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EFFECTS OF ATMOSPHERE, TEMPERATURE AND EMITTANCE ON REFLECTED AND EMITTED ENERGY

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Abstract

The purpose of this work was to study the effects of temperature and emittance on the relative magnitude of reflected energy and emitted energy from a target including atmospheric effects. From the calculations of energy reflected and emitted from a target including atmospheric effects using LOWTRAN 3 program for Midlatitude Summer model, the following conclusions were obtained: At 3.5 μm, q (energy emitted by a target/energy reflected from it) << 1 except at high temperatures and for high emittance. At 4 μm, q is of the order of magnitude = 1 for most targets. At 4.6 μm, q >> 1 at high temperatures and high emittance. In addition, incident atmospheric emission reflected from the target was found to be negligible except for targets having low temperature and low emittance. Previously acquired field spectroradiometric data on soils in 4 to 14 μm were found to agree closely with the theoretical calculations of reflected and emitted energy.

A part of this work was done at and sponsored by the Canada Centre for Remote Sensing, Dept. of Energy, Mines and Resources, Ottawa, Canada. Experimental spectroradiometric data were available through the Laboratory for Applications of Remote Sensing, Purdue University, W. Lafayette, Indiana under Grant No. NGL 15-005-112 of the National Aeronautics and Space Administration.

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Introduction

The purpose of this work was to study the effects of temperature and emittance on the relative magnitude of energy reflected and energy emitted from a natural target, taking into account atmospheric effects. In addition, previously acquired spectroradiometric data were compared with the theoretical calculations.

Determination of Atmospheric Transmittance

A literature review of the techniques for determining transmittance of the atmosphere was done. There have been innumerable investigations from which methods are derived for calculating atmospheric transmittance[1]. However, most of these are especially designed for a singular purpose and not directly useful to the general community of persons interested in solving atmospheric transmittance problems. The general categories of calculations of atmospheric transmittance are: the direct integration or line-by-line method, the empirical methods using one or two parameters and the multiparameter analytical methods. Even with the time-saving approximations applied to the line-by-line calculation, the costs are often excessive. In addition, line-by-line calculation gives quite accurate results; however considering the magnitude of errors and uncertainties involved in the multispectral scanner (MSS) data applicable to earth resources, such accuracy is really not required. Out of these categories, empirical methods are most suitable for correcting MSS data applicable to earth resources. Out of the empirical methods investigated, LOWTRAN 3 program[2] developed by the Airforce Geophysics Laboratories (formerly Airforce Cambridge Research Laboratories) was found to be the most suitable for our purpose. The LOWTRAN 3 program is strictly empirical and calculates the transmittance (averaged over a 0.014 μm interval) for a given atmospheric path from sea level to 100 km in the wavelength range 0.25 to 28.5 μm for six model[3] atmospheres (1962 U.S. Standard Atmosphere, Tropical (15° N), Midlatitude Summer (45° N, July), Midlatitude Winter (45° N, January), Subarctic Summer (60° N, July), and Subarctic Winter (60° N, January) and two aerosol models based on measurements of continental aerosols under moderate visibility conditions (5 km and 23 km at sea level). This program is reasonably accurate, user oriented, computationally very efficient, well documented and revised by Airforce Geophysics Laboratories at regular periods of times based on recent laboratory measurements and theoretical calculations. Aggregate method developed by the Environmental Research Institute of Michigan is also suitable for our purpose but this method does not cover the visible wavelength region, is not well documented and is computationally more time consuming than the LOWTRAN 3 method. LOWTRAN 3 program accounts for molecular absorption, molecular scattering, and aerosol extinction. Refraction and earth curvature effects are also included. In addition to these model atmospheres, the user has the option of inserting his own model atmosphere (specifically designed for direct insertion of radiosonde data) or of building another model by combining various parts of the six standard models. The main assumptions made in the model are that the atmosphere can be represented by a 33 layer model, and that the average transmittance over a 20 cm^{-1} interval (due to molecular absorption) can be represented by a single parameter model of the form

$$\bar{\tau} = f\,(C_\nu W^*) \qquad (1)$$

where C_ν is a wavelength (or wavenumber) dependent absorption coefficient and W^* is an "equivalent absorber amount" for the atmospheric path, which is defined in terms of pressure, temperature, concentration of absorber and an empirical constant, n. The atmospheric constituents considered are uniformly mixed gases (CO_2, N_2O, CH_4, CO, and O_2), nitrogen, water vapor, ozone and water vapor continuum.

Method of Calculation and Results

Experimental calibrated data of Exotech Model 20 C spectroradiometer (described in the later part of the paper) on corn plants taken during summer of 1972 in the Purdue University Agronomy Farm, W. Lafayette, Indiana were available. The solar energy incident on the target was calculated knowing the zenith angle of the sun at the time of acquiring spectroradiometric data and applying corrections for atmospheric effects using the LOWTRAN 3 program for the Midlatitude Summer Model. Assuming diffuse reflectance and emittance of the target and applying Kirchhoff's Law, the energy reflected and emitted from the target was calculated for ranges of temperature and emittance of 230°K to 330°K and 0.20 to 0.90 respectively at 3.5 μm, 4 μm and 4.6 μm. The plot of ratio of the solar energy reflected from the target to the energy emitted by the target (p) at 3.5 μm is plotted against temperature of the target in Fig. 1. The following conclusions are obtained for most natural targets in the temperature interval 0 to 40°C. Fig. 1 shows that the energy reflected from a natural target is considerably more than the energy emitted by it. However, the energy emitted by the target cannot be neglected compared to the energy reflected from it except at extremely low temperatures and for low emittance. Note that in Figs. 2 and 3, q (q = 1/p) is plotted instead of p as in Fig. 1. Fig. 2 shows that both the energy reflected as well as emitted from a target should be taken into account at 4 μm. This is why it is difficult to interpret aircraft and/or satellite data around this wavelength. Fig. 3 shows that although the energy reflected from a target is smaller as compared to the energy emitted from it, the reflected energy cannot be safely neglected except at high temperatures and high emittance. For a given temperature and emittance, an enormous change in the value of p in Figs. 1 to 3 should be noted.

To create an illustration of the incident atmospheric emission reflected from the natural target, the downward spectral radiance from a clear sky was calculated for the Midlatitude Winter Model at 8 μm using the following equation:

$$L(\lambda) = \sum_{i=1}^{33} L_{bb}(\lambda, T_i)\, \epsilon_i(\lambda)\, \tau(\lambda)_{ig}$$

where summation is done for 33 layers of Midlatitude Winter Model

$L_{bb}(\lambda, T_i)$ = blackbody spectral radiance at wavelength λ and temperature T_i

T_i = temperature of the i^{th} layer of the atmosphere

$\tau(\lambda)_{ig}$ = transmission of the atmosphere from i^{th} layer to ground

$\epsilon_i(\lambda)$ = $\alpha_i(\lambda)$ |Kirchhoff's Law where $\alpha_i(\lambda)$ = spectral absorptance|

$\tau(\lambda)_{ig}$ and $\alpha_i(\lambda)$ were calculated using LOWTRAN 3 program. Assuming diffuse reflectance and emittance of the target and applying Kirchhoff's Law, the incident atmospheric emission reflected from the target and energy emitted by the target were calculated for ranges of temperature and emittance of 230°K to 330°K and 0.2 to 0.9 respectively. Fig. 4 shows a plot of q (radiation emitted by the target to the incident atmospheric emission reflected from the target) at 8 μm vs. temperature of the target (T) for values of emittance ranging from 0.2 to 0.9. It shows that the incident atmospheric emission reflected from the target can be neglected as compared to the energy emitted by the target for most natural targets. However, for targets having low temperatures and low emittance, incident atmospheric

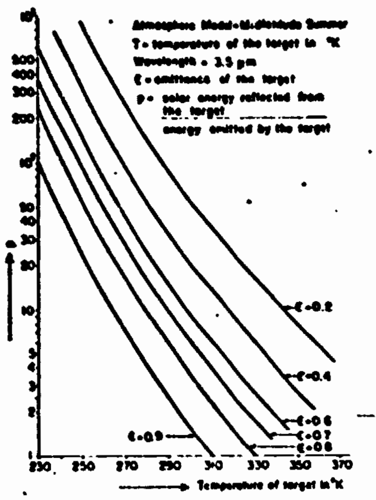

Fig. 1 Relative magnitudes of reflected solar energy and emitted energy from a target at 3.5 μm

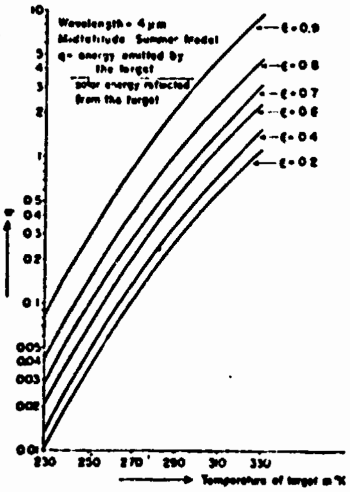

Fig. 2 Relative magnitudes of emitted and reflected solar energy from a target at 4 μm

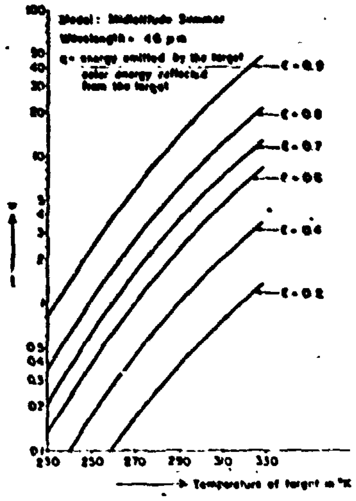

Fig. 3 Relative magnitudes of emitted and reflected solar energy from a target at 4.6 μm

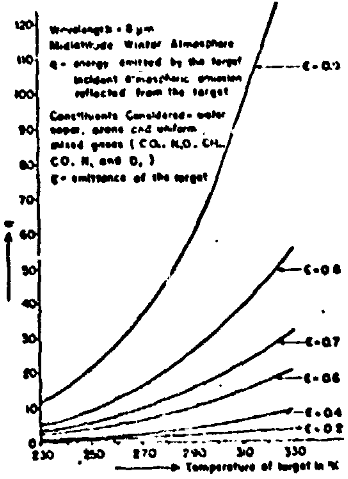

Fig. 4 Relative magnitudes of energy emitted by the target and incident atmospheric emission reflected from the target at 8 μm

emission reflected from the target may not be safely neglected. Calculations of incident atmospheric emission for many model atmospheres in the thermal infrared wavelength region are being done.

Comparison of Theoretical Calculations with Experimental Results

As pointed out earlier, previously acquired spectroradiometric data on corn plants and soils, in the wavelength ranges 2.8 to 5.6 μm and 7 to 14 μm, were available for comparing theoretical calculations with the experimental results[4]. These experimental data were acquired by the Exotech Model 20-C spectroradiometer. The Exotech Model 20-C spectroradiometer is a rugged field instrument which has four circular - variable - filters to provide spectral resolution ($\Delta\lambda/\lambda$) of approximately two percent[5,6]. This instrument is ideally suited to the rigors of a field environment, embodying sealed circuits for protection against dust and condensation, modular construction modules for simplified maintenance, and operational features to reduce the time necessary to secure data. The instrument may be operated as two separate units: the short wavelength (SWL) unit and the long wavelength (LWL) unit. In this study, only the long wavelength unit (LWL) responsive to radiation in the wavelength ranges 2.8 to 5.6 μm and 7.0 to 14 μm was used. This spectroradiometer has two remotely selectable fields of views (F.O.V) - 0.75° and 15°. In this study, the experimental data was obtained with a F.O.V. of 15°. The Hi-Ranger mobile tower was used to lift the LWL head to about nine meters above the ground. The control electronics, recording equipment, and other data recording instruments are located in the instrument van. Further details of the Exotech Model 20C spectroradiometer are available in Robinson et. al.[6] and Silva et. al.[5] These data had been carefully calibrated in the field conditions. A data processing software system for calibrating spectral radiance and spectral radiance temperature of these data was available[4, 6].

As pointed out earlier, the solar energy incident on the target at the time of acquiring spectroradiometric data was calculated taking into account atmospheric effects using LOWTRAN 3 program for Midlatitude Summer model. Calibrated spectroradiometric data on Russell Silt Loam Soil taken during summer of 1972 in the Purdue University Agronomy Farm, W. Lafayette, Indiana were available.[4] The contact temperature of the soil measured by precision thermistor thermometer at the time of acquiring spectroradiometric data was available[4]. Assuming the soil to have a diffuse emittance of 0.9, knowing the contact temperature of the soil, and calculated value of incident solar energy, calculations of energy reflected as well as emitted from the soil were done using Kirchhoff's law. These values are compared with the experimental results of the spectroradiometer in Table 1. Table 1 shows that there is an excellent agreement between the experimental results and theoretical calculations in the wavelength intervals 3.6 to 3.9 μm and 3.9 to 4.15 μm. In 4.5 to 4.8 μm, 4.8 to 5.1 μm and 5.1 to 5.4 μm, the theoretical calculations give values a bit smaller than the experimental results because the incident atmospheric emission reflected from the soil was not included in the theoretical calculations. In addition, the spectral emittance of the soil was not known and assumption of gray emittance of 0.9 is questionable. In 3.6 to 3.9 μm and 3.9 to 4.15 μm, the incident atmospheric emission reflected from the soil is expected to be very small as compared to the solar energy reflected plus emitted from it, and thus there is a close agreement between the theoretical and experimental results in these wavelength intervals.

The work presented here helps in understanding interaction of radiation with the natural targets. It has application to the general area of remote sensing of agriculture and earth resources for it gives an estimate of the relative magnitudes of energy reflected and emitted from a natural target. The author gratefully acknowledges the assistance of Dr. Celso de Renna e Souza of Instituto de Pesquisas Espaciais (INPE / CNPq) for his assistance with this work.

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Table 1. Comparision of theoretical and experimental results

Wavelength Range	Energy emitted by the target	Solar energy reflected from the target	Energy emitted + reflected from the target	Energy received by the calibrated spectroradiometer
3.6 to 3.9 µm	0.6131	0.2386	0.8517	0.8570
3.9 to 4.15 µm	0.8258	0.1482	0.9740	0.9811
4.5 to 4.8 µm	2.2545	0.0617	2.3161	2.3744
4.8 to 5.1 µm	3.0070	0.0248	3.0318	3.1980
5.1 to 5.4 µm	3.8242	0.0019	3.8261	4.0359

Note: The target was assumed to be diffuse with emittance = 0.90 and reflectance = 0.10. Temperature of the target = 311°K. The energy is given in watts $cm^{-2} \times 10^{-4}$.

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