

THERMAL DIFFERENCES IN REFORESTED CLEARCUTS AND OLD GROWTH FOREST ON
MOUNTAINOUS TERRAIN USING THERMAL INFRARED MULTISPECTRAL SCANNER DATA

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ABSTRACT

The objective of the investigation was to relate the Thermal Infrared Multispectral Scanner (TIMS) data to changes in green biomass levels exhibited in recent and older clearcuts at H.J. Andrews Forest. An important part of the investigation was to isolate that portion of the thermal emission that could be contributed to surface properties other than the vegetation biomass. A digital terrain data base (e.g., elevation, slope gradient, aspect) was generated for three experimental areas that represented the range of topographic variation within the H.J. Andrews Forest while corresponding to the best available site-specific ecological data.

Analysis of the TIMS data indicated that aspect and slope gradient had a greater effect on the thermal emission recorded by the TIMS in younger reforested clearcuts than in older stands. Forest stands in older age classes (>25 years) with higher green biomass and canopy closure had lower effective radiant temperatures (ERT) than younger, less densely vegetated stands while aspect and slope had little effect on the ERT. Surface temperature recorded by TIMS at approximately 1:30 pm local time July 29, 1983 were nearly equal to maximum daily air temperature recorded at eight reference stands.

The investigation provided some insights into the utility of TIMS for detecting surface temperature differences related to forest composition and green leaf biomass in mountainous terrain.

INTRODUCTION

Use of Thermal Sensors in Forestry

Certainly, the most successful use of thermal sensors in forestry, has been in real time detection of forest fires. Forest fires create targets of intense heat that can be easily detected by thermal sensors in all weather, at night, and through thick smoke. An operational system utilizing two detectors sensitive in the 3-4 μm and 8.5-11 μm wavelengths has been in use for several years (Hirsch, et al., 1971).

In the late 1960's the U.S. Forest Service became interested in the use of thermal sensors for previsual detection of insect attacked and diseased trees (Weber and Olson, 1967). Some pine trees under moisture stress and bark beetle attack were shown to have higher canopy temperatures than surrounding healthy trees (Olson, 1972, Weber, 1971). Temperature differences as high as 7°C were recorded between attacked and control trees, but average temperature differences were only 1°C. It was not known whether small temperature differences were associated with physiologically induced changes within the trees or merely variation in microclimate, atmospheric perturbations and/or random noise levels. As a result of these and other studies funded by NASA and the USDA-Forest Service, little attention has been given to thermal sensor applications in forestry since the early 1970's, except in forest fire detection.

Although, progress in measurement of parameters important for estimation of evapotranspiration has created new interest in thermal sensors (Soer, 1980, Gurney, 1978, Heimberg, 1982), the investigators have chosen homogeneous targets of crop or pasture on level terrain, and avoided more complex forest targets. An important area for future research in estimating evapotranspiration is to develop remote sensing methods for measuring surface temperature

and net radiation, while accounting for atmospheric corrections, in more complex canopies (than crop or pasture) and in terrain with different sun-sensor-surface geometry (Heimberg, 1982).

Thermal Characteristics of Vegetated Mountainous Terrain

All objects with temperatures greater than absolute 0 (0°K or -273°C) emit radiation. Longwave energy emitted from a surface is a function of its absolute temperature and emissive power. Emissivity can be considered essentially constant for many surfaces, including most vegetation in the thermal region ($8\text{-}14\mu\text{m}$). Emissivity of vegetated targets are generally in the range of .90 to .98 m (Anderson, 1983). Atmospheric effects (atmospheric absorption, scattering and emission from particles and gases) can significantly influence thermal measurements. Other authors (Anderson, 1983, Lillisand and Kiefer, 1979, Nunnally, 1973) provide a detailed review of thermal infrared theory, emissivity and the effects of the atmosphere on measurements recorded by thermal sensors, therefore those discussions will not be duplicated here.

The net surface temperature of a vegetated landscape is composed of contributions from soil, rock, plant litter, and from the living biomass making up the plant canopy. In mountainous terrain, the temperature response of the land surface is strongly influenced by the angle between the sun and surface plane (Lillisand and Kiefer, 1979). Sun angle effects on solar loading at the surface is much more pronounced where soils are exposed or vegetation canopies are open. In mature or closed forest canopies, on clear summer days, the temperature of the canopy is generally within a few degrees ($\pm 3^{\circ}\text{C}$) of air temperature (Smith et al., 1981; Kaufman, 1984). Canopy temperatures are influenced by elevation changes but slope gradient and aspect have almost no

effect (Kaufman 1984, Zobel et al., 1976). Correction techniques, for topographic effects (Smith and McGuire 1982, Smith 1981) and atmospheric effects (Anderson 1983, Smith 1981) can improve vegetation classification results from remotely sensed data when the targets are positioned on mountainous terrain.

Site Description

The H.J. Andrews Experimental Forest (Fig. 1) is located approximately 50 miles east of Eugene, Oregon (latitude $44^{\circ}14'N$, longitude $122^{\circ}11'W$). The site is within the Willamette National Forest - Blue River Ranger District and is administered jointly by the U.S. Forest Service and Oregon State University (OSU) Forest Sciences Department. The elevation ranges from about 500 to 1600 meters (Dryness et al., 1976). The western Hemlock (Tsuga heterophylla (raf.) Sarg.) habitat type is found at lower elevations (<900 meters or 3000 feet) and the higher elevations (>1100 meters or 3600 feet) are classified as the Pacific Silver Fir (Abies amabilis(Dougl)Forbes) habitat type. Various age classes of forest vegetation, from recent clearcuts (<1 year) to old growth Douglas-fir (Pseudotsuga menziesii (Mirbel) Franco) exceeding 450 years, are contained within H.J. Andrews Experiment forest. Mountain slopes are oriented primarily north-south and terrain is rough.

Since 1977, the National Science Foundation (NSF) has supported a baseline monitoring program. A data bank maintained by OSU contains over 150 data sets supporting many separate research investigations. Several remote thermograph stations continuously record soil and air temperature and a central meteorological station records hourly max/min air temperature, precipitation, relative humidity, wind speed and other climatic data. Several watersheds are being studied intensively. Accurate records exist pertaining to stand history

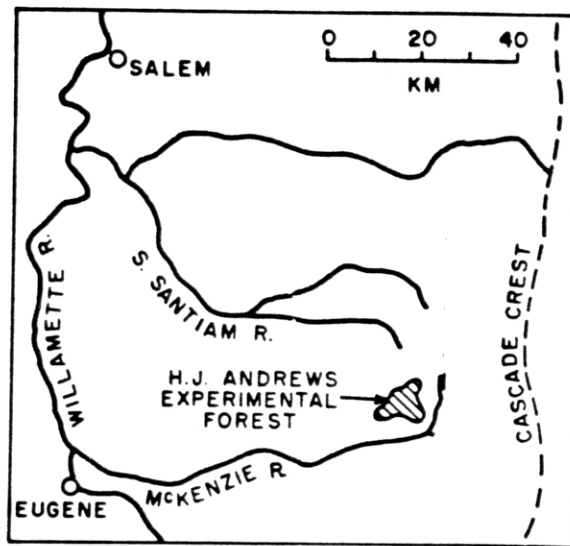


Figure 1. The Location of H.J. Andrews Experimental Forest in Western Oregon (After D.B. Zobel Et al., 1976).

(harvest date, site preparation, artificial or natural generation, precommercial thinning, etc.) and stand exam data including thinning and stocking levels (trees/acre, basal area, etc.). Vegetation transects and permanent sample plots are measured periodically to describe the composition and structure of vegetation successional stages.

METHODS

Thermal Infrared Multispectral Scanner data were analyzed to determine whether temperature differences in reforested clearcuts of various ages and old growth forests could be explained by relative changes in green leaf biomass. Because the TIMS data were collected at approximately 1:30 pm. PST, corresponding to a period of maximum diurnal surface temperatures, it was anticipated that differential heating of north and south slopes could be a significant variable in the TIMS thermal return on clearcuts with lower biomass or less dense canopy closures. To examine this phenomena, polygons were selected to investigate the effect of aspect and slope gradient on temperatures recorded by TIMS. Also, polygons were selected to represent different forest habitat types (potential climax vegetation zones) corresponding to elevational/site gradients within Andrews Experimental forest.

Data Acquisition

The Thermal Infrared Multispectral Scanner (TIMS) is a six channel scanner flown in a Lear 23 aircraft operated by the National Space Technology Laboratories (NSTL). Specifications of the TIMS are provided in Figure 2.

TIMS data were collected over H.J. Andrews Experimental Forest as a target of opportunity when the NSTL aircraft was dispatched to the Pacific Northwest

Figure 2. Thermal Infrared Multi Spectral Scanner (TIMS) Specifications.

		<u>BAND</u>	<u>SPECTRAL COVERAGE</u>	<u>NE ΔT</u>
Focal Length	13.0 inches	1	8.2 μ m - 8.6 μ m	0.09 ⁰ C
Clear Aperture	7.5 inches	2	8.6 μ m - 9.0 μ m	0.09 ⁰ C
System IFOV	2.5 MR	3	9.0 μ m - 9.4 μ m	0.09 ⁰ C
Ground Resolution	5-33 meters	4	9.4 μ m - 10.2 μ m	0.12 ⁰ C
Swath Width	1.3 - 8.3 miles	5	10.2 μ m - 11.2 μ m	0.14 ⁰ C
Scan Speeds	7.3, 8.7, 12.0, 25.0	6	11.2 μ m - 12.2 μ m	0.32 ⁰ C

region to fly other scheduled missions. Because the mission was "opportunistic" in nature, there were no ground measurements made during the mission to address specific research goals. The aircraft was flown at altitudes near its upper and lower ceiling. On July 29, 1983 several low altitude lines were flown at 7600 feet above mean terrain (AMT) between 12:47 and 1:23 pm local time. High altitude lines were flown at 35,600 between 1:34 and 1:40 pm. The low altitude lines resulted in a 6 meter IFOV and the high altitude lines yielded a 27 meter IFOV at nadir. As a result of clear atmospheric conditions (no clouds or apparent haze) and minimum air turbulence (except one high altitude line), the data sets were of high quality.

One of the high altitude data sets covering the western one-third of the study site was declared unusable as a result of air turbulence encountered on that flight line. Therefore, a low altitude data set covering the western area was selected for further processing. This area hereafter will be referred to as "watershed 1, 2, 3". A high altitude line was also selected for the larger central and eastern portion of H.J. Andrews. The high flight line encompasses two areas hereafter referred to as "watershed 6, 7, 8 and Lookout Mountain".

Although it was not feasible for concurrent ground data to be collected during the TIMS mission, daily air temperature records for July 29th and stand history and stocking data were made available to allow comparisons of thermal data with forest stand conditions on many sites.

Data Processing

Several programs in the ELAS software package (Graham et al., 1980) at NASA-ERL were available to process the TIMS aircraft data. A series of pre-

processing steps were necessary to correct line or pixel "dropout" values, generate effective radiant temperature (ERT) values, and register the scanner data to a UTM grid coordinate system.

After some minor data editing, the ELAS module GASP was run on both data sets. Figure 3 reproduces GASP output showing overall channel means, standard deviations and correlation for each channel pair. The six thermal channels were highly correlated, indicating that little would be gained by processing all channels. Channel 3 was chosen arbitrarily for further processing. The raw digital values were converted to effective radiant temperatures through an ELAS module (TERT) that utilizes the "housekeeping" data recorded by the sensor to allow calibration of high and low blackbody temperatures to high and low digital values. The resulting digital numbers are matched to table look up values which provide the ERT in $.5^{\circ}\text{C}$ increments.

The watershed 1, 2, 3 (6 meter) data set was rotated to North prior to georeferencing. Matching points were located in the data (channel 3 only) and on a 1:15,840 scale topographic map. A transformation was developed to register and resample the TIMS data to a 10 meter UTM grid. TIMS data for watershed 6, 7, 8 and lookout mountain were georeferenced to a 30 meter UTM grid.

Generate Elevation Data

Contour lines were digitized from a 1:15,840 scale topographic map for the areas corresponding to watershed 1, 2, 3; watershed 6, 7, 8 and Lookout Mountain vicinity. It was decided that digitizing every third contour line would be adequate to represent the topography for the purposes of this investigation. The ultimate use of these data (to generate broad aspect and slope classes) did not require the highest precision that would be achieved by digitizing every contour line at 1:15,840 scale.

Figure 3. Output from ELAS Module - GASP, Showing Effective Radiant Temperature Statistics for Two Data Sets.

	Watershed 1,2,3					
	<u>CH1</u>	<u>CH2</u>	<u>CH3</u>	<u>CH4</u>	<u>CH5</u>	<u>CH6</u>
Means	116.95	123.40	122.96	130.80	125.13	133.68
S.D.	18.57	21.18	21.68	26.33	24.58	19.76
COV.	0.16	0.17	0.18	0.20	0.20	0.15

CORRELATION MATRIX						
CH1	1.00					
CH2	1.00	1.00				
CH3	1.00	1.00	1.00			
CH4	0.99	1.00	1.00	1.00		
CH5	0.99	1.00	1.00	1.00	1.00	
CH6	0.98	0.99	0.99	0.98	0.99	1.00

	Watershed 6,7,8 and Lookout Mountain					
Means	109.52	122.01	115.26	111.18	123.58	126.97
S.D.	16.25	18.82	18.55	21.16	21.17	18.08
COV.	0.15	0.15	0.16	0.19	0.17	0.14

CORRELATION MATRIX						
CH1	1.00					
CH2	1.00	1.00				
CH3	1.00	1.00	1.00			
CH4	0.99	1.00	1.00	1.00		
CH5	0.99	1.00	1.00	1.00	1.00	
CH6	0.95	0.95	0.95	0.95	0.95	1.00

The contour lines were converted to raster elevation at 10 meters for watershed 1, 2, 3 and 30 meters for the other sites. Another ELAS program (TOP6) generated files containing 16 aspect and slope gradient classes in 1% increments from the rasterized elevation data. The 16 aspect classes were combined into 8 classes (N, NE, E, SE, S, SW, W, NW) and the slope data were grouped into 5 classes (0-15%, 16-30%, 31-45%, 46-60%, >60%). Frequency tables were generated to list the percentage of land area occupied by aspect and slope for the three areas (Table 1). Nearly all aspect and slope classes were well represented except there were few NE aspects (1.1%) in watershed 6,7,8. Only 7.4% of the terrain in watershed 6,7,8 contained slope classes >45%. These groupings were selected arbitrarily because it was unknown, apriori, to what degree aspect and slope gradient would influence the thermal return given different vegetation compositions and densities.

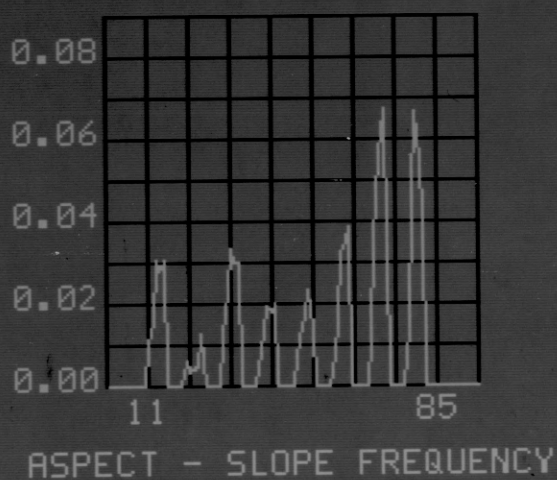
Logical operations were performed to code and combine the 8 aspect and 5 slope classes. The output file could contain up to 40 possible aspect-slope combinations: the first digit represented aspect and the second digit was the slope gradient. For example, class 11 had a North aspect (1 = 315° to 45° azimuth) and a slope gradient of 0 to 15%. The aspect-slope image and frequency distribution for watershed 1, 2, 3 is shown in Figure 4.

Polygon Selection in Reforested Clearcuts and Old Growth Stands

A map was available depicting the location of all forest unit boundaries, old growth reference stands and remote thermograph stations. Using the map as a reference, polygons were selected in the TIMS data in an effort to obtain a representative sample of age classes and topographic variation. Most of the polygons were selected in watersheds where the rasterized slope and aspect data were available.

Table 1. Percentage of Land Area in Aspect and Slope Classes for Three Study Sites.

<u>Aspect</u>	<u>Code</u>	<u>Watershed 1,2,3</u>	<u>Watershed 6,7,8</u>	<u>Lookout Mountain</u>
		<u>% of Total Area</u>	<u>% of Total Area</u>	<u>% of Total Area</u>
N	1	11.3	10.8	17.2
NE	2	2.8	1.1	9.8
S	3	12.7	13.3	5.6
SE	4	7.7	17.0	3.3
S	5	7.5	13.8	14.3
SW	6	12.9	19.3	15.2
W	7	23.1	13.0	22.1
NW	8	21.9	11.8	12.5
<u>Slope %</u>				
0-15	1	19.6	29.4	6.5
16-30	2	14.3	45.6	18.0
31-45	3	22.4	17.6	29.4
46-60	4	21.9	4.4	33.0
>60	5	21.7	3.0	13.1
TOTAL HECTARES		825.2	546.8	1218.2



ASPECT - SLOPE
WATERSHED 1,2,3 VICINITY

8 ASPECT CLASSES
5 SLOPE CLASSES
—
40 POSSIBLE CLASSES

FIGURE 4.

12 84 045
NASA/NSTL/ERL

The selection of polygons was conducted in an interactive mode. The forest units were located on the computer display screen and a moving cursor was used to draw each polygon and save it in a separate file for subsequent computation. Within each designated forest unit boundary, the polygon was selected in a manner to be as "homogeneous" as possible in forest composition and density. For example, logging roads transversing the plot, or disturbed areas atypical of the site were excluded in an attempt to reduce variation within the polygons.

Forty-one polygons were selected in the 30 meter data set, however only twenty-eight corresponded to watershed 6,7,8 and Lookout Mountain where terrain data were digitized. Twenty-two polygons were selected for watershed 1,2,3 where terrain data were available. The polygon names which correspond to H.J. Andrews Forest units are provided in Appendix A. The polygons and their mean ERT are listed in descending rank (warmest to coolest) along with the age since last harvest and reforestation.

Air temperatures recorded at remote thermograph stations and watersheds at H.J. Andrews on July 29 were compared to mean ERTs computed in the polygons that encompassed the station locations (Table 2). The ERTs recorded at 8 locations were nearly equal to maximum daily air temperatures.

Merge Forest Age Class - Terrain Data

The ERT polygon files were combined with the terrain data to generate statistics that could be used to analyze the effects of age class, aspect, and slope on the ERT's recorded by TIMS. The following data file manipulations were conducted:

Table 2. Comparison of Effective Radiant Temperature and Maximum Daily Air Temperatures Recorded July 29, 1983 at Eight Remote Thermograph Stations - H.J. Andrews Expt. Forest.

<u>Station</u>	<u>Maximum Air Temp.(°C)</u>	<u>TIMS ERT (°C)</u>
Reference Stand 1	25.3	22.5
Reference Stand 2	25.4	24.5
Reference Stand 3	26.1	22.5
Reference Stand 17	26.2	24.5
Reference Stand 20	23.9	24.0
Reference Stand 26	22.2	23.0
Watershed 6	27.8	24.0
Watershed (North) 10	29.4	30.0

$$\bar{x} = 25.8$$

$$\bar{x} = 24.4$$

$$\text{St. Dev.} = 2.2$$

$$r = .68$$

1. Calculation of mean ERT and standard deviation by polygon.
2. Calculation of mean ERT and S.D. by aspect class.
3. Calculation of mean ERT and S.D. by slope class.
4. Calculation of mean ERT and S.D. by aspect-slope class.

Printouts were generated showing the frequency of each aspect-slope combination within the polygons of interest. As was expected, not all aspect-slope combinations were equally represented, and a few combinations did not occur at all in any of the polygons. In order to reduce the amount of missing data, aspect was grouped from 8 to 4 classes (representing cardinal directions). This procedure reduced the amount of missing data but did not completely eliminate it. For the 30 meter data sets, even combining the two areas - watershed 6,7,8 with Lookout Mountain - did not produce all aspect-slope combinations. There was a severe lack of data on the steeper slope classes (45-60% and >60%). Therefore, it was decided to include only 3 slope classes (0-15, 16-30, 31-45%) for subsequent data analysis.

The limitation of not having all age classes represented on all aspect-slope positions influenced the manner by which the classes were grouped to allow significant temperature differences, if any, to be detected. The classes were grouped as follows:

1. Age classes (years since clearcut - reforestation)
 - a. 0-12
 - b. 13-25
 - c. 26-33
 - d. Old growth (relatively undisturbed primary forest)
2. Aspect class (and Azimuth)
 - a. North 316-45°
 - b. East 46-135°

- c. South 136-225°
- d. West 225-315°
- 3. Slope %
 - a. 0-15
 - b. 16-30
 - c. 31-45
 - d. 46-60 (only for watershed 1,2,3)
 - e. >60 (only for watershed 1,2,3)

Watershed 1,2,3 was located in a lower elevation zone (Western Hemlock habitat type) and watershed 6,7,8 and Lookout Mountain represented the transition zone of Western Hemlock - Pacific Silver Fir at higher elevations.

RESULTS AND DISCUSSION

Watershed 1,2,3 - 10 Meter Data

The combined mean ERT of all age classes were plotted by aspect and slope class for watershed 1,2,3 (Figure 6). East and south facing aspects had higher ERT's (3-4°C) than west and north aspects, when averaged across all age classes and slope gradients. The 0-15% slope class was 2 to 3° degrees (C) warmer than other slope gradients on the average. Better insights about temperature differences on variable terrain can be gleaned from Figure 7. Mean ERT decreased as age class increased. The decrease in ERT as age class increased was independent of aspect and slope. Temperature differences related to aspect revealed the following:

1. The north aspect was coolest for all age classes and the differences were approximately 3°C for the 0-12 age class.
2. South aspect mean ERT was highest for the 13-25 year age class.

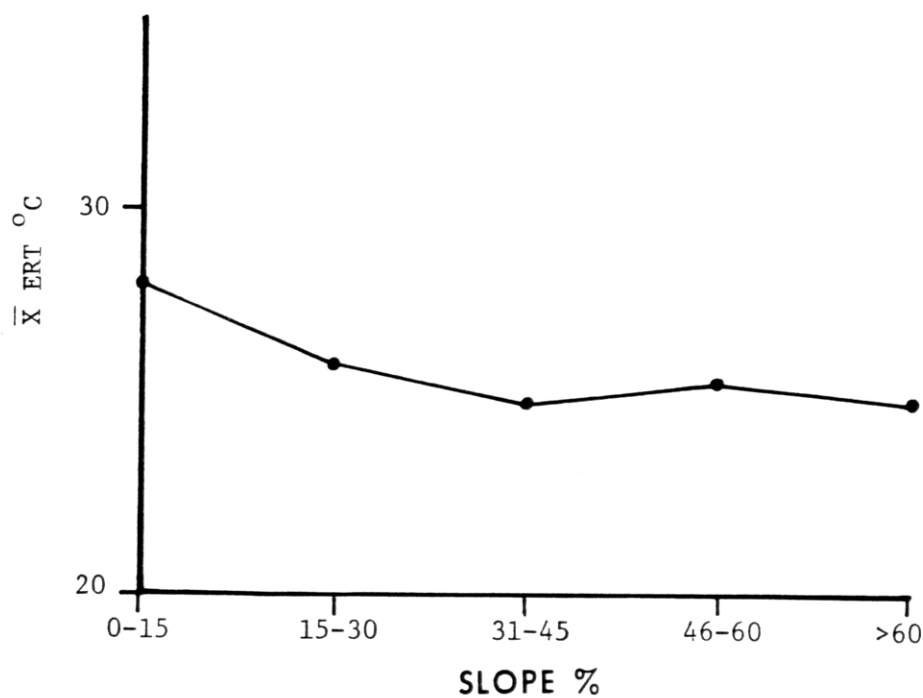
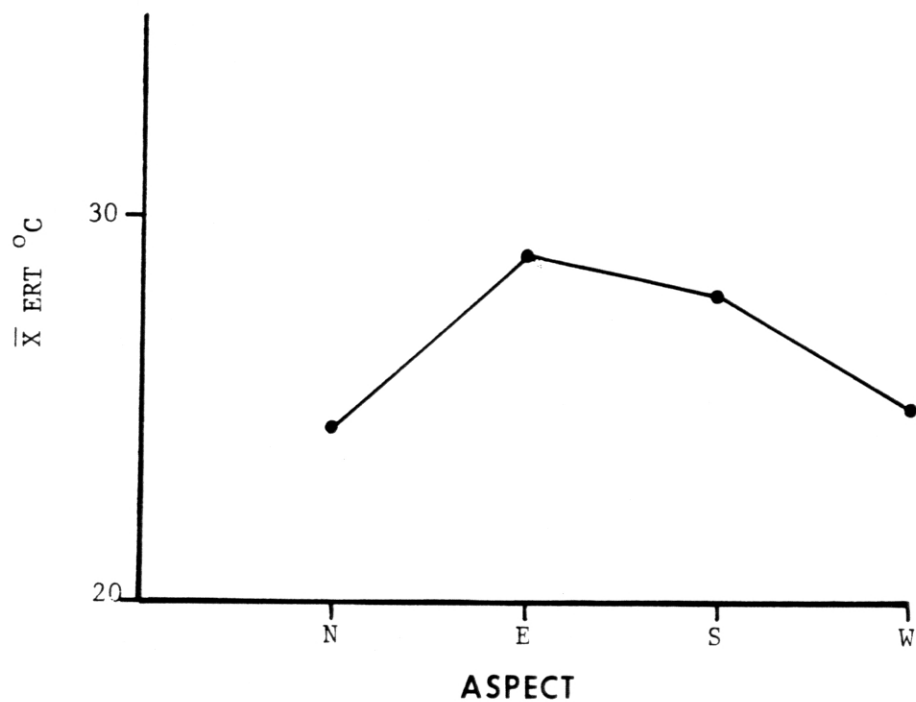
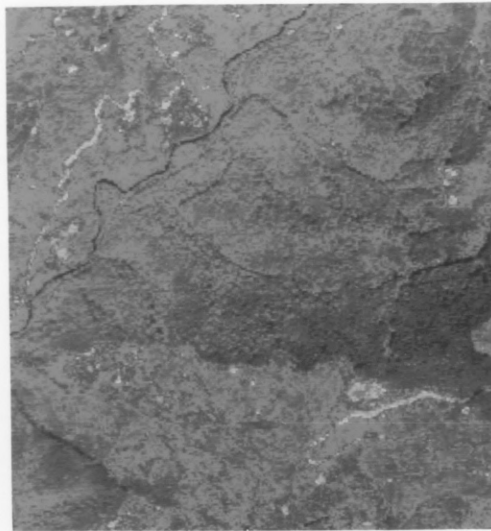
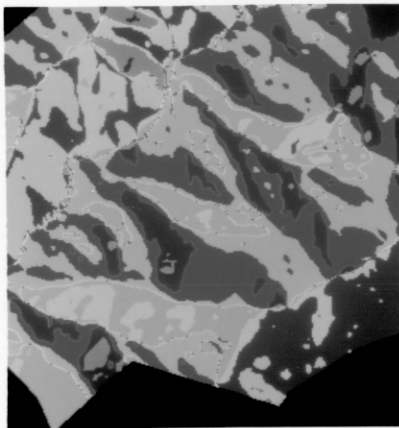


Figure 6. WATERSHED 1, 2, 3 - EFFECTIVE RADIANT TEMPERATURE, ALL AGE CLASSES COMBINED



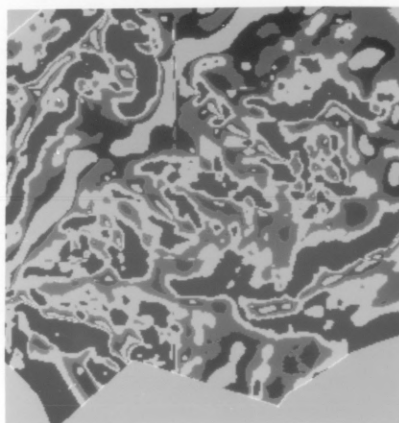
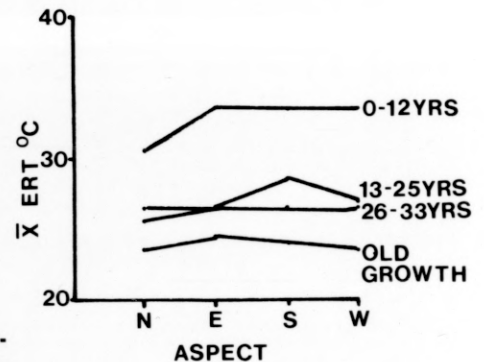
Several polygons were selected which represented various age classes and stocking levels. The ERT data were combined with slope and aspect data. The testing of interaction between slope and aspect by age class/stocking will indicate if temperature differences can be linked to biomass levels.

**Effective Radiant Temperature (ERT),
Channel 3**



Aspect

Eight aspect classes were grouped into four cardinal directions. Temperature decreased as age of forest increased.



Slope

Five slope classes were grouped by 15% increments. Temperatures were generally cooler on slopes >30% except in the 0-12-year age class.

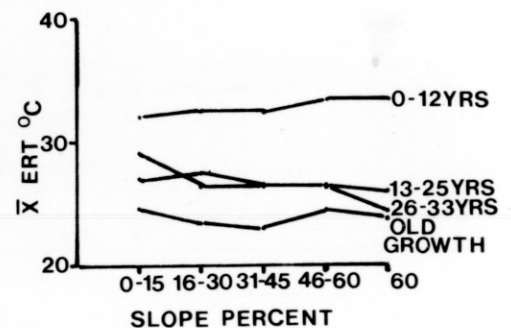


Figure 7. THERMAL DIFFERENCES OF FOREST VEGETATION ON MOUNTAINOUS TERRAIN FOR WATERSHEDS 1, 2, AND 3 — H. J. ANDREWS EXPERIMENTAL FOREST

3. Aspect orientation had little effect on mean ERT for the 25-33 and old growth age classes.

Trends in temperature differences (ERTs) were less apparent when age classes were plotted by slope gradient (Figure 7).

An analysis of variance were performed on the 10 meter data using a randomized complete block design. The null hypothesis was tested: no temperature differences would occur between age classes, aspects, or slope gradients. Age classes were used as blocks and the F test revealed that age class and aspect were highly significant but slope and aspect-slope interaction was nonsignificant (Table 3). Response curves of aspect plotted by slope class (Figure 8) for each age class indicated that age class 1 (0-12 years) and age class 2 (13-25 years) were contributing most of the variability in ERT related to terrain positions. The terrain had little effect on ERT for age class 3 (25-33 years) and age class 4 (old growth). The effect of aspect within age class 1 and 2 were tested using single degrees of freedom for each aspect sum of squares. In age class 1, the north aspect had significantly different mean ERT (@ .01 level) from the east, south, and west aspects. The south aspect in age class 2 was highly significant and north, east and west aspects were non-significant.

Missing data was a problem in age class 3 and 4. Six of the aspect-slope combinations did not occur in age class 3 and three cases were missing in age class 4. There were no data for east facing aspects. For purposes of the analysis of variance, the missing data were replaced with an average value. The value was computed by summing the means of other slope classes on the same aspect, summing the other aspect ERT's for the same slope class and dividing by the number of means that were summed.

Table 3. Watershed 1,2,3 - Randomized Complete Block Anova (Forest Age Class = Blocks)

	Degree of Freedom	Sum of Square	Mean Square	F
AGE	3	3365.37	1121.79	121.80**
ASPECT	3	121.29	40.43	4.39**
SLOPE	4	32.17	8.04	.87
ASPECT-SLOPE	12	53.96	4.50	.49
ERROR	57	525.11	9.21	

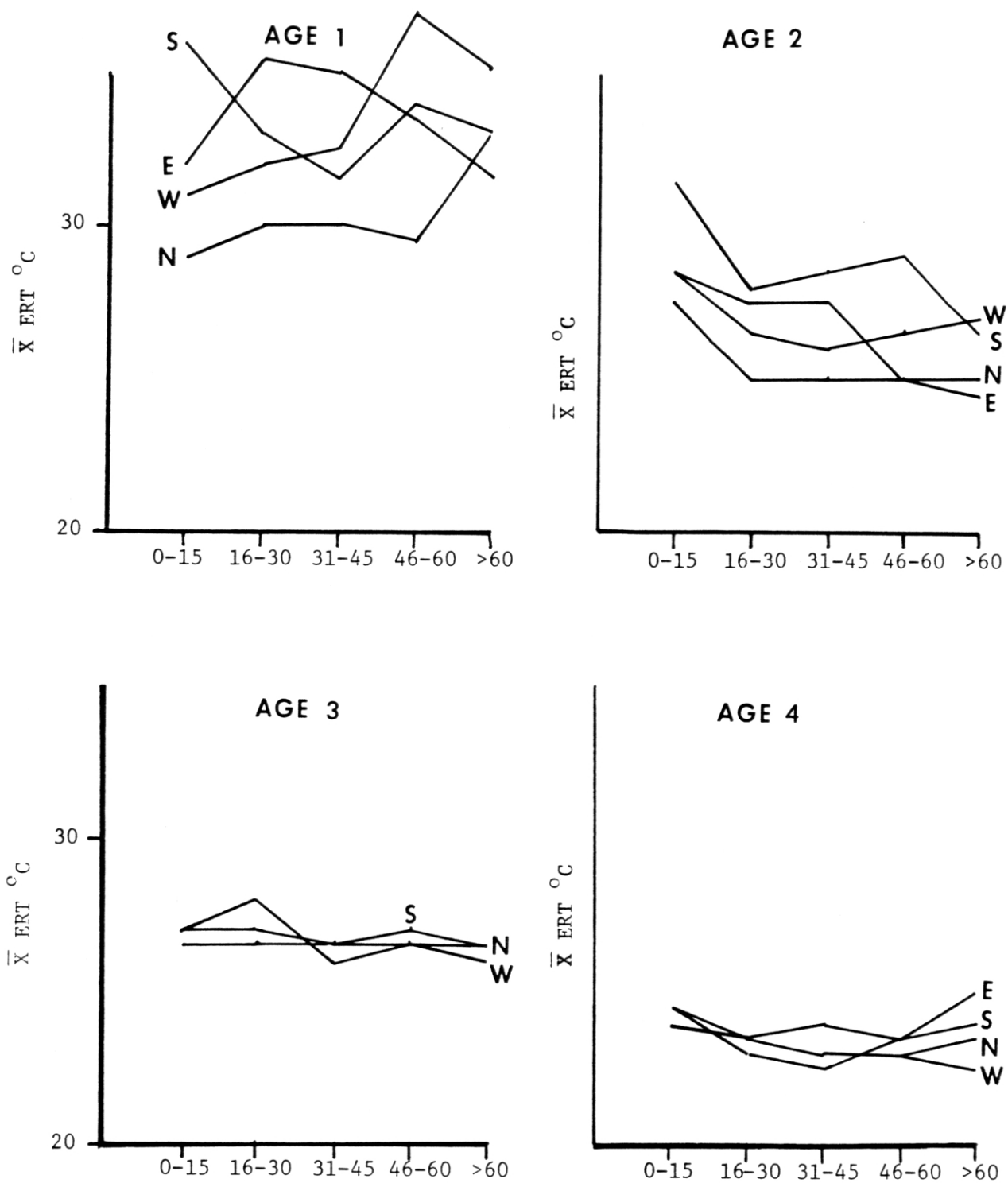


Figure 8. WATERSHED 1, 2, 3 - EFFECTIVE RADIANT TEMPERATURE, ASPECT BY SLOPE % CLASS FOR AGE CLASS 1-4

Watershed 6,7,8 and Lookout Mountain - 30 Meter Data

Very little variation in ERT was apparent when all age classes were combined and plotted by aspect and slope class (Figure 9). However, when age class mean ERTs were plotted separately against aspect and slope (Figure 10), the obvious relationship was the decrease in ERT as age of the forest increased. The same trend was observed in the 10 meter data for watershed 1,2,3.

The analysis of variance on the 30 meter data for watershed 6,7,8 and Lookout Mountain revealed a highly significant difference in age class (block) ERT, however aspect, slope and aspect-slope interactions were nonsignificant (Table 4). The 45-60% and >60% slopes were excluded from the analysis due to lack of data. Also, three missing ERT's were estimated and replaced in age class 1.

The range and variability of ERT, especially in age class 1 and 2, was not as great as was observed in the watershed 1,2,3 data. East facing slopes were warmer in age class 1, however west facing slopes produced higher mean ERT's for age class 2 and 3 (Figure 11). Mean ERT decreased as slope gradient decreased in age class 1 and 2 (Figure 12). In the age classes 3 and 4 the trend was reversed: the 31-45% slopes had lower ERT.

A comparison of the ERT data between the watershed 1,2,3 data set and the watershed 6,7,8 and Lookout Mountain data set is provided in Figure 13. The mean ERT's of all age classes, slopes and aspects were lower in watershed 6,7,8 and Lookout Mountain than in the same classes representing watershed 1,2,3. The former study area represented elevations that are approximately 1000 feet higher on the average than watershed 1,2,3, thus cooler temperatures were predictable. The difference in ERT between the two data sets was larger in the 0-12 year age class, and the range in mean ERT between age classes was larger in watershed 1,2,3.

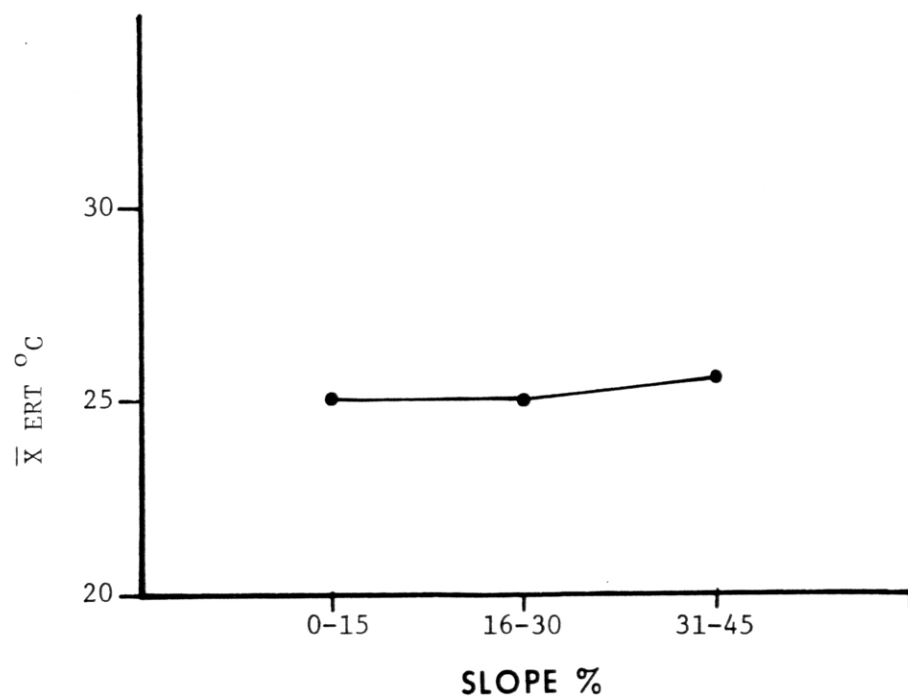
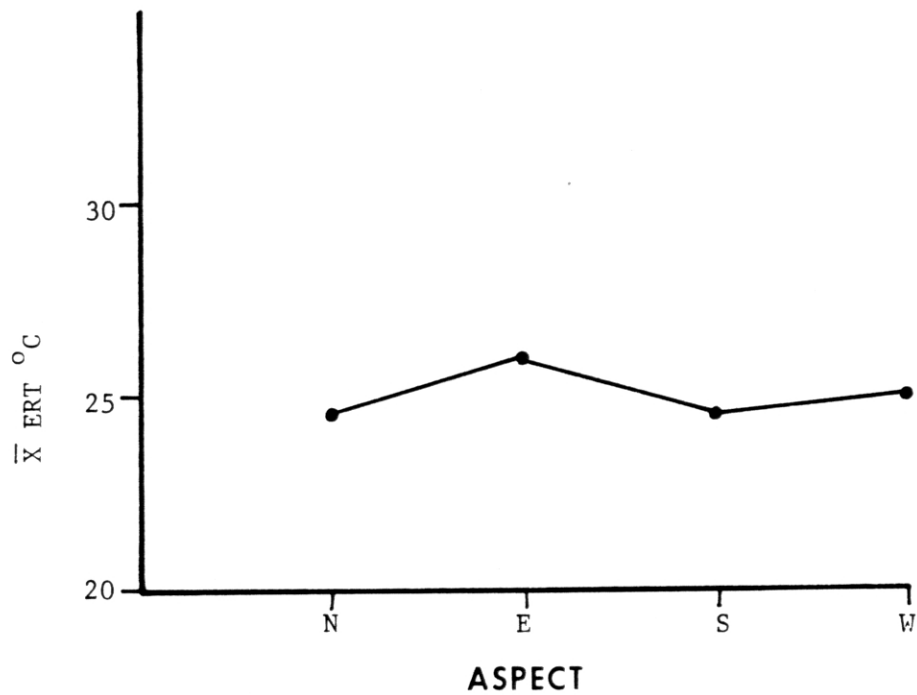


**Figure 9. WATERSHED 6, 7, 8 AND LOOKOUT MT.
EFFECTIVE RADIANT TEMPERATURE, ALL
AGE CLASSES COMBINED**

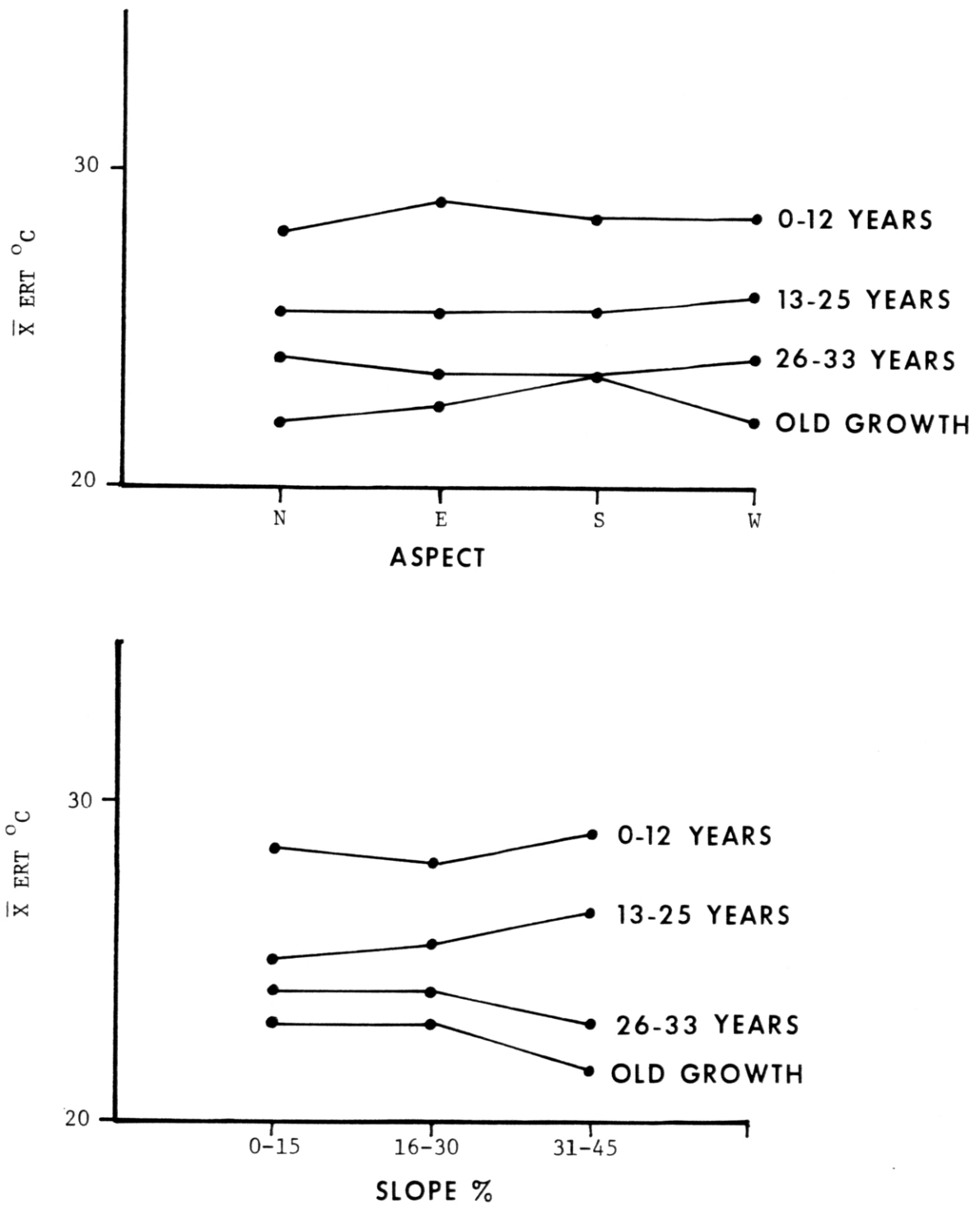


Figure 10. Watershed 6, 7, 8 AND LOOKOUT MT. - EFFECTIVE RADIANT TEMPERATURE BY ASPECT AND SLOPE FOR EACH FOREST AGE CLASS

Table 4. Watershed 6,7,8 and Lookout Mountain - Randomized Complete Block
Anova (Forest Age Class = Blocks)

	Degree of Freedom	Sum of Square	Mean Square	F
AGE	3	1012.09	337.36	9.97**
ASPECT	3	2.69	.90	.03
SLOPE	2	.23	.12	.004
ASPECT-SLOPE	6	5.73	.96	.03
ERROR	33	1117.07	33.85	

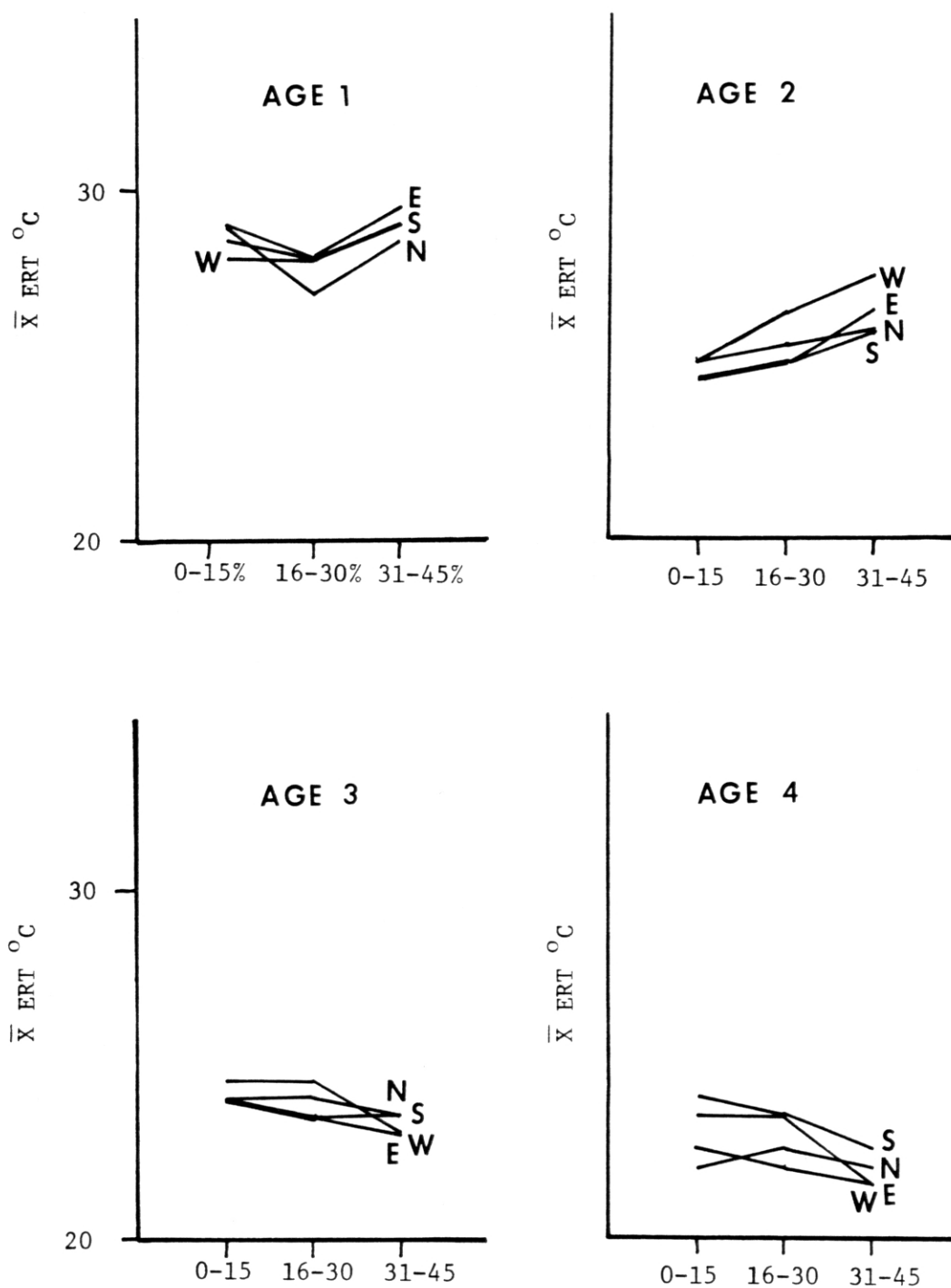


Figure 11. WATERSHED 6, 7, 8 AND LOOKOUT MT. - EFFECTIVE RADIANT TEMPERATURE, ASPECT BY SLOPE CLASS FOR AGE CLASS 1-4

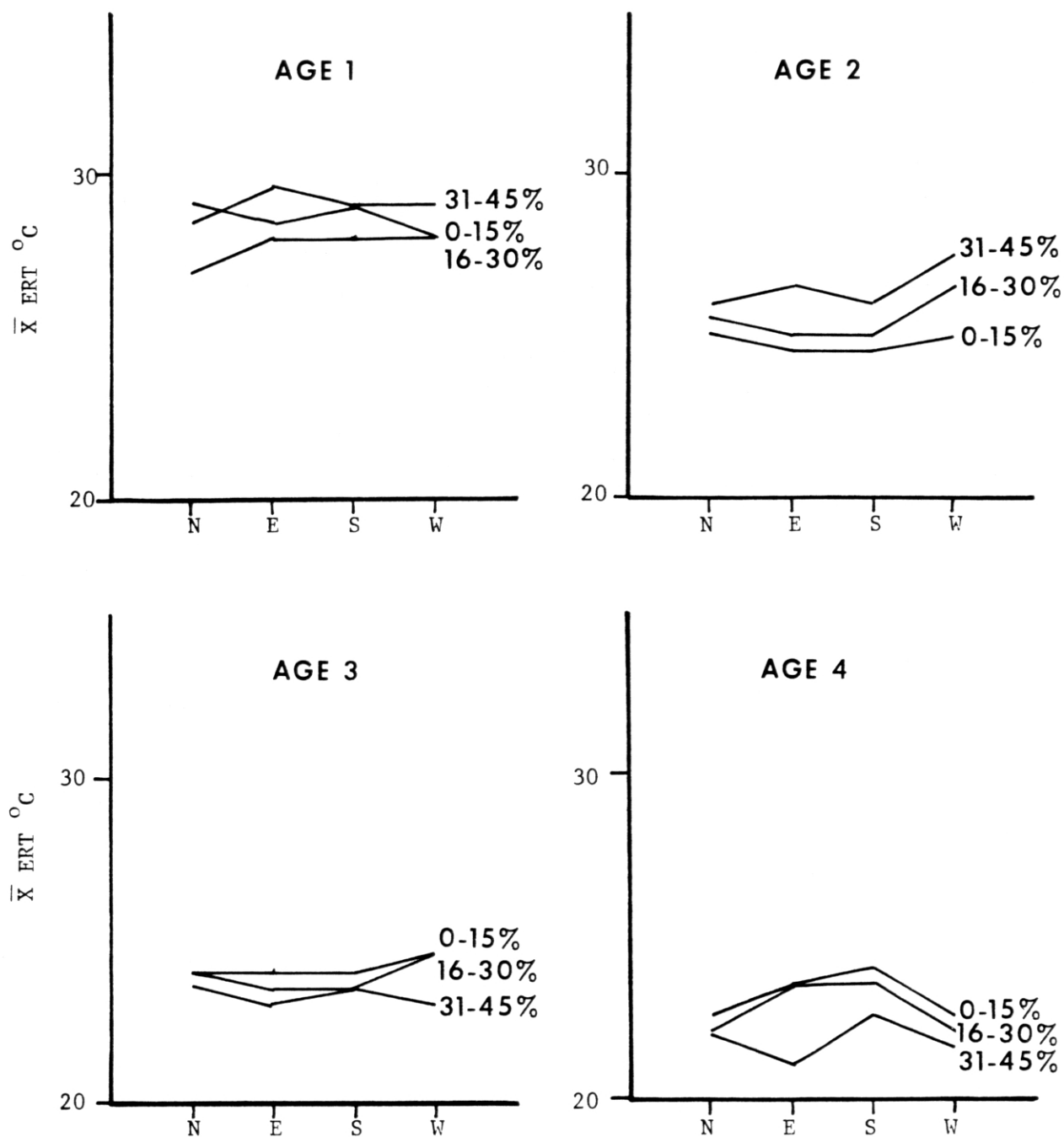


**Figure 12. WATERSHED 6, 7, 8 AND LOOKOUT MT.-
EFFECTIVE RADIANT TEMPERATURE,
SLOPE % BY ASPECT CLASS FOR AGE
CLASS 1-4**

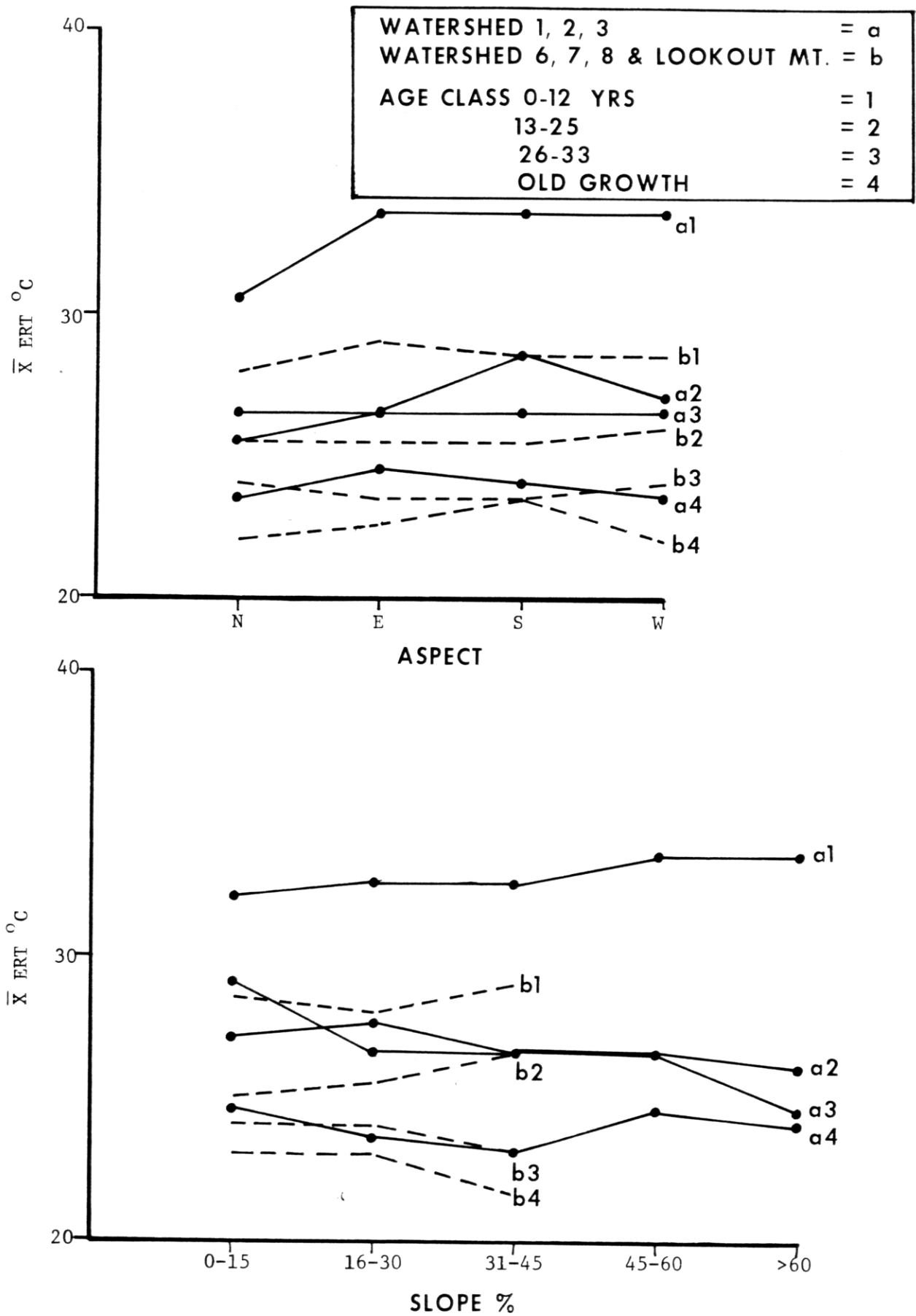


Figure 13. COMPARISON OF EFFECTIVE RADIANT TEMPERATURE OF TWO DATA SETS

CONCLUSIONS

ERT differences corresponding to aspect and slope variation in age class 1 and 2 may be attributable to the amount of green leaf area and canopy closure present in the sensor field of view. Differential heating and cooling related to sun angle had a greater influence on ERT recorded by TIMS when forest canopies were not completely closed. As the forest matures and the canopy closure and green leaf area approaches maximum, the influence of surface emittance below the canopy contributes less to the total return. This may explain why aspect and slope variation appeared to have little effect on ERT in the older age classes. According to Appendix A, near maximum canopy leaf area at H.J. Andrews may occur at around 25 to 30 years on sites replanted to Douglas-Fir.

These results were confounded by the fact that all combinations of age class, aspect and slope gradients were not equally represented (equal repetitions), and some combinations were totally absent. Replacement of the missing data by average values raises a question of whether real differences in ERT related to those terrain conditions may have gone undetected in the analysis of variance. Regardless of the problems encountered in interpreting the influence of aspect and slope on ERT, the amount of data available to detect significant differences among age classes was quite sufficient to have confidence in the results. The number of "pixels" or cells representing each class in both data sets were several hundred, at least. Stratification of the old growth and reforested clearcuts into age classes was appropriate because significant ERT differences between age classes (blocks) were detected in both data sets. Some variability within stratum was unavoidable because not all forest units of similar age were completely homogeneous in composition, structure, stocking and other physical characteristics which had some influence on the thermal return.

The results of the preliminary analysis were intended to guide the experimental design of a more structured investigation which would attempt to correlate TIMS temperature differences to green leaf biomass levels or leaf area index. A follow-on or future investigation might benefit from the insights gained through this preliminary work. First, future investigations should address the earlier forest successional or regeneration stages representing the full range of Leaf Area Index (LAI) from near zero (<1 year old clearcuts) to near maximum levels typical of some older stands (>25 years). It would not be necessary to sample intensively in many old growth stands where only minor temperature differences ($\pm 1^{\circ}\text{C}$) would be expected. Secondly, some numerical expression of the sun-sensor-target geometry such as "cos i" may be preferable to aspect-slope in order to explain temperature differences not contributed by the vegetation component. Finally, additional field measurements concurrent with TIMS data acquisition would be necessary to characterize green biomass or LAI, in addition to providing descriptions of other canopy structure components, soil conditions, percentage of litter, rock and other surface cover materials.

The TIMS appears to be capable of detecting subtle differences in ERT related to canopy closure and green leaf area, but calibration techniques are needed to correct for emissivity differences and atmospheric effects. A new capability in making surface temperature measurements remotely will have important applications in the earth sciences including forest climatology and hydrology studies where evapotranspiration estimation, moisture stress and nighttime energy budgets are difficult to measure accurately for large land areas.

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Appendix A. Effective Radiant
Andrews Expt. Forest.

Watershed 1,2,3			Watershed 6,7,8 and Lookout Mountain					
Forest Unit	ERT °C	Age Years	Forest Unit	ERT °C	Age	Forest Unit	ERT °C	Age
WS10(B)	36.0	7	L383	32.0	10	L503	24.5	33
B133A	33.5	11	L113A	29.5	17	L505	24.0	24
WS1(B)	30.5	13	L352	29.5	15	L504	24.0	20
B131	30.0	23	WS6	29.0	8	RS32	24.0	OG
WS10(A)	30.0	7	L374	28.5	15	L108	24.0	31
B133	27.5	21	WS7	28.0	8	RS27	24.0	OG
L141	27.0	30	L382	28.0	16	RS31	24.0	OG
L141A	26.5	30	L704	27.5	17	RS29	23.5	OG
L101	26.0	23	L381	27.5	16	L109	23.5	26
WS1(D)	25.0	15	L351	27.0	16	RS30	23.0	OG
RS2	24.5	OG	L209	27.0	21	WS8	23.0	OG
B131A	24.5	19	L602	27.0	21	RS3	22.5	OG
WS1(A)	24.5	16	L111	26.0	18	RS5	22.5	OG
RS17	24.5	OG	L110	25.5	18	RS12	22.0	OG
RS7	24.0	OG	L109B	25.5	16	RS23	22.0	OG
RS8	24.0	OG	L405A	25.5	17	LK0.CR	22.0	OG
RS20	24.0	OG	L701	25.5	21	MACK.CR	21.5	OG
L222	23.5	20	L405	25.5	20			
WS2	23.0	OG	L112	25.0	17			
RS1	22.5	OG	L522	25.0	20			
			L702	25.0	23			
			L521	24.5	30			
			L107	24.5	24			
			L301	24.5	26			

OG = Old Growth Forest
 RRS = Reference Stand
 WS = Watershed
 LK0.CR = Lookout Creek
 MACK.CR = Mack Creek