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Paper I 3

A TECHNIQUE FOR CORRECTING ERTS DATA FOR SOLAR AND ATMOSPHERIC EFFECTS

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ABSTRACT

A technique is described by which an ERTS investigator can obtain absolute target reflectances by correcting spacecraft radiance measurements for variable target irradiance, atmospheric attenuation, and atmospheric backscatter. A simple measuring instrument and the necessary atmospheric measurements are discussed, and examples demonstrate the nature and magnitude of the atmospheric corrections.

1. INTRODUCTION

Measurements of atmospheric parameters and their use to transform ERTS data to absolute target reflectances are essential if the observations and reports of a large number of PIs are to be correlated and compared by NASA and other PIs in a meaningful way. ERTS-1 Experiment PR303 is evaluating the techniques for determining and removing solar and atmospheric effects that degrade the radiometric fidelity of ERTS data. This paper describes one technique, use of a Radiant Power Measuring Instrument (RPMI) to determine target irradiance, H, atmospheric transmittance for one air mass, τ, and the sky radiance seen by the spacecraft, L_{ATM}. Techniques for determining these parameters and the result of their use in transforming ERTS data to target reflectance is reported.

The total radiance, L, recorded by ERTS from a target of reflectivity, ρ, is related to these parameters by:

$$L = \frac{\rho H \tau}{\pi} + L_{ATM} \tag{1}$$

for a spacecraft looking vertically.

The target irradiance H can be further subdivided into:

$$H = H_o \tau^m \cos\theta + H_{sky} \tag{2}$$

where H_o is the solar irradiance outside the atmosphere, m is the atmospheric air mass in terms of the air mass at the zenith, θ is the solar zenith angle and H_{sky} is the sky irradiance. An Earth Resources investigator must therefore have an independent knowledge of H, τ, and L_{ATM} if he is to obtain the spectral reflectances of his target from the ERTS data.

2. RADIANT POWER MEASURING INSTRUMENT (RPMI)

The RPMI, developed specifically for this experiment and shown in Figure 1, provides an ERTS investigator with the capability of obtaining radiometric measurements needed to determine solar and atmospheric parameters that affect the ERTS radiance measurements.

The RPMI is a rugged, hand-carried instrument accurately calibrated to measure both downwelling and reflected radiance within each ERTS multispectral scanner (MSS) band. A foldover handle permits a quick change from wide-angle global or sky irradiance measurements to narrow-angle (6.0° circular) radiance measurements from sky and ground targets. These measurements yield ground truth site reflectance and permit calculation of additional parameters such as beam transmittance between spacecraft and ground, and path radiance (path reflectance).

12 range scales permit irradiance measurements from 0.001 to 300 W/M^2 and radiance measurements from 0.1 to 3×10^4 Wm^{-2} Sr^{-1}. The instrument is calibrated to 5% absolute and 2.0% relative from band to band.

3. MEASUREMENT OF ATMOSPHERIC PARAMETERS

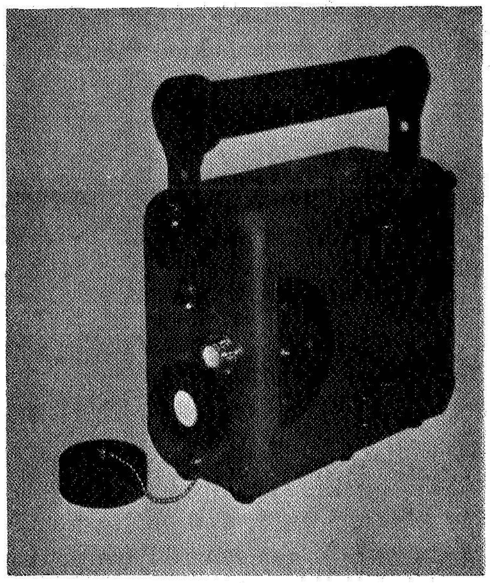
As Figure 1 shows, the RPMI is deployed in concert with ERTS overflights to obtain the direct measurements, within the four ERTS MSS bands, of: (1) global irradiance, H, (2) sky irradiance H_{sky} (i.e., by shadowing sun, and reading global minus direct beam-solar), (3) radiance from a narrow solid angle 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 and path radiance L_{ATM} are determined, and target reflectance ρ computed using equations (1) and (2) for each spectral band.

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) independently and computing the total target irradiance, using:

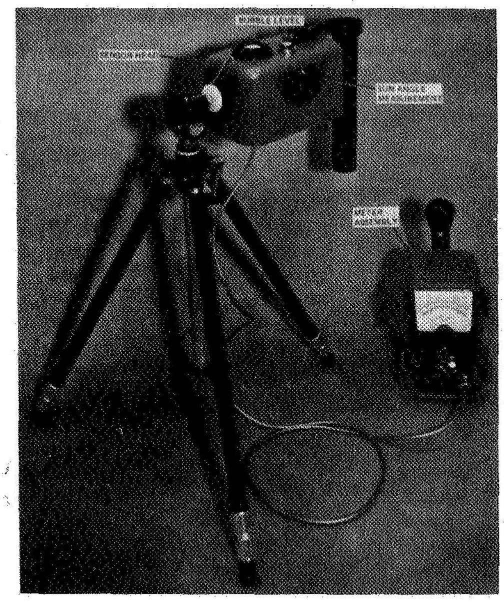
$$H = H_{sun}(m) \cos \theta + H_{sky} \tag{3}$$

The sun angle is read from the sun dial on the side of the RPMI after leveling the instrument with its bubble level.

Beam Transmittance, τ, is determined by plotting an "extinction" curve, as shown in Figure 2. The direct-beam solar irradiation is plotted on a logarithmic scale as a function of the air mass. The

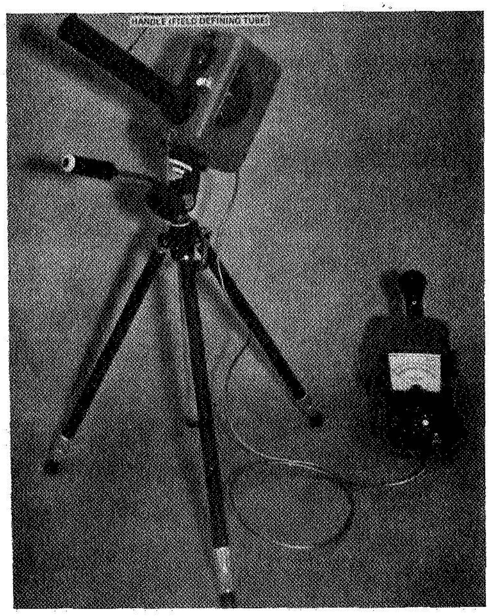


RPMI Assembled

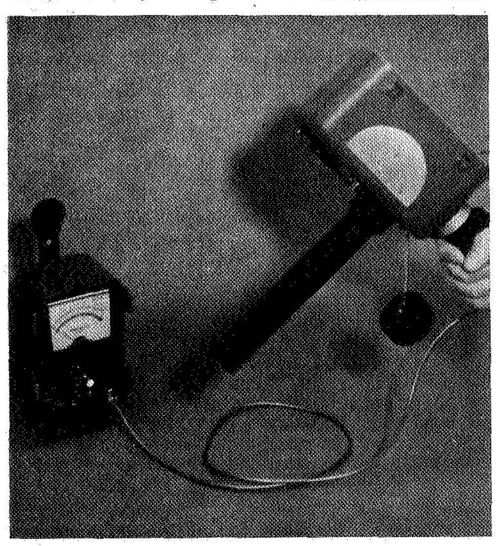


Global Irradiance (H) — 2π steradian field of view for measuring downwelling (incident) radiation ERTS MSS bands. Bubble level aids this measurement.

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 6.0° circular field of view. This mode is also used to measure direct beam irradiance.



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

Figure 1 Radiant Power Measuring Instrument intercepts of the lines on the vertical axis give the solar irradiance, H_o, outside the atmosphere in each of the ERTS MSS bands, and the beam transmittance can be computed from the slope of the lines using the equation in Figure 2. Measurement of H_o can also be used for recalibration of the instrument, without the use of additional equipment, at any location in the world.

If H_o is known from prior observations, τ could be determined by making a single-point measurement of $H_{sun}(m)$. A correction can be made for the different zenith angles of the sun and spacecraft. This beam transmittance calculation assumes that the atmospheric properties in sun-to-target path are the same as in target-to-spacecraft path. Tests are being performed to determine the accuracy of this single-point measurement technique.

Path Radiance, L_{ATM}, 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 measurements of the backscatter. The simplest technique is to use RPMI to measure the sky radiance $L_{meas}(\phi)$ scattered at an angle, ϕ (as in Figure 3B) such that ϕ is identical to ϕ', the angle through which radiation is scattered to the spacecraft and correct the measurement for the difference in air masses between the direction of observation and the direction of the spacecraft. As this technique can only be used when $\theta > 45°$, atmospheric modeling is being performed to extrapolate from the available measurement angles to the desired angle.

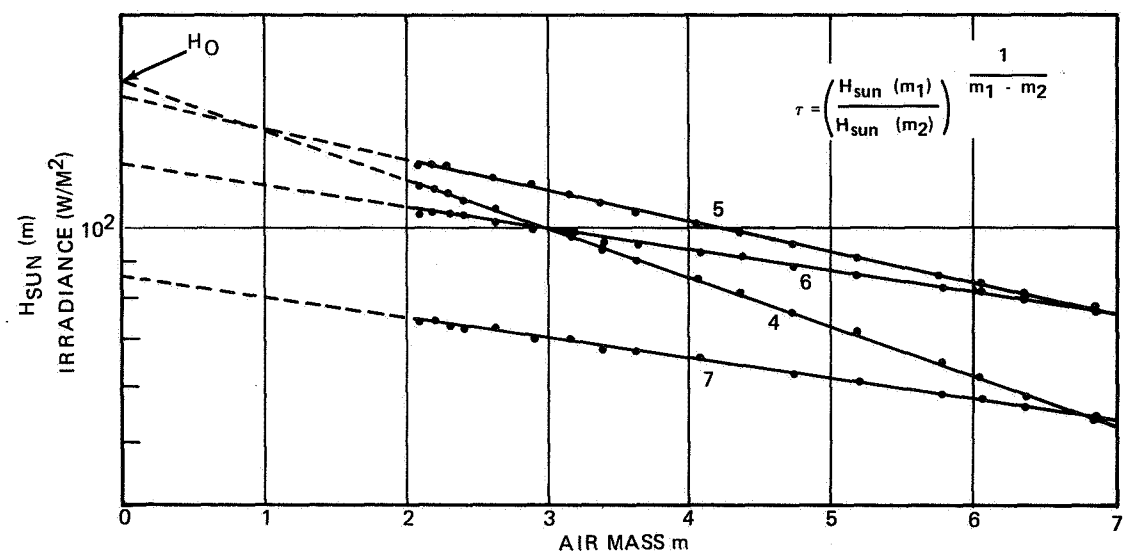


Figure 2 Atmospheric Extinction Curves

Figure 3A shows RPMI sky radiance measurements as a function of scattering angle ϕ and air mass. Each of the solid lines was obtained by pointing the RPMI at the sun and then sweeping it in azimuth, taking readings at 20° intervals for a particular elevation angle. The broken line was produced by taking readings at different elevation angles from the sun for zero azimuth. The scattering angle, ϕ, is found from:

$$\cos \phi = \sin \theta \sin \beta \cos \alpha + \cos \theta \cos \beta \tag{4}$$

in which θ is the solar zenith angle, β is the zenith angle of the observation, and α is the azimuth measured from the sun. The air masses given in Figure 3A are the values in the direction of the observation. The air mass is continuously variable along the broken curve.

The atmospheric scattering along the line of sight should be proportional to $(1 - \tau^m)$ in which τ is the atmospheric transmission for one air mass and τ^m is the transmission of air mass m. Thus, if the RPMI radiance measurement L_{meas} is taken at a scattering angle equal to the scattering angle to the ERTS, the path radiance seen by ERTS should be related by:

$$L_{ATM} = L_{meas} \left[\frac{1 - \tau}{1 - \tau^m}\right] \tag{5}$$

assuming the spacecraft is looking vertically through one air mass. This formula has been used by S.Q. Duntley, C.F. Edgerton, and others.

The validity of this formula was checked by multiplying the data in Figure 3A by the term containing τ in equation (5), using a value of τ determined from its extinction curve. The results are shown in Figure 3B. The radiance variation at any angle is only ±5%, which is within the measurement errors. These results can be used to give the atmospheric radiance seen by ERTS by selecting the correct scattering angle. These observations are continuing in order to determine the repeatability of the curves and the accuracy if measurements at only one or two angles are used to determine L_{ATM}.

4. EXAMPLE OF ERTS DATA CORRECTION

Since the completion of the RPMIs, local weather conditions have prevented atmospheric observations on the day of an ERTS overpass. Thus, the following comparison of atmospheric data from 12 Feb 1973 with ERTS data from 28 Sept 1972 is only to demonstrate the magnitude of the corrections and is not intended to be an accurate analysis.

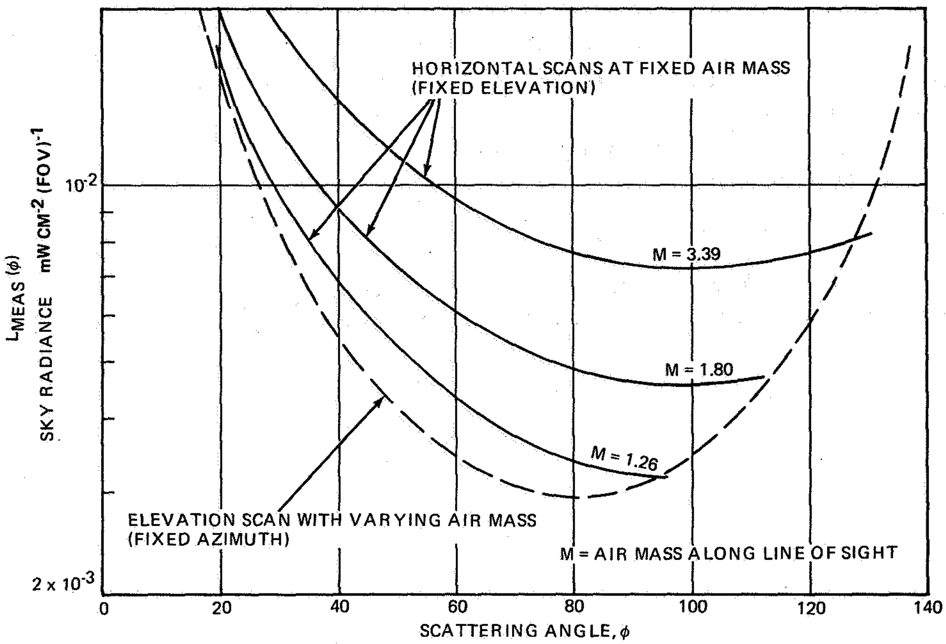


Figure 3A Atmospheric Radiance: Band 4

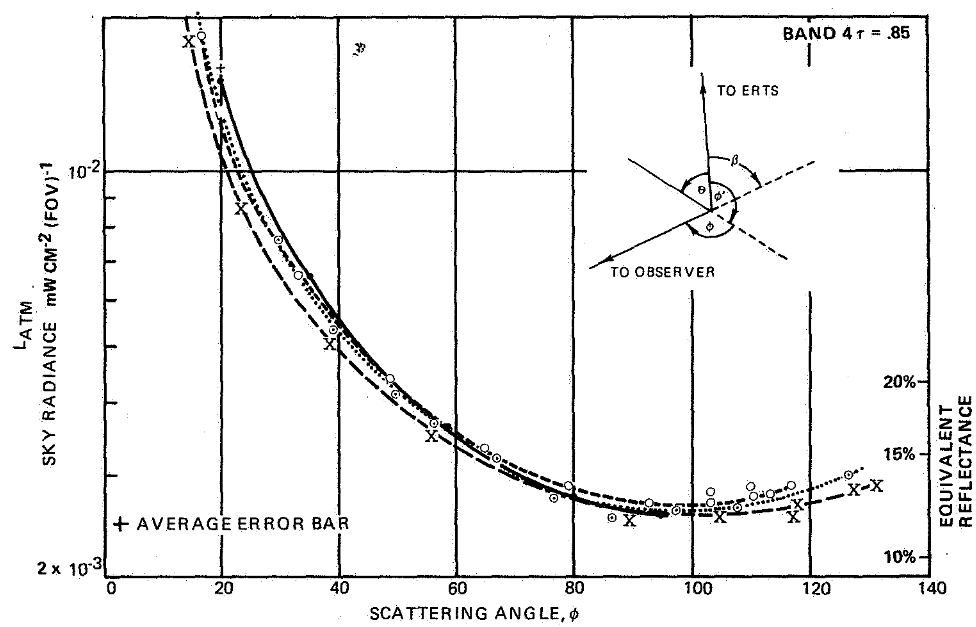


Figure 3B Scattering Data Corrected for Air Mass

Values of ERTS atmospheric path radiance were derived from data taken at Bendix in Ann Arbor, Michigan on 12 Feb 1973. Using the procedure described above, the RPMI sky radiance measurements, L_{meas}, were corrected to one air mass, and the corrected values in each of the four ERTS MSS bands were plotted as a function of the scattering angle. For a scattering angle of 131° (solar zenith angle 49°) to the ERTS, the values of L_{ATM} computed for bands 4 to 7 are listed in Table 1. These have also been converted to bit equivalents based on 7-bit levels for bands 4, 5, and 6, and a 6-bit level for band 7. The table also lists the atmospheric path radiance signal as a percentage of the full scale ERTS channel reading.

Listed in the last two columns of Table 1 are radiance values taken from ERTS data for 28 Sept 1972. The first is for water and the second is a low-lying area near the Huron River in Ann Arbor. For water, it is noted from the table that over 50% of the signal received by the spacecraft is atmospheric path radiance.

Table 2 summarizes the additional data necessary for the calculations of target reflectances. The values of H_o and τ are derived from the extinction curve as described in Section 3 using data from 12 Feb 1973. The global irradiance H is derived from the previous equation 2 using a typical measured value of sky irradiance H_{sky}. Finally, the data were used to calculate the reflectance of the target using equation (1). The results are now absolute values and are free of atmospheric and solar effects. Examples of two different targets, a small lake and a low-lying river bank, are given in Table 2.

Table 1 Atmospheric Radiance Values

Band	L_{ATM} (mW/cm^2-sr)	Bit Equivalent	% Full Scale	ERTS Data (mW/cm^2-sr) Barton Pond	Bank of River
4	0.274	14	11	0.476	0.508
5	0.118	7.5	5.9	0.242	0.276
6	0.082	6	4.7	0.141	0.402
7	0.1062	1.5	2.4	0.234	1.10

Table 2 Calculation of Target Reflectivity

Band	H_o (mW/cm^2)	τ	Global Irradiance (mW/cm^2)	Target Reflectivity	
				Barton Pond (%)	River Bank (%)
4	15.05	0.81	8.41	9.3	10.8
5	13.98	0.865	8.14	5.5	7.5
6	12.00	0.909	7.38	2.8	15
7	8.57	0.913	5.02	0.9	6.8

5. SUMMARY

Solar and atmospheric parameters degrade the radiometric fidelity of ERTS data by large amounts. Without direct measurements, the unknown atmospheric transmission, target irradiance, and sky radiance prevent the measurement of absolute target reflectance. Preliminary results indicate that the RPMI will provide a straightforward, low-cost procedure that could be employed by all PIs to obtain the needed radiometric calibration of ERTS data, thus making accurate, unambiguous interpretations possible. The ERTS-1 experiment will determine the best procedures and techniques using RPMI to obtain the needed solar and atmospheric parameters, and will utilize the performance achieved by RPMI as a baseline to evaluate alternative calibration techniques.

It is hoped that the results of this investigation will support NASA in its continuing effort to identify and bring together the most cost-effective grouping of instruments and techniques to achieve radiometric calibration of ERTS data gathered on a world-wide basis.