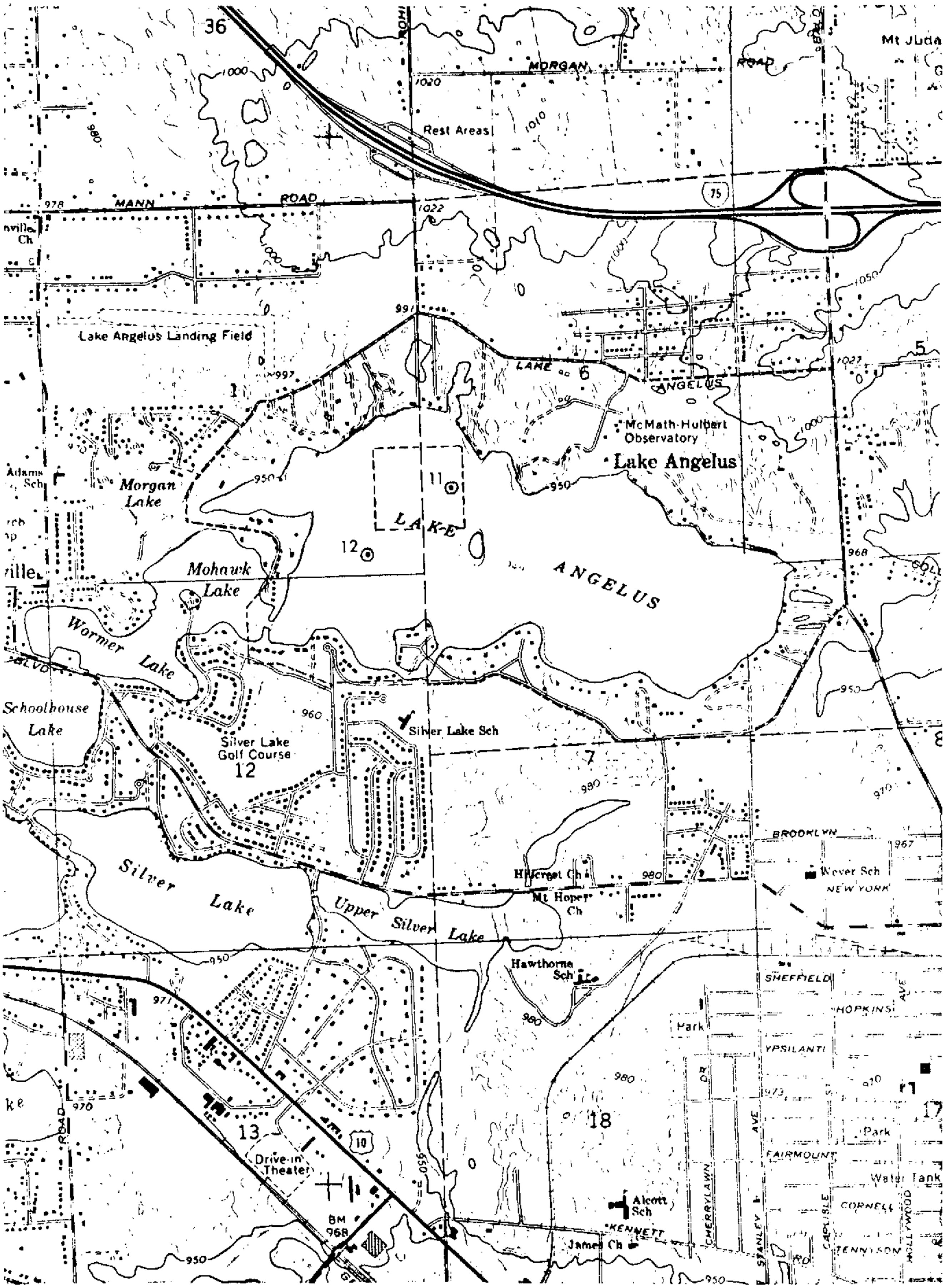
Aerial Photograph



Reflectance Gray Scale Printout

TV Display of ERTS Reflectance

Figure 13. Comparative Views of Orchard Lake



Scale 1:24, 000

Figure 14. Study Lakes

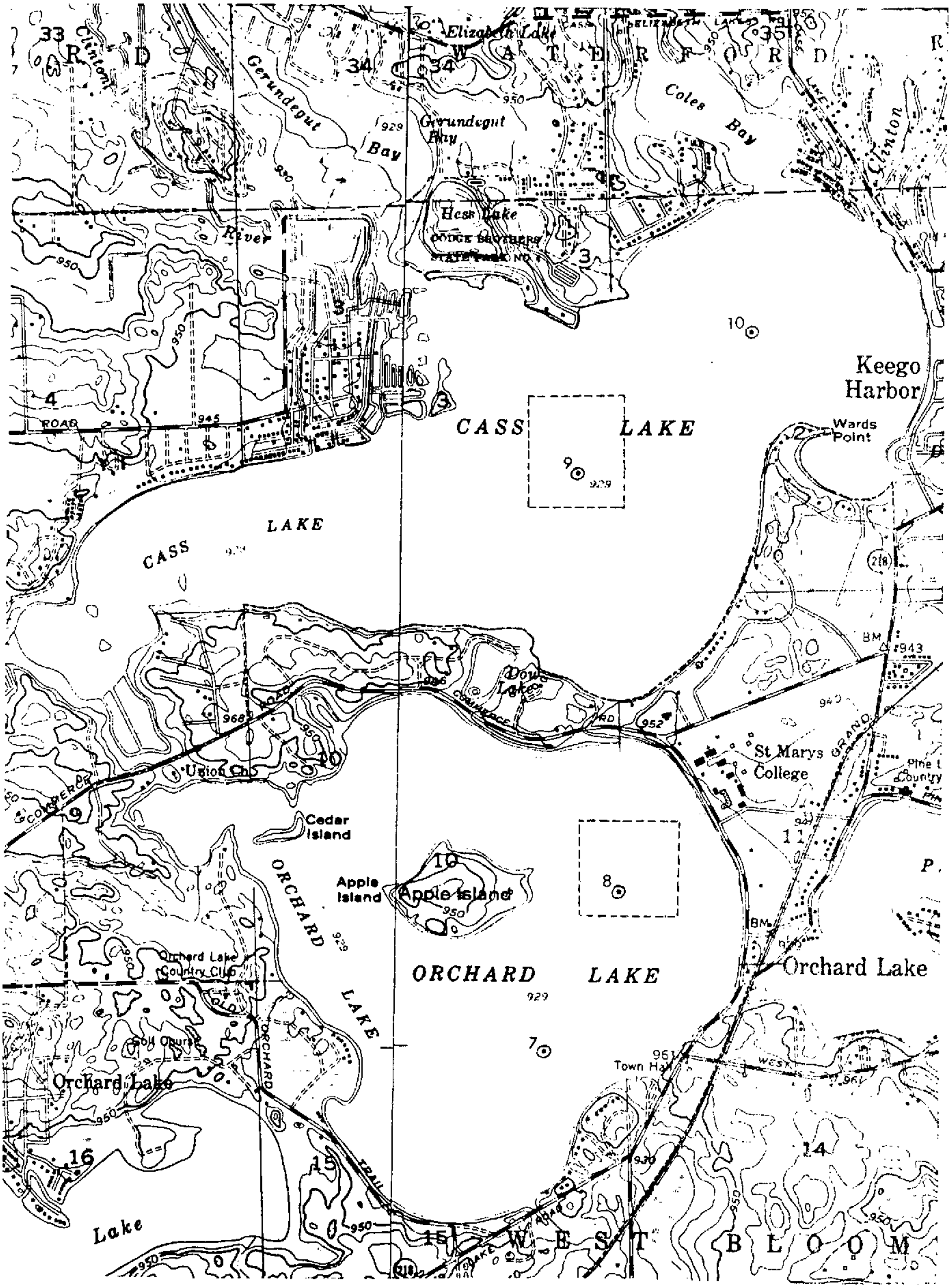


Figure 14. Study Lakes (Cont.)

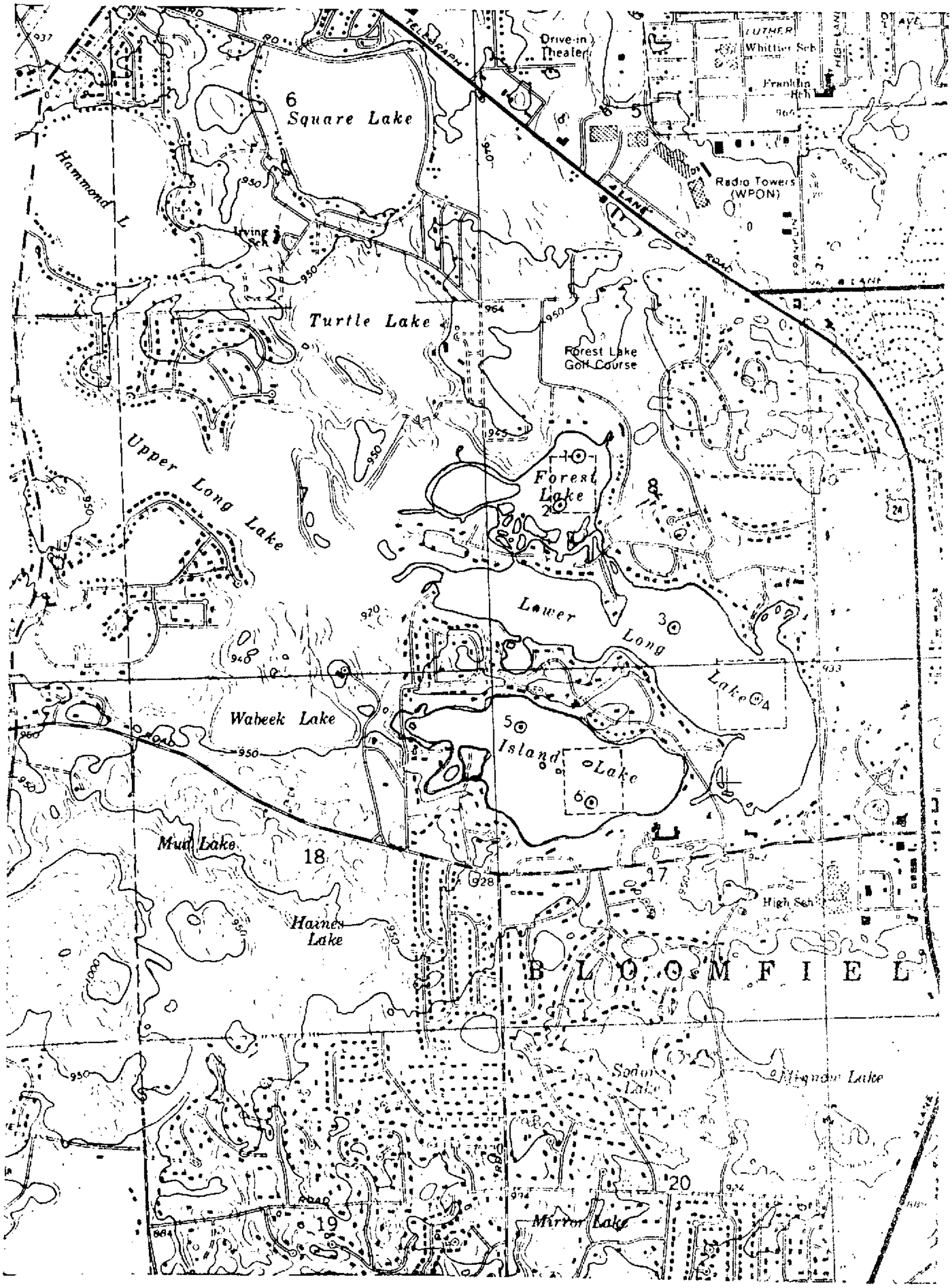


Figure 14. Study Lakes (Cont.)

a. Computing average signal count.

b. Transferring the average signal count to radiance by Equation 6.

c. Using this radiance value to compute, by Equation 5, reflectance, which transforms ERTS radiance measurements and solar and atmospheric parameters into the desired absolute target reflectance.

Application of this process to the deep water areas of lakes (Huron, Orchard, Lower Long, Forest, and Island Lakes) resulted in the data of Table 5.

The table also includes lake reflectance measured directly with the RPMI, as described in Section 2. 2, and water transparency and color estimates made concurrently on the lakes. Finally, the ERTS and RPMI MSS band ratios (Band 4 to Band 5) are compared.

The test lakes are listed in the table in order of increasing trophic level, as indicated by their transparency and color values. On comparing the ERTS and RPMI data by MSS band, the following trends are noted:

a. Bands 4 and 5 - ERTS values are consistently larger than RPMI values (except for Orchard Lake, Band 5).

b. Bands 4 and 5 - The proportional differences between ERTS and RPMI data increase.

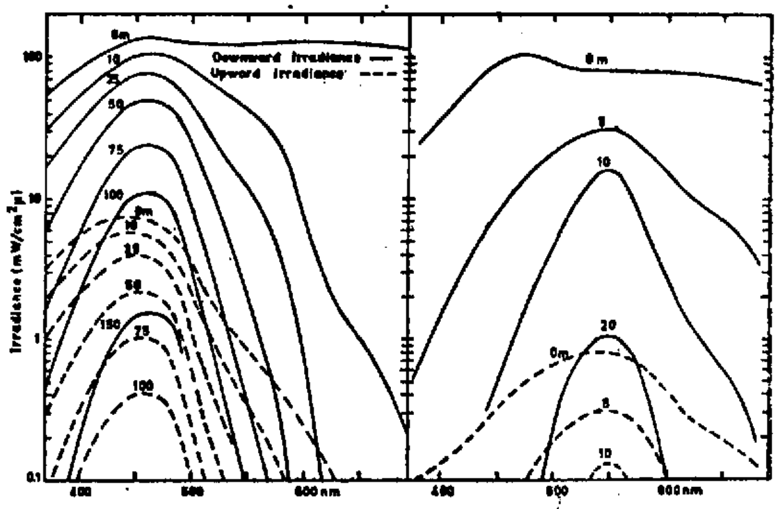
c. Bands 6 and 7 - ERTS values are consistently smaller than RPMI values.

d. Band 4 to Band 5 ratio - ERTS ratios are consistently larger (although both ERTS and RPMI ratios decrease).

The significance of the differences between ERTS and RPMI is hard to assess with so few data. However, it appears that either ERTS MSS is not fully calibrated, as expected, or atmospheric corrections for the ERTS data are not yet fully adequate. The margin of error seems to vary with wavelength. Yet it is important to note that the band ratios (Band 4 to Band 5) in both ERTS and RPMI data follow an expected pattern; that is, the proportion of green to red upwelling light decreases as the lakes become more turbid and brown-colored. Jerlov (1968) has described the same kind of relationship for ocean waters, as shown in Figure 15(a). Clarke et al. (1970) also presented radiometric curves of Atlantic Ocean water, showing that a spectral shift toward longer wavelengths was correlated with increasing chlorophyll content, as shown in Figure 15(b).

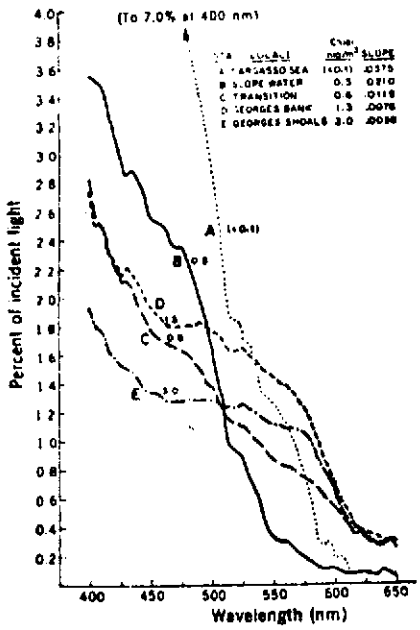
Table 5. Percent Surface Reflectances of Lakes, Recorded by ERTS and RPMI Sensors on 27 March 1973, Compared to Water Transparency and Color on the Same Date

Lake	Sensor	MSS Band				MSS Band Ratio (4 to 5)	Transparency (Secchi Depth)	Forel-Ule Color
		4	5	6	7			
Huron	ERTS	4.40	0.060	0	0	73.33	No readings taken	
	RPMI	No readings taken						
Orchard (Station 8)	ERTS	4.00	0.520	0	0	7.69	4 m	10
	RPMI	2.38	0.717	0.218	0	3.32		
Lower Long (Station 4)	ERTS	3.60	1.20	0.270	0.150	3.00	4.0 m	14
	RPMI	1.84	0.997	0.490	-	1.85		
Forest (Stations 1 and 2)	ERTS	3.30	1.20	0	0	2.75	2.8 m	16-17
	RPMI	1.34	0.997	0.474	-	1.34		
Island (Stations 5 and 6)	ERTS	3.97	1.60	0.350	0.370	2.48	1.5 m	16
	RPMI	1.610	1.010	0.460	0.0767	1.59		

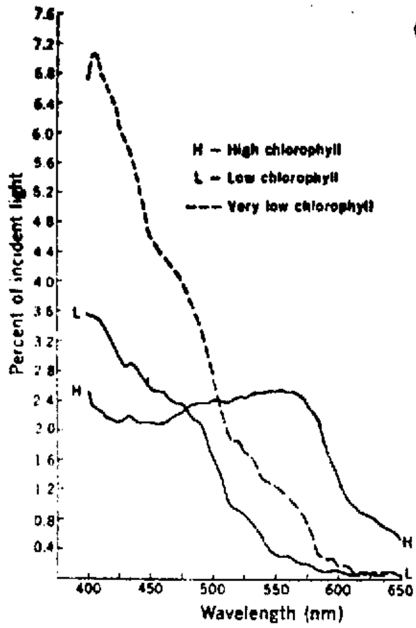


(a) (from Jerlov, 1968)

Comparison between spectral distribution of downward and upward irradiance for solar elevation of 55–60°. Left: Sargasso Sea ("Dana" expedition, 1966). Right: Baltic Sea (after AHLQUIST, 1965).



Spectra of backscattered light measured from the aircraft at 305 m on 27 August 1968 at the following stations (Fig. 2) and times (all E.D.T.): Station A, 1238 hours; Station B, 1421 hours; Station C, 1428.5 hours; Station D, 1445 hours; Station E, 1315 hours. The spectrometer with polarizing filter was mounted at 53° tilt and directed away from the sun. Concentrations of chlorophyll a were measured from shipboard as follows: on 27 August, Station A, 1238 hours; on 28 August, Station B, 0600 hours; Station C, 0730 hours; Station D, 1230 hours.



Data from the high and low chlorophyll curves plotted as percentage of the incident light and compared with data taken on the same day from an area with very low chlorophyll concentration south of the Gulf Stream.

(b) (from Clarke, et al., 1970)

Figure 15. Correlations of Organic Content and Spectra of Upwelling Light for Ocean Waters

To establish the effect of atmospheric scatter (path radiance), L_A, on the accuracy of computing reflectance of lakes from ERTS data, the same lake edits were processed using RPMI-derived L_A values and using $L_A = 0$. The results of this processing are shown in Table 6 and establish that, if L_A is ignored (i.e., assumed zero), then errors of 400 to 500 percent result when attempting to determine the reflectance of water surfaces. That is, the lakes have a reflectance of approximately 4 percent in Band 4 and 1 percent in Band 5, whereas the apparent reflectance of the atmosphere in Band 4 is 11 percent and in Band 5 is 5.5 percent.

Table 6. Percent Lake Reflectance Derived from ERTS Data, Showing Effects of Atmospheric Scatter, L_A

Lake	Band 4		Band 5	
	$L_A = 0.268$	$L_A = 0$	$L_A = 0.127$	$L_A = 0$
Huron	4.4	15.6	0.06	5.5
Orchard	4.0	15.1	0.52	6.0
Lower Long	3.6	14.7	1.2	6.6
Forest	3.3	14.6	1.2	6.6
Island	3.97	15.0	1.6	7.1

To evaluate the possibility of using historical values of atmospheric parameters to reduce ERTS data, atmospheric parameters determined for March were used to process April and May CCTs. The results of this trial are recorded in Table 7 and show errors that also range up to 400 percent. The error here, however, is not as large as that which results from neglecting path radiance completely; i.e., $L_A = 0$. The error in this reflectance computation is caused primarily by the improper choice of L_A, which can not be assumed to be a constant. This could have been predicted since the scattering angle, ϕ, varies from month to month with the sun angle, i.e., $\phi = 180 - Z$. A technique for obtaining a better prediction of L_A is being developed.

Table 7. Percent Lake Reflectance Derived from ERTS Data, Showing Effect of Using March Atmospheric Parameters to Compute Lake Reflectance in April and May

MSS Band	Orchard Lake			Lower Long Lake			Forest Lake		
	March	April	May	March	April	May	March	April	May
4	4.0	5.7	8.5	3.6	5.8	7.6	3.3	5.8	7.5
5	0.52	2.1	5.1	1.2	3.0	4.2	1.2	3.2	4.3
6	0	0.98	4.1	0.27	2.5	3.9	0	2.5	4.3
7	0	0.23	3.9	0.15	2.7	3.5	0	1.9	4.0

3. NEW TECHNOLOGY REPORT

A new technology report which described the RPMI was submitted to the Goddard Space Flight Center in January of 1973.

4. FUTURE WORK PLANNED

The research reported here is continuing. Field measurements with RPMIs are made on every suitable ERTS overpass of Michigan test sites. The performance achieved by the RPMI calibration technique is being used as a baseline to compare effectiveness of alternative techniques to correct ERTS data for effects of atmosphere that degrade radiometric fidelity of spacecraft data.

The final report on this effort will be developed and submitted to NASA prior to April of 1974.

5. CONCLUSIONS

The significant conclusions which can be made at this time include the following:

a. Results of computer processing of ERTS CCTs and atmospheric parameters derived for the 27 March mission have established the feasibility of the techniques for obtaining and using atmospheric parameters to transform spacecraft data into absolute target reflectance characteristics.

b. The RPMI's wide dynamic range was found to be essential for obtaining the full set of measurements needed to derive atmospheric parameters and spot reflectances of ground-truth targets. The measurement extremes were determined to be direct-beam solar irradiance up to 25 mW/cm^2 in Band 7, sky radiance as low as 0.077 mW/cm^2-Sr in Band 6, and radiance reflected from water in Bands 6 and 7 as low as 0.02 mW/cm^2-Sr.

c. Solar irradiance outside the atmosphere was determined from RPMI measurements and compared with those published by NASA (Dr. Thekaekara). The measurements derived from the RPMI were found to compare with Dr. Thekaekara's data within 5 percent in Band 4, 1 percent in Bands 5 and 6, and 1.2 percent in Band 7.

d. Field measurements obtained during the period from January through May of 1973 show that the atmospheric attenuation (beam transmittance) varies from 13 to 18 percent in each ERTS band. The largest variation occurs in Band 4.

e. Energy scattered to the spacecraft from the atmosphere (path radiance) was determined to be equivalent to that which would be produced by a target having a reflectance on the order of 11 percent in Band 4, 5 percent in Band 5, 3 percent in Band 3, and 1 percent in Band 7. This 'path reflectance', if not properly determined and removed from ERTS data, can be a major source of error. This is of particular concern when computing reflectance of water and other targets of low reflectance as it can cause an error of several hundred percent.

f. Analysis of ground measurements acquired during the January-through-May time period show that this radiance, reflected back to the spacecraft from the atmosphere, is a function of sun angle (scattering angle) and, for ERTS/Sun angles available at the Michigan test site, can be expected to vary on the order of 30 percent.

g. Reflectance derived from ERTS CCTs on the deep water area of six lakes established that lake reflectance ranges from 3 to 5.5 percent in Band 4, 0 to 2.3 percent in Band 5, 0 to 0.5 percent in Band 6, and 0 to 0.37 percent in Band 7.

h. Direct spot reflectance measurements made on the same lakes with the RPMI show the values to be 1.3 to 2.5 percent in Band 4, 0.7 to 1.1 percent in Band 5, 0.2 to 0.5 percent in Band 6, and 0 to 0.08 percent in Band 7. The major difference between reflectances derived from ERTS and reflectances derived from ground measurements occurred in Band 4. Reasons are yet to be determined.

i. When atmospheric parameters derived for the 27 March mission were applied to the computer processing of CCTs generated from ERTS data acquired in April and May, an error of several hundred percent occurred in computing lake reflectance. This large error, again, was caused by an improper choice of path radiance. The error, however, was partly expected since this parameter is known to change from month to month as a function of the scattering angle, which, in turn, is a function of Sun zenith angle.

j. Absolute reflectance of any target within an ERTS scene can be immediately determined by computer processing ERTS CCTs and producing color-coded TV display and computer-generated gray scaled maps wherein color and computer symbols designate a specific reflectance level or range. ERTS CCTs from March, April, and May have been processed in this manner. In ERTS Band 4, up to seven reflectance levels were viewed in test lakes.

k. The water quality in test lakes, as indicated by water transparency and color, appears measurable in the reflectance derived from ERTS Bands 4 and 5 and from the ratios of these bands.

6. RECOMMENDATIONS

As a result of the work performed to date, the following tasks are recommended on the basis of an urgent need to identify the components and procedures of the most cost-effective ERTS radiometric calibration technique.

1. Continue investigations to develop and inter-compare the capabilities of correcting the ERTS data for solar and atmospheric parameters by techniques that include the use of (1) transfer calibration from known reflectance targets, (2) RPMI, (3) spacecraft data alone (no auxiliary inputs), and (4) radiation transfer models. Use the RPMI technique as a base with which to compare the capability of the other techniques.

2. Continue the RPMI field and rooftop measurements needed to obtain an understanding of the effects of seasonal variations on beam transmittance and path radiance parameters and to provide sufficient data to complete the development of correlations between these parameters and other environmental factors (i.e., visual range, cloud cover, etc.).

3. Continue to use the full set of solar and atmospheric parameters determined by the RPMI technique as a basis from which to develop and evaluate techniques which require little or no concurrent ground truth measurements. These techniques should include:

   a. A procedure for developing and using historical atmospheric parameters, i.e., atmospheric parameters derived from previous RPMI/ERTS missions. This is a possible approach when no ground truth is available.

   b. A technique for improving these historical parameters based on visual range.

   c. A procedure for mapping ERTS radiance received under an atmospheric condition two, L_2, into radiance that would have been received under atmospheric condition one, L_1. This is possible if two or more targets of the same reflectance can be located in each of the two conditions (Crane, 1971).

4. Compare results of radiation transfer models with direct RPMI measurements. Models available at GSFC or from Robert S. Fraser should be used for this analysis.

5. Continue to utilize the RPMI to develop absolute reflectance of large natural and man-mand targets from ground-based spot sampling. Evaluate the techniques

of transforming these reflectance data to ERTS measurements by the transfer calibration procedure.

6. Identify those ERTS Principal Investigators (PIs), having practical applications of ERTS data, that would most likely benefit from support by a radiometric calibration technique for correcting ERTS data for solar and atmospheric effects, and obtain an initial estimate of the value of these corrections from the PIs.

7. Develop an informed core of ERTS PIs who have a knowledge of the procedures and techniques established for correcting ERTS data for stmospheric effects.

8. A program to determine the value of atmospheric corrections is also recommended. One approach to this would be to select and support a group of ERTS PIs having experiments that represent a broad range of ERTS data applications, i.e., Agriculture (crop and soil survey), Environmental (air and water pollution), etc., with a radiometric calibration system. This system might be composed of RPMIs or equivalent instruments that would permit the PIs to correct their own data for atmospheric effects. The activity could be initiated immediately by scheduling and shipping the government owned RPMIs to select PIs. With careful scheduling and shipping of some of the five RPMIs, this activity would (1) enhance achievement of this atmospheric experiment's objectives, (2) enhance achievements of ERTS experiments supported, and (3) permit a dollar estimate of benefits contributal to atmospheric corrections to be determined.

An alternative to providing PIs RPMIs would be to provide them with both corrected and uncorrected ERTS data (tapes and imagery). The atmospheric parameters for this case could be derived from the GSFC atmospheric model, RPMI measurements, or from a combination of the two techniques. The PIs would then interpret their ERTS data with and without the atmospheric correction and interpret results evaluated from a cost-benefit standpoint.

Cost of providing atmospheric corrections, based on level and type of support provided, would be derived for each PI. The ratio of application benefit to support cost would immediately provide the desired value (cost-effectiveness) of the atmospheric corrections for each ERTS data application.

7. REFERENCES CITED

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APPENDIX A

PROCEDURE FOR DETERMINING REFLECTANCE USING RADIANT POWER MEASURING INSTRUMENT

A.1 EQUIPMENT REQUIRED

- Radiant Power Measuring Instrument (RPMI) (see Figure 1)
- Unknown reflectance targets

1. Unclasp and open RPMI.
2. Separate two halves of RPMI.
3. Unfold and connect cable.
4. Turn ON-OFF switch to ON.
5. Check battery by depressing BATT. TEST switch. Meter should indicate between 0.6 and 1.0.
6. To zero meter, turn RANGE switch to 0.003. (0.03 on production instruments, 2373045 Assembly).
7. Turn BAND SELECT switch to ZERO.
8. Using ZERO adjust knob, set indicator of meter at zero.

A.2 TO MEASURE H_{SUN}

9. Set RADIANCE/IRRADIANCE switch to IRRADIANCE. Set meter range to 300.
10. Uncover diffuser. Place telescope on diffuser. Lock telescope in place.
11. Point RPMI directly at sun until sun shadow is symmetrical about bottom of telescope tube. (See Figure 1, lower right illustration). Record time.

Note

During Steps 12 through 15, adjust RANGE switch to obtain mid-meter indication. Re-check meter zero on each range used.

12. Switch BAND SELECT switch to ERTS Band 4. Read meter. Record indication on data sheet.

13. Switch BAND SELECT switch to ERTS Band 5. Read meter. Record indication on data sheet.

14. Switch BAND SELECT switch to ERTS Band 6. Read meter. Record indication on data sheet.

15. Switch BAND SELECT switch to ERTS Band 7. Read meter. Record indication on data sheet.

A.3 TO MEASURE H_{SKY}

16. Unlock and fold telescope. Relock.

17. Using tripod if available, level and point diffuser upward, as shown in Figure 1, lower left illustration.

18. Shade diffuser from direct sun.

Note

During Steps 19 through 22, adjust RANGE switch to obtain mid-meter indication. Re-check meter zero on each range used.

19. Switch BAND SELECT switch to ERTS Band 4. Read meter. Record indication on data sheet.

20. Switch BAND SELECT switch to ERTS Band 5. Read meter. Record indication on data sheet.

21. Switch BAND SELECT switch to ERTS Band 6. Read meter. Record indication on data sheet.

22. Switch BAND SELECT switch to ERTS Band 7. Read meter. Record indication on data sheet.

A.4 TO MEASURE SUN ZENITH ANGLE

23. With instrument level, determine zenith angle, Z, as follows:

    Rotate RPMI in horizontal plane until sun shadow from pin falls on protractor. Read elevation angle, θ, (less than 90°) from sun protractor. Record indication on data sheet. Compute Z and cos Z in the manner shown on the data sheet.

A.5 TO MEASURE L_T (RADIANCE FROM TARGET)

24. Place telescope on diffuser and lock telescope in place.

25. Switch RADIANCE/IRRADIANCE switch to RADIANCE.

26. Point telescope vertically down at object whose reflectance is desired, as shown in Figure 1, upper right illustration, except that RPMI is vertically down.

Note

> During Steps 27 through 30, adjust RANGE switch to obtain mid-meter reading. Recheck meter on each range used.

27. Switch BAND SELECT switch to ERTS Band 4. Read meter. Record indication on data sheet.

28. Switch BAND SELECT switch to ERTS Band 5. Read meter. Record indication on data sheet.

29. Switch BAND SELECT switch to ERTS Band 6. Read meter. Record indication on data sheet.

30. Switch BAND SELECT switch to ERTS Band 7. Read meter. Record indication on data sheet.

A.6 TO DETERMINE REFLECTANCE, ρ

Note

Refer to data sheet shown in Figure A-1.

31. For each ERTS band, calculate ρ from:

Reflectance Determination Data

ERTS Band	H_{sun} (Pointing at Sun with telescope)	H_{sky} (Level without telescope; shaded)	L_T (Point at target)	ρ
*(1) 4				
(2) 5				
(3) 6				
(4) 7				

*Prototype instrument numbering

θ = ______degrees (less than 90°)

Z = 90 - θ = ______degrees

cos Z = ______

Time__________________

Date__________________

Location__________________

Figure A-1. Data Sheet for Step 31

$$\rho = \frac{\pi L_T K_1}{K_2 (H_{sun} \cos Z + 1.11 H_{sky})}$$

For K_1, see Table A-1.

For K_2, see Table A-2.

31A. An an alternate calculation, use the formula

$$\rho = \frac{\pi L_T K_1}{H K_2}$$

Note

Refer to data sheet shown in Figure A-2.

H = global irradiance determined with instrument leveled and pointed upward, with diffuser uncovered, and without telescope as shown in Figure 1, lower left illustration. Place IRRADIANCE/RADIANCE switch in IRRADIANCE position.

Note

K_1 = 100 and K_2 = 1.0 for all production instruments (2373045 Assembly).

Table A-1 Sky Radiance Correction Factors (5500°K), K_1

ERTS Band	Instrument Band	Prototype Instrument Number			
		100	101	102	103
4	1	1.01×10^3*	9.02×10^2	9.08×10^2	8.95×10^2
5	2	7.98×10^2	7.88×10^2	7.85×10^2	7.59×10^2
6	3	7.96×10^2	7.94×10^2	7.86×10^2	7.78×10^2
7	4	2.355×10^3	2.331×10^3	2.331×10^3	2.247×10^3

*Instrument reading, when multiplied by these values, will be radiance in units of W m^{-2} (Δ Band)$^{-1}$ Sr^{-1}.

Table A-2 Correction Factors for Solar Irradiance, K_2

ERTS Band	Instrument Band	Prototype Instrument Number			
		100	101	102	103
4	1	12.43	11.81	12.30	11.58
5	2	10.72	10.43	10.64	9.85
6	3	10.71	10.46	10.67	10.10
7	4	32.3	31.05	32.3	29.65

*This multiplier transforms RPMI reading to irradiance in Wm^{-2} $(\Delta \text{ Band})^{-1}$.

Reflectance Determination Data

ERTS Band	H (Level, without telescope)	L_T (Point at target)	ρ
(1)* 4			
(2) 5			
(3) 6			
(4) 7			

*Prototype instrument numbering.

Time_______________

Date_______________

Location___________

Figure A-2. Data Sheet for Step 32