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MACHINE PROCESSING OF ERTS AND GROUND TRUTH

DATA

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I. ABSTRACT

Results achieved by ERTS-Atmospheric Experiment PR303, whose objective is to establish a radiometric calibration technique, are reported. This technique, which determines and removes solar and atmospheric parameters that degrade the radiometric fidelity of ERTS data, transforms the ERTS sensor radiance measurements to absolute target reflectance signatures. A Radiant Power Measuring Instrument (RPMI) and its use in determining atmospheric parameters needed for ground truth are discussed. The procedures used and results achieved in machine processing ERTS computer-compatible tapes and atmospheric parameters to obtain target reflectance are reviewed.

II. INTRODUCTION

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, the 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 Radiant Power Measuring Instrument (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.

This paper describes the results achieved to date in the development of the ERTS radiometric calibration technique employing the RPMI. Section III describes the atmospheric problem and defines the solar and atmospheric parameters needed to transform ERTS radiance measurements into reflectance. Section IV describes the RPMI and, in Section V, methods for deploying RPMI to obtain required atmospheric parameters are described. The procedures used and the results achieved in machine-processing ERTS computer-compatible tapes and atmospheric parameters to obtain the reflectance of a number of lakes is reported in Section VI.

III. ATMOSPHERIC PROBLEM

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

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

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 due to atmospheric radiance, L_A . The desired target reflectance in terms of the remote radiance measurement, L , is then

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

The target irradiance, H , also has two components; one due to the direct sun, denoted $H_{\text{sun}} \cos Z$ (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 due to the sky, denoted H_{sky} . Expanding H of Equation 2 in terms of the direct sun and sky components results in

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

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

$$H_{\text{sun}} = H_0 \tau^m \quad (4)$$

in terms of the solar irradiance normal to the sun's rays outside the atmosphere, H_0 . Combining Equations 3 and 4, the desired target reflectance, ρ , in terms of ERTS radiance, L , measurements is

$$\rho = \frac{(L - L_A) \cdot \pi}{\tau (H_0 \tau^m \cos Z + H_{\text{sky}})} \quad (5)$$

where L_A , τ , H_0 , m , $\cos Z$, and H_{sky} are the solar and atmospheric parameters that must be known to accurately compute target reflectance.

In the machine processing of ERTS computer compatible tapes (CCT's), the parameters L , H_0 , m , and Z of Equation 5 are easily and quickly determined. Target counts, c_i , are recorded on ERTS CCT's and easily transformed to the desired target radiance, L of Equation 5, by

$$L_i = c_i K_i \text{ mw/cm}^2 \text{ - Sr} \quad (6)$$

where i indicates MSS band number and constants K_i are determined as described on Page 6-14 of the ERTS Data User Handbook ($K_4 = 0.0195$, $K_5 = 0.0157$, $K_6 = 0.0138$, $K_7 = 0.0730$). 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

$$m = \sec Z - 0.001867 (\sec Z - 1) - 0.002875 (\sec Z - 1)^2 - 0.0008083 (\sec Z - 1)^3 \quad (7)$$

The solar irradiance, H_0 , outside the earth's atmosphere is well known and changes less than 6 percent over a 12-month period. Its value(s) can be determined from the published data (Thekaekara, 1971) or measured by procedures described in Section V. 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 by the Principal Investigator at the time of ERTS overflight, if accurate spectral reflectance of his targets are to be derived.

IV. RADIANT POWER MEASURING INSTRUMENT (RPMI)

The RPMI shown in Figure 1 was developed specifically to provide an ERTS investigator with the capability of obtaining the complete set of solar and atmospheric measurements he needs to determine target reflectance from the ERTS radiance data.

The RPMI is a rugged, hand-carried, portable instrument calibrated to measure both downwelling 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) is 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 $0.077 \text{ mw/cm}^2 - \text{Sr}$ in Band 6, and radiance reflected from water surfaces in Bands 6 and 7 as low as $0.02 \text{ mw/cm}^2 - \text{Sr}$. The RPMI measurements are traceable to an NBS 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.

V. DETERMINATION OF ATMOSPHERIC PARAMETERS

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 $L_{MEAS}(\phi)$, 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_0 , are determined. With these parameters, Equation 5 is then applied to transform the ERTS radiance measurements, L , into absolute target reflectance units.

GLOBAL IRRADIANCE

Global irradiance, H , is measured directly in each 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

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

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.

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.

BEAM TRANSMITTANCE

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

$$\tau = \left(\frac{H_{\text{sun}}}{H_0} \right)^{\frac{1}{m}} \quad (9)$$

when the solar irradiance outside the atmosphere, H_0 , is known. The air mass is calculated from the solar zenith angle, using Equation 7.

BEAM TRANSMITTANCE AND SOLAR IRRADIANCE OUTSIDE THE ATMOSPHERE

Beam transmittance, τ , and solar irradiance outside the atmosphere, H_0 , 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_0 in each ERTS MSS band. The beam transmittance per unit air mass, τ , is then computed from either Equation 9 or from

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

where

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

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

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

The value of H_0 (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.

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.

PATH RADIANCE

Path radiance, L_A , is the energy reaching the spacecraft from Rayleigh and aerosol scattering by the atmosphere. As it 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 $L_{\text{MEAS}}(\phi)$ 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

$$L_A = L_{\text{MEAS}} \left(\frac{1 - \tau}{1 - \tau^{m_0}} \right), \quad (11)$$

in which m_0 is the air mass in the direction of observation (in this case $m_0 = \frac{1}{\cos \beta}$) and τ , as previously defined, is the atmospheric transmission per unit air mass. The validity of this formula has been demonstrated by Rogers and Peacock (1973) and discussed by Gordon, Harris, and Duntley (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 ERTS overpass of test site and sky radiance observations is significantly different. An approach for determining this correction factor is 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

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

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

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

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 $\exp(-\tau_{\infty 0})/\tau$, in which τ is the measured atmospheric transmission and $\tau_{\infty 0}$ 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:

$$L_A = L_{MEAS}(\phi) \left[\frac{1 - \tau}{1 - \tau \frac{m_0}{m_0}} \right] \frac{T_{ERTS}}{T_Z}, \quad (14)$$

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 it 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 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.

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.

VI. MACHINE PROCESSING OF ERTS AND RPMI DATA

The ERTS CCT's and RPMI measurements are machine-processed in the Bendix Earth Resources Data Center (ERDC) pictured in Figure 6. 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.

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 7. 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_0 , τ , and H_{sky}) as defined in Section V.

Another approach, also illustrated in Figure 7, 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.

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 7.

These approaches to the machine processing of ERTS CCT's are illustrated, using ERTS data acquired on 27 March, 14 April and 21 May over Lake Huron and the four small lakes, Orchard, Lower Long, Forest, and Island, which are located in Oakland County, Michigan. Personnel from Bendix, Cranbrook Institute, and Oakland University deployed (1) RPMI's 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.

One of the first data reduction steps is to transform RPMI measurements into a complete set (H_0 , τ , H_{sky} , and Z) of solar and atmospheric parameters. These parameters for the 27 March mission are recorded in Table 1. Two methods of utilizing these parameters to obtain a quick-look view of the ERTS scene is to utilize Equation 5 to transform ERTS data to reflectance units and then to produce a color-coded or gray-scaled computer printout of the ERTS scene, as shown in Figure 8. In this case, the color on the TV monitor and the symbol on the computer print-out is directly related to target reflectance. The scenes shown in Figure 8 are those of Orchard Lake. The lake is approximately three miles on a side and the scene is approximately six miles on a side.

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, etc., 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.

Utilizing this procedure, the computation of average reflectance in the deep water areas of the lakes; Huron, Orchard, Lower Long, and Forest; was obtained. The results of these computations, recorded in Table 2, show that the reflectance of the lakes vary from a high of 4.4 percent (Band 4 in the deep clean area of Lake Huron) to a low of essentially zero in Band 7. Also listed in Table 2 is the spot reflectance of the lakes measured directly with the RPMI. The ERTS MSS Band 4 is shown to be giving a higher reflectance value than the RPMI ground truth value. The reason for this difference has not been established at this time. Also recorded in Table 2 is the ratio of ERTS and RPMI Band 4 to Band 5, the Secchi Disk measurements, and the Forel-Ule measurements. Quick-look analysis of the data in Table 2 shows a strong correlation between the ERTS reflectance ratios (Bands 4 to 5), the distance which light penetrates the water, and the water color, i. e., the higher the ratio, the greater the water transparency and the bluer the water. This finding has great value to water quality applications.

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 3 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.

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 CCT's. The results of this trial are recorded in Table 4 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., $\phi = 180 - Z$.

VII. SUMMARY

This ERTS experiment is determining the procedures and techniques for obtaining and utilizing solar and atmospheric parameters in the machine processing of spacecraft data. Results of field test show that the RPMI will provide the full range of solar and atmospheric measurements needed by machine processing techniques to transform spacecraft data into absolute target reflectance.

The results of processing ERTS CCT's and RPMI ground truth measurements gathered in Michigan on 27 March 1973 establish that the removal of atmospheric parameters from ERTS data permits the computation of the absolute reflectance of lakes. The reflectance of these lakes, in deep water areas, was determined to range from 5 percent in Band 4 to zero in Band 7. Lake water quality, as indicated by water transparency and color, appears measurable in the reflectance derived from ERTS Bands 4 and 5 and the ratios of the reflectances of these bands.

Neglecting path radiance, L_A , in the computation of lake reflectance results in errors in the order of 400 to 500 percent in Bands 4 and 5. When atmospheric parameters (H_0 , τ , H_{sky} , and L_A) derived for the March mission were applied to the ERTS data acquired in April and May again, the major source of error, which ranged from 200 to 400 percent in lake reflectance computations, was found to be contributable to an improper choice of path radiance, L_A . This error was expected since this parameter changes from month to month as the scattering angle ($\phi = 180 - Z$) changes as a function of sun zenith angle. A more accurate technique for predicting path radiance based on previous measurements is under development.

The research reported here is continuing. Field measurements with RPMI's 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. It is hoped that the results of this research will contribute to the identification of the most cost-effective grouping of instruments and processing techniques to achieve radiometric calibration of ERTS data gathered on a world-wide basis.

VIII. REFERENCES

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2. ERTS Data User Handbook; NASA Document 71SD4249; Revised Sept 1972; pg G-14.
3. R. H. Rogers and K. Peacock; "Investigation of Techniques for Correcting ERTS Data for Solar and Atmospheric Effects"; NASA-CR-131258, E73-10458; April 1973.
4. M. P. Thekaekara et al. ; NASA Document SP-8005; Revised May 1971.
5. S. L. Valley, Editor; Handbook of Geophysics and Space Environments; AFCRL; 1965; pgs 7-14 to 7-35.

Table 1. Atmospheric Parameters
March 1973

Parameter	Band Number			
	4	5	6	7
Solar Irradiance outside Atmosphere, H_0 (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°			

Table 2. March Mission

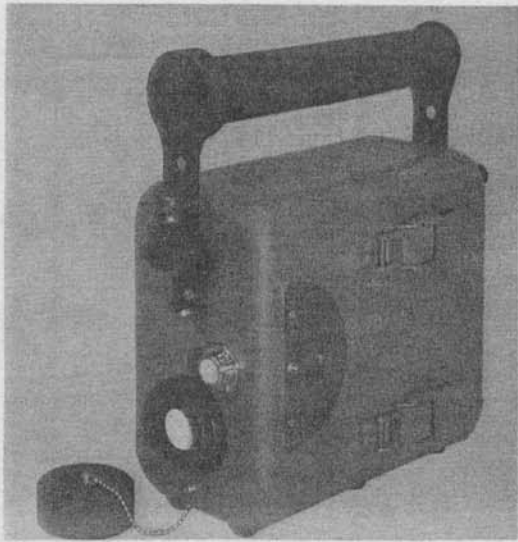
Lake	Lake Reflectance, ρ , Computed from ERTS Data and RPMI Atmospheric Measurements				Lake Reflectance, ρ , Measured Directly by RPMI				Band 4 to Band 5 Reflectance Ratio		Secchi Disk Readings (Light Penetration in Meters)	Forel-Ule Number (Water Color)
	Band				Band				ERTS	RPMI		
	4	5	6	7	4	5	6	7				
Huron	4.4	0.06	0	0	-	-	-	-	73.3	-	-	-
Orchard	4.0	0.52	0	0	2.4	0.72	0.22	0	7.7	3.3	5.0	X
Lower Long	3.6	1.2	0.27	0.15	1.8	1.0	0.5	0	3.0	1.9	4.0	XIV
Forest	3.3	1.2	0	0	1.55	1.0	0.5	0	2.75	1.55	3.0	XVII

Table 3. Effect of Atmospheric Scatter (Path Radiance)
 L_A on Lake Reflectance Derived from ERTS Data

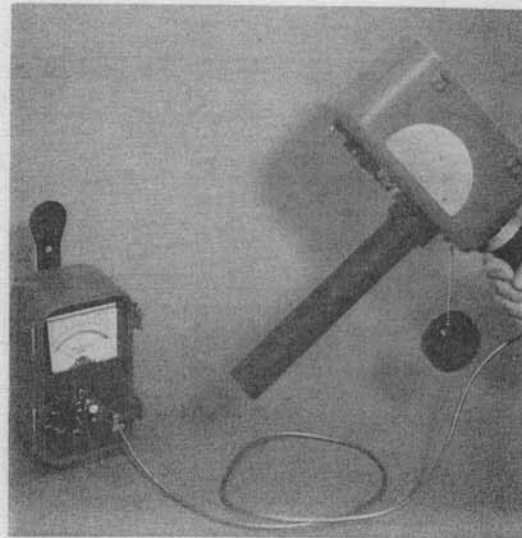
Lake	Band 4		Band 5	
	$L_A = 0.268$	$L_A = 0$	$L_A = 0.127$	$L_A = 0$
Huron	4.4	15.6	0.06	5.5
Orchard	4.0	15.1	0.52	6.0
Lower Long	3.6	14.7	1.2	6.6
Forest	3.3	14.6	1.2	6.6
Island	3.97	15.0	1.6	7.1

Table 4. Using March (Historic) Atmospheric Parameters
to Compute Lake Reflectance in April and May

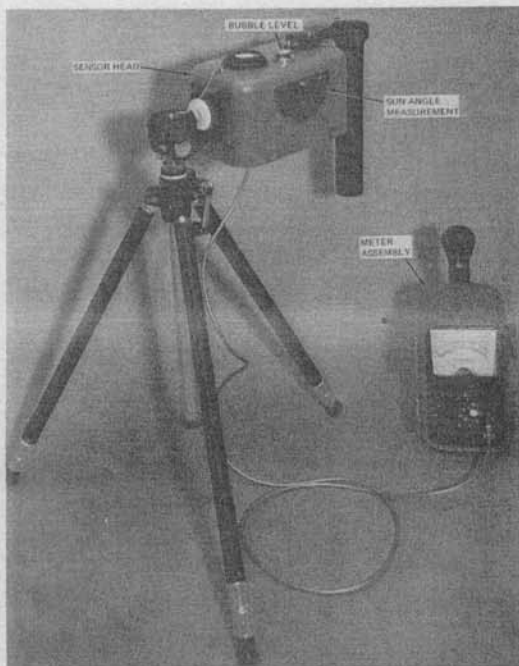
MSS Band	Orchard			Lower Long			Forest		
	March	April	May	March	April	May	March	April	May
4	4.0	5.7	8.5	3.6	5.8	7.6	3.3	5.8	7.5
5	0.52	2.1	5.1	1.2	3.0	4.2	1.2	3.2	4.3
6	0	0.98	4.1	0.27	2.5	3.9	0	2.5	4.3
7	0	0.23	3.9	0.15	2.7	3.5	0	1.9	4.0



RPMI assembled

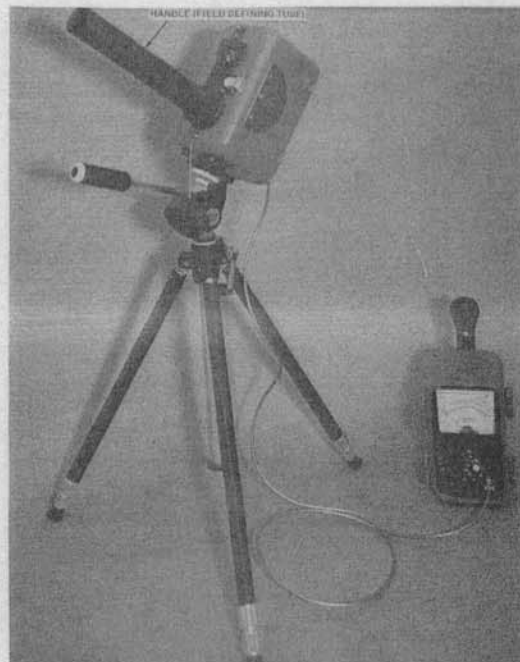


Reflected Radiation — Used with small calibration panels and cards, to obtain direct measurement of truth site reflectance. Reflectance also immediately derived from ratio of reflected radiance and global irradiance.



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

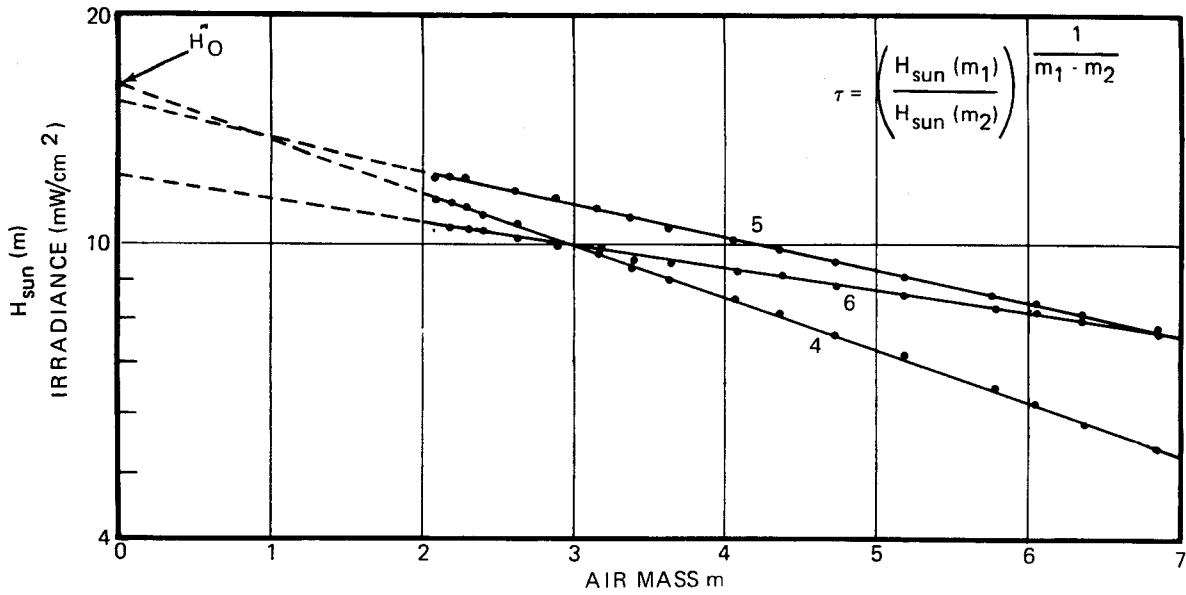


Figure 2. Atmospheric Extinction Curves

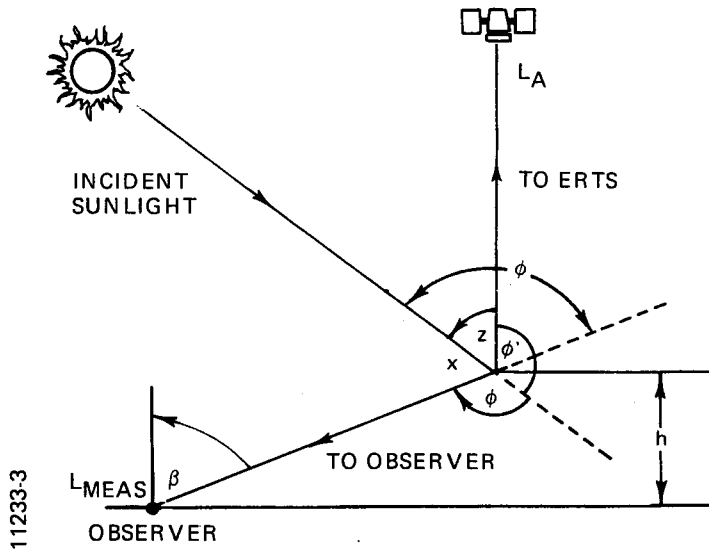


Figure 3. Sky Radiance Measurements

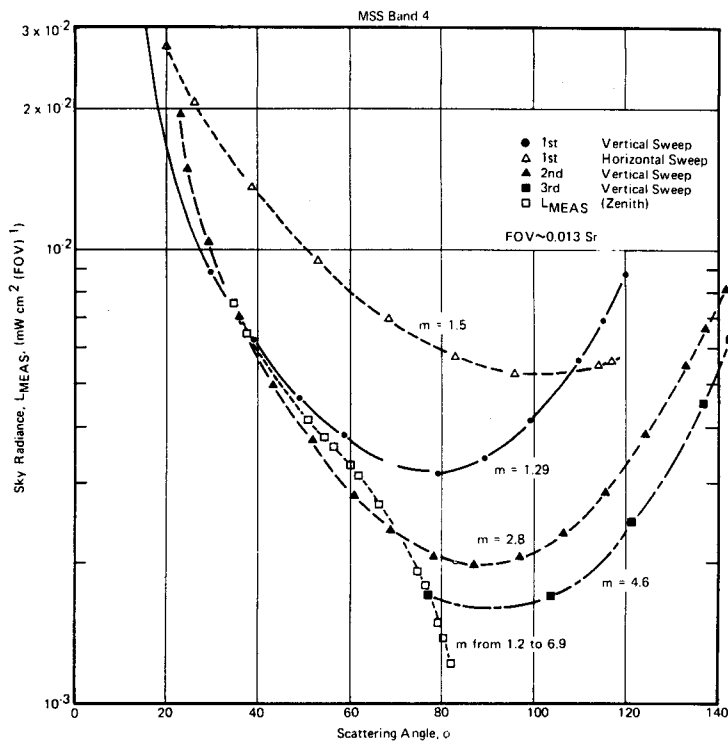


Figure 4. RPMI Sky Radiance Measurements

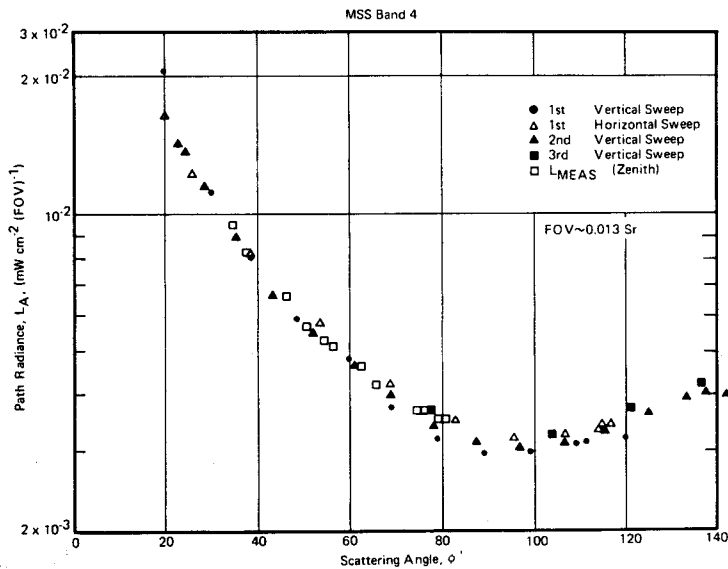


Figure 5. Path Radiance Viewed by ERTS Band 4



Figure 6. Earth Resources Data Center

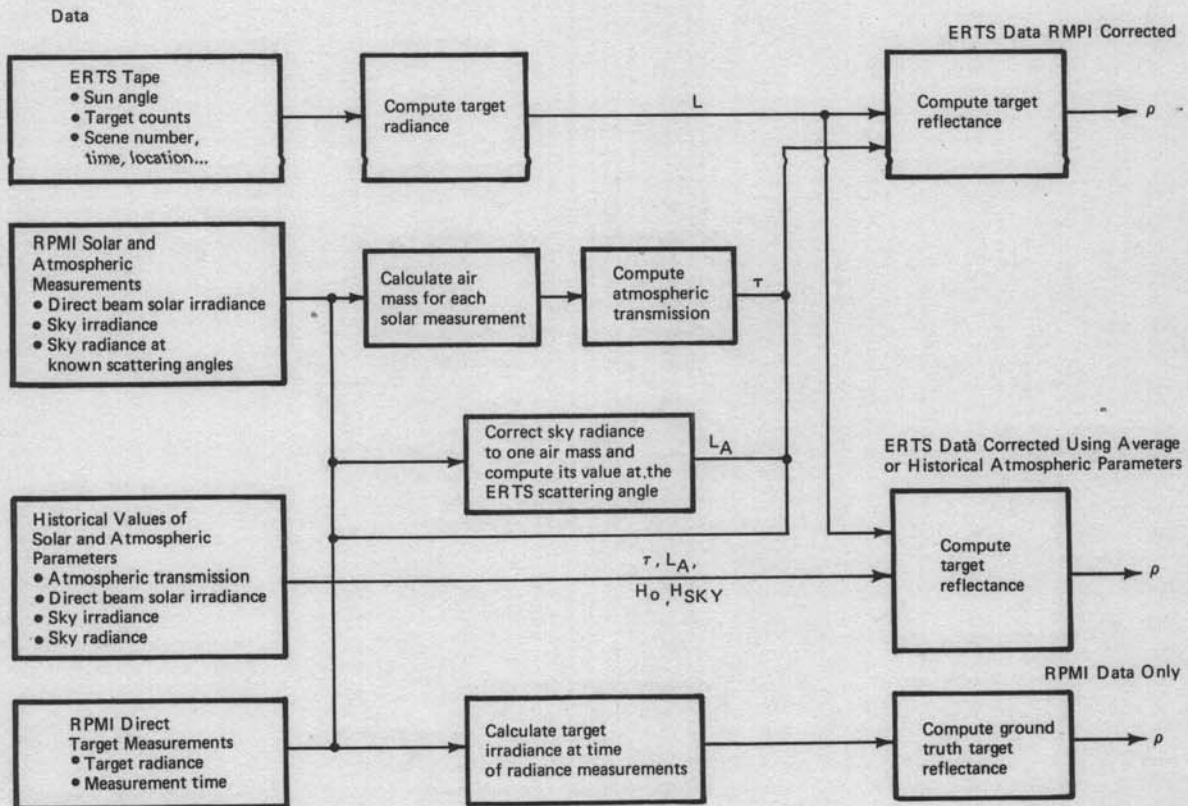


Figure 7. Machine Processing of ERTS and RPMI Data

