Holbo, H.R. 1988. Resource management applications for remotely sensed thermal images, Proc. Resource Technology 88: An International Symposium on Advanced Technology in Natural Resouces Management, 20-23 June 1988, Fort Collins, CO, Amer. Soc. for Photogram. and Remote Sens., Falls Church, VA. p.18-27.

1062

RESOURCE MANAGEMENT APPLICATIONS FOR REMOTELY SENSED THERMAL IMAGES

H.R. HOLBO
John C. Stennis Space Center
Earth Resources Laboratory (ERL)
National Aeronautics and Space Administration
Stennis Space Center (SSC), Mississippi 39529

ABSTRACT

Thermal imagery reveals surface features very differently than does conventional visible light or infrared imagery. A thermal image is primarily due to energy emitted from all surface elements in a scene by virtue of their individual temperatures. Unlike most remote sensing data products, a thermal image is not the result of sunlight reflecting from the surface elements. A thermal image is an instantaneous measure of the spatial distribution of surface temperatures, exhibiting details about the microclimate which can then be utilized to address many resource management questions.

Thermal images acquired with SSC-ERL's TIMS (Thermal Infrared Multispectral Scanner) or CAMS (Calibrated Airborne Multispectral Scanner) provide important new opportunities for natural resource managers. Applications of remotely sensed thermal imagery which could be developed include: avoiding or managing stressful microclimates (high temperature/low moisture) in plantation silviculture or cropland agriculture; frost protection planning for nurseries and orchards; watershed, crop, or forest evapotranspiration estimation; evaluation of thermal habitats of fish and wildlife (buffer strip effectiveness along mountain streams or in riparian zones); predicting nighttime airshed smoke impact regions during controlled burns; thermal recognition and classification of landscape types; predicting microclimatic change due to landscape type conversion (fire, logging); detection and delineation of micro-topographic terrain features (soil erosion control structures, locating archeological sites); and, assessment of vegetatively-moderated urban heat islands.

THERMAL REMOTE SENSING

1. Proxy versus actual thermal images.

A thermal image shows the distribution of temperatures within a scene in a manner analogous to the way that a visible image reveals a scene by the variability in the distribution of light reflecting from various surfaces. But there is often some confusion about how to evaluate the information content, in terms of natural resources management, of a remotely sensed thermal image. In part, this confusion persists because of changes which have occurred in thermal imaging technology, particularly changes affecting the spectral characteristics of the image.

When the idea of a temperature picture was first introduced, it involved the use of (near-)infrared-sensitive color film, with which it was possible to interpret certain colors in the image to the warmer and cooler parts of the scene. The film image really did not contain actual temperature measurements. Brighter reds in such images were often the result of the normally high near-infrared reflectivity of healthy vegetation. Conversely, darker reds were likely to appear when a plant was absorbing abnormally large amounts of infrared radiation from the sun, becoming warmer. Film images of this kind have been used to help foresters identify diseased trees, for example. And many natural resource management applications still depend on human interpretations of filmed images taken from aircraft.

But film cannot be made directly responsive to the region of the electromagnetic spectrum where surfaces of terrestrial temperatures emit energy, which is in the far-infrared wavelength range of 8 to 14 microns (u). The energy levels involved are much lower than in the visible part of the spectrum (0.4 to 0.7u). Film is limited to wavelengths shorter than about 1.2u. Film is not suited for image transmission by radio, nor for producing the digital files needed for computerized data processing and analysis.

Remote sensing imaging technology for each different region of the electromagnetic spectrum (e.g. visible, near-infrared, far-infrared, and microwave) depends on the utilization of spectrally-selective radiometric sensors to produce electrical signals which can be recorded on magnetic tape and/or transmitted to ground receivers for computer processing. Unlike film, these sensors do not provide an image directly. Instead, the image is constructed by successively scanning the scene line-by-line in much the same way that a picture is produced on a television screen. Multispectral line scanning refers to the simultaneous use of several detector/lens combinations to cover different portions of the electromagnetic spectrum, each portion being called a channel, or band. The sensors used in the thermal portion are optimized for response within the 8-14u thermal waveband. Most of these incorporate blackbody radiance standards, making them capable of producing accurate, calibrated measurements of the radiance in their field of view, i.e., an infrared thermometer.

2. Significance of thermal radiation to natural resources.

Thermal emissions from the land represent the net product of the way in which the vegetation, soils, water, snow, and ice respond to the energy from the sun and energy exchanges with earth's atmosphere. Thermal emissions data is essentially surface temperature data, and therefore contains critical information about evapotranspiration and the surface microclimate. These biophysical processes are extremely important to natural resources management; they determine the availability of water in the terrestrial environment, its vegetative productivity, and ultimately, the suitability of that environment for all life forms.

Three decades of basic research on the relationships between radiometrically-measured surface temperatures and the associated atmospheric and soils environments has unquestionably demonstrated the fundamental significance of thermal radiation processes to all natural resources, both renewable and non-renewable (Goward and Taranik 1986). In terms of natural resource management, however, the potentials for applications of thermal remote sensing technology to forestry, range management, watershed management, landscape ecology, urban planning, and other areas are largely unrealized, and remain to be developed.

THERMAL IMAGE ACQUISITION AND DATA PROCESSING

1. Operational thermal scanner instruments.

Stennis Space Center - Earth Resources Laboratory engineers have developed two remote sensing instrument packages that have exceptional thermal measurement capabilities. They are: the Thermal Infrared Multispectral Scanner, called TIMS (Palluconi and Meeks 1985); and, the Calibrated Airborne Multispectral Scanner, or CAMS. Both are aircraft-mounted scanners.

TIMS has 6 spectral channels, all in the thermal wavelength region of the spectrum from 8.2 to 11.6 microns (u). This region of the spectrum brackets the wavelengths where emissions from surfaces with temperatures from -23°C to 80°C will be greatest. TIMS has multiple thermal channels primarily to allow discriminating between lithologic units in the resultant images for geological mapping purposes (Kahle 1987). Most renewable natural resource applications would need only one thermal channel.

CAMS has 9 channels, one of which is in the thermal region from 10.5 to 12.5u. CAMS has 4 contiguous channels in the visible portion of the spectrum from 0.45 to 0.69u, and 4 in the (near-)infrared region of the spectrum from 0.69 to 2.35u.

Each has a field of view of 0.12°, affording excellent spatial resolution. Depending on flightline altitude above terrain, TIMS and CAMS can provide spatial resolutions (pixel sizes) from 5 to 30 meters. For natural resources or landscape ecology applications, 5 meters is a very useful spatial scale. It is about the size of many plant crowns and canopy openings, assuring good correspondence with many features of land management interest.

Since these 2 ERL instruments are deployed on aircraft, flightlines can be repeated at intervals of a few minutes, and measures of surface temperature change of the same ground locations can be acquired. This can be a very useful temporal scale for re-sampling surface processes, such as cooling or heating rates.

2. Instrument calibration, data resolution and accuracy.

Both TIMS and CAMS incorporate 2 blackbody references maintaining calibration of the thermal scanner data to within 0.1°C during operation. Readings from these 2 standards become part of the data record. The blackbodies are set to bracket the expected surface temperature range to enable optimizing signal resolution before digitizing.

The resolution of the digital data from both TIMS and CAMS is 8 bits, or 1 part in 256 (0.39%). Over a bracketed range of 10°C to 60°C, this translates to a temperature resolution (or precision) of about 0.2°C. The result is that TIMS and CAMS can acquire images with a typical precision of 0.2°C. When corrections for atmospheric attenuations and emissions are applied, surface temperature inaccuracies as small as 0.5°C can be realized.

3. Compensating for the atmospheric pathway.

Although the atmosphere is nearly transparent in the 8-14u region, accurate surface temperatures can be achieved only when corrections for atmospheric attenuation and emission of thermal radiance are applied. The atmospheric correction is accomplished using air temperature and humidity measurements made from a radiosonde, launched just prior to, or after, the imaging mission. Corrections for atmospheric radiance effects in the pathway between the surface and the instrument can be made using the LOWTRAN-6 algorithm (Kneizcys et al. 1983; Anderson 1985). The effect of not performing this correction is a pronounced compression of surface temperature values, comparable to the diminished visual contrast evident in distant scenes. If uncorrected, atmosheric effects place unacceptable limitations on the biophysical relevance of the image data.

NATURAL RESOURCE MANAGEMENT APPLICATIONS

Figure 1 illustrates the type of thermal images that might be acquired from a mountainous, forested landscape. The 2 scenes shown in the figure are from the H.J. Andrews Experimental Forest in western Oregon, one taken at noon, the other, shortly after sunset on 5 August 1985. Lighter portions of the images represent warmer temperatures, darker parts are cooler. The dominant feature in these images are the patches which have been clearcut logged.

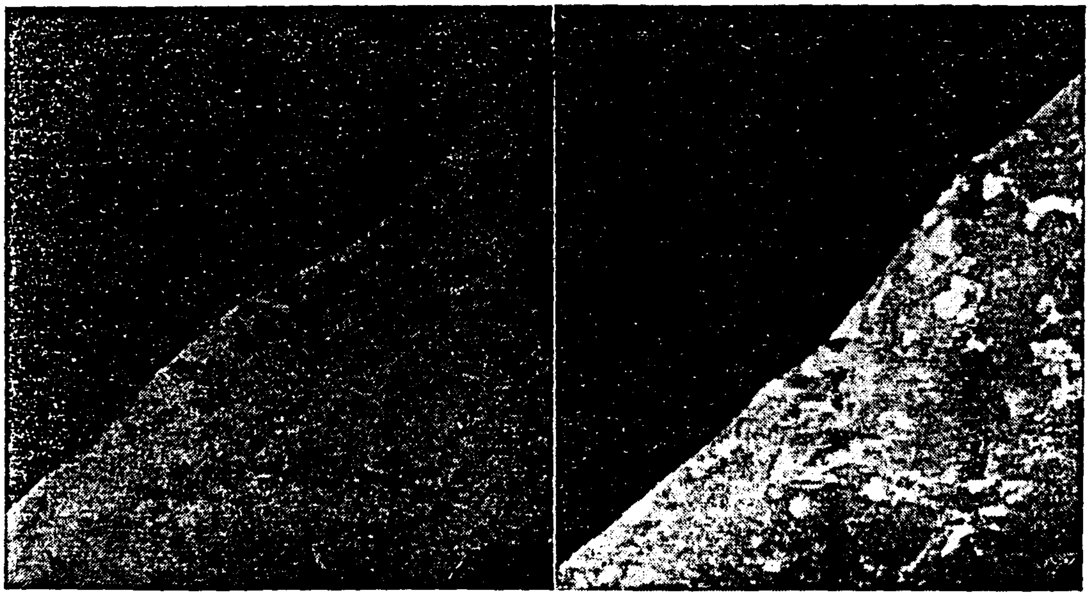

FIGURE 1. Night (left) and day (right) thermal images of a forested landscape. North is up; flightline azimuth, N45E.

1. Avoiding or managing microclimatic extremes.

Surface temperature is of decisive importance to many ecological processes. It, together with moisture availability, act to encourage or restrict the initiation of plant life on a site. Until the advent of spatial surface temperature sampling by instruments like TIMS and CAMS, management of the microclimate of plant establishment largely depended upon relationships based on air temperature measurements. But air temperature is far more conservatively behaved, and rarely reveals the true extremes experienced by plants (and animals) at the surface.

Plantation forestry is one area where avoidance of surface temperature extremes seems to be critical to the success of reforestation efforts (Childs et al.1985). The experienced manager may have intuitive beliefs about this type of environment. But the example shown in Figure 2 illustrates how a site-specific investigation, using measurements provided by TIMS, can quantify it, objectively improving the land manager's interpretive ability of the situation.

Figure 2 is a series of 4 temperature transects, 2 daytime (thermal image acquisitions separated by 28 minutes) and 2 just after sunset at night (separated by 12 minutes), across one of the clearcuts (SNOWBRUSH) in Fig. 1. Each transect covers the same ground, different only in the time of imaging. Each begins in the forest at the edge of the clearcut, across its logged and burned southwest slope, through an isolated stand of mature Douglas-fir, across a flatter part of the same clearcut, and then across a 15-year-old Douglas-fir plantation. Each point along the transect represents the average temperature of a 10m by 10m patch (the pixel size for this dataset) of surface.

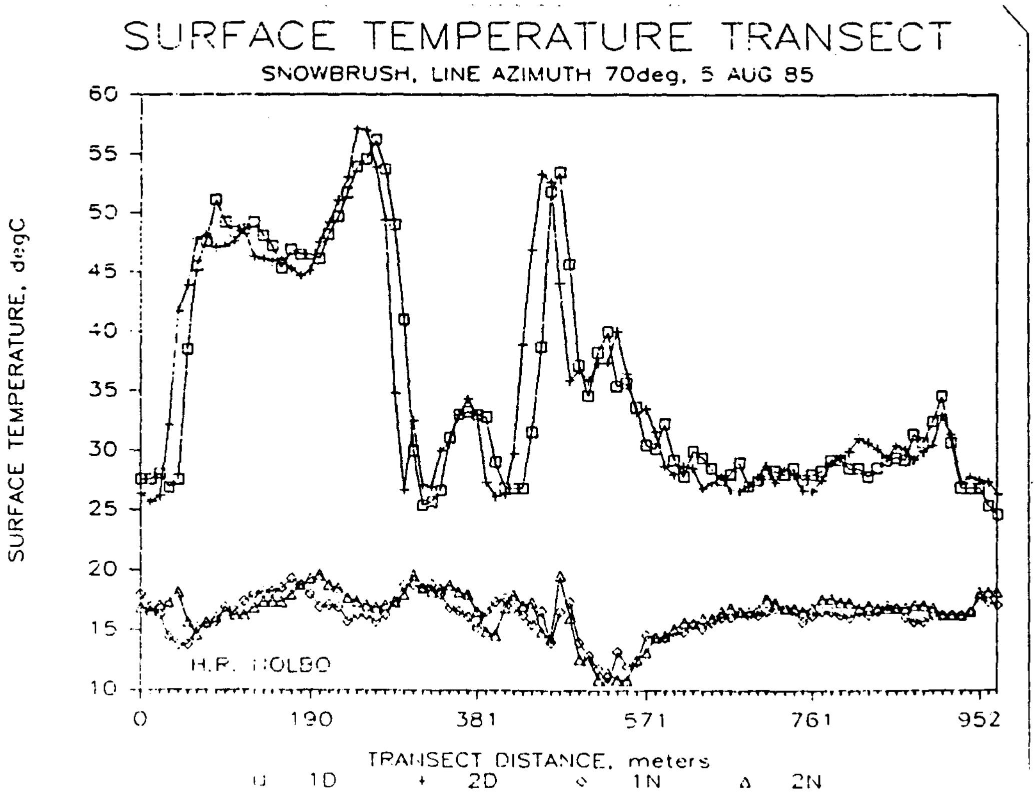

FIGURE 2.

In Fig. 2, notice that the surface temperature transitions across the abrupt boundaries between forest and clearcut are seen to be about 30m in length. Imagine how difficult would it otherwise be to quantify this "edge effect" with ground-based sampling. It is of interest that a meteorological station on the same clearcut measured average air temperatures (at 2m height) of 25°C during the daytime imaging overflights, and 14°C during the nighttime imaging. Yet, nearly all points along the transect were warmer than the daytime air temperature, with a few exceeding 55°C. At night, most points were slightly warmer than the air, with a small section along the transect dropping to nearly 10°C. This section seems to indicate the onset of cold air drainage from up-slope, apparently being dammed by topography in that part of the clearcut (see part 3).

2. Evaluation of thermal habitats of fish and wildlife. Increasing utilization of the landscape has resulted in contention for resource values in some areas. As logging activities encroach the boundaries of small mountain streams, it is critical to assure adequate shading to prevent water temperatures from rising to inhabitable levels for desired fish species. Thermal imagery could be used to gauge the effectiveness of buffer strips along riparian zones, or help locate stretches which might need special protective measures.

3. Frost protection planning for nurseries and orchards. Thermal images can reveal the presence of cold air collection areas and drainage paths when a foliar cover is present. High elevation grasslands and clearcuts become sources of cold air, as can be deduced from nighttime imagery like Fig.1. Forests exhibit much smaller changes in temperature from day to night. And they may extend into warmer air aloft, in effect buffering the intrusion into the canopy space of colder air (Holbo 1983). Nighttime radiation losses of non-forested surfaces under cloud-free skies is about 50 W/m^2 (Holbo and Childs 1987). Each 1°C drop in surface temperature represents an additional 5 W/m^2 differential in the radiation balance, progressively accelerating the heat loss rate and increasing the chance of freezing.

4. Predicting nighttime airshed smoke impact. The cold air drainage patterns seen in Fig. 1 also identify areas which will tend to entrain smoke originating with controlled burning activities, such as slash burning done following logging. These activities are subject to increasing regulation, especially near population centers. Studies of thermal imagery before scheduling a burn might help a manager avoid a PSD (prevention of significant deterioration) violation, and could be used for mapping areas likely to provide routes for nighttime air drainage (Gossmann 1986).

5. Estimating evapotranspiration. Water is a critical resource and, although the level of interest in its conservation has waned recently, history indicates that good evapotranspiration estimation tools will be needed again. So it is not surprising that a substantial amount of effort has been directed towards the development of evapotranspiration estimation methods which

use remotely sensed thermal data as a primary input variable (e.g. Abdellaoui et al. 1986; Heilman et al. 1976; Ho 1985; Reginato et al. 1985; Seguin and Itier 1983; Soer 1980; Stone and Horton 1974). With the improved spatial resolution and surface temperature accuracy offered by TIMS and CAMS, such methods should be adapted to the site-specific levels of interest in natural resources management (Luvall 1988).

6. Detection and delineation of micro-topographic terrain features.

The direct linkage between thermal emissions from a surface and its physical properties (e.g. thermal diffusivity) permits the extraction of information about features too subtle to appear in un-enhanced thermal images (Pelletier 1985; Pelletier et al. 1985). Features which can be located in this way include soil conservation measures, minor drainages and archeological structures.

7. Assessment of vegetatively-moderated urban microclimates.

Microclimatic issues are important to urban planners. Structural materials within the urban environment often result in hostile microclimates. Using remotely sensed thermal image data, the influence of various amounts and arrangements of vegetation in those environments can be evaluated, and mediating alternatives recommended (Quattrochi and Rowntree 1988).

8. Recognition of landscape type with thermal image data.

Thermal remote sensing offers many possibilities for studying landscape ecology because there is virtually no other means by which the spatial character of the surface

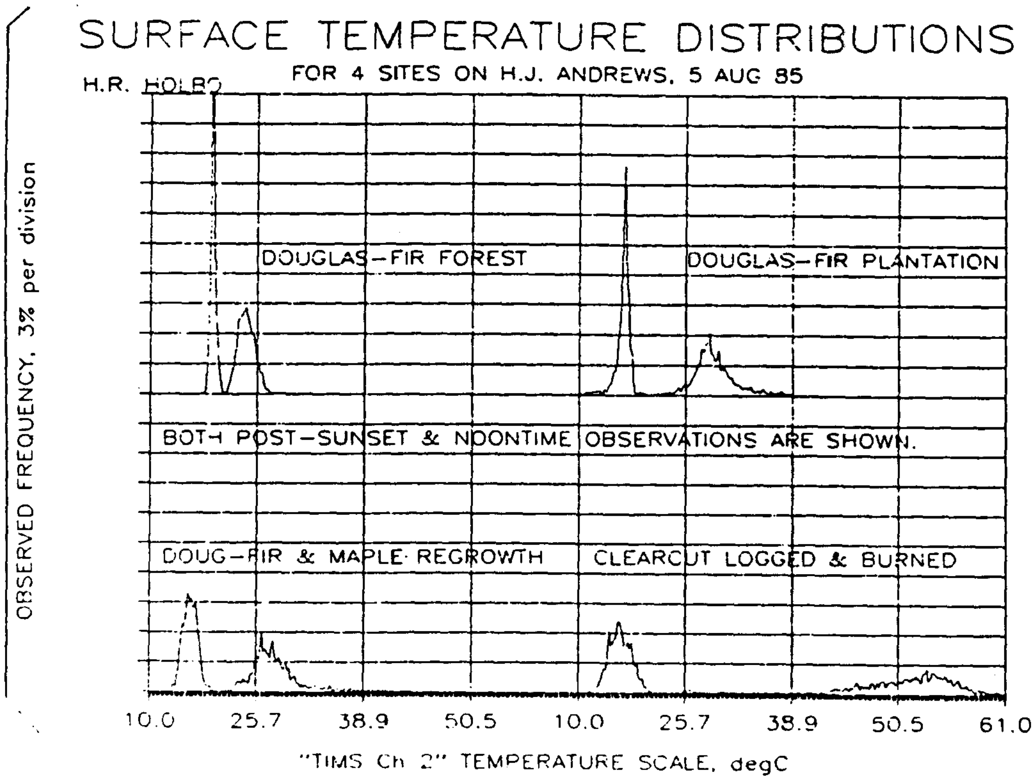

FIGURE 3.

temperature field in those systems could be observed. This spatial character tends to be diagnostic of the type of surface from which the thermal image is taken. For example, Figure 3 contains observed (nighttime and daytime) frequency distributions of surface temperature of 4 landscape types. It can be seen that each surface type exhibits a different pattern of dispersion, especially in the daytime.

By using a Beta probability distribution as a model, these patterns can be described in terms of just 2 parameters (Holbo and Luvall 1988). Different landscape types yield unique combinations of these parameters. It may be possible to implement this technique for landscape recognition. And, owing to the microclimatic information also available from this data, the association to specific landscape types should improve evapotranspiration estimation methods.

9. Predicting microclimatic change due to landscape type conversion.

The interrelationships between the 4 components of a surface's thermal energy budget (radiation, convection, conduction, and latent heat, or evapotranspiration) make it difficult to predict the consequences of converting from one landscape type to another. These components respond to both external and internal factors, but it is the internal biophysical properties of the site that are changed by management practices. When complicated even more by multiple land management practices across a landscape, assessing the net impact is beyond the scope of traditional approaches.

A remote sensing approach to this question has been proposed (Holbo and Luvall 1988). It takes advantage of TIMS capability for repeating surface temperature observations from the same site at short intervals. Combining the net radiation of a particular site with its observed rate of temperature change yields a surface property called a Thermal Response Number (TRN).

Forested sites and forest plantations were found to have large TRNs, consistent with their tendency to exhibit moderated microclimates. Clearcuts and barren sites had quite small TRNs, indicating little capacity to resist microclimatic extremes. Sites mid-way in their development toward becoming a forest had intermediate TRN values. The TRN seems to characterize the combined influences of surface properties controlling microclimatic processes.

SUMMARY

Thermal remote sensing offers special and unique qualities to the natural resources manager that cannot be obtained from other kinds of remote sensing data products. Thermal remote sensing instruments can function as environmental measuring tools, with capabilities leading toward new and specialized kinds of natural resource mapping. At present, analytical models and image processing techniques for the examples discussed remain largely undeveloped.

ACKNOWLEDGEMENTS

Part of the research upon which this report is based was funded by the Terrestrial Ecosystems Program of NASA. For assistance, the author thanks: Dr A.T. Joyce, Chief, ERL Earth Sci. Res. Div.; Dr J.C. Luvall; R.E. Pelletier; and D.A. Quattrochi.

LITERATURE CITED

Abdellaoui, A., F. Becker & E. Olory-Hechinger. 1986. Use of Meteosat for mapping thermal inertia and evapotranspiration over a limited region of Mali, J. of Climate and Appl. Meteorol. 25: 1489-1506.

Anderson, J.E. 1985. Thermal infrared data: Its characteristics and use, Amer. Soc. Photogram. Remote Sens. Tech. Paper 1: 143-155.

Childs, S.W., H.R. Holbo & E.L. Miller. 1985. Shadecard and shelterwood modification of the soil temperature environment, Soil Sci. Soc. Amer. J. 49: 1018-1022.

Gossmann, H. 1986. The influence of geography on local environment as inferred from night thermal infrared imagery, Remote Sens. Rev. 1: 249-275.

Goward, S.N., & J.V. Taranik, chairpersons. 1986. Commercial Applications and Scientific Research Requirements for Thermal-Infrared Observations of Terrestrial Surfaces, A Report of the Joint EOSAT/NASA Thermal Infrared Working Group. 5-7 Mar 1986, Earth Observation Satellite Co., 4300 Forbes Blvd, Lanham, MD 20706, 145p.

Graham, M.H., B.G. Junkin, M.T. Kalcic, R.W. Pearson & B.R. Seyfarth. 1986. ELAS - Earth Resources Laboratory Applications Software, rev.Jan 1986, NASA/NSTL/ERL Report No. 183.

Heilman, J.L., E.T. Kanemasu, N.J. Rosenberg & B.L. Blad. 1976. Thermal scanner measurement of canopy temperatures to estimate evapotranspiration. Remote Sens. Environ. 5: 137-145.

Ho, D. 1985. Soil thermal inertia and sensible and latent heat fluxes by remote sensing, Proc. 4th Thematic Conf.: Remote Sensing for Exploration Geology, San Francisco, CA, 1-4 Apr 1985, pp.635-643. Environ. Res. Inst. of Michigan, Ann Arbor, MI. pp.635-643.

Holbo, H.R. 1983. Wind patterns in a clearcut and an adjacent forest. FIR REPORT 5(2). Oregon St. U. Coop. Ext. Service.

Holbo, H. R. & S.W. Childs. 1987. Summertime radiation balances of clearcut and shelterwood slopes in southwest Oregon, Forest Sci. 33: 504-516.

Holbo, H.R. & J.C. Luvall. 1988. Thermal responses and surface temperature distributions of forested landscapes, Proc. *2nd Forest Service Conf. Remote Sens.*, 11-15 Apr 1988, NSTL, MS, Amer. Soc. Photogram. Remote Sens., Falls Church, VA.

Kahle, A.B. 1987. Surface emittance, temperature, and thermal inertia derived from Thermal Infrared Multispectral Scanner (TIMS) data for Death Valley, California, Geophysics 52: 858-874.

Kneizys, F.X., E.P. Settle, W.O. Gallery, J.H. Chetwynd, Jr., L.W. Abreu, J.E.A. Selby, R.W. Fenn & R.A. McClatchey. 1983. Atmospheric transmittance/radiance: computer code LOWTRAN-6, Air Force Geophysics Laboratory Rep. AFGL-TR83-0187. Optical Physics Division, Hanscom Air Force Base, MA 01731. 200pp.

Luvall, J.C. 1988. Using the TIMS to estimate evapotranspiration from a white pine forest, Proc. *2nd Forest Service Conf. Remote Sens.*, 11-15 April 1988, NSTL, MS, Amer. Soc. Photogram. Remote Sens., Falls Church, VA.

Palluconi, F.D. & G.R. Meeks. 1985. Thermal Infrared Multispectral Scanner (TIMS): An Investigator's Guide to TIMS Data, JPL pub. 85-32. 14 pp.

Pelletier, R.E. 1985. Identification of linear features in agricultural landscapes through spatial analysis of thermal infrared multispectral data, Proc. *Tech. Papers Amer. Soc. Photogram.*, Wash. DC, 10-15 Mar 1985, pp 381-390.

Pelletier, R.E., M.C. Ochoa & B.F. Hajek. 1985. Agricultural applications for thermal infrared multispectral scanner data, Proc. *11th Internat. Symp. Mach. Process. of Remotely Sensed Data*, W. Lafayette, IN, 25-27 Jun 1985, pp 321-328.

Quattrochi, D.A. & R.A. Rowntree. 1988. Potential of Thermal Infrared Multispectral Scanner (TIMS) data for measurement of urban vegetation characteristics, Proc. *2nd Forest Service Conf. Remote Sens.*, 11-15 Apr 1988, NSTL, MS, Amer. Soc. Photogram. Remote Sens., Falls Church, VA.

Reginato, R.J., R.D. Jackson & P.J. Pinter, Jr. 1985. Evapotranspiration calculated from remote multispectral and ground station meteorological data, Remote Sens. Environ. 18: 75-89.

Seguin, B., & B. Itier. 1983. Using midday surface temperature to estimate daily evaporation from satellite thermal IR data, Int. J. Remote Sens. 4:371-383.

Soer, G.J.R. 1980. Estimation of regional evapotranspiration and soil moisture conditions using remotely sensed crop surface temperatures, Remote Sens. Environ. 9: 27-45.

Stone, L.R., & M.L. Horton. 1974. Estimating evapotranspiration using canopy temperatures: Field evaluation, Agron. J. 66: 450-454.