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EFFECT OF SUN ANGLE AND HAZE ON GENERATION OF LANDSAT IMAGERY

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Effect of Sun Angle and Haze On Generation of Landsat Imagery

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1.0 INTRODUCTION

In the first phase of the LACIE operations, several questions surfaced concerning the rationale of attempting to obtain maximum color contrasts in all Landsat Multispectral Scanner (MSS) imagery by using scaling factors derived from histogramming the radiance values for each scene on all data passes. It was suspected that changes in sun elevation angles and atmospheric conditions possibly were causing undesirable variations in colors of crops on successive data passes. The current procedures for generating imagery from the MSS data requires computation of input gains and biases (scaling factors) from the radiance values of each MSS channel for each individual scene. Only those radiance values which are within a fixed number of standard deviations from the mean value are used in the computations. Corrections based specifically on changes in sun elevation angle or atmospheric conditions occurring on successive data passes are not made during these calculations.

The above questions prompted the development of this investigation, with the following objectives being used as guidelines for the experimental procedures in the investigation:

a. To determine the influence that changes in sun elevation angle have upon the radiance values of scenes recorded by Landsat sensor.

b. To determine the relationship between sun elevation angle changes and the current method of obtaining scaling factors by histogramming procedures.

c. To determine the effect that haze, sufficiently concentrated to be visible on Channel 1 Landsat imagery, has upon the crop colors on successive data passes.

2.0 EXPERIMENTAL PROCEDURES

A review of the literature on the effects of sun angle and atmospheric conditions on ERTS-1 data showed that most research had been concentrated on analyzing these effects from a viewpoint of automated data processing classifications and mathematical modeling. Since the objectives of this study were related more specifically to the generation of optimum quality imagery from the original computer compatible tapes, priority consideration was given to finding existing imagery from available Landsat files in which the effects of sun angle and haze were readily apparent. It was considered desirable to find several large unvegetated targets in an area where haze was clearly visible during at least one pass, and where repetitive coverage provided a reasonable range of differences in sun angle. These criteria appeared to be satisfied by the available data collected over the HATS (Houston Area Test Site) during five passes in the fall of 1972 and spring of 1973 — a period during which the change in sun angle was very pronounced. Two passes contained very noticeable amounts of haze in the displayed images, while three passes were relatively free from haze.

In order to eliminate the seasonal effects of vegetation growth, it was believed desirable to study targets which would be approximately neutral spectrally in the MSS wavelengths. A search was made on available aerial photography for large areas of paved surfaces, bare soil, water, etc., which would most likely appear to be reasonably homogeneous to the MSS sensors. For comparison purposes, a few vegetated targets (heavily forested and brush covered areas) were also included in the study.

It was anticipated that histograms would be required of relatively small areas for each of the data passes. This would necessitate locating the boundaries of these areas precisely (within one pixel) so that the same areas would be histogrammed from pass to pass. To achieve one pixel accuracy most readily, it was considered desirable to register the individual data passes onto one computer compatible tape. The size and complexity of the Houston area made registration difficult, and several attempts were required before a satisfactory registered tape was achieved.

The August 29, 1972 data pass was used as the basis for choosing numerous targets covered with a very pronounced layer of haze (smog) in the southwest portion of the urban scene. Targets with similar appearances were also chosen as far from the haze layer as possible and yet were within the registered portion of the Houston data tape. Results obtained from analyses made of the radiance values recorded in these histograms are reported in section 4.0.

A more detailed description of the selected targets is as follows:

a. The Central Commercial target encompasses an area of 100 pixels covered with low commercial buildings, paved streets and large paved parking lots. The area did not include any of the adjacent Central Business District with its pronounced shadows from the sky-scraper buildings. Virtually no vegetation was integrated into the spectral signature of this target.

b. The Water target, an area of 405 pixels, was selected near the deepest end of Lake Houston. The water at this location should be relative free from suspended matter during the entire year.

c. The Shell-Covered Surface target was a large outdoor drive-in theater complex comprising one projection building and three screens. The paved area was large enough to permit selection of 15 pixels from the center so that surrounding vegetation would not be integrated into the spectral signature.

d. The Bare Soil target of 30 pixels covered a large area containing extensive mounds of unvegetated earth. The higher elevation of this area and an adjacent large dredged ditch would indicate that the area was probably well-drained during all of the data passes.

e. The New Residential target was a new suburban housing development with bright roof-covered single houses, extensive concrete pavings and very little, if any, established landscaping that could effect the spectral signature of this target. An area of 50 pixels was selected near the center of this development.

f. The Rural Forest target was selected from an extensive forested area as far away from the urban environment as possible. An area of 200 pixels was selected where the forest cover appeared to have the most uniform appearance on the aerial photography.

g. The Urban Forest target was selected from a large park area as near to the urban core as possible. The most homogeneous appearing forest cover was selected as the target area (200 pixels).

h. The Brush target was a large uncultivated field over-grown with brush ranging from small areas of very dense, tall brush to areas containing low brush, weeds, and a few scattered trees. An area of 100 pixels was selected from this field.

A cursory examination of the radiance values of the four MSS channels for several data passes revealed that a pronounced change in brightness occurred as the sun elevation of the overall scene varied from one pass to the next. To illustrate this effect, a series of graphs was designed in which the mean radiance values for the eight previously described targets were plotted for each channel (Figures 1, 2, and 3). A curve showing the annual variation in the declination of the sun has been superimposed on each graph, since sun elevation angle is dependent upon solar declination as well as target latitude and local time of data pass. The latter two factors are constant for a Landsat pass over a specific target area. The channel numbers used in this report correspond to the designation of channels used in the histogram program on the Aerojet Data Analysis Station and are equated as follows: Channel 1 = MSS 4; Channel 2 = MSS 5; Channel 3 = MSS 6, and Channel 4 = MSS 7.

The elevation and declination of the sun for the particular dates of the five data passes used in this study are shown in Table 1.

Table 1

Elevation and Declination of Sun for Houston

Data Pass	Sun Elevation	Sun Declination
August 29, 1972	55^{o}	$+9^{o}$
October 4, 1972	47^{o}	-4^{o}
November 27, 1972	32^{o}	-21^{o}
February 25, 1973	40^{o}	-9^{o}
May 8, 1973	61^{o}	$+17^{o}$

A general description of the atmospheric conditions as seen in the Landsat imagery of the Houston area for each data pass is tabulated in Table 2.

Table 2

Atmospheric Conditions Over Houston

Data Pass	General Description
August 29, 1972	Heavy haze (smog) layer in southwestern portion of area distinctly visible on MSS Channel 1 imagery, barely noticeable on Channel 2 and not visible on Channels 3 and 4. Remainder of area relatively free from haze.
October 4, 1972	Few scattered cumulus clouds over eastern portion of area visible on all channels. Remainder of area free from visible haze.
November 27, 1972	Few scattered cumulus clouds over eastern portion of area visible on all channels. Remainder of area free from visible haze.
February 25, 1973	Thin veil of high clouds and haze cover most of the area, with the heaviest layers in the western and southwestern quadrants. These clouds and haze visibly effect the clarity of the imagery from all channels, although much of the cloud cover is too thin to produce shadows.
May 8, 1973	No clouds or visible haze over the metropolitan area.

Table 3 gives a more specific description of the atmospheric conditions over the selected targets at the time of the data pass. Reference should be made to curves in Figures 1 and 2 as this table is studied.

Table 3

Atmospheric Conditions Over Selected Targets					
Targets	Aug 29 1972	Oct 4 1972	Nov 27 1972	Feb 25 1973	May 8 1974
Central Commercial	Light haze	No haze	No haze	Light haze	No haze
Water	No haze	No haze	No haze	Mod. haze	No haze
Shell-covered Surface	Heavy haze	No haze	No haze	Mod. haze	No haze
Bare Soil	Mod. haze	No haze	No haze	Mod. haze	No haze
New Residential	No haze	No haze	No haze	Mod. haze	No haze
Rural Forest	No haze	No haze	No haze	Light haze	No haze
Brush	Heavy haze	No haze	No haze	Light haze	No haze
Urban Forest	Light haze	No haze	No haze	Light haze	No haze

3.0 OBSERVED EFFECTS OF SUN ELEVATION ANGLE

The influence of sun elevation upon target radiance is shown for each of the selected features in Figures 1 and 2. The histogrammed mean values for the targets are plotted as a function of date and may be compared with the curve showing the relative changes in sun declination for a one-year cycle. It can be seen that the means for all non-vegetated targets, except water, vary closely in the same manner as the declination curve. Scattering of sunlight by the water gave it a nearly uniform radiance level throughout the year.

In order to test the effect of correcting for sun angle changes, it would be desirable to produce a data tape in which all data passes are corrected to a common sun angle. Then, each target would be re-histogrammed to obtain corrected means. If these corrected means were plotted on a graph, they should fall on a straight line providing the sun angle was the only variable. Unfortunately, a program was not available for making such a corrected data tape and corrected means were therefore predicted mathematically. The predicted means were computed by applying a sun angle correction factor to the radiance values of each data pass. The correction factor was derived from a comparison of incident solar energy for each date relative to a reference date. For this investigation, October 4 was used as a reference from which values for all other dates were predicted. The correction factor is defined as equal to:

$$\frac{\text{Sine of sun elevation for other date}}{\text{Sine of sun elevation for reference date}}$$

The correction factor for August 29 = 1.12, November = 0.73 February = 0.88 and May = 1.21. The predicted means are shown in Figure 3. The histogram calculated means are the same values plotted in Figures 1 and 2.

Figure 3 was used in making the following observations:

a. On the premise that the test scene on October 4 was relatively clear of haze, it was expected that the ratio between the sun elevation of that date and the other dates would give predicted mean radiance values which would follow very closely the plotted curve of the declination of the sun. Figure 3 shows this close correlation for three non-vegetated and two vegetated targets for both visible (Channel 1) and infrared (Channel 4) wavelengths. This would indicate that sun elevation is a significant variable, and corrections for it should be considered when using the raw Landsat data.

b. Although the non-vegetated targets gave the most predictable radiance means, the fact that the histogram calculated means departed from the predicted means curve on certain dates would indicate that other variables influenced the mean values to a greater degree than did the sun elevation at that time. The maximum departure from the predicted mean curve occurred in Channel 1 for the Shell-covered

Surface for August 29 and May 8. On August 29 the target was immersed in a heavy haze which caused a reduction in its radiance. The May 8 curve departure cannot be explained in this manner, since the area appeared to be clear. Channel 4 is closely predicted for May 8, however, which leads to the conclusion that either an unnoticeable haze must have been present or incorrect pixels were included in the target histograms. Water was not included in Figure 3, since it was shown in Figure 1 that the incident sunlight was scattered through the water to give about the same radiance regardless of date (sun elevation angle).

c. The mean radiance values for vegetated targets were not as predictable as the non-vegetated targets. This was due to spectral changes occurring during the growing season. The departure of the predicted mean curve from the histogrammed mean does, however, give a relative measure of vegetation changes that occurred from one date to another.

Gains and biases are computed for the DAS by a histogram program which calculates the scaling factors using the standard deviation (σ) about the mean value. The effect of changes in sun elevation angle upon these factors was investigated by mathematical analysis. Gain (A) and bias (b) are computed with the following equations:

$$A = \frac{256}{\pm 3\sigma} \qquad B = \text{mean} - 3\sigma$$

Table 4 was prepared to show the relationship between the Landsat measured radiance values (R_m) and the radiance values when corrected (R_c) to a nominal 60° sun elevation angle. The second and fourth columns are the final values as expanded by the scaling factors. It is seen that the expanded values for the corrected and uncorrected data are almost identical. Numerous other elevation angles were tested and the same results were found in each case. The small differences between column 2 and 4 are due to rounding off of calculations. From this analysis, it is evident that sun elevation angle changes do not have to be considered if gain and bias factors used to produce imagery or display are computed from a histogramming routine. With this consideration, it may be seen that a set of constant scaling factors is possible only if a small range in sun elevation is present.

Table 4

Correction for Sun Elevation Angle

Target: Central Commercial, Houston, Texas   Date: Oct 4, 1972

Elevation angle of sun = 47^{o} Landsat Channel 4

Measured Radiance (R_m) at 47^{o}	R_m x 3σ Scaling Factors	Radiance Corrected (R_c) to 60^{o}	R_c x 3σ Scaling Factors
9	14	10.7	14
10	35	11.9	35
11	56	13.0	54
12	76	14.2	76
13	97	15.4	97
14	117	16.6	118
15	138	17.8	139
16	159	19.0	160
17	179	20.2	181
18	200	21.3	200
19	220	22.5	221
20	241	23.7	242

3σ Scaling factors:

	47^{o} Sun Elevation	60^{o} Sun Elevation
	Gain = 20.6 Bias = -8.3	Gain = 17.6 Bias -9.9
	σ = 2.07	σ = 2.43

4.0 OBSERVED EFFECTS OF HAZE

The following observations were derived from examination of Figures 1 and 2:

a. The mean radiance values of all MSS channels for non-vegetated surfaces (except water) follow fairly closely the change in sun declination (or sun elevation) from month-to-month, except for targets covered by haze. When heavy haze is present (Shell-covered Surface and Bare Soil in August), the mean radiance values for all MSS channels are lowered significantly, with the greatest decrease occurring on the visible Channels 1 and 2.

b. The mean radiance values of the infrared channels (3 and 4) for the forest and brush surfaces follow fairly closely the change in sun declination from month-to-month. In contrast the mean radiance values for the visible channels (1 and 2) appear to be greatly influenced by the presence of haze and changes in plant vigor during the vegetation growth cycle. Consequently, uncultivated vegetation targets were selected for this investigation so that the effect of changes in soil color and amount of plant canopy on the spectral signatures would be minimized.

c. A comparison of the three vegetated targets shows that a slight increase in brightness occurred in Channels 1 and 2 during the August and February passes. The brush target was covered with a heavy haze for the August pass and a light haze for the February pass. This is in contrast to the decrease in radiance values for channel 1 and 2 that occurred when heavy haze covered the non-vegetated targets. It is suspected that somewhat higher radiance values for vegetation would have occurred on the passes with haze if it were not for the normal lowering of brightness that occurs as the perennial vegetation increases in vigor. An inverse relationship also appears to exist between channels 1 and 2 and the declination of the sun for the two forest targets. In this case, as the sun elevation increases and the forest increases in vigor, the radiance values of the forest image decreases as expected.

d. It should be noted that if channel 4 radiance values (plotted here as compressed values based on a maximum of 63 instead of 127 as used on the other channels) were plotted on a comparable scale, they would exceed almost all radiance values of the other channels for the vegetated targets. Likewise, the other infrared channel(3) also exceeds the two visible channels for most radiance values. In contrast to this, it should be noted that the radiance values for the visible channels usually are higher than the infrared channels for the non-vegetated targets, with channel 4 having the lowest values even if plotted on the same scale.

e. The radiance values for the water target remained very uniform throughout the five data passes. The slight fluctuation of radiance values occurring in channel 1 is not pronounced enough to provide a valid correlation between the effect of haze or sun angle on these values. Unfortunately, no suitable water targets were located in the area with the heaviest concentration of haze.

5.0 CONCLUSIONS

The following conclusions were derived from this investigation:

a. When heavy haze is present over a non-vegetated scene the mean radiance values for all MSS channels are lowered, with the greatest decrease occurring in channels 1 and 2 (visible wavelength channels).

b. Over a vegetated scene any apparent decrease in mean radiance values due to haze may be masked by an increase in mean radiance values which occurs as vegetation increases in vigor during its growth cycle.

c. To relate the amount of decrease in mean radiance values to specific densities of haze, it would be necessary to measure the amount of haze over specific targets at the time of several Landsat overflights. This type of detailed ground truth data was not available for this investigation.

d. Mean radiance values for non-vegetated targets (except water) are closely correlated to the changes in sun elevation angles throughout the year. Where vegetated surfaces predominate in a scene, the mean radiance values of Channels 3 and 4 follow closely the annual change in sun elevation angles, whereas the mean radiance values for Channels 1 and 2 appear to depart from the sun elevation curve as the vigor of the vegetation increases. This is due to the darkening of the green color of vegetation as it approaches its most vigorous growth stage.

e. A sun angle correction to a fixed reference date appeared to offer the possibility of compensating for haze-covered areas by predicting the mean radiance values which would be closely correlated to the normal sun declination curve.

f. Making sun angle corrections to a specific angle showed that changes in radiance values due to changes in sun angle were being compensated by the current method of generating images after calculating gain and bias values from the histogram of each specific scene.

g. Because the test scene used in this study did not have extensive cultivated areas, and Landsat data were not available for the period of the growing season when changes in sun elevation were at a minimum, it is not possible to conclude from this report what specific effects that changes in sun angle and haze will have upon the classification signatures and imagery of various crops. It is believed that the results of this preliminary investigation indicate that additional research would be warranted over an agricultural test site where haze has been found to be a problem in crop classification, and where haze observations are available for ground truth.

MEAN RADIANCE VALUES OF HOUSTON SCENES

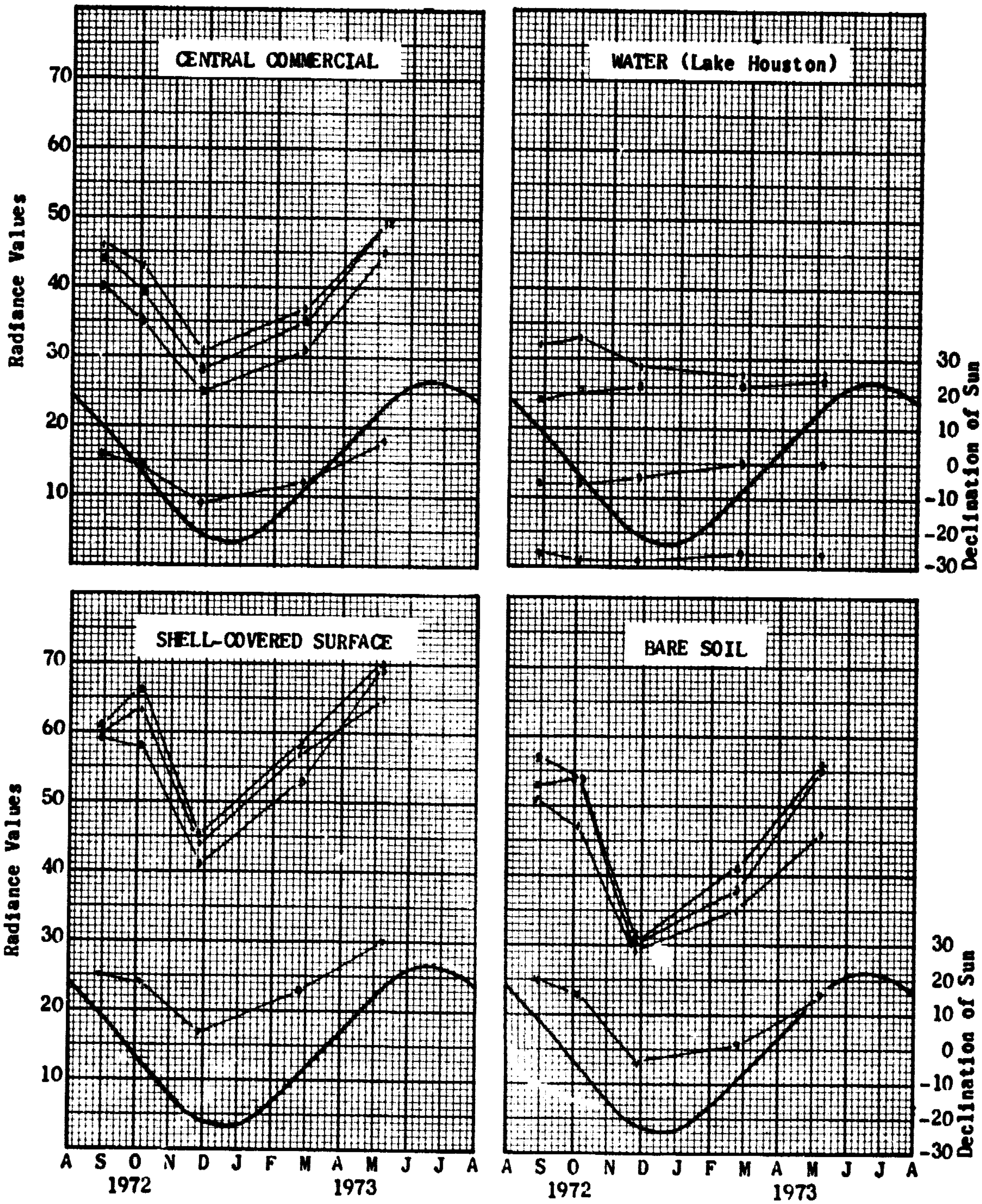

FIGURE 1

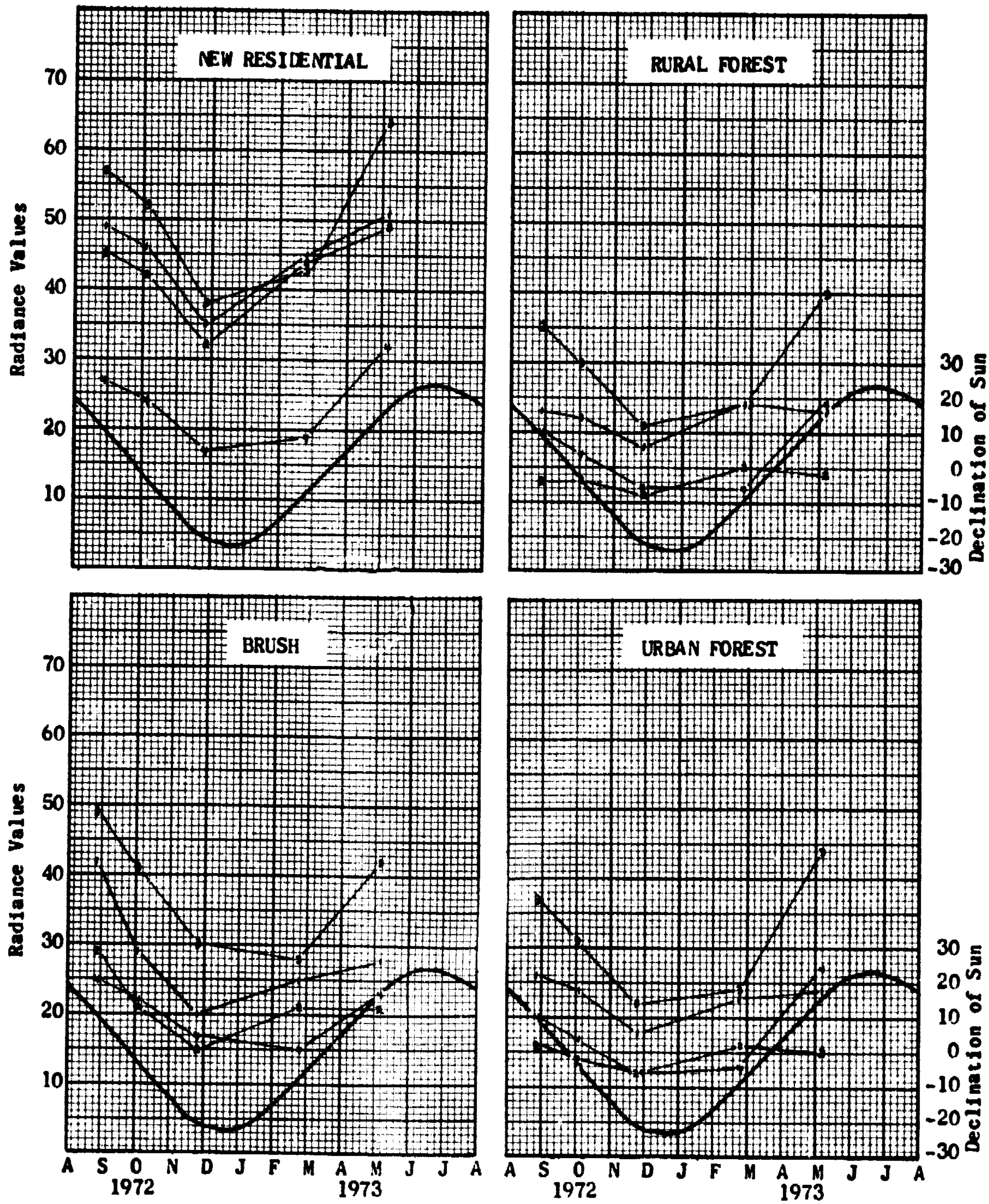
NEW RESIDENTIAL
RURAL FOREST
BRUSH
URBAN FOREST
Radiance Values
70
60
50
40
30
20
10
Declination of Sun
30
20
10
0
-10
-20
-30
A S O N D J F M A M J J A
1972
1973

FIGURE 2

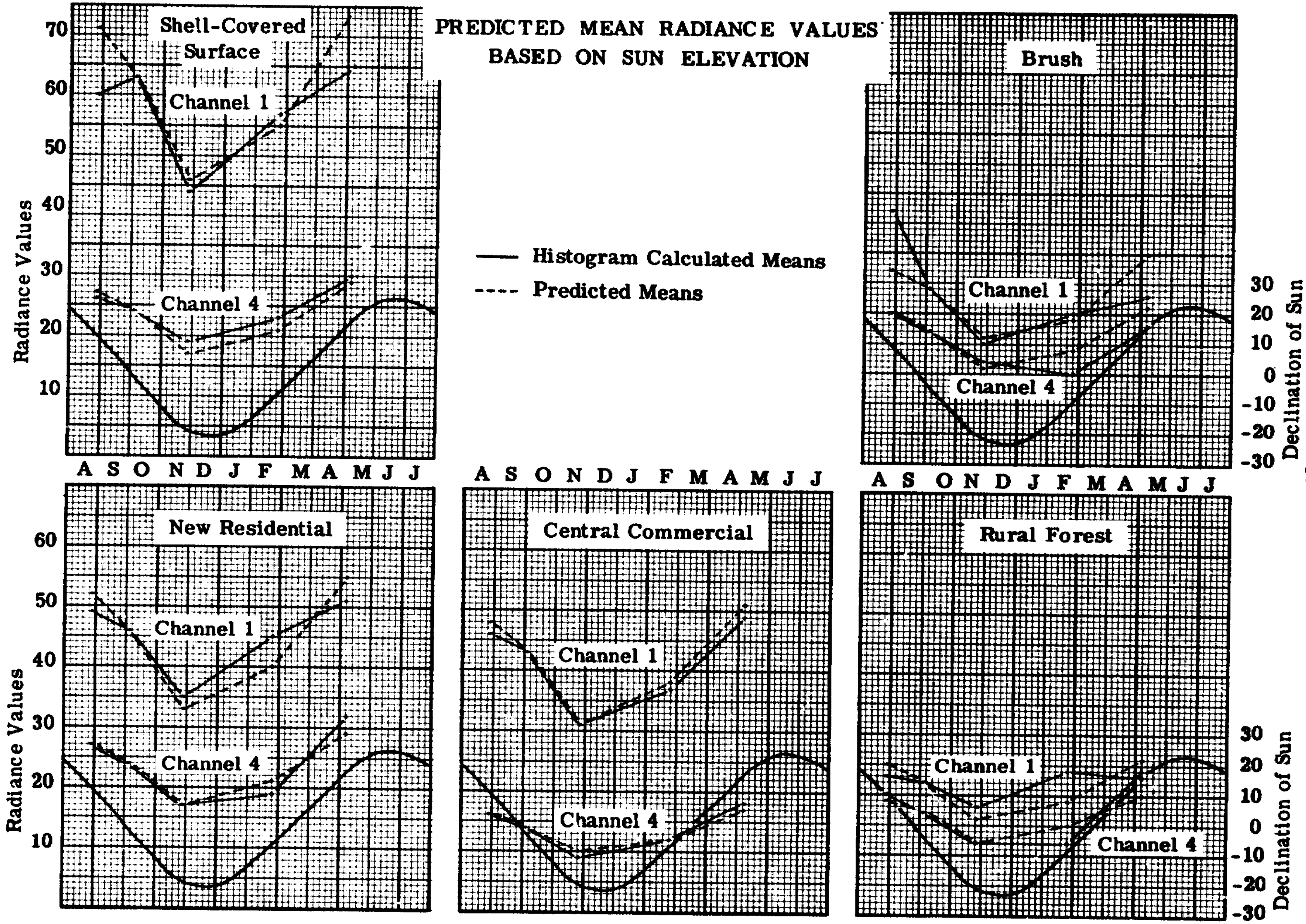
PREDICTED MEAN RADIANCE VALUES
BASED ON SUN ELEVATION
Histogram Calculated Means
Predicted Means
Shell-Covered Surface
Brush
New Residential
Central Commercial
Rural Forest
Channel 1
Channel 4
Radiance Values
Declination of Sun
A S O N D J F M A M J J

FIGURE 3

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