IN-FLIGHT ABSOLUTE RADIOMETRIC CALIBRATION OF THE THEMATIC MAPPER

K.R. Castle, R.G. Holm, C.J. Kastner, J.M. Palmer, and P.N. Slater

Optical Sciences Center
University of Arizona
Tucson, Arizona 85721, USA

M. Dinguirard

Center d'Etudes et de Recherches de Toulouse
2, Avenue Edouard-Belin
31055 Toulouse, Cedex, FRANCE

C.E. Ezra and R.D. Jackson
Agricultural Research Service
U.S. Department of Agriculture
Phoenix, AZ 85040, USA

R. Savage
Atmospheric Sciences Laboratory
White Sands Missile Range, NM 88002, USA

(E84-10064) IN-FLIGHT ABSOLUTE RADIOMETRIC CALIBRATION OF THE THEMATIC MAPPER (Arizona Univ., Tucson.) 10 p HC A02/MF A01 CSCL 14B

N84-15633

Unclas
G3/43 00064

The Thematic Mapper (TM) multispectral scanner system was placed into earth orbit on July 16, 1982 as part of NASA's Landsat-4 payload. The entire system was calibrated in an absolute sense at Santa Barbara Research Center before launch.[1,2] During flight, an internal calibration system is used to monitor the calibration of the focal plane.[3] In order to determine temporal changes of the absolute radiometric calibration of the entire system in flight, we initiated a program at White Sands, New Mexico, on January 3, 1983, to make spectroradiometric measurements of the ground and the atmosphere simultaneously with TM image collections over that area.[4] By entering the measured values in an atmospheric radiative transfer program,[5] the radiance levels in four of the spectral bands of the TM were determined, band 1: 0.45-0.52µm, band 2: 0.53-0.61µm, band 3: 0.62-0.70µm and band 4: 0.76-0.91µm. These levels were compared to the output digital counts from the detectors that sampled the radiometrically measured ground area, thus providing an absolute radiometric calibration of the entire TM system utilizing those detectors.

On 3 January 1983, an 80 mm layer of two-day-old snow covered the flat gypsum surface at the White Sands Missile Range. The reflectance of the snow was measured by reference to a 1.2 m square barium sulfate panel using a Barnes Modular Multispectral 8-Channel Radiometer, that collected radiant flux simultaneously in all the TM spectral bands over a total field angle of 15°. The instrument was mounted on a rotatable boom 2.5 m above the snow to allow an average reflectance value to be determined for an area of about 0.5 x 5 m. The measurements were made at 10.08 hours coinciding with the overpass of the TM and a solar zenith angle of 60°. When ratioed to the reflectance of the barium sulfate panel at 60°, the reflectance of the snow in TM bands 1 to 4 was found to be 0.769, 0.761, 0.756 and 0.732 respectively, with an rms uncertainty of ±0.023 in all cases.

A solar radiometer[6] using nine 10-nm spectral bands in the visible and near ir was used to determine the total spectral optical depths τ_T at these nine wavelengths. The measured barometric pressure of 889.5 mB allowed the Rayleigh spectral optical depth τ_{Ray} to be determined. From these data the Mie and ozone spectral optical depths were determined.

In bands 1, 2, and 3, the component of τ_T due to molecular absorption, τ_{abs}, is entirely due to ozone. Water vapor and CO_2 are present in addition to ozone in band 4. Their effects have been included in Table 1 which lists the values of the various atmospheric constituents in bands 1 through 4.

Table 1. Atmospheric values.

Band	λ_c(μm)	τ_T	τ_{Mie}	τ_{Ray}	τ_{abs}
1	0.485	0.2913	0.1475	0.1424	0.0014
2	0.57	0.2177	0.1382	0.0736	0.0059
3	0.66	0.1718	0.1282	0.0406	0.0030
4	0.84	0.1344	0.1099	0.0153	0.0092

Using the data in Table 1 as input to the radiative transfer code, the following quantities were calculated:

$E_{D,Dir}$: the direct solar irradiance at the ground = $\cos\theta_z \exp(-\tau_T \sec\theta_z)$
$E_{D,Dif}$: the diffuse solar irradiance at the ground
L_{Dir}: the direct radiance at the TM due to $E_{D,Dir} + E_{D,Dif}$
L_p: the path radiance at the TM = $L_T - (E_{D,Dir} + E_{D,Dif}) \frac{\rho}{\pi} \exp(-\tau_T \sec 5°)$
L_T: the total radiance at the TM

Table 2. Irradiances and radiances (normalized to unity solar exoatmospheric irradiance).

Band	Solar Zenith Angle	$E_{D,Dir}$	$E_{D,Dif}$	L_{Dir}	L_p	L_T
1	55°	0.345	0.185	0.097	0.033	0.1301
	65°	0.212	0.152	0.067	0.025	0.092
2	55°	0.392	0.145	0.105	0.024	0.129
	65°	0.253	0.122	0.043	0.019	0.092
3	55°	0.425	0.122	0.111	0.019	0.130
	65°	0.282	0.104	0.078	0.015	0.093
4	55°	0.454	0.095	0.112	0.014	0.126
	65°	0.308	0.082	0.079	0.011	0.090

Using the equivalent passband technique of Palmer and Tomasko[7] and the exoatmospheric solar spectral irradiance values of Neckel and Labs,[8] the values for the exoatmospheric irradiances within the TM passbands ($E\times\Delta\lambda$), were calculated for the earth-sun distance on January 3. The required values of L_T for the solar zenith angle of 60° were found by interpolating between the 55° and 65° data from Table 2. These, when multiplied by their corresponding $E\times\Delta\lambda$ values, gave the radiances in mW/cm^2-sr in the TM passbands listed in Table 3.

Table 3. Exoatmospheric irradiances and the radiances at the TM in the TM passbands.

Band	Equivalent bandwidth in μm	$E x \Delta\lambda$ mW/cm^2	L_T mW/cm^2-sr
1	0.0712	12.2	1.36
2	0.0884	13.8	1.52
3	0.0773	10.7	1.19
4	0.1345	13.7	1.47

By identifying our site on the raw image data, we determined which detectors scanned the area and how many samples each collected. Detectors 1, 2, 3, 15 and 16 collected 5, 3, 1, 2, and 4 samples respectively. We found the average digital count for each detector, then calculated the average detector spectral radiance using offset and gain values reported by Barker et al.[1] These spectral radiances were multiplied by the number of samples for each detector. The resultant products were added and then divided by the total number of samples, 15. Thus we derived a value for the average spectral radiance of our site as measured by the TM, proportionally weighted according to the number of samples per detector.

The final step in the calculation was to multiply the average spectral radiance at the TM by the equivalent passband to determine the radiance within each TM band (Table 3). These values are compared in Tables 4, 5 and 6.

Table 4. Calculation of radiance in TM band 2 from preflight calibration data[1] and comparison with inflight White Sands data.

Detector	Average Count	Average Spectral Radiance	Gain	Offset
3	139.0	17.04	8.014	2.41
2	143.7	17.42	8.117	2.33
1	146.2	17.52	8.174	2.99
16	141.5	17.43	7.979	2.43
15	147.5	17.71	8.195	2.83

Weighted average = 17.47 mW cm^{-2} sr^{-1} μm^{-1}
Equivalent band radiance from weighted average = 1.537 mW cm^{-2} sr^{-1}
Equivalent band radiance from Table 3 = 1.52 mW cm^{-2} sr^{-1}
Agreement = -1.0% and +2.5% with reference to preflight calibration and December 8, 1982 inflight data[2] respectively.

Table 5. Calculation of radiance in TM band 3 from preflight calibration data[1] and comparison with inflight White Sands data.

Detector	Average Count	Average Spectral Radiance	Gain	Offset
3	165.0	15.40	10.590	1.89
2	169.7	15.86	10.602	1.57
1	171.6	15.73	10.777	2.13
16	167.8	15.85	10.484	1.63
15	172.5	15.88	10.769	1.53

Weighted average = 15.78 mW cm^{-2} sr^{-1} μm^{-1}
Equivalent band radiance from weighted average = 1.215 mW cm^{-2} sr^{-1}
Equivalent band radiance from Table 3 = 1.19 mW cm^{-2} sr^{-1}
Agreement = -1.8% and 3.0% with reference to preflight and December 8, 1982 inflight data[2] respectively.

Table 6. Calculation of radiance in TM band 4 from preflight calibration data[1] and comparison with inflight White Sands data.

Detector	Average Count	Average Spectral Radiance	Gain	Offset
3	133.0	11.89	11.019	1.96
2	132.0	12.02	10.817	1.94
1	134.2	12.00	10.972	2.53
16	132.0	12.01	10.828	2.00
15	131.5	12.05	10.771	1.69

Weighted average = 12.01 $mWcm^{-2}\ sr^{-1}\ \mu m^{-1}$
Equivalent band radiance from weighted average = 1.609 $mWcm^{-2}\ sr^{-1}$
Equivalent band radiance from Table 3 = 1.47 $mWcm^{-2}\ sr^{-1}$
Agreement = -8.5% and -5.6% with reference to preflight and December 8, 1982 inflight data[2] respectively.

Because of the limitations of the instruments used on January 3, τ_{abs} in band 4 due to water vapor and CO_2 could not be measured. Instead, the LOWTRAN code was used to compute the water vapor and CO_2 transmittances across band 4 at 5 cm^{-1} intervals. The water vapor transmittance was scaled, to account for the 44% relative humidity measured at White Sands on January 3, then averaged to find $\tau_{H_2O+CO_2}$. Finally, the measured value of τ_{oz} = 0.0003 was added to provide τ_{abs}. The effect of an error in this estimate can be judged by noting that the inclusion of water vapor and CO_2 lowered the predicted radiance level at the TM by only 2%.

Band 1 saturated over the snow field at White Sands. Pre-flight data[1] indicate that a saturation level of 255 counts corresponds to a radiance at the sensor of 1.14 $mWcm^{-2}sr^{-1}$ in TM band 1. Our estimate is that the snowfield provided a radiance level of 1.36 $mWcm^{-2}sr^{-1}$ at the sensor.

The estimated uncertainty in the results of this first measurement is ±5%, while the estimated uncertainty in the preflight calibration is no better than ±6%.[1,9] We are encouraged that our results for TM bands 2, 3 and 4 fall between 1% and 8.5% of the preflight measurements and between 2.5% and 5.6% of the December 8, 1982 inflight data.

We are presently fabricating field equipment to provide more detailed and accurate measurements of the surface and atmosphere at White Sands. Our goal is to reduce the uncertainty in sensor absolute calibration to less than ±3%. We plan to continue the work described here to include the inflight absolute radiometric calibration of the second TM and the Système Probatoire d'Observation de la Terre, Haute Résolution Visible (SPOT/HRV) systems.

We wish to thank B.M. Herman for the use of his radiative transfer code and J.A. Reagan for the use of his solar radiometer. The University of Arizona authors wish to acknowledge support from NASA contract number NAS5-27382, J.L. Barker, Science Representative, and the USDA, broadform contract number 12-14-5001-38.

REFERENCES

1. Barker, J. L., D. L. Ball, K. C. Leung, and J. A. Walker, "Prelaunch absolute radiometric calibration of the reflective bands on the Landsat-4 protoflight thematic mapper." Proceedings of the Landsat-4 Early Results Symposium, NASA Goddard Space Flight Center, in press, (1983).

2. Barker, J. L., R. B. Abrams, D. L. Ball, and K. C. Leung, "Characterization of Radiometric Calibration of Landsat-4 TM reflective bands." Proceedings of the Landsat-4 Early Results Symposium. NASA Goddard space Flight Center, in press, (1983).

3. Slater, P. N., "A review of radiometric calibration problems." Proc. Int'l Coll. on spectral signatures of objects in remote sensing, Bordeaux, France. In press. (1983).

4. Kastner, C. J. and P. N. Slater, "In-flight radiometric calibration of advanced remote sensing systems." Proc. SPIE Symposium, <u>Field Measurement and Calibration Using Electro-Optical Equipment: Issues and Requirements</u> 356, pp. 158-165, (1982).

5. Herman, B. M. and S. R. Browning, "The effect of aerosols on the earth-atmosphere albedo." <u>J. Atmos. Sci</u>, 32, 1430, (1975).

6. Shaw, G. E., J. A. Reagan, B. M. Herman, "Investigations of atmospheric extinction using direct solar radiation measurements made with a multiple wavelength radiometer." <u>J. Appl. Meteor</u>, 12, 374, (1973).

7. Palmer, J. M. and M. G. Tomasko, "Broadband radiometry with spectrally selective detectors." Optics Letters, 5, pp. 208-210 (1980).

8. Neckel, H. and D. Labs, "Improved data of solar spectral irradiance from 0.33 to 1.25 μm." Solar Phys. 74, 231 (1981).

9. Norwood, V. T. and J. C. Lansing, Jr., "Electro-optical imaging sensors." Chapter 8 in Manual of Remote Sensing, 2nd ed., ed. R. N. Colwell, 367, (1983).