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PHENOLOGY SATELLITE EXPERIMENT

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16. Abstract

The 1972 Brown Wave and 1973 Green Wave were detected at 24 sites located in four north-south corridors across the United States through analysis of ERTS-1 imagery and multispectral scanner digital tapes. Ground observations from these sites were correlated with ERTS data. These two phenological events were documented by observations from more than 3200 sites across the United States.

The problem of changing atmospheric and illumination conditions were studied and corrections to ERTS data suggested.

Band-to-band ratios were developed and correlated with the fall and spring phenological changes in field crops and forests. The results to date show the feasibility of developing and refining phenoclimatic models for use in characterizing crop status and as an aid to yield prediction.

17. Key Words (Selected by Author(s)) Phenology Green Wave Brown Wave	18. Distribution Statement

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Preface

The objective of the project is to develop techniques for identifying phenological changes and plant types on a broad scale. Phenological sequences under study are the Green Wave and the Brown Wave (p. 4). Temporal comparisons have been made for 10 of the 14 test sites in the Appalachian and Mississippi Corridors (2.1.1). In addition to temporal studies for each individual test site, a new technique has been developed that permits the use of data where only one good overpass occurred.

Three subsites have been identified within each of the 10 test sites in the Rocky Mountain and Columbia Valley Corridors (p. 27). These are (1) rangeland, (2) alfalfa fields, and (3) wheat fields. The band ratio parameter (BRP) and the transformed vegetation parameter (TVP) are also calculated for these sites.

The problem of changing atmospheric and illumination conditions was studied by both LARS, Purdue University, and RSC, Texas A & M University (2.1.2). Tests so far indicate that corrections to ERTS data for the Eastern Corridors may be necessary for sun angle change and for variations of water vapor and particulate matter in the atmosphere. In the clearer atmosphere over the Western Corridors, correction for sun angle change is the only correction necessary.

The BRP (p. 27) appears to provide a responsive indicator of greenness. Data available from the Rocky Mountain and Columbia Valley Corridors show this is especially true of the measurements of alfalfa fields.

Ground photography documenting phenological events was continued at the 24 established sites in the four corridors for the 1973 Green Wave.

Observations, from more than 3200 sites, on two lilac phenophases in the spring of 1973 documented the 1973 Green Wave.

Phenological changes have been correlated with density differences within each band and with the BRP. This ratio continuously decreased with the progression of fall phenological changes in field crops and forests.

Regression analysis was performed on the spectral response as a function of latitude for different days during the 1972 Brown Wave.

Results to date from the Phenology Satellite Experiment shows the feasibility of the development and refinement of phenoclimatic models.

Satellite data, from an operational ERTS system, will make worldwide phenological monitoring possible. This is necessary to develop universally applicable phenoclimatic models.

For countries with highly developed agriculture, such information would be useful in characterization of crop status and an aid to yield prediction and management planning. Phenological data in less-developed countries could be useful for agricultural land-use planning and for determining site suitability.

TABLE OF CONTENTS

1.0 INTRODUCTION

This study is being conducted by the NE-69 and W-48 Regional Research Technical Committees[1] as an extension of their ongoing research in the development of methods for evaluation and utilization of remotely sensed data pertinent to agricultural ecosystems by ERTS and aircraft. The project involves research on the interpretation of remotely sensed data relevant to the Green Wave and Brown Wave (the seasonal and geographic procession of foliage development and senescence over wide areas) and their relationship to agricultural production.

The ERTS program is coordinated and directed by Dr. B. E. Dethier, Professor of Meteorology, Division of Atmospheric Sciences, Department of Agronomy, Cornell University, Ithaca, New York 14850. It uses the established facilities of 16 State Agricultural Experiment Stations, their substations and Phenological Network Stations and benefits from the experience gained through 16 years of closely coordinated regional and interregional research projects.

About one-half of the cost of the research in Agricultural Research programs has been funded by the cooperating states and about one-half by federal (USDA) regional research money distributed through State Agricultural Experiment Stations.

The diverse components of the ERTS-1 project necessitated close cooperation and coordination. To achieve the meaningful merging of research products, the following organization structure, as shown on page 2 was successfully implemented.

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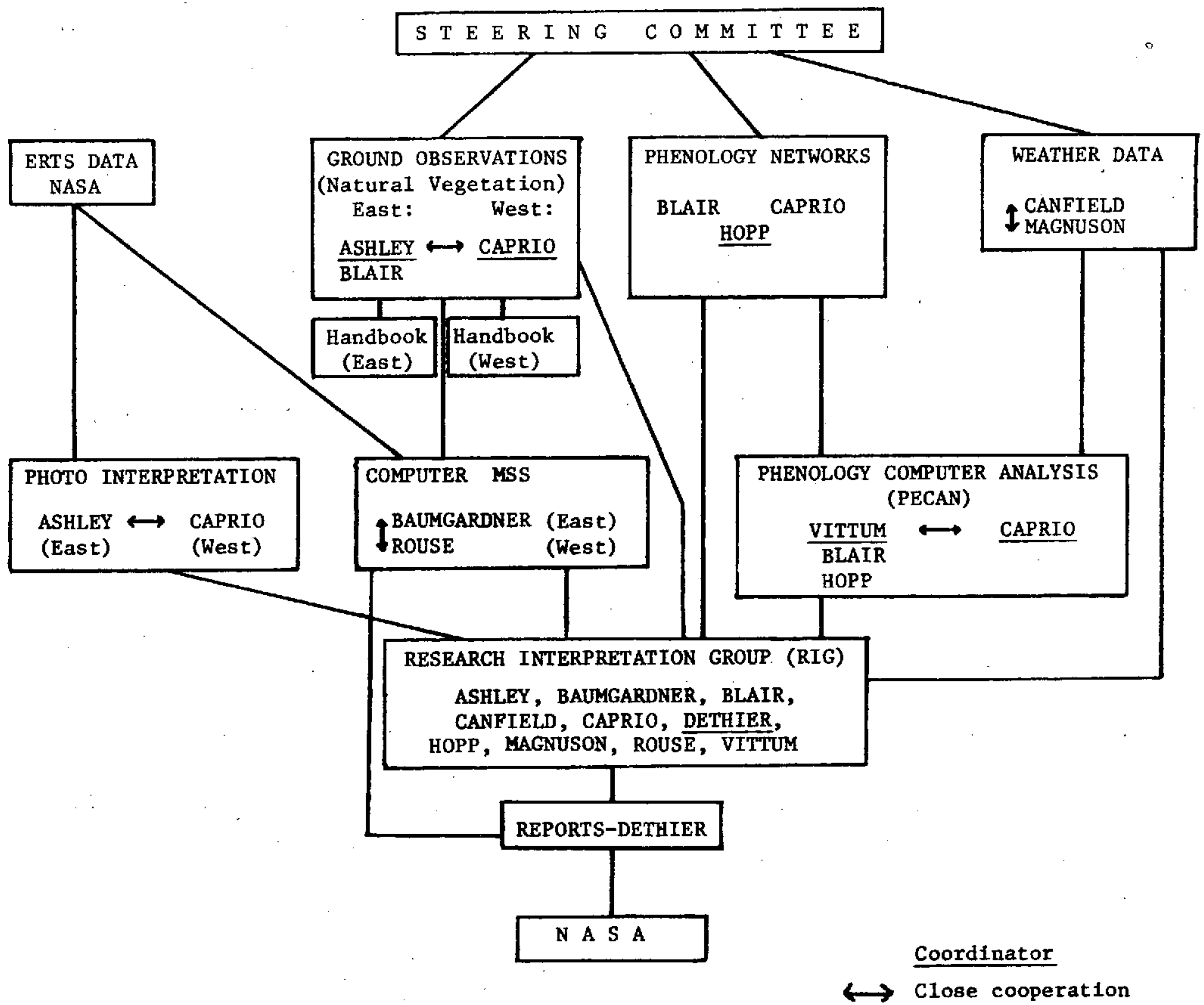
[1]Regional Research projects such as NE-69, Atmospheric Influences on Ecosystems and Satellite Sensing, and W-48, Climate and Phenological Patterns for Agriculture in the Western Region, are funded jointly by participating State Agricultural Experiment Stations and by federal regional research money from Cooperative State Research Service, USDA.



STEERING COMMITTEE
ERTS DATA NASA
GROUND OBSERVATIONS (Natural Vegetation)
East: West:
ASHLEY CAPRIO
BLAIR
PHENOLOGY NETWORKS
BLAIR CAPRIO
HOPP
WEATHER DATA
CANFIELD
MAGNUSON
Handbook (East)
Handbook (West)
PHOTO INTERPRETATION
ASHLEY (East) CAPRIO (West)
COMPUTER MSS
BAUMGARDNER (East)
ROUSE (West)
PHENOLOGY COMPUTER ANALYSIS (PECAN)
VITTUM CAPRIO
BLAIR
HOPP
RESEARCH INTERPRETATION GROUP (RIG)
ASHLEY, BAUMGARDNER, BLAIR,
CANFIELD, CAPRIO, DETHIER,
HOPP, MAGNUSON, ROUSE, VITTUM
REPORTS-DETHIER
N A S A
Coordinator
Close cooperation

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School of Forest Resources

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Plant and Soil Science Department

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University of Vermont
Department of Plant and Soil Science

Dr. W. C. Kennard
University of Connecticut
Agricultural Experiment Station

Mr. Marvin D. Magnuson
NOAA-National Weather Service

Dr. John W. Rouse, Jr.
Texas A & M University
Remote Sensing Center

Dr. M. T. Vittum
N.Y.S. Agricultural Experiment Station
Department of Vegetable Crops

The Phenology Satellite Experiment is a temporal study of the variations in spectral properties of plants for various test sites in the United States. The broad aim of this project is to observe the temporal and geographical progression of the plant life cycle through the use of ERTS data. The two phenological sequences under study are:

1. The Green Wave - a record of the geographical progression with time of foliage development over wide areas in the spring.
2. The Brown Wave - a similar record of vegetation senescence or maturation in the autumn.

A well-coordinated nationwide network of 24 ground observation sites in four corridors (Figure 1) has been established and ground photography documentation of phenological events has been continuous since the launch of ERTS-1.

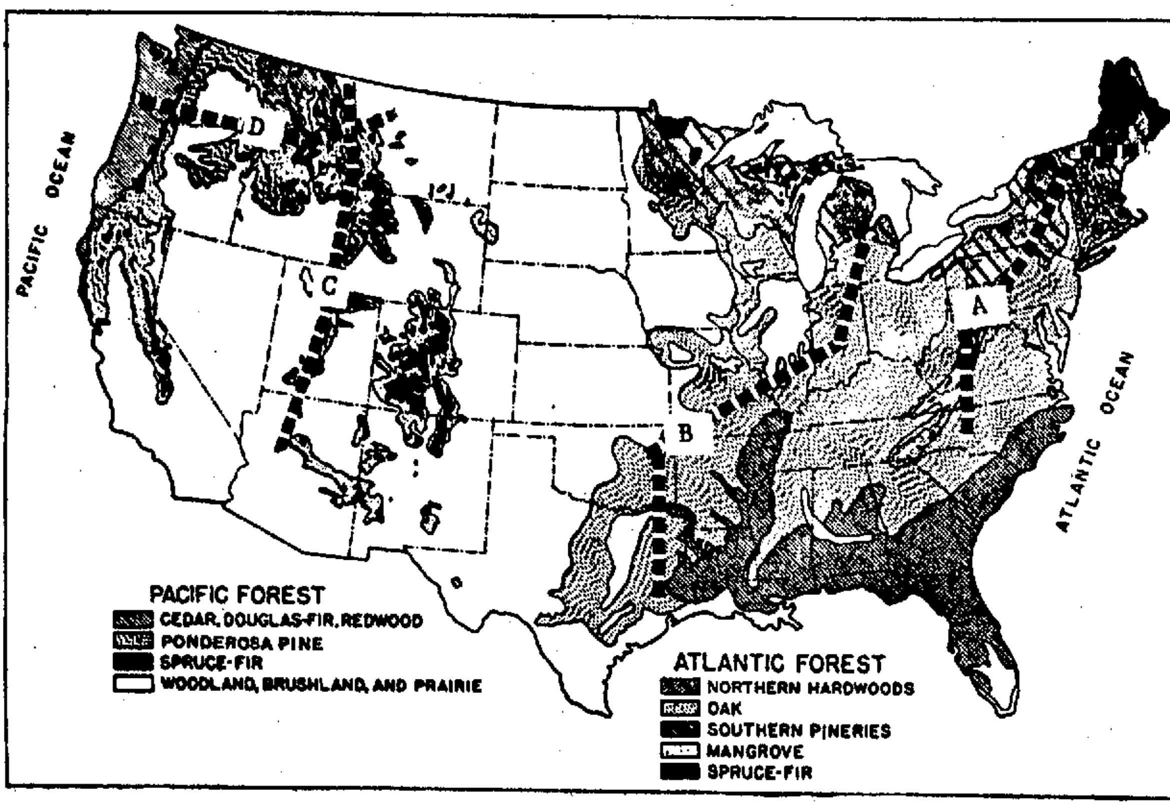


Figure 1. A - Appalachian Corridor, B - Mississippi Valley Corridor, C - Rocky Mountain Corridor, D - Columbia Valley Corridor.

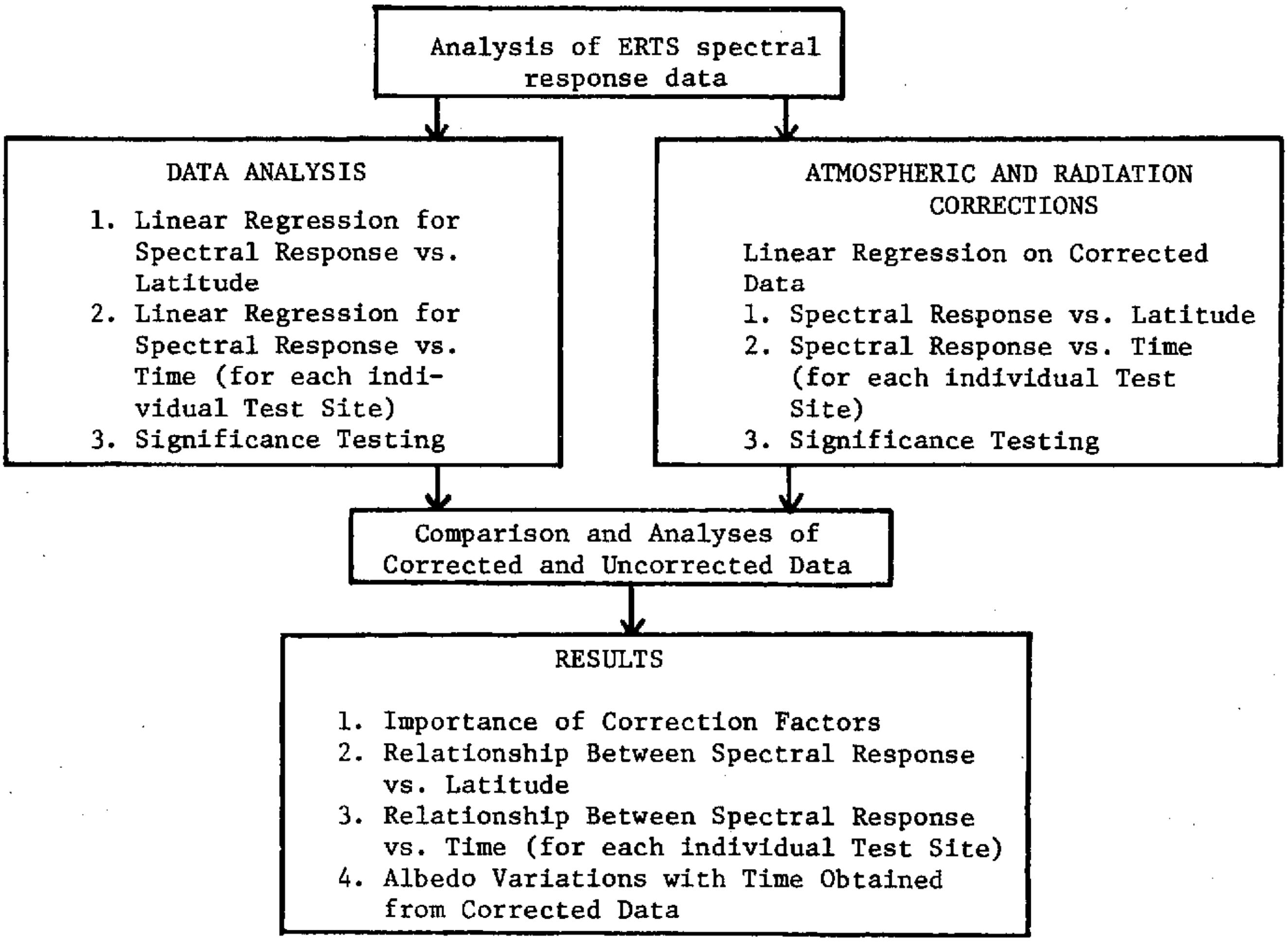
2.0 ACCOMPLISHMENTS

2.1 Data Handling

2.1.1 Qualitative Analysis of Individual Test Site Data

Appalachian and Mississippi Corridors

A flow chart illustrating the sequence of tests and correction factors used to infer the project results is illustrated below. Results so far include the phases of data analysis for each site and atmospheric and radiation corrections as applied to Lafayette, Indiana with a comparison of the Lafayette analyses and conclusions drawn thus far.



To date, temporal comparisons have been made for 10 of the 14 test sites with only one date analyzed for State College, Pennsylvania and Orono, Maine. Texas (north) appears to have no useable data for the Brown Wave and special orders had to be placed for West Virginia data as the original incoming imagery did not include the test site. Table 1 shows all data received and analyzed for each test site. A considerable number of tapes have not yet been received.

TABLE 1

Analysis Summary
Breakdown According to Test Site

Appalachian Corridor

Orono, ME	Richmond, ME	Burlington, VT
1 Sept. 1972	15 Aug. 1972	21 Sept. 1972
	1 Sept. 1972	10 Oct. 1972
		27 Oct. 1972

Ithaca, NY	State College, PA	Raleigh, NC
19 Aug. 1972	6 Sept. 1972	19 Aug. 1972
5 Sept. 1972		6 Sept. 1972
23 Sept. 1972		24 Sept. 1972
11 Oct. 1972		12 Oct. 1972
9 Apr. 1973		

Mississippi Corridor

Lansing, MI	Lafayette, IN	Southern Indiana
25 Aug. 1972	30 Sept. 1972	26 Aug. 1972
30 Sept. 1972	1 Oct. 1972	12 Sept. 1972
	19 Oct. 1972	13 Sept. 1972
	24 Nov. 1972	30 Sept. 1972
	16 Jan. 1973	1 Oct. 1972
	4 Feb. 1973	19 Oct. 1972
	5 May 1973	5 Nov. 1972
		6 Nov. 1972
		16 Jan. 1973
		4 Feb. 1973
		5 May 1973

Jefferson City, MO	Barnsdall, OK	College Station, TX (central)
11 Aug. 1972	13 Aug. 1972	30 Aug. 1972
29 Aug. 1972	18 Sept. 1972	23 Oct. 1972
		16 Mar. 1973

Table 2 shows the 1972 and 1973 listing of data expected and received.

TABLE 2

Data Summary

	1972				1973		
Imagery Frames							
Received:	127	Expected:	168	Received:	88	Expected:	230
Computer Compatible Tapes							
Received:	45	Expected:	56	Received:	10	Expected:	40

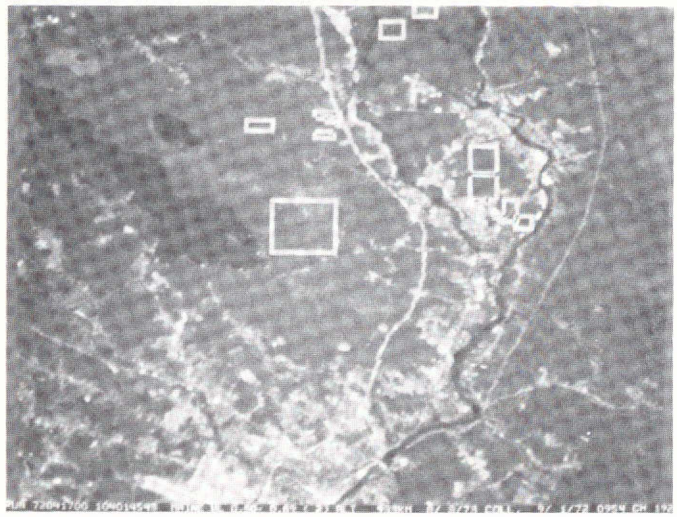
Breakdown of Tapes Received

Reformatted		Analyzed		Useless	
1972	1973	1972	1973	1972	1973
45	10	37	8	8	2

The temporal analyses of the Brown Wave and Green Wave data are shown in Figures 2-13. All analyses completed thus far is for forested areas only. The fields chosen are outlined on the representative digital display image with each graph. On the graph, the ordinate gives the mean relative spectral response as determined from statistics obtained from a grouping of test fields at each site. The abscissa shows the overpass day for each data element. All four ERTS bands are shown separately on each graph.

In the case of the 10 test sites where time-lapse analysis of the data could be made, bands 4 and 5 showed no significant change over time for the Brown Wave. Notable exceptions to this observation include 24 September for North Carolina (Figure 7), and 12 and 13 September for Southern Indiana (Figure 10) where the test site at the time of overpass was observed to be under some haze which appears to have affected the data response. Both Barnsdall, Oklahoma (Figure 12) and College Station, Texas (Figure 13) show a slight decrease in response with no obvious explanation for the differences.

In bands 6 and 7, the near infrared region of response, there is a



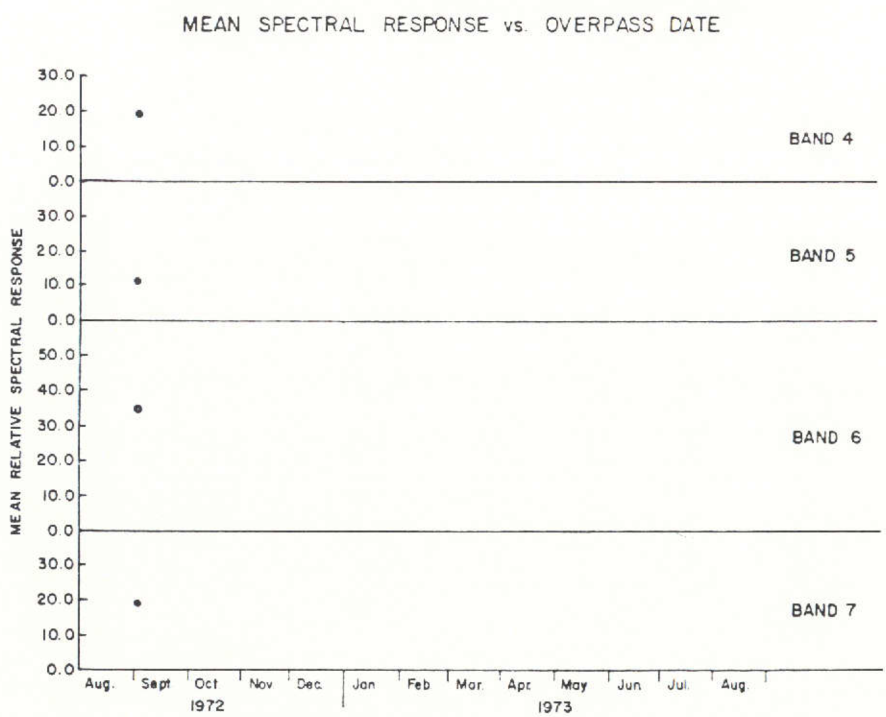
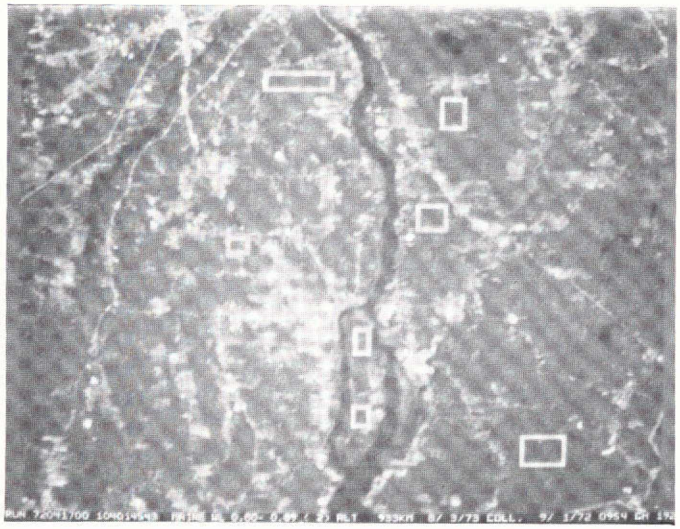


Figure 2. Orono, Maine



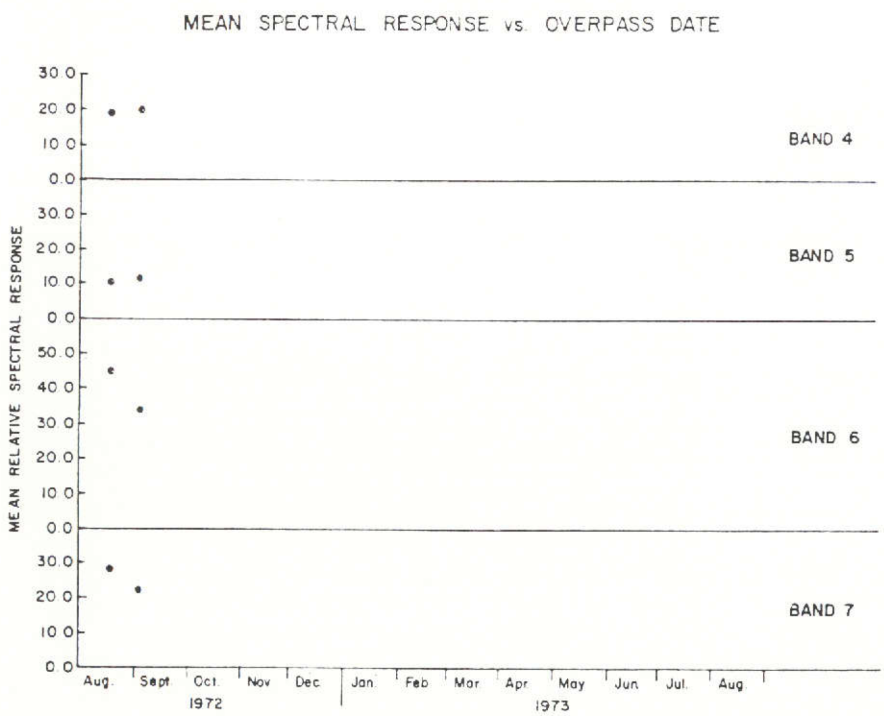
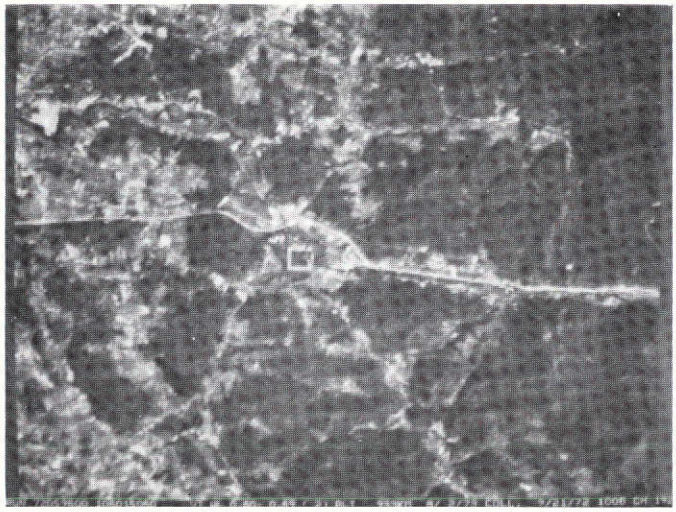


Figure 3. Richmond, Maine



MEAN SPECTRAL RESPONSE vs. OVERPASS DATE

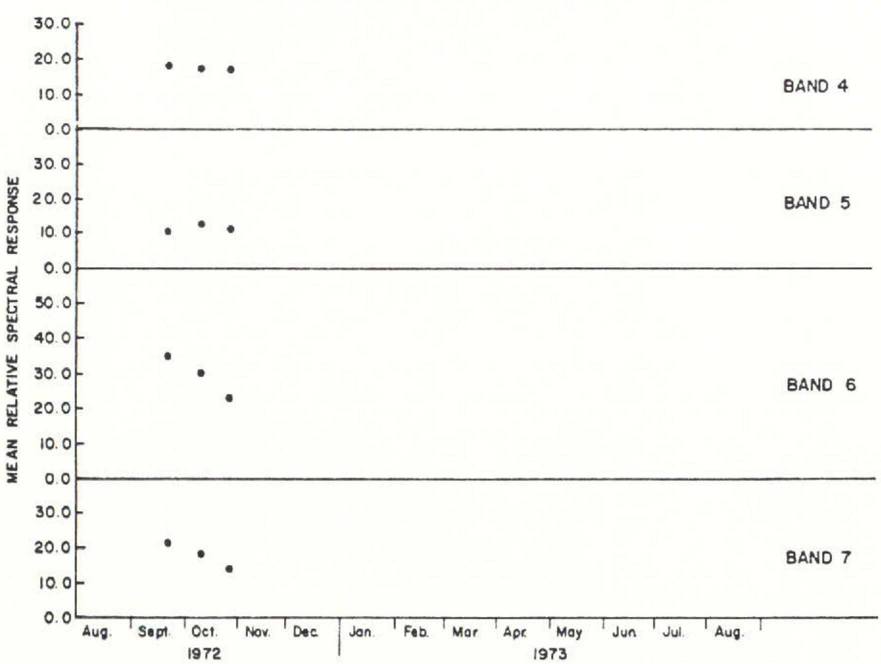
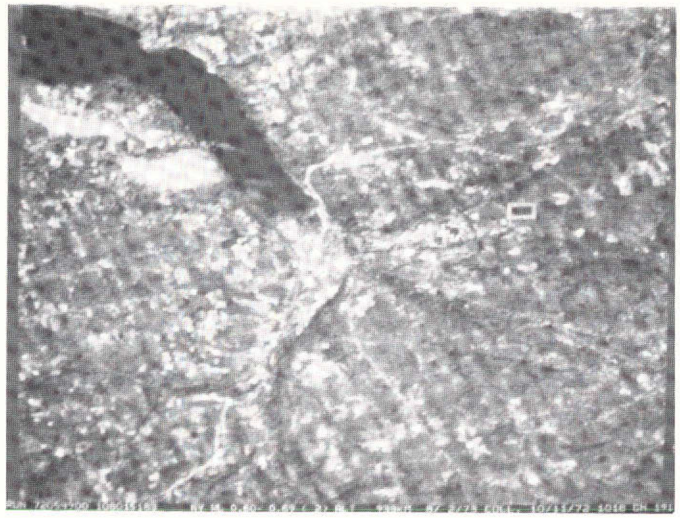


Figure 4. Burlington, Vermont



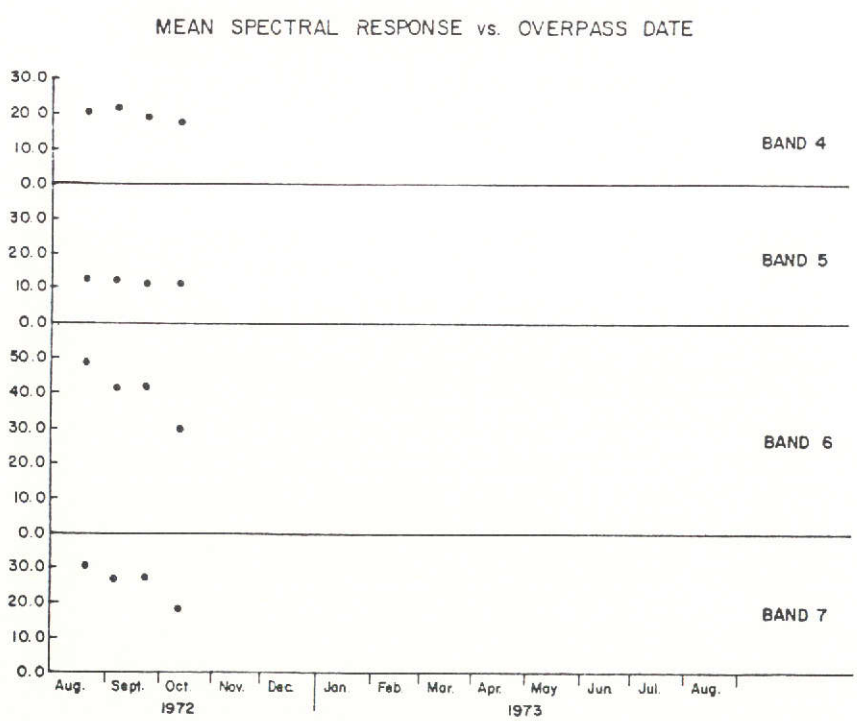
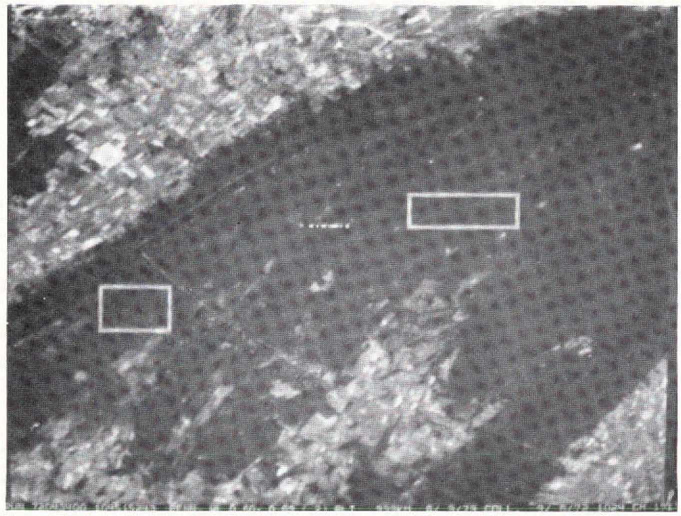


Figure 5. Ithaca, New York



MEAN SPECTRAL RESPONSE vs. OVERPASS DATE

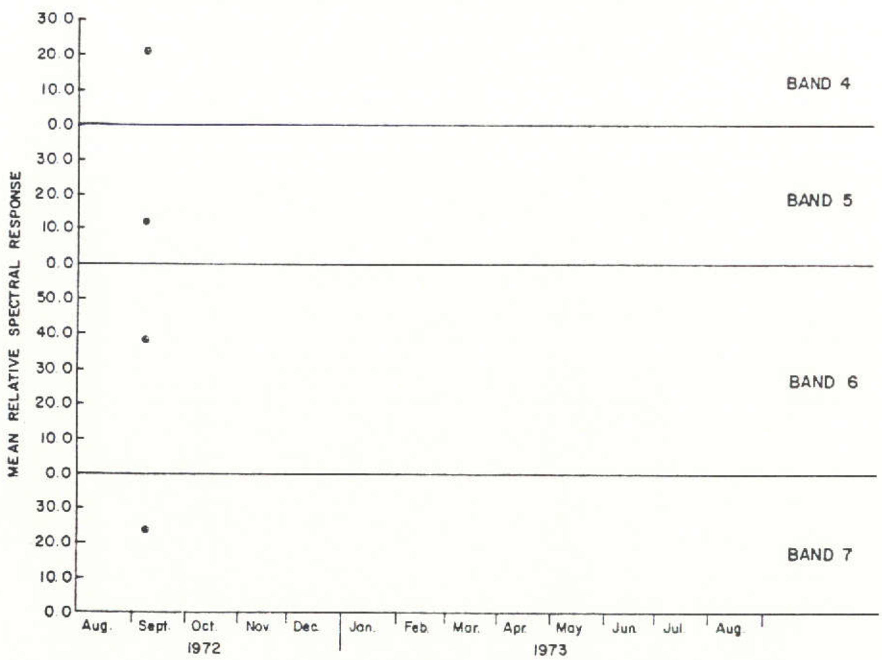
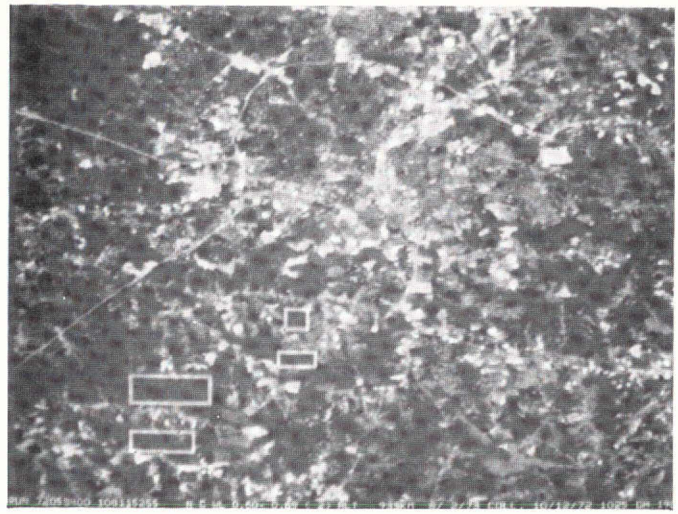


Figure 6. State College, Pennsylvania



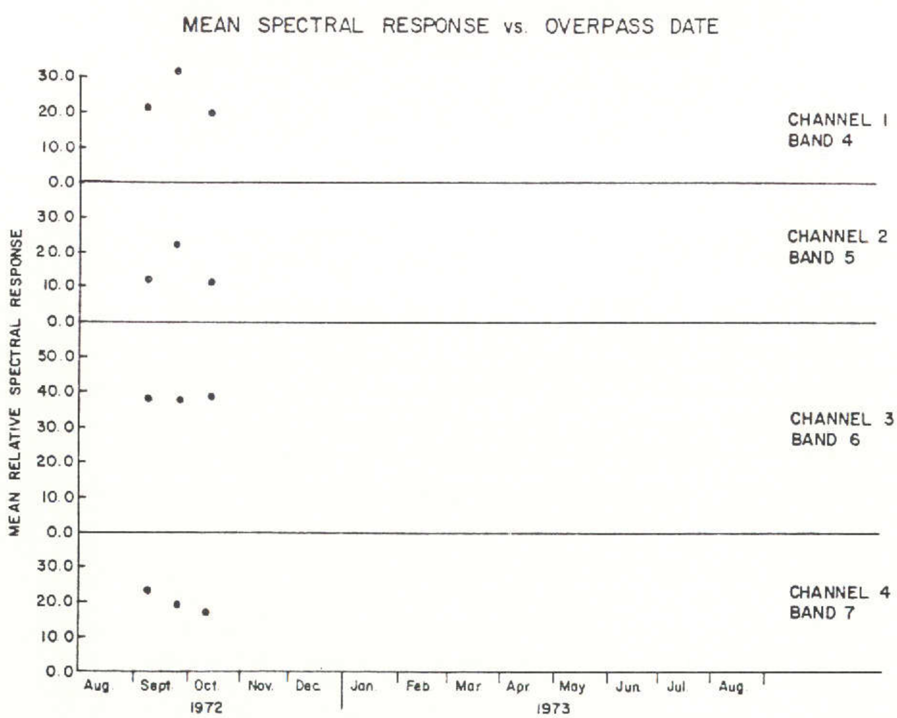
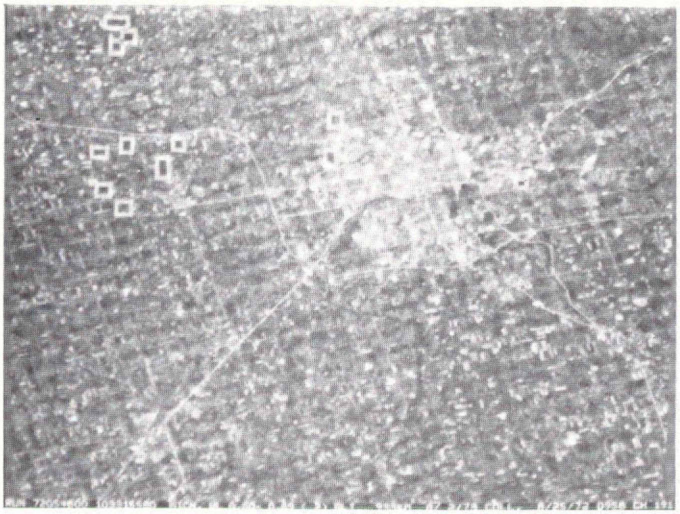


Figure 7. Raleigh, North Carolina



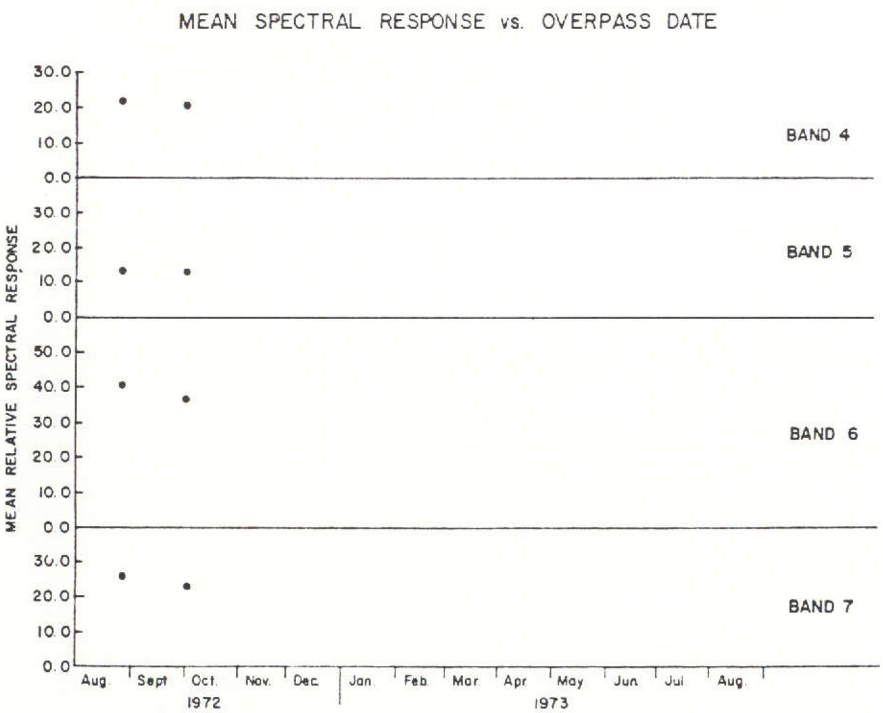
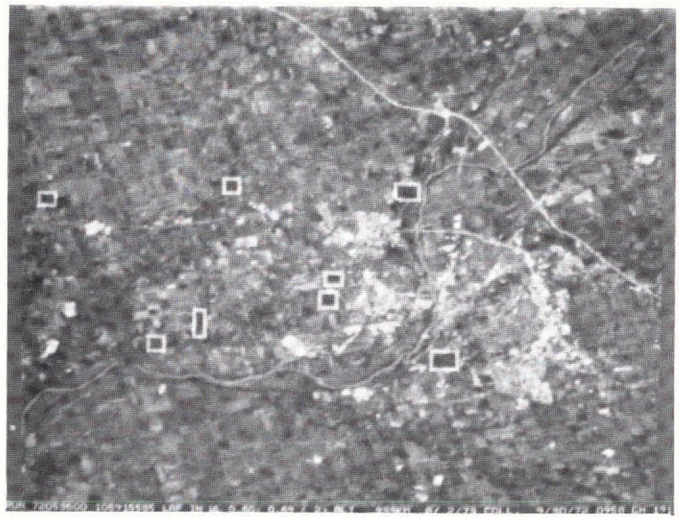


Figure 8. Lansing, Michigan



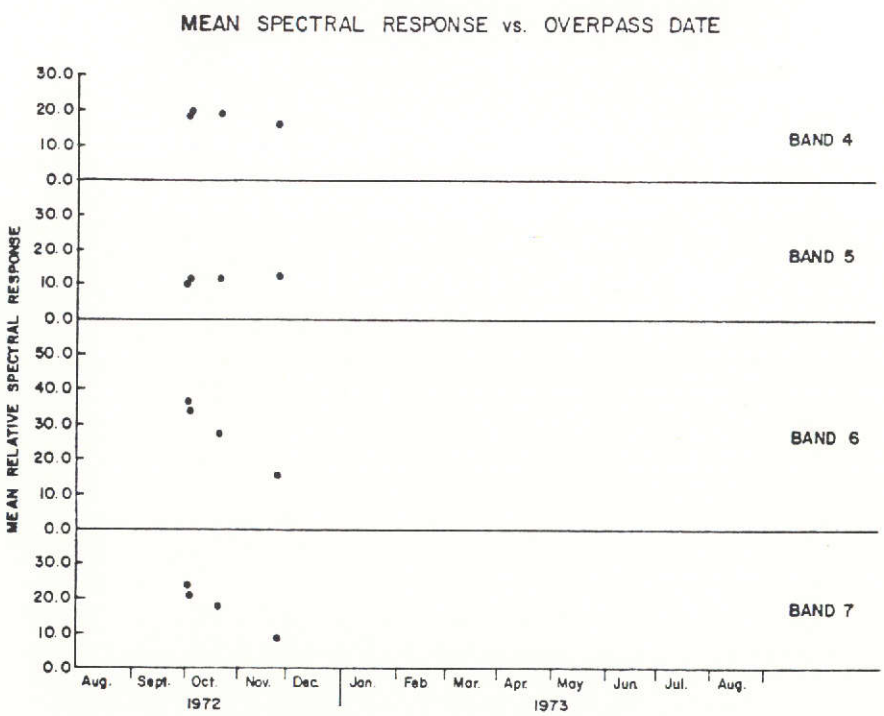
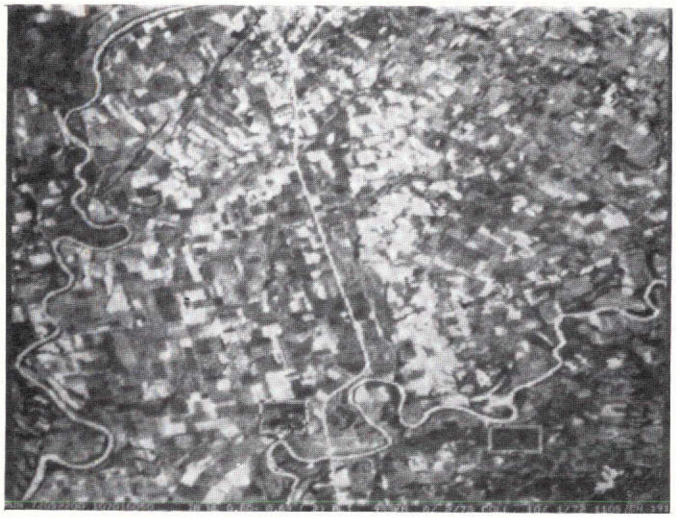


Figure 9. Lafayette, Indiana



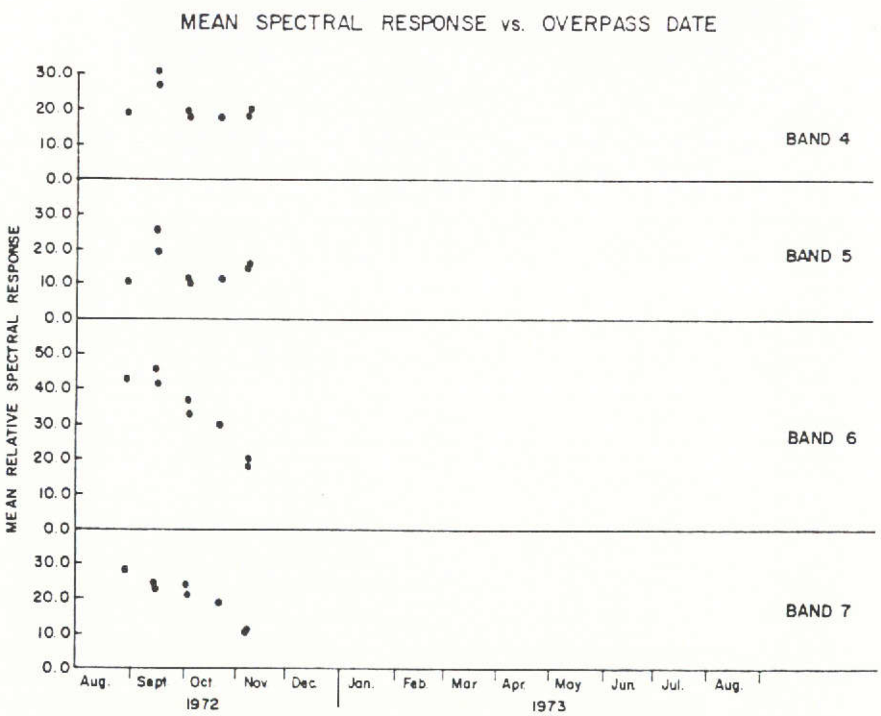
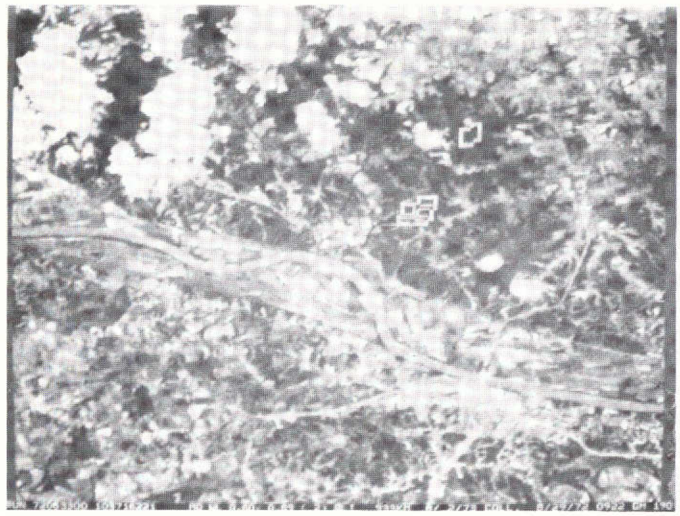


Figure 10. Southern Indiana



MEAN SPECTRAL RESPONSE vs. OVERPASS DATE

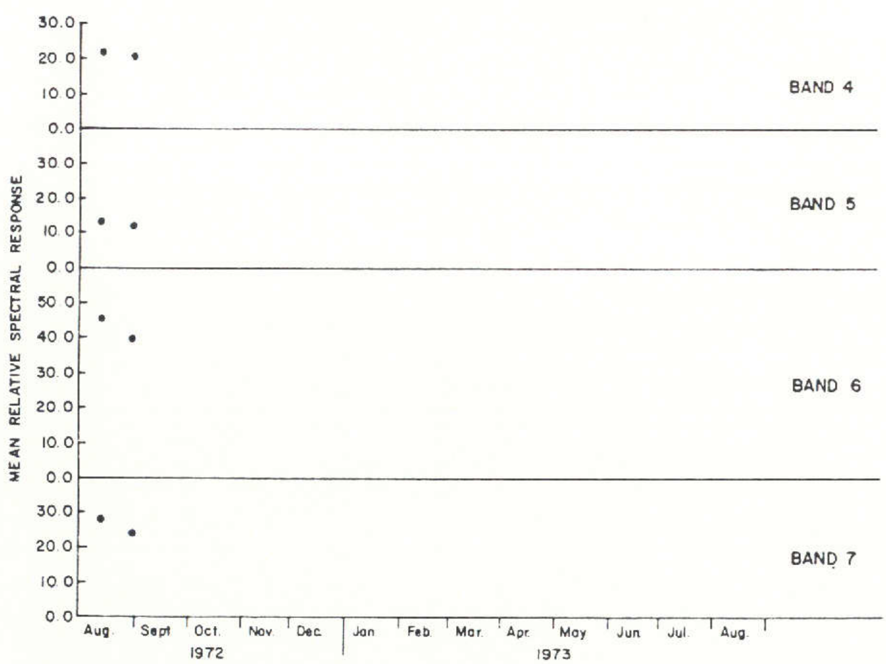
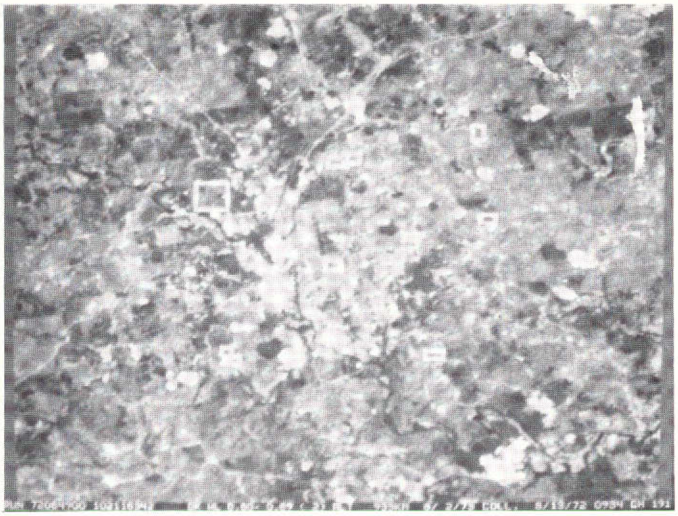


Figure 11. Jefferson City, Missouri



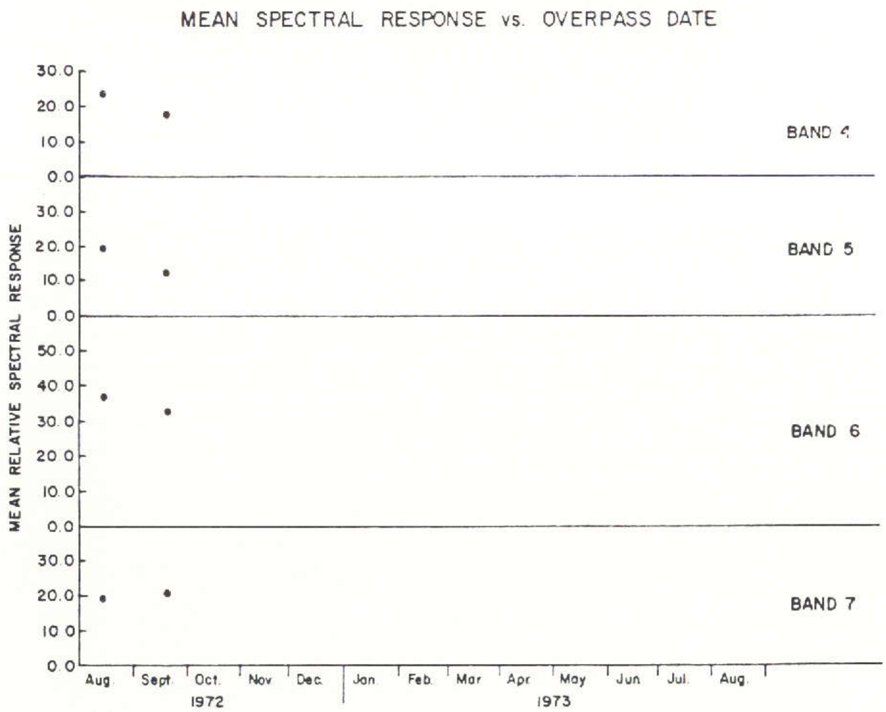
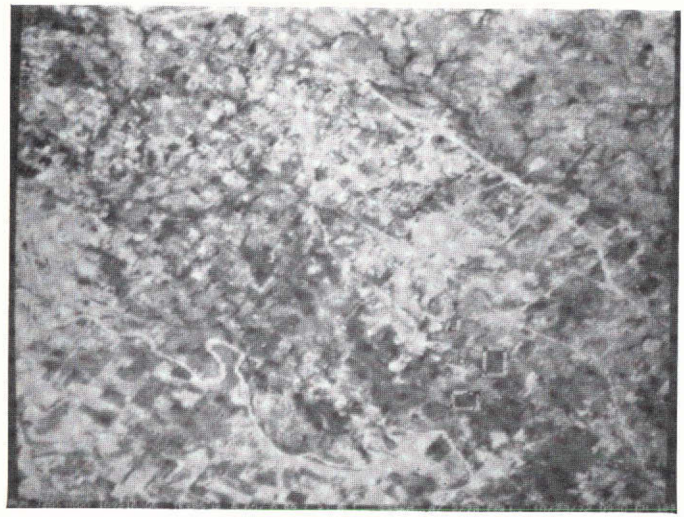


Figure 12. Barnsdall, Oklahoma



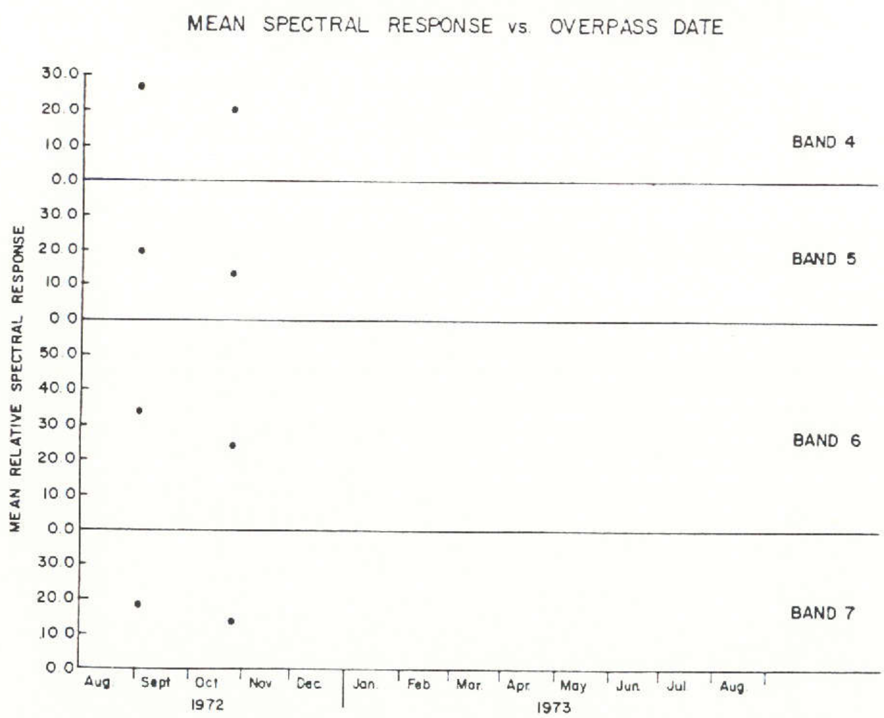


Figure 13. College Station, Texas (Central)

definite decrease in spectral properties as the Brown Wave progresses. The only two exceptions are for band 6 at North Carolina (Figure 7) and for band 7 at Oklahoma (Figure 12) where no significant pattern is detectable.

The reliability of the analysis of these data is enhanced in that the fields chosen for each test site are uniquely defined and consistent from one overpass date analyzed to another.

In addition to temporal studies for each individual test site, a new technique has been developed that permits the use of data from test sites where only one good overpass occurred. This involves plotting, for a given day, spectral response at a test site versus latitude of the sites for all test locations. Thus, all data can be utilized for temporal studies.

Figures 14, 15 and 16 illustrate spectral response as a function of latitude for three different days during the Brown Wave. Some interpolation of data was necessary to accomplish this.

Regression analysis was then performed for the data on each of these graphs. The Fischer t-test was employed to determine the probability of the regression statistics being meaningful.

Table 3 shows the outcome of the regression analysis applied to three different sets of data. The analyses look at the peak relative spectral response versus latitude for 15 August 1972, 5 September 1972 and 10 October 1972, respectively.

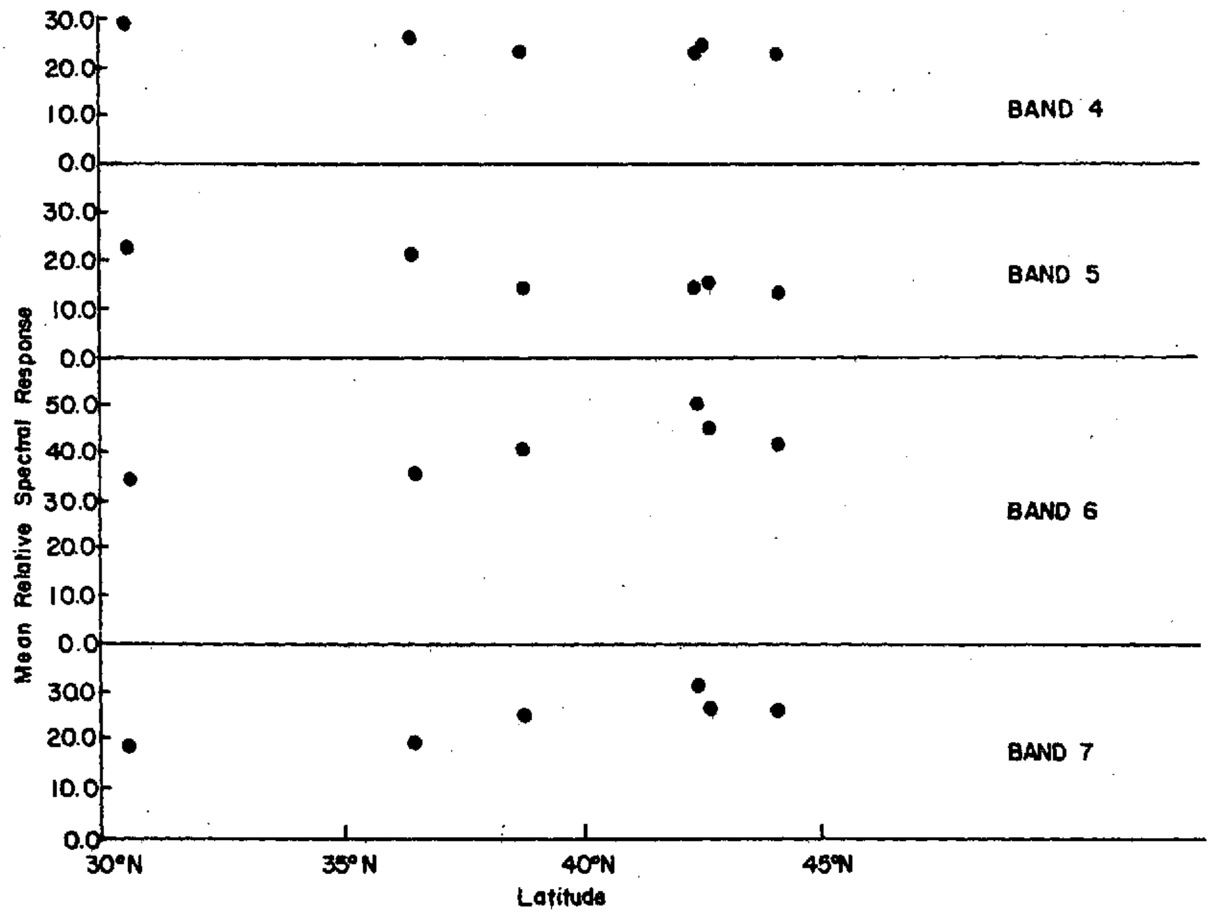


Figure 14. Mean Relative Spectral Response vs. Latitude, 15 August 1972

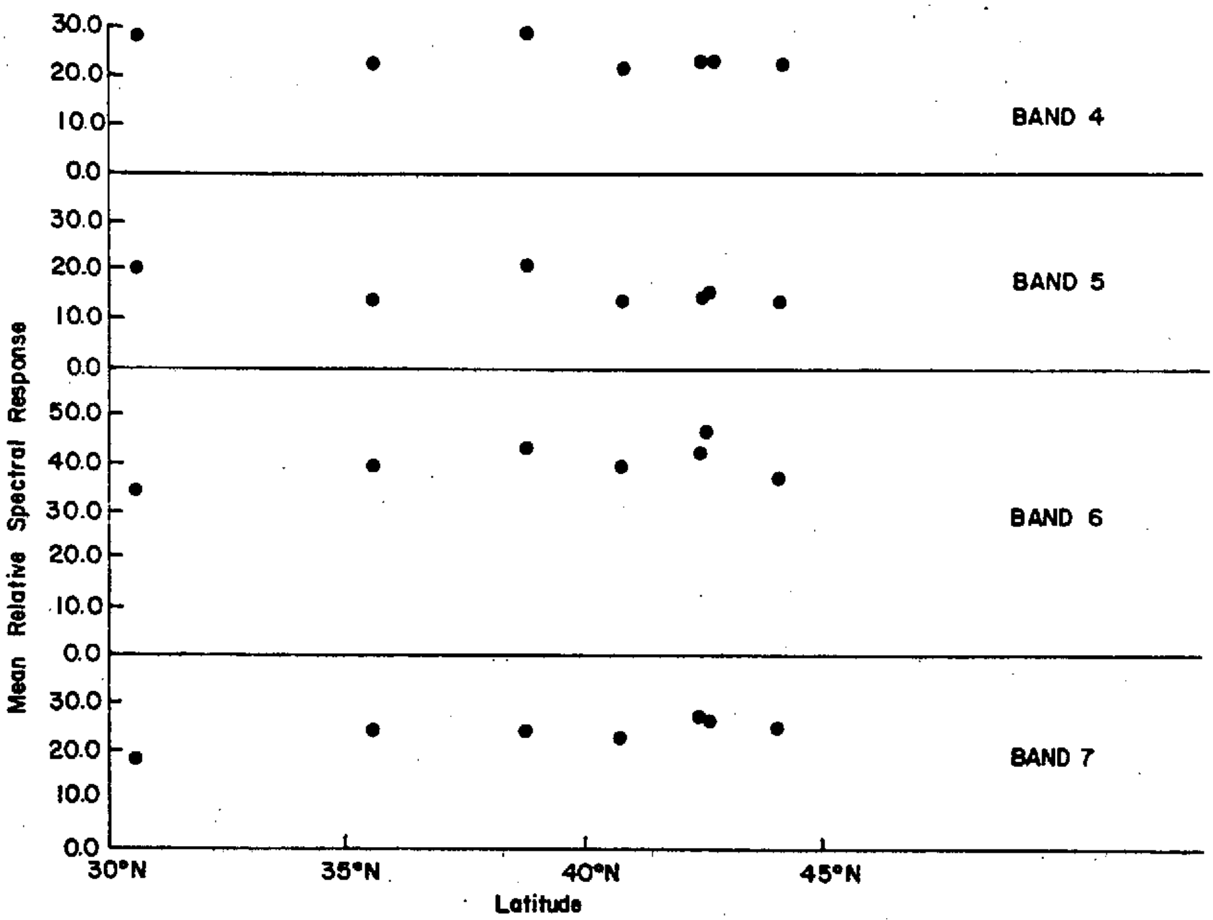


Figure 15. Mean Relative Spectral Response vs. Latitude
5 September 1972

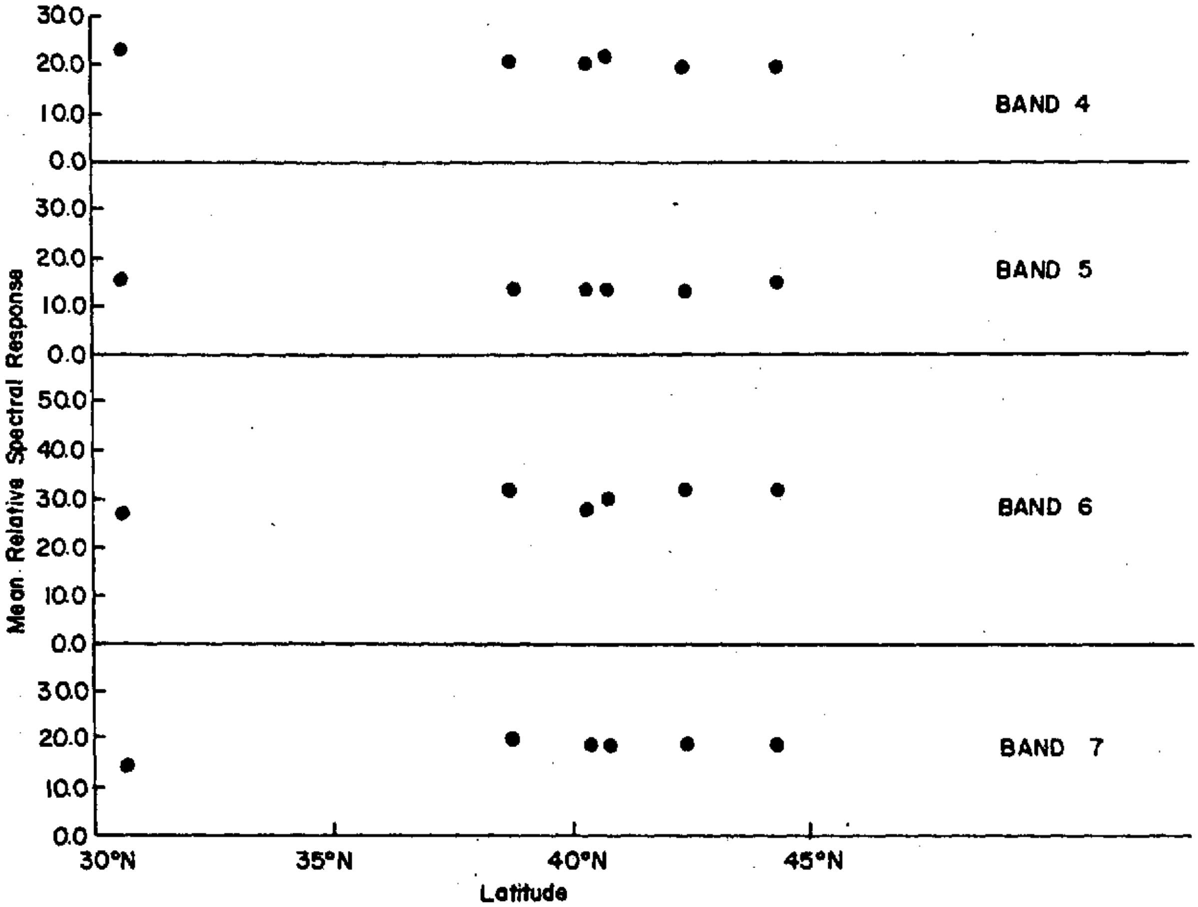


Figure 16. Mean Relative Spectral Response vs. Latitude
10 October 1972

TABLE 3

Relative Spectral Response Versus Latitude

	ERTS band	r	b	a	t
15 August 1972	4	.94	-.52	44.4	5.27
	5	.90	-.76	45.6	3.23
	6	.76	.86	7.2	2.34
	7	.78	.71	-3.6	2.49
5 September 1972	4	.67	-.41	40.4	2.02
	5	.63	-.42	31.9	1.82
	6	.54	.42	23.0	1.44
	7	.53	.34	10.0	1.40
10 October 1972	4	.92	-.30	32.3	4.72
	5	.66	-.18	21.0	1.76
	6	.72	.25	19.6	2.09
	7	.81	.26	7.7	2.76

The regression results may be summarized as follows:

Spectral Response Versus Latitude

a. Correlation coefficients seem to be somewhat higher in bands 4 and 5.

b. Significance of the correlation coefficients is easier to obtain in bands 4 and 5.

c. Regression slopes are consistently negative for bands 4 and 5 and positive for bands 6 and 7.

d. The regression slopes tend to become consistently "flatter" as the Brown Wave progresses. This effect is observed in all four bands. Perhaps this reflects the fact that differences in spectral response with latitude are decreasing in that the vegetative condition becomes more uniform over the U.S. towards the end of the Brown Wave.

A regression analysis was also performed on the Southern Indiana test site for relative spectral response versus time of overpass (Figure 10). The results are shown in Table 4.

TABLE 4

Relative Spectral Response Versus Date for Southern Indiana

ERTS band	r	b	a
4	-.47	-2.3	106.6
5	-.20	-1.0	69.9
6	-.96	-2.48	137.5
7	-.95	-3.78	130.5

This was the only individual test site for which such an analysis could be successfully conducted so far as no other site has more than four points to plot. Later, as spring data are added to the present analysis for all sites, a curvilinear regression may prove useful for each location.

Although it was not possible to compare the regression results from Southern Indiana with other sites (due to lack of enough data so far), it is possible to infer some information from Table 4.

1. Higher correlation coefficients are found in bands 6 and 7 (in contrast to the findings for Spectral Response versus Latitude).
2. The slopes are negative in <u>all</u> four channels. This fact suggests the possibility that the correction factor is important (in that a decrease in actual albedo at all wavelengths is unlikely for the vegetation being studied).

Rocky Mountain and Columbia Valley Corridors

Imagery from 18 cycles of ERTS-1 have been received for almost all 10 test sites in the Rocky Mountain and Columbia River Valley Corridors. Data were not received for Cycle 12, and Cycle 20 data are yet to arrive. On hand are 216 sets of MSS images. Of these, 34 provided data resulting in the ordering of magnetic tapes. Twenty-seven of these have been computer processed to a finished Site Processing Report.

Three subsites have been identified within each of the 10 test sites. These are (1) rangeland sites, (2) alfalfa fields, and (3) wheat fields. At least one cycle of MSS data for each site has been computer-processed to extract radiance values for each subsite. The task of accurately identifying each of the three subsites is extremely tedious. Numerous maps, aerial photographs, and positive transparencies of aerial photographs were required to accomplish this task.

A standard format report is provided at the completion of site processing. Data presented by this report is corrected for sun intensity variation due to sun elevation at the time of the imagery (see section 2.1.2). Included in the report is the site designator, which shows the corridor, site, and subsite designation. For example, "CV7" designates site 7 in the Columbia Valley Corridor. Subsites have been designated as "A" Alfalfa, "W" Wheat, and "R" Range (Figures 17-19). Additional information in the report heading includes the NASA image identifier 1304-17461, and the date of the satellite overpass 23MAY73. Other data includes the data cell and line extents of the site and the total number of points in the full site. Subsite band means and covariances are tabulated and a graph of the mean values is printed. Data points are indicated by the symbol "*" and interconnecting plot lines by the symbol "-". Also included is a printout of two calculated data parameters, the band ratio parameter defined as $BRP = \frac{\text{Band 7} - \text{Band 5}}{\text{Band 7} + \text{Band 5}}$ and the transformed vegetation

ERTS-1

SITE PROCESSING REPORT

SITE DESIGNATOR:	CV 7 A	CELLS	2765 TO 2768
IMAGE IDENTIFIER:	1304-17461	LINES	1671 TO 1673
DATE ACQUIRED:	23MAY73	TOTAL POINTS	12

CORRECTED FOR SUN ELEVATION 56 DEGREES

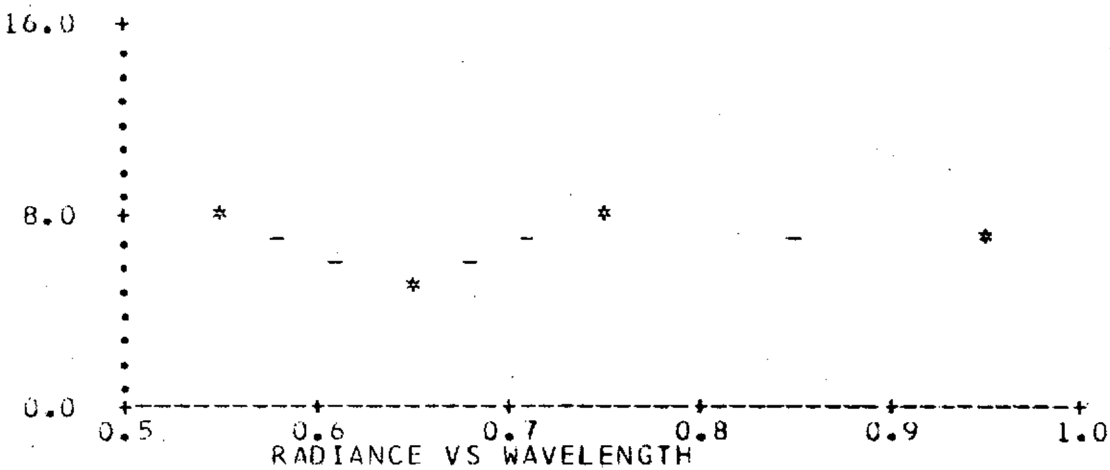
RADIANCE(MWATTS/SQCM-STR-MICROMETER)

	MEAN	STANDARD DEVIATION	WAVELENGTH (MICROMETERS)
BAND 4	7.85	0.45	.5 - .6
BAND 5	5.41	0.57	.6 - .7
BAND 6	7.69	0.53	.7 - .8
BAND 7	7.23	0.81	.8 -1.1

NORMALIZED COVARIANCES

	BAND 4	BAND 5	BAND 6	BAND 7
BAND 4	1.000	0.898	0.179	-0.011
BAND 5	0.898	1.000	0.086	-0.142
BAND 6	0.179	0.086	1.000	0.901
BAND 7	-0.011	-0.142	0.901	1.000

BAND RATIO PARAMETER 0.143
TRANSFORMED PARAMETER 0.802



PREPARED BY:TEXAS A&M UNIVERSITY, REMOTE SENSING CENTER
DATA ANALYSIS LABORATORY 27SEP73

Figure 17. Site Processing Report for Havre, Montana, subsite alfalfa 23 May 1973.

ERTS-1

SITE PROCESSING REPORT

SITE DESIGNATOR: CV 7 W
IMAGE IDENTIFIER: 1304-17461
DATE ACQUIRED: 23MAY73

CELLS 2751 TO 2754
LINES 1674 TO 1681
TOTAL POINTS 32

CORRECTED FOR SUN ELEVATION 56 DEGREES

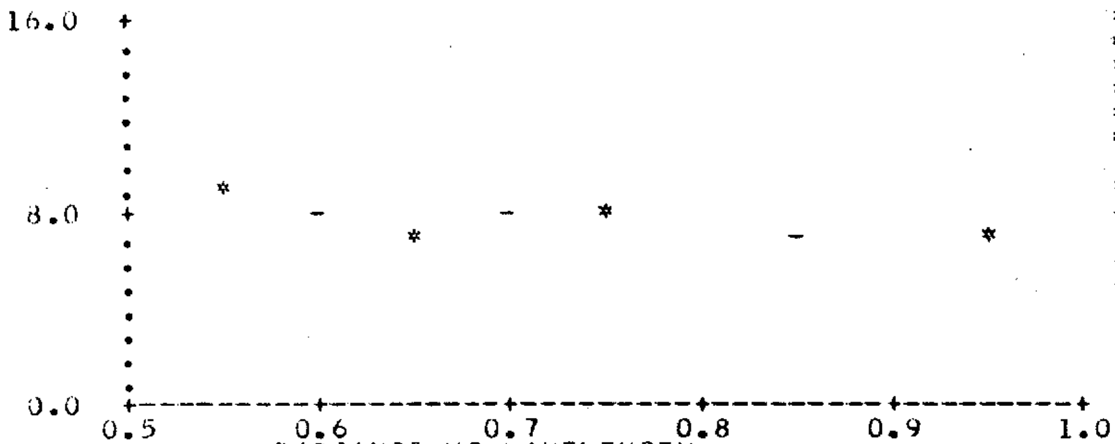
RADIANCE(MWATTS/SQCM-STR-MICROMETER)

	MEAN	STANDARD DEVIATION	WAVELENGTH (MICROMETERS)
BAND 4	9.16	0.43	.5 - .6
BAND 5	7.21	0.50	.6 - .7
BAND 6	7.72	0.34	.7 - .8
BAND 7	6.67	0.42	.8 -1.1

NORMALIZED COVARIANCES

	BAND 4	BAND 5	BAND 6	BAND 7
BAND 4	1.000	0.684	0.350	-0.182
BAND 5	0.684	1.000	0.121	-0.380
BAND 6	0.350	0.121	1.000	0.508
BAND 7	-0.182	-0.380	0.508	1.000

BAND RATIO PARAMETER -0.038
TRANSFORMED PARAMETER 0.679



RADIANCE VS WAVELENGTH

PREPARED BY:TEXAS A&M UNIVERSITY, REMOTE SENSING CENTER
DATA ANALYSIS LABORATORY 27SEP73

Figure 18. Site Processing Report for Havre, Montana, subsite wheat 23 May 1973.

ERTS-1

SITE PROCESSING REPORT

SITE DESIGNATOR: CV 7 R — CELLS 2771 TO 2780
IMAGE IDENTIFIER: 1304-17461 — LINES 1716 TO 1726
DATE ACQUIRED: 23MAY73 — TOTAL POINTS 110

CORRECTED FOR SUN ELEVATION 56 DEGREES

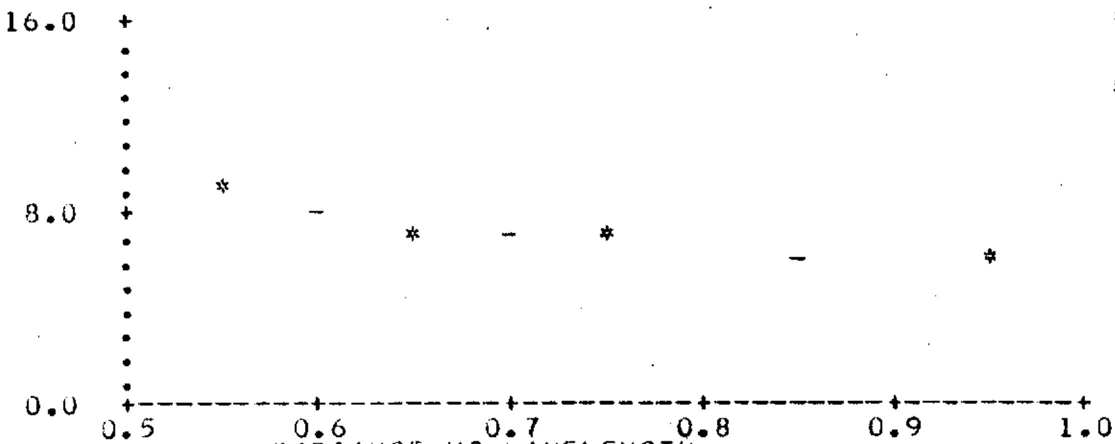
RADIANCE(MWATTS/SQCM-STR-MICROMETER)

	MEAN	STANDARD DEVIATION	WAVELENGTH (MICROMETERS)
BAND 4	8.74	0.45	.5 - .6
BAND 5	6.64	0.49	.6 - .7
BAND 6	7.03	0.34	.7 - .8
BAND 7	5.91	0.37	.8 -1.1

NORMALIZED COVARIANCES

	BAND 4	BAND 5	BAND 6	BAND 7
BAND 4	1.000	0.759	0.405	0.110
BAND 5	0.759	1.000	0.313	0.068
BAND 6	0.405	0.313	1.000	0.691
BAND 7	0.110	0.068	0.691	1.000

BAND RATIO PARAMETER -0.058
TRANSFORMED PARAMETER 0.665



RADIANCE VS WAVELENGTH

PREPARED BY:TEXAS A&M UNIVERSITY, REMOTE SENSING CENTER
DATA ANALYSIS LABORATORY 27SEP73

Figure 19. Site Processing Report for Havre, Montana, subsite range 23 May 1973.

parameter, TVP = $(BRP + 0.5)^{1/2}$. These reports show the results of integrating the reflectance values from scenes which were located by use of a Band 5 gray map (Figure 20). The gray map coordinates were provided by Montana State University, and are verified by them upon receipt of the site reports. Phenological progressions can be detected using Bands 5 and 7. The data available from Rocky Mountain and Columbia Valley corridors show evidence that vegetation conditions strongly effect radiance values. This is especially true of the measurements of alfalfa fields. In addition, the BRP appears to provide a responsive indicator of greenness. This is illustrated in the seven cycles of data available for the Havre, Montana Site. The data values are listed in Table 5. These data are plotted in Figure 21 for each subsite. An option in the programming has also been included to allow mean and covariance calculations to be made and printed for 4 mile square sites including all subsites in essentially the same format as the full subsite report. This provides an integrated measure of the composite vegetation development.

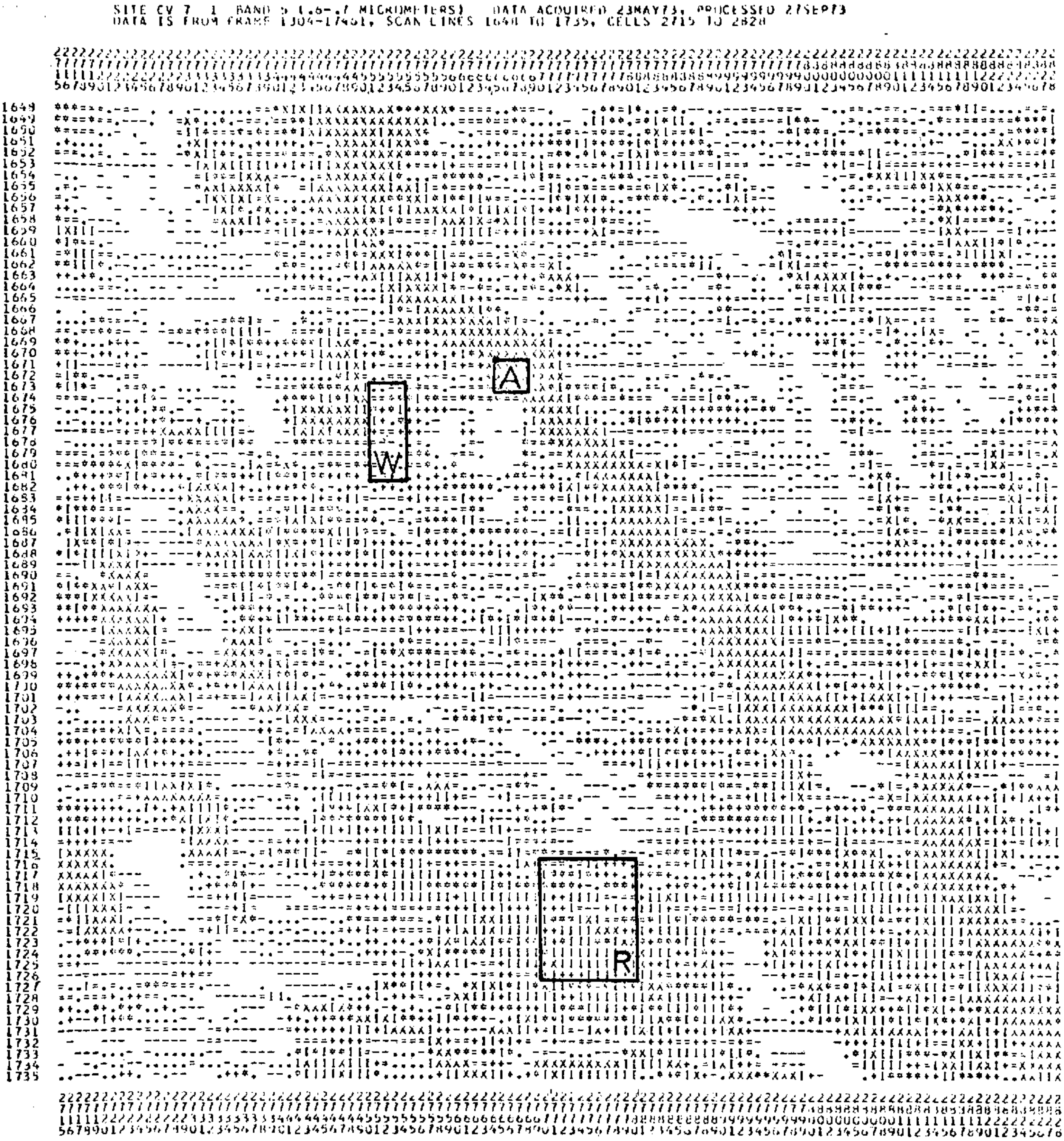


Figure 20. Band 5 gray map for Havre, Montana, 23 May 1973.

Table 5

Mean Radiance and Band Ratio Parameters

Havre, Montana	Band Mean Radiance (mw/cm^2-STR-μm)				
Date	Band 4	Band 5	Band 6	Band 7	BRP
Alfalfa subsite					
26 Aug. 72	8.91	5.91	8.45	7.93	.146
13 Sept. 72	7.16	4.86	6.79	6.49	.143
12 Mar. 73	8.45	6.69	5.93	5.52	-.096
30 Mar. 73	9.11	7.17	6.54	6.12	-.079
5 May 73	8.53	6.38	6.60	5.93	-.036
23 May 73	7.85	5.41	7.69	7.23	.143
10 June 73	7.10	4.60	8.36	8.62	.304
Wheat subsite					
26 Aug. 72	10.09	7.90	7.81	6.48	-.099
13 Sept. 72	8.71	6.45	6.45	5.69	-.062
12 Mar. 73	9.24	7.12	6.29	5.55	-.124
30 Mar. 73	9.14	7.34	6.46	5.63	-.131
5 May 73	9.65	7.65	7.60	6.44	-.086
23 May 73	9.16	7.21	7.72	6.67	-.038
10 June 73	8.61	6.45	7.87	7.28	.060
Range subsite					
26 Aug. 72	9.01	6.64	6.34	5.31	-.111
13 Sept. 72	8.13	5.74	5.69	4.83	-.086
12 Mar. 73	8.79	6.57	5.56	4.82	-.154
30 Mar. 73	8.92	6.76	5.72	4.95	-.154
5 May 73	9.98	8.01	7.35	6.06	-.138
23 May 73	8.74	6.64	7.03	5.91	-.058
10 June 73	8.12	5.96	7.15	6.62	-.052
4 x 4 area					
26 Aug. 72	--	--	--	--	--
13 Sept. 72	--	--	--	--	--
12 Mar. 73	9.15	7.12	6.21	5.42	-.136
30 Mar. 73	9.34	7.43	6.55	5.70	-.132
5 May 73	10.30	8.33	7.68	6.42	-.129
23 May 73	8.99	7.10	7.61	6.51	-.044
10 June 73	8.46	6.55	7.88	7.36	.059

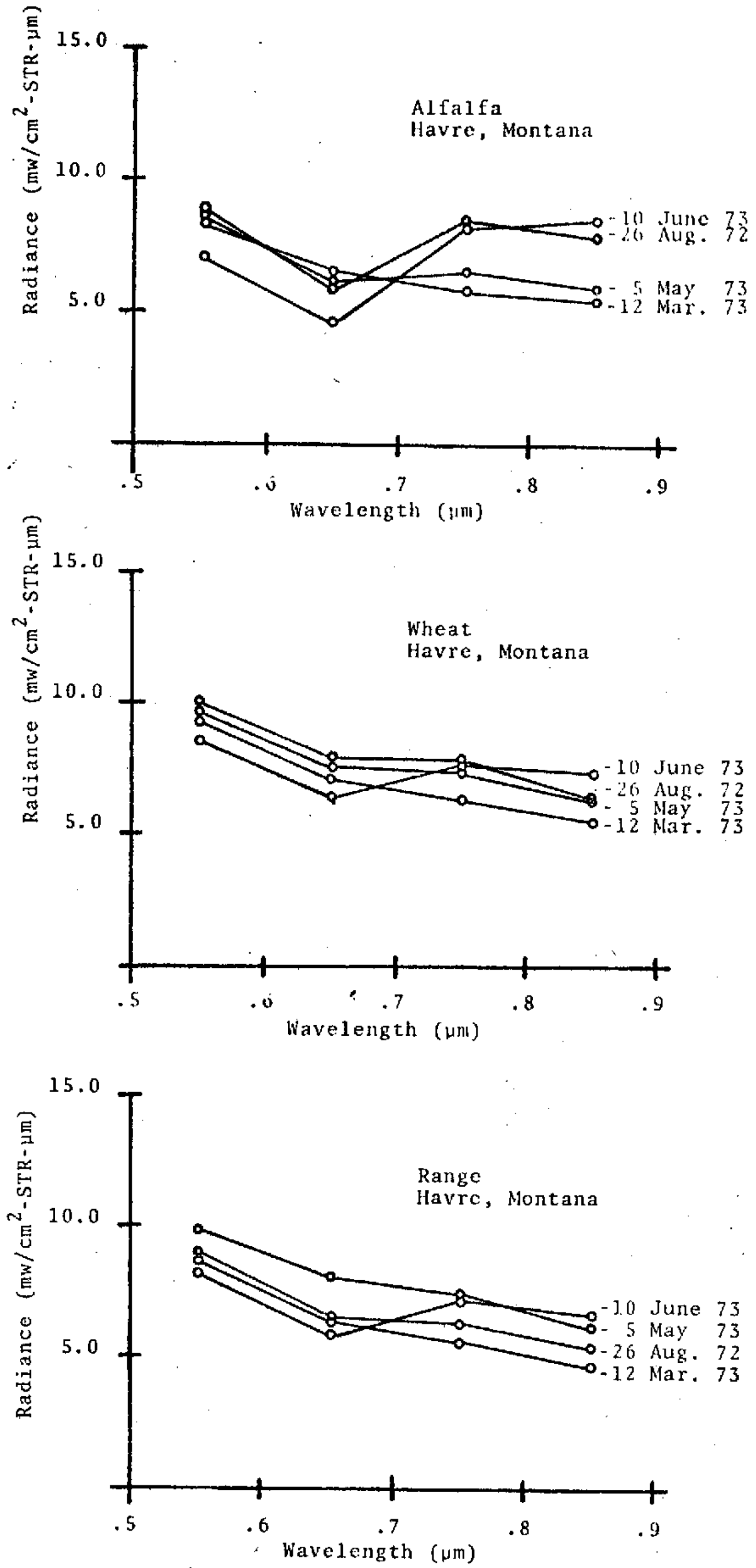


Figure 21. ERTS-1 Radiance Readings Havre, Montana.

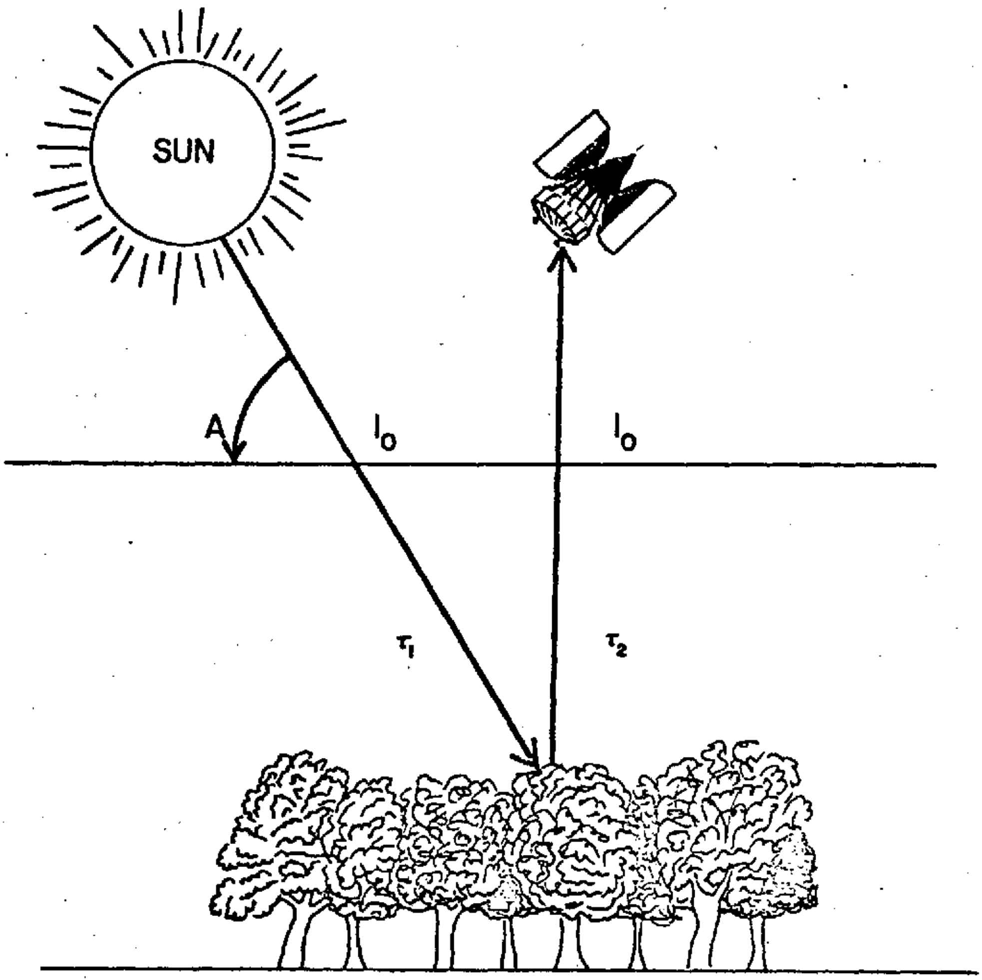
2.1.2 Radiation and Atmospheric Correction Factors

The problem of changing atmospheric and illumination conditions has been recognized since the beginning of the ERTS project. These changing conditions generally affect the absolute variations of the spectral signatures recorded from different times and locations, and will in general have some unspecified effect on the results derived from these signatures. It is, therefore, necessary to correct the data for variations in solar elevation and atmospheric transmissivity before a meaningful comparison can be made.

Research on this problem is being conducted both by LARS, Purdue University and RSC, Texas A & M University. At LARS a simple geometrical model utilizing satellite and ground radiation data has been developed. The model permits the comparison of the albedo of a canopy at two different points in time. Using the peak values of spectral response sensed by the satellite, these data were corrected for the aforementioned factors using the solar elevation at the time of overpass as listed on the ERTS imagery frames as well as the direct beam solar radiation received at the earth's surface from the weather station nearest the test site.

In the cases of Orono, Maine; Barnsdall, Oklahoma; and Commerce, Texas the necessary instrumentation was not available within a 30-mile radius of the site. In these cases, no correction factors could be applied to the data. For Southern Indiana, it will be necessary to interpolate the approximate radiation value at the test site from several locations about the state.

Figure 22 illustrates a monochromatic direct beam of radiation, I_o, striking a plane at the top of the atmosphere which is parallel to the terrain immediately below. I_o is given by equation (1) (Appendix A), Z being the zenith angle of the sun (90°-A) and S_o being the solar constant



A = Solar Elevation Angle

Z = 90°-A Zenith Angle of Sun

I_o = S_o cos Z

S_o = Solar Constant

I_c = Intensity at Canopy Top

I_s = Monochromatic Intensity Measured by Satellite

τ_1 = Transmissivity for I_o-I_c Path

τ_2 = Transmissivity for I_c-I_s Path

a = Albedo Canopy

Figure 22. Factors Affecting Satellite Sensed Data.

for a particular monochromatic beam. Beer's Law allows the calculation of the surface, I_c. This is shown by equation (2).

Equation (2) can be rewritten in the form of equation (4) by substituting for the negative exponential through equation (3). If a is the canopy's albedo, equation (5) indicates the direct beam monochromatic radiation returning to the satellite (assuming the satellite is directly overhead). Equation (5) may again be rewritten in the form of equation (7) by substituting for the negative exponential through (6). The two transmissivity factors, τ and τ_2 are related through (8) and (9) if the monochromatic extinction coefficients for the paths $I_o \rightarrow I_c$ and $I_c \rightarrow I_s$ are assumed equal. Thus (11) results from (7) by using (2), (4), and (9). If τ is used to represent a "combined" monochromatic atmospheric transmissivity (12) factor (11) is simplified to (13).

Equation (13) can be considered for two different months, i and j, and with the appropriate superscripting, (14a) and (14b) result. Taking the ratio of (14a) to (14b) results in (15) and this may be solved in turn for $\frac{a^i}{a^j}$, which is (16). Equation (16) shows that the ratio of the albedos of a canopy at two different times is given by the product of A·B·C where:

$$A = \frac{I_s^i}{I_s^j} \quad \rightarrow \quad \text{ratio of direct beam intensities at satellite at times i and j}$$

$$B = \frac{\gamma^j}{\gamma^i} \quad \rightarrow \quad \text{ratio of "combined" transmissivity at times j and i}$$

$$C = \frac{\cos^j Z}{\cos^i Z} \quad \rightarrow \quad \text{ratio of cosines of zenith angle at times j and i}$$

A and C can be obtained from the ERTS data, but what about the combined transmissivity term B? The transmissivity τ_1 can also be expressed as the ratio of the actual monochromatic direct beam intensity striking the surface, I_c, and the monochromatic intensity that would strike the surface in the absence of an atmosphere, I_o. This is expected in (17). Using (17), (12) may be rewritten for times i and j to obtain (18a) and (18b). The ratio of (18a) and (18b) results in (19), and (19) substituted into (16) results in the final equation (20)

$$\frac{a^i}{a^j} = \left(\frac{I_s^{\,i}}{I_s^{\,j}}\right)\left(\frac{I_c^{\,j}}{I_c^{\,i}}\right)\left[\frac{\left(\dfrac{I_c^{\,j}}{\frac{I_o^{\,j}}{I_o^{\,j}}}\right)\cos^j Z}{\left(\dfrac{I_c^{\,i}}{I_o^{\,i}}\right)\cos^i Z}\right].$$

This equation permits a direct comparison of the albedo of a canopy at two different times. Since it is a ratio comparison, I_s and I_c need not have the same units.

Caution must be exercised in the application of equation (20) due to its monochromatic nature. For example, when the solar constant is used in the equation, it does not have the value of 2 ly min^{-1} but rather the sum of the direct beam energy in the waveband interval being considered.

						ly $min.^{-1}$
Band	4	.5 - .6μ	→	S_{o1}	→	.277
	5	.6 - .7μ	→	S_{o2}	→	.236
	6	.7 - .8μ	→	S_{o3}	→	.193
	7	.8 - 1.1μ	→	S_{o4}	→	.370

Figure 23 illustrates the results of corrections applied to some ERTS data for Lafayette, Indiana for three different ratio comparisons. The ratio of the data $I_s^i \,/\, I_s^j$, the ratio after correcting with direct beam radiation measured at the surface, and the ratio after correcting using total solar radiation (not strictly justified since total solar measurements are flux measurements) are all portrayed for the 4 ERTS bands. The following conclusions can be drawn:

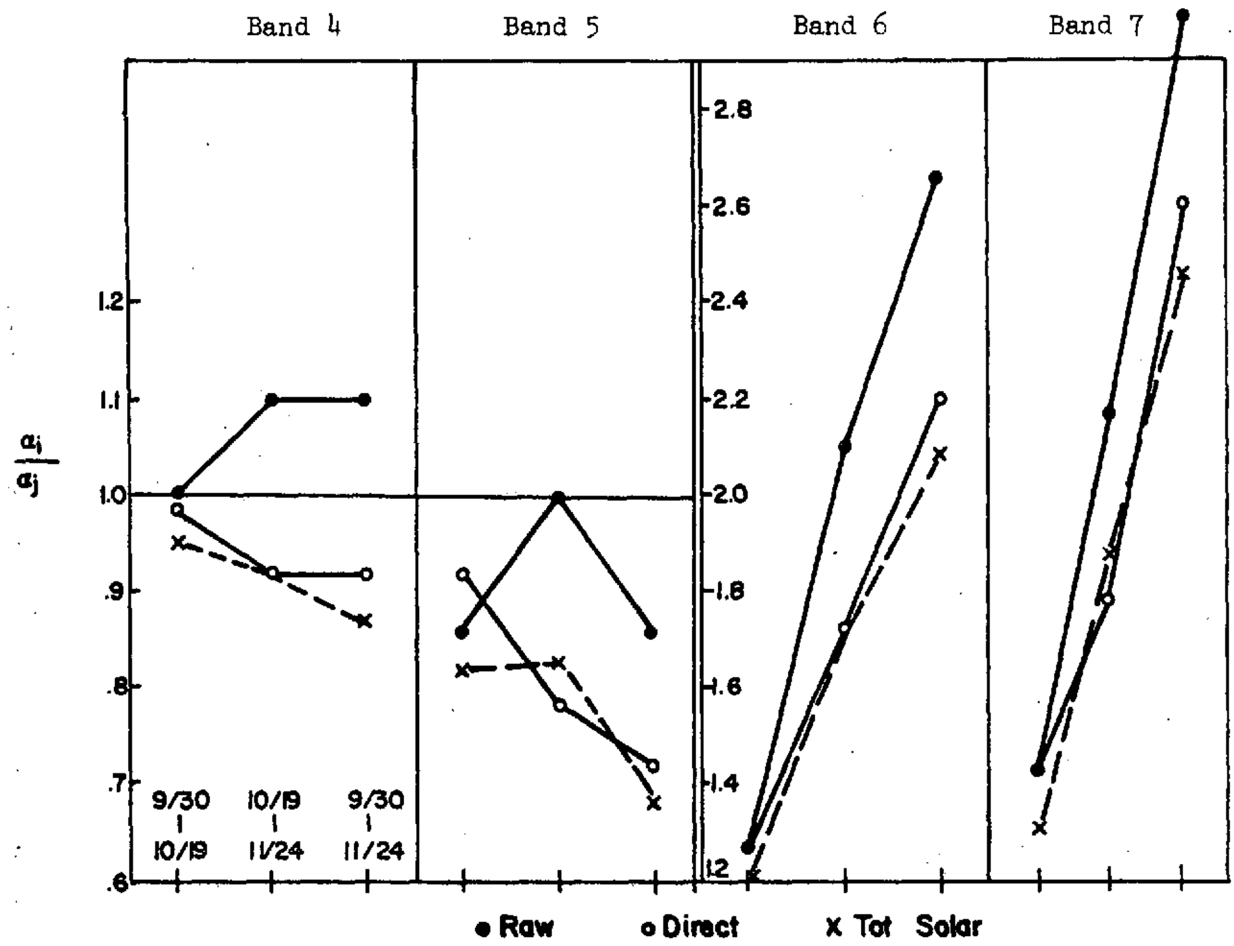


Figure 23. Ratio Graphs of Applied Correction Factors Compared to Uncorrected Data for Lafayette, Indiana.

a. The longer the time between observations, the more important the correction factor becomes.

b. In the visible bands, 4 and 5, where the initial analysis showed no systematic change, the corrected values indicate a definite increase in response as senescence occurs.

c. While there is a significant shift in the infrared bands, 6 and 7, after applying corrections, they are not sufficient to reverse the direction of the change in response. The near infrared still shows a decrease in reflectance as the Brown Wave progresses.

d. Similar results are obtained whether direct or total solar radiation is used in the equation.

These results are consistent with what would be expected during vegetative maturation--an increase in response in the visual bands while the infrared shows a decrease. They show that bands 6 and 7 are still meaningful for analysis thus far in their unaltered form. When bands 4 and 5 are corrected for outside factors influencing the plant's satellite sensed response, the pattern of changes in spectral properties is enhanced.

At RSC, Texas A&M University, a data analysis project is underway to determine the amount of variation introduced as a result of changes in atmospheric and illumination conditions. This project also investigates methods and models which will be useful in reducing these effects upon the results of the phenology study.

Analyses are being conducted to gain experience with the satellite data to correlate with observed albedo changes. Initial studies were conducted by examination of between-band probability density functions of the sensor data values from multitemporal and multiple site sources. A scene (32 km x 32 km) was selected for the College Station area for three dates in 1972 (30 August, October 23, and December 16). Two-dimensional frequency counts were made of two-band data value pairs for each date. A frequency threshold was selected (700 points) and all data pairs having a higher rate than this threshold were plotted on a two-dimensional cluster plot (Fig. 24). In examining the aggregate of superimposed clusters from multiple dates, two characteristics are noted. Changes in scene characteristic signatures apparent in the shape of the clusters are noted, especially between the October and the December data. This relationship between the August and October data sets is relatively consistant at the level of significance of the display. However, the dominant trend apparent in the data is a general decrease in scene data values over time. This result immediately suggests scene illumination variations (as might be expected), and emphasizes the magnitude of their effect, which dominates the data relationships.

Sun angle corrections were implemented using a simple mathematical relationship of the intensity of solar radiation, I_H, falling upon a horizontal plane as a function of the solar constant I_O, and the solar elevation γ. This relationship ($I_H = I_O \sin\gamma$) was used to apply corrections to satellite data for variations due to the changes in source illumination intensity as a function of solar elevation angles. These illumination corrections appear to be reasonably successful in removing bias from the data sets apparent as a function of time.

In parallel with these solar illumination studies, an activity was initiated to obtain multitemporal, spectral signatures from terrain areas generally expected to vary the least, such as urban areas and cultural features. A test site from the non-industrial, downtown area of Bryan, Texas was selected for initial study. Multitemporal spectral signatures

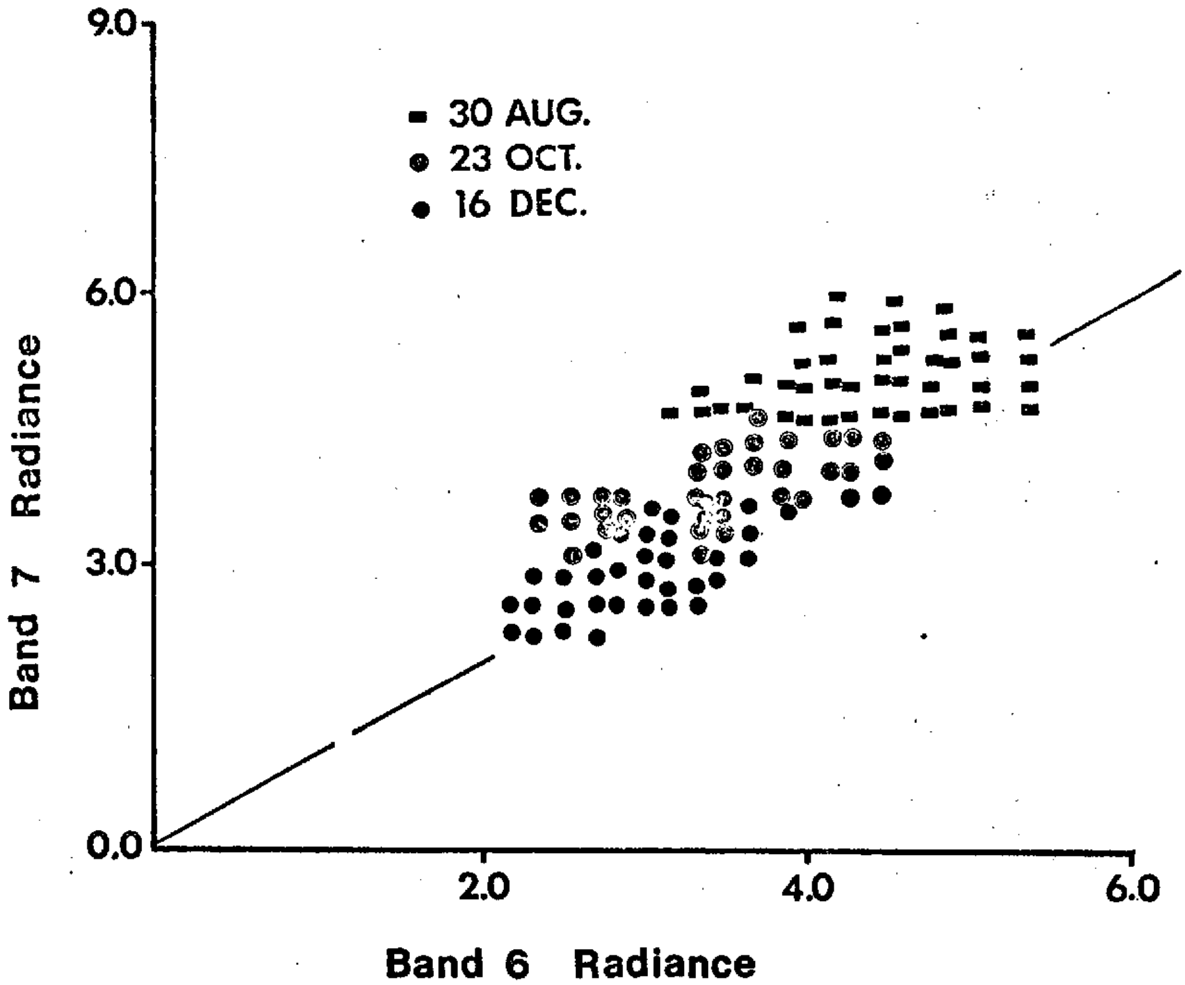


Figure 24. Two-dimensional cluster plot for Bands 6 radiance, College Station, Texas.

were computed for the three dates which were available. In Figure 25 is shown the relationship between these signatures. The temporal variation is readily apparent. Applying the sun angle corrections described above, the data fall into alignment. In fact, the sun angle correction puts all of the signatures within one sample standard deviation.

Atmospheric studies are continuing to determine the extent of atmospheric attenuation and spectral dispersion through the identification of atmospheric models and by comparison of data from ground targets of relatively consistent spectral signatures over time. It appears that vegetative scene inhomogenieties are the major contributor to data variance, and that variance produced as a result of atmospheric variation in non-industrial regions from some nominal value is small in comparison. Direct application of ERTS data to the problems addressed in this study is not dependent upon precise atmospheric correction, and it appears from the data considered that sun angle correction will provide adequate reduction of multitemporal data variance.

Corrections to ERTS data for the Eastern Corridors are found necessary due to variations of water vapor and particulate matter in the atmosphere. In the clearer atmosphere over the Western Corridors, correction for sun angle change is the only correction necessary.

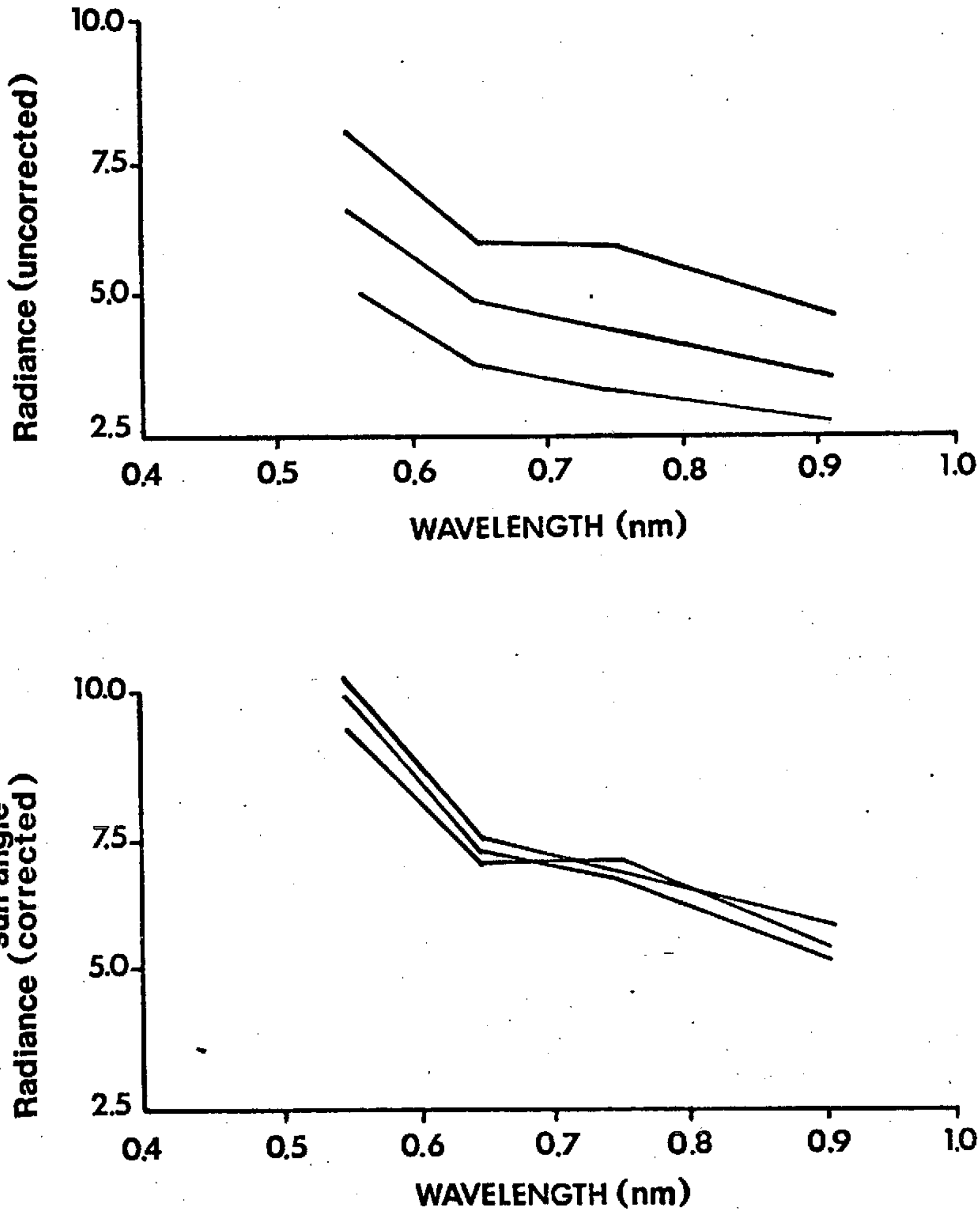


Figure 25. Multitemporal spectral signatures, Bryan, Texas.

2.1.3 Photo Interpretation

Data handling has included the determination of the quality, cataloging, and filing of MSS imagery (Appendix B) and ground observation photography as it arrived. Color composites (bands 4, 5, and 7) were ordered for all imagery of good quality and covering the project sites.

Image interpretation methods were successfully used to map fall-related phenological events at two sites. Forest and crop changes at the southern Indiana and Vermont study areas were documented from the ground observation photography and tonal changes on the MSS imagery (1, 2, 3).

Work was also initiated to evaluate the relationship between phenological events and image (film) density changes. A Welsh Scientific density analyzer has been used to make some initial test measurements. The results indicate that for the scale imagery and site area in this project, the instrument will provide better measurements with a smaller aperture. This modification is now being made.

The preliminary density analysis of Lafayette, Indiana and Vermont imagery has given results consistent with those found in the image interpretation study. Phenological changes have been correlated with density differences within each band and with changes in band to band ratios. The form of this ratio involving bands 5 and 7 was suggested, Texas A&M University, and is expressed as:

$$R_{5-7} = \frac{\text{Density Band 5} - \text{Density Band 7}}{\text{Density Band 5} + \text{Density Band 7}}$$

This ratio continuously decreased with the progression of fall phenological changes in field crops and forests.

2.1.4 Color Reconstitution Techniques

As an aid to analyzing the data and for a better visual representation of the area under study, a photographic technique developed by the Laboratory for Applications of Remote Sensing (LARS) at Purdue University was employed for at least one good set of data for each site to produce color images similar to color infrared photographs. The process, referred to as color enhancement, uses a sequence of color filters for simultaneous exposures utilizing bands 4, 5, and 6 of the ERTS data. The color images show the forested areas very distinctly and in many cases make it easier to locate such regions. The technique was also quite useful in locating wheat fields in the winter data since wheat and grass are about the only areas expected to be green (showing up bright red on the false color images) at this time of year.

2.2 Ground Observations

2.2.1 Corridor Sites

Ground photography documenting phenological events, was continued at the 24 established sites in the four corridors (see Figure 1).

The advance of the Green Wave (foliage development) with time at Orono, Maine is illustrated in Figure 26.

Ground photographs at all observation sites in the Rocky Mountain and Columbia Valley corridors have been classified as to the percent of the view which is covered with living green vegetation. This provides information on the beginning, development, recession and ending of the Green and Brown Waves.

In addition, considerable information on visual observations of the Green Wave on irrigated and non-irrigated acreages throughout the West have been obtained.

Hundreds of cooperators in the Western Phenological Network recorded the dates when vegetated land (devoid of trees) changed from predominant non-green, usually yellowish or brownish, to predominant green. These data are now being related to phenophases of purple common lilac and honeysuckle. A preliminary study conducted in the spring of 1972 indicated that the "Green Wave" and "95% leaf phase" of purple common lilac occur on about the same date. Observations were also recorded for the first time throughout the West on the dates of the Brown Wave (the change from predominant green to non-green).

ERTS-1 imagery also shows the initiation of the drought-caused Brown Wave. As the natural vegetation begins to dry, the circular irrigated fields remain green. The resulting difference in radiance can be correlated to the onset of the dry period.

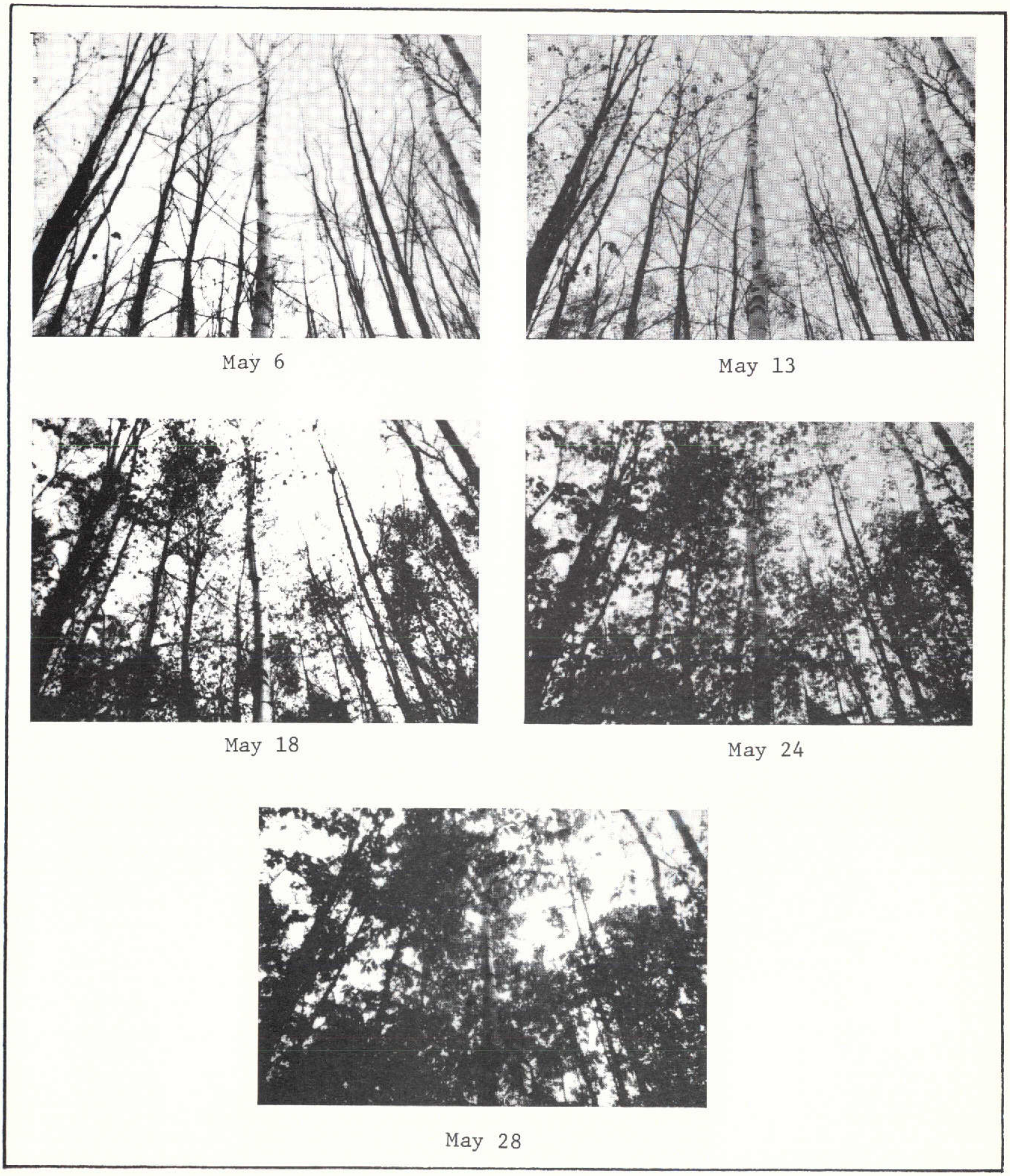


Figure 26. Green Wave (foliage development with time) at Orono, Maine.

2.2.2 Phenological Networks

Phenological observations contributed to this project by the State Agricultural Experiment Stations are obtained from two large networks (Figures 27 and 28). The more than 3200 sites constitute the observational base of regional phenological research carried out by W-48 and NE-69.

"Red Rothomagensis" lilac is used as an indicator plant in the Central and Eastern United States and purple common lilac and two honeysuckle cultivars in the West.

Figures 29 and 30 are preliminary maps of the Brown Wave (fall 1972) for the common purple lilac and Zabeli Honeysuckle, respectively. Isolines on the maps are for the dates by which 95% of the leaves have lost their green color.

Observations on two "Red Rothomagensis" lilac phenophases in spring 1973, first leaf and first flowers, were selected to document the "Green Wave". Isophanes for these phenophases, the lines on the maps connecting locations where phenological events occur simultaneously are shown in Figures 31 and 32. A more detailed map of the first leaf isophanes in the Northeast is shown in Figure 33. The maps are based on data supplied by 207 observers in the eastern section of the NE-69 study area and 66 observers in the western section. The dividing line of the two sections follows the western borders of Pennsylvania and West Virginia.

The spring progression of the common purple lilac in the Western United States for the spring of 1973 is shown in Figure 34.

The spring progression of first leaf of "Red Rothomagensis" lilac in 1973 was characterized by initial earliness followed by considerable delays in certain areas. First flowers followed a more normal pattern of development.

The overall departure from the average is also demonstrated by multiple

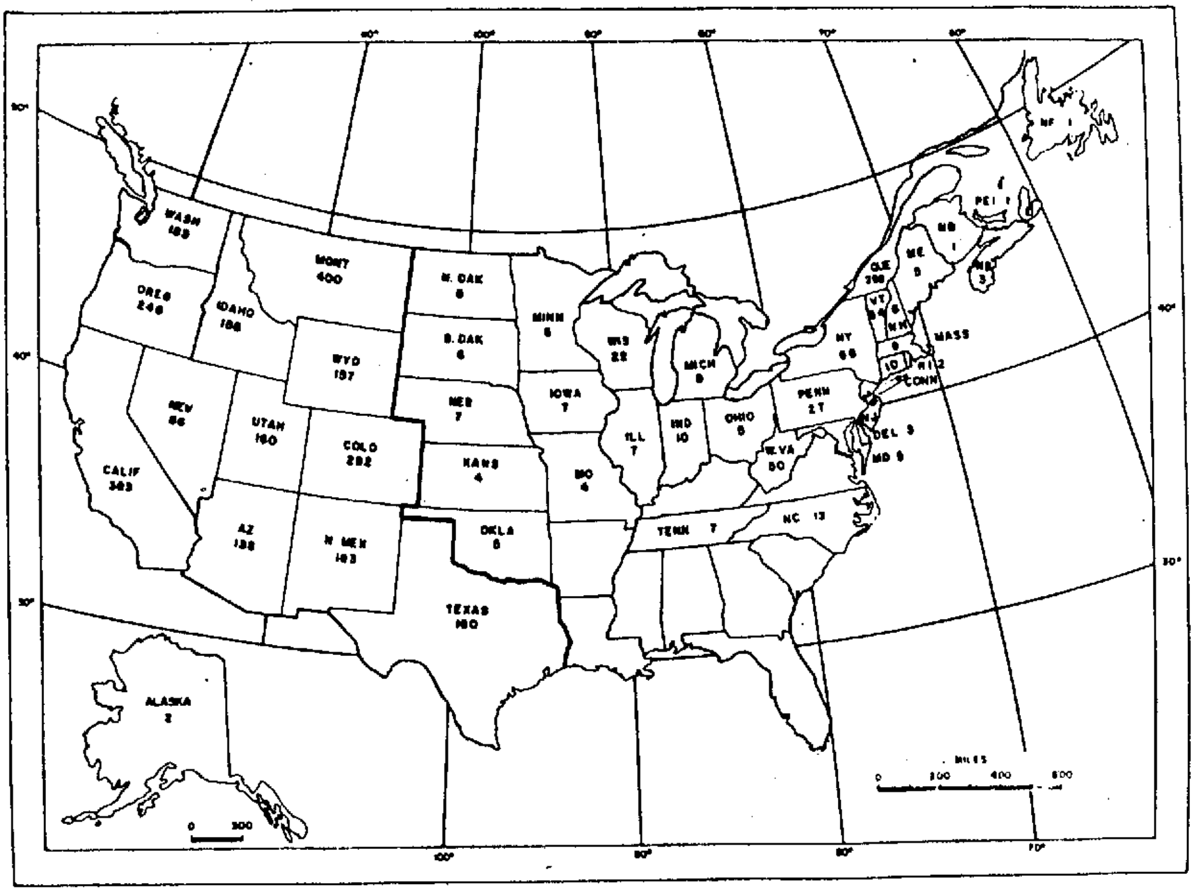


Figure 27. Phenology Networks. Numbers indicate total observation sites in each state or province.

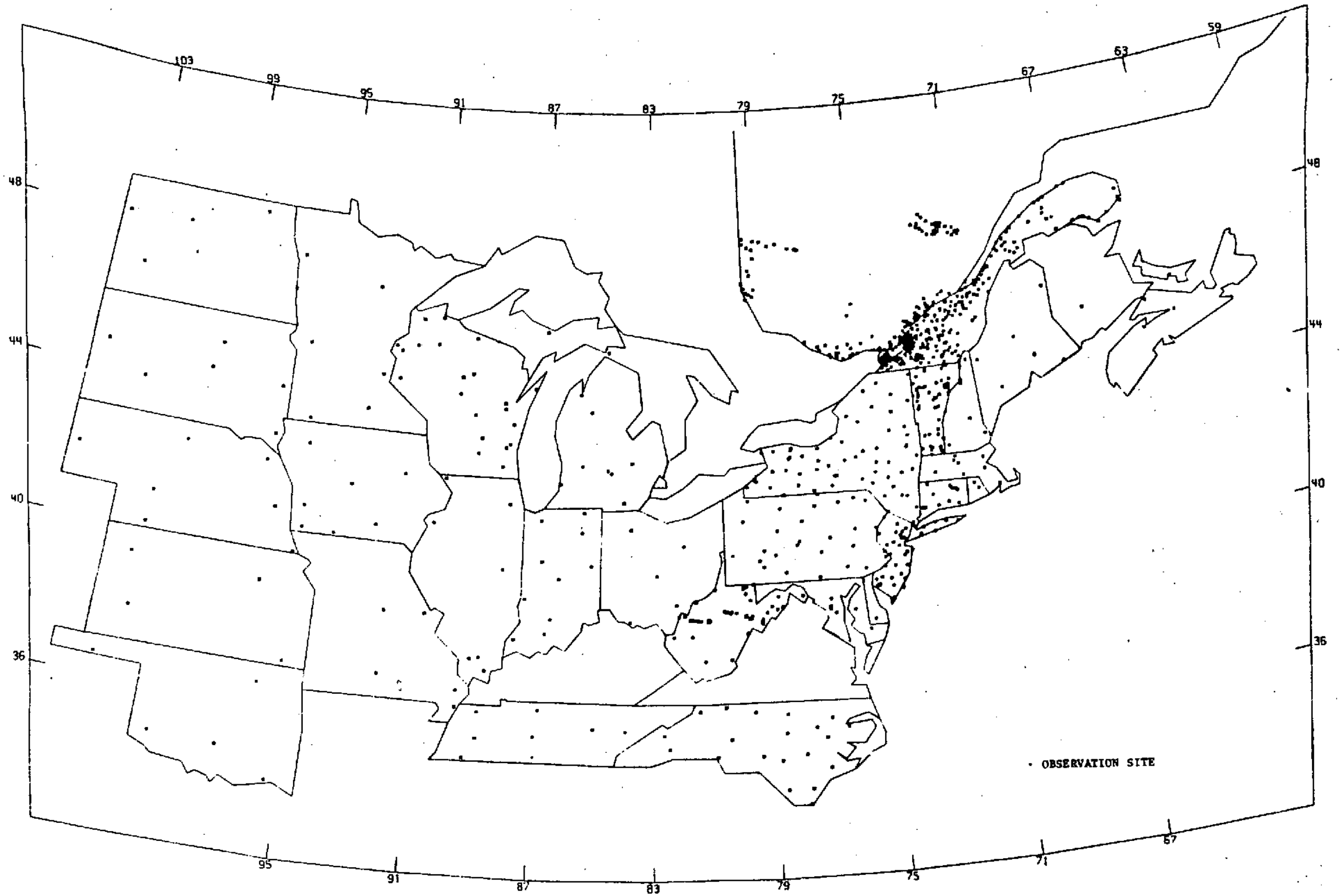


Figure 28. NE-69 Phenology Network.

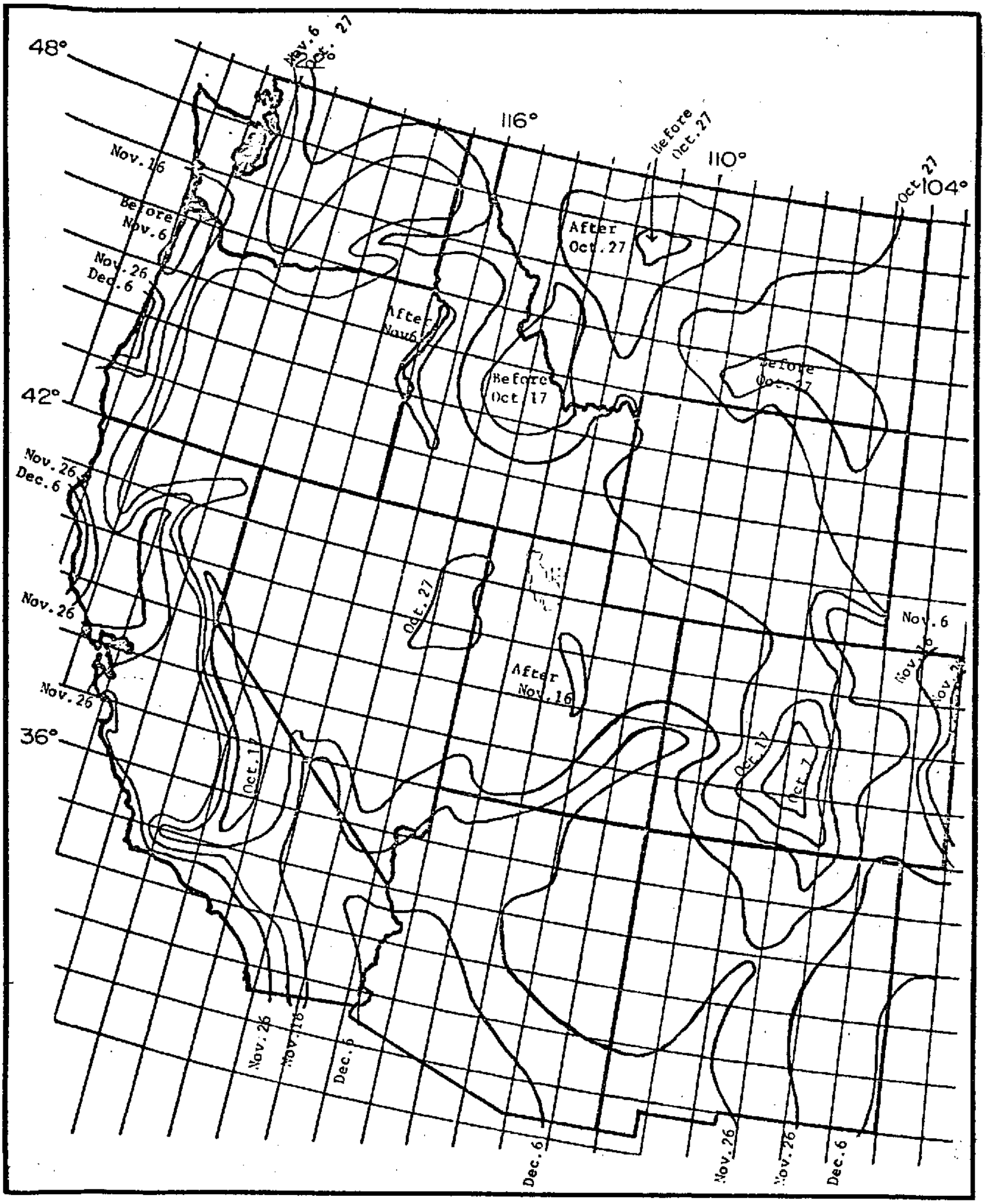


Figure 29. Brown Wave (1972) as indicated by date on which 95% of Common Purple Lilacs lost green color.

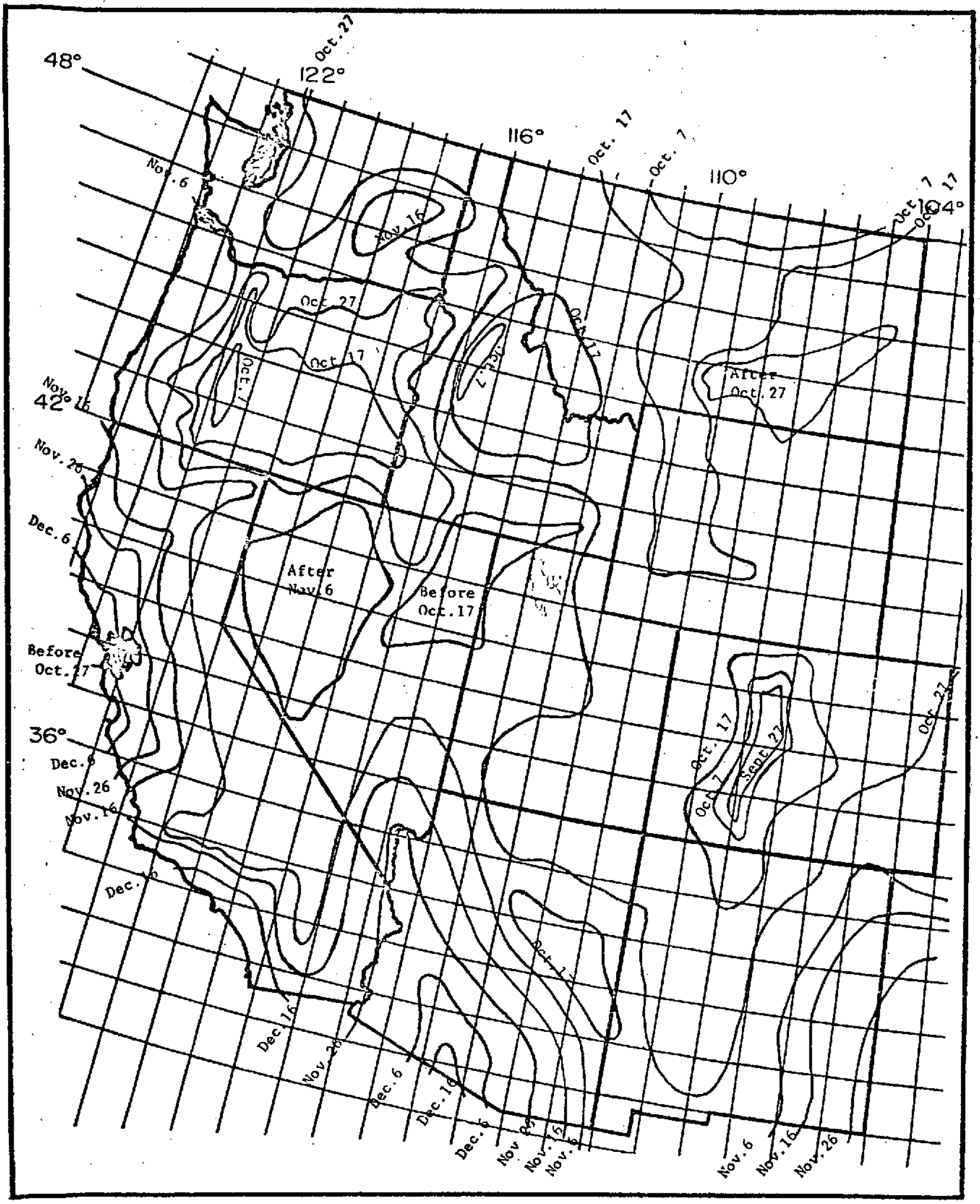


Figure 30. Brown Wave (1972) as indicated by date on which 95% of Zabeli Honeysuckle lost green color.

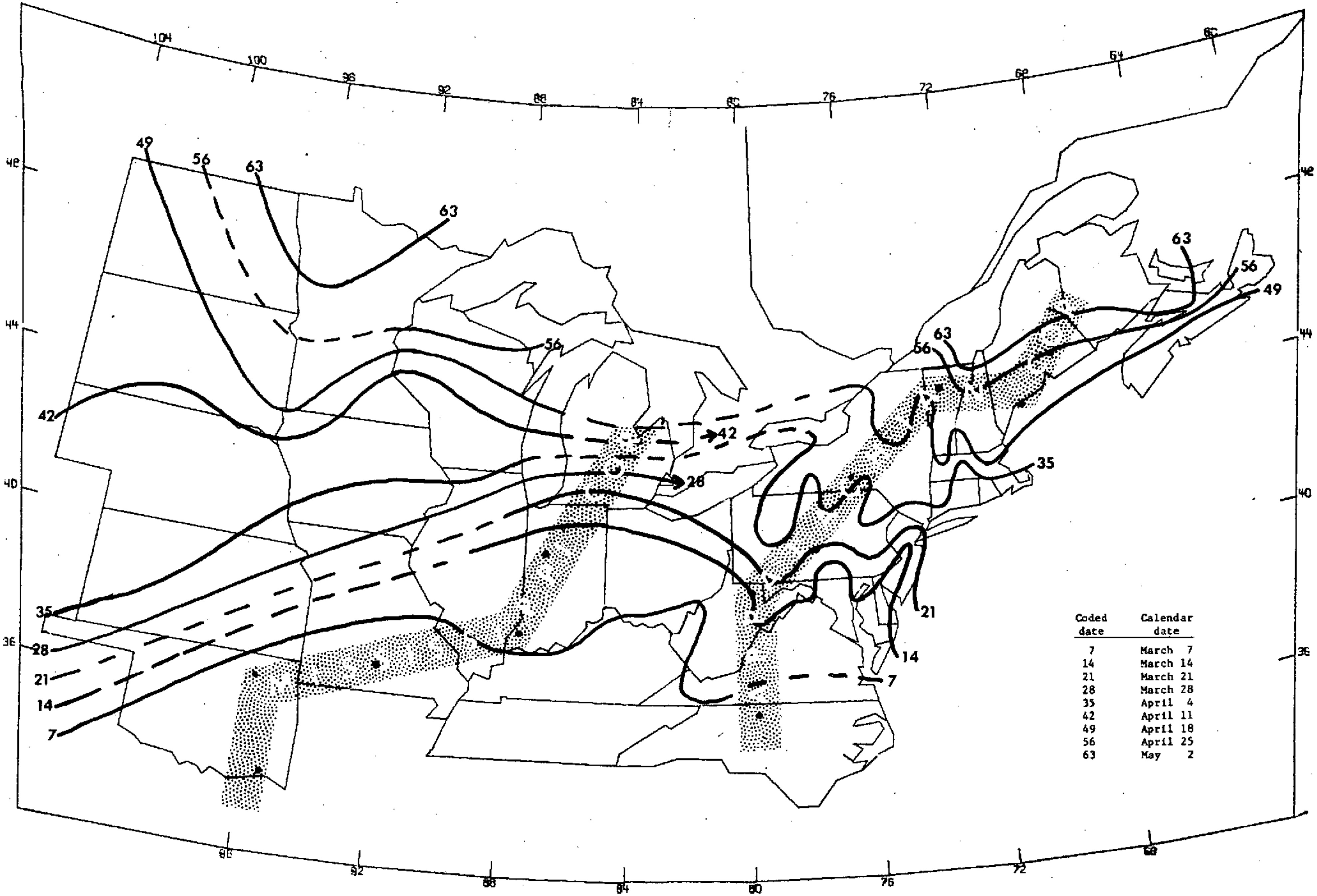


Figure 31. "Red Rothomagensis" lilac, first leaf, 1973 Eastern United States.

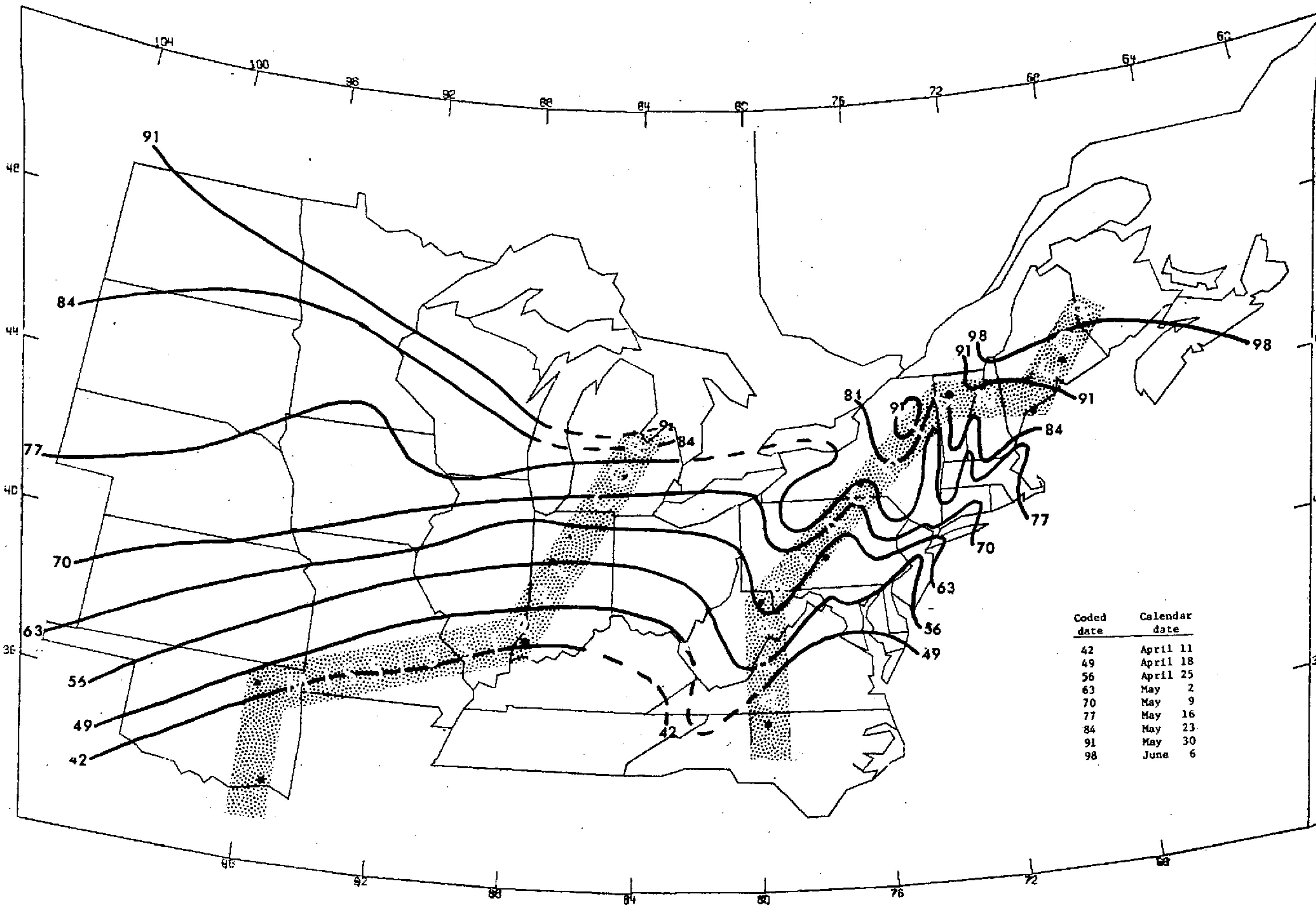


Figure 32. "Red Rothomagensis" lilac, first flowers, 1973 Eastern United States.

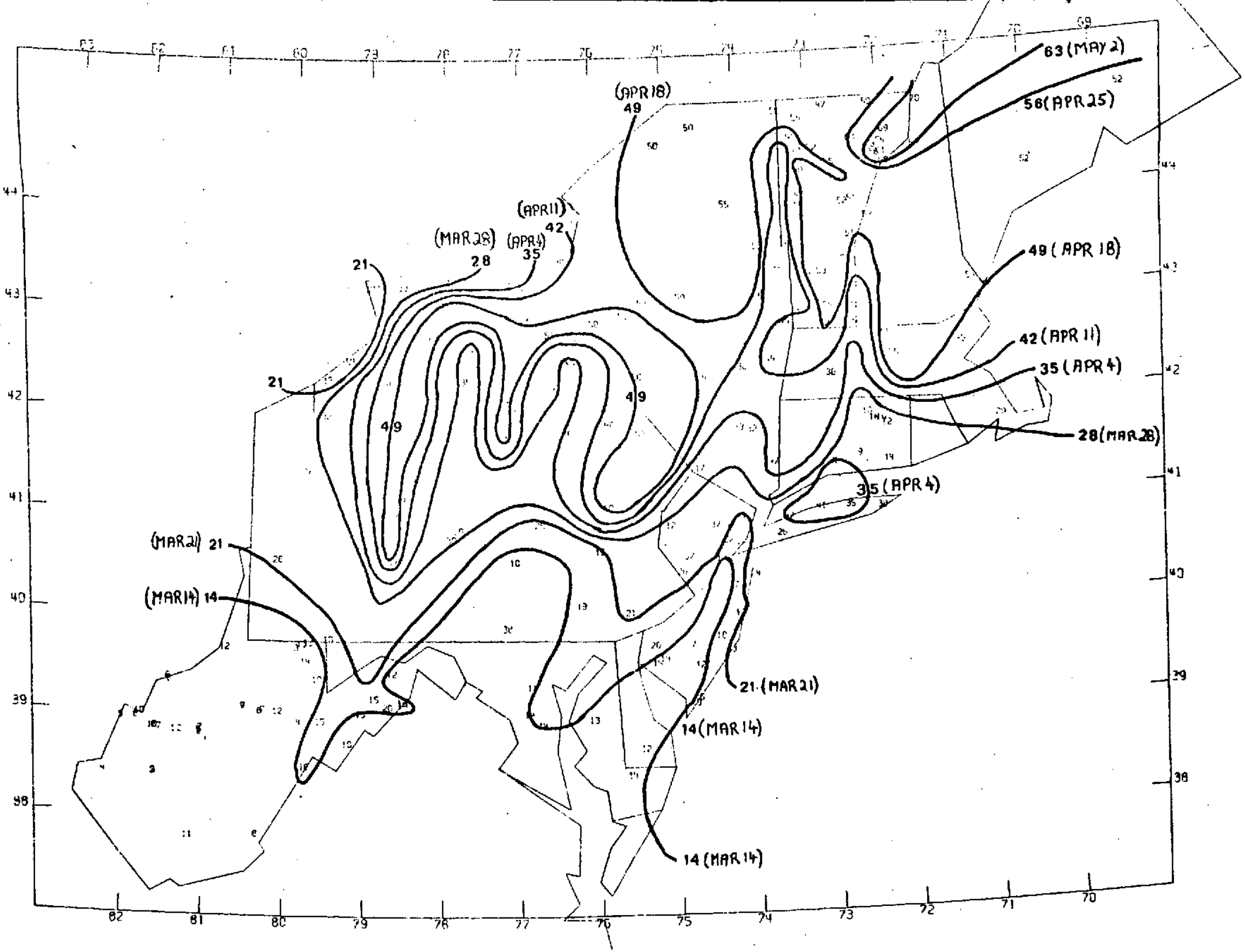


Figure 33. "Red Rothomagensis" lilac, first leaf, 1973 New England.

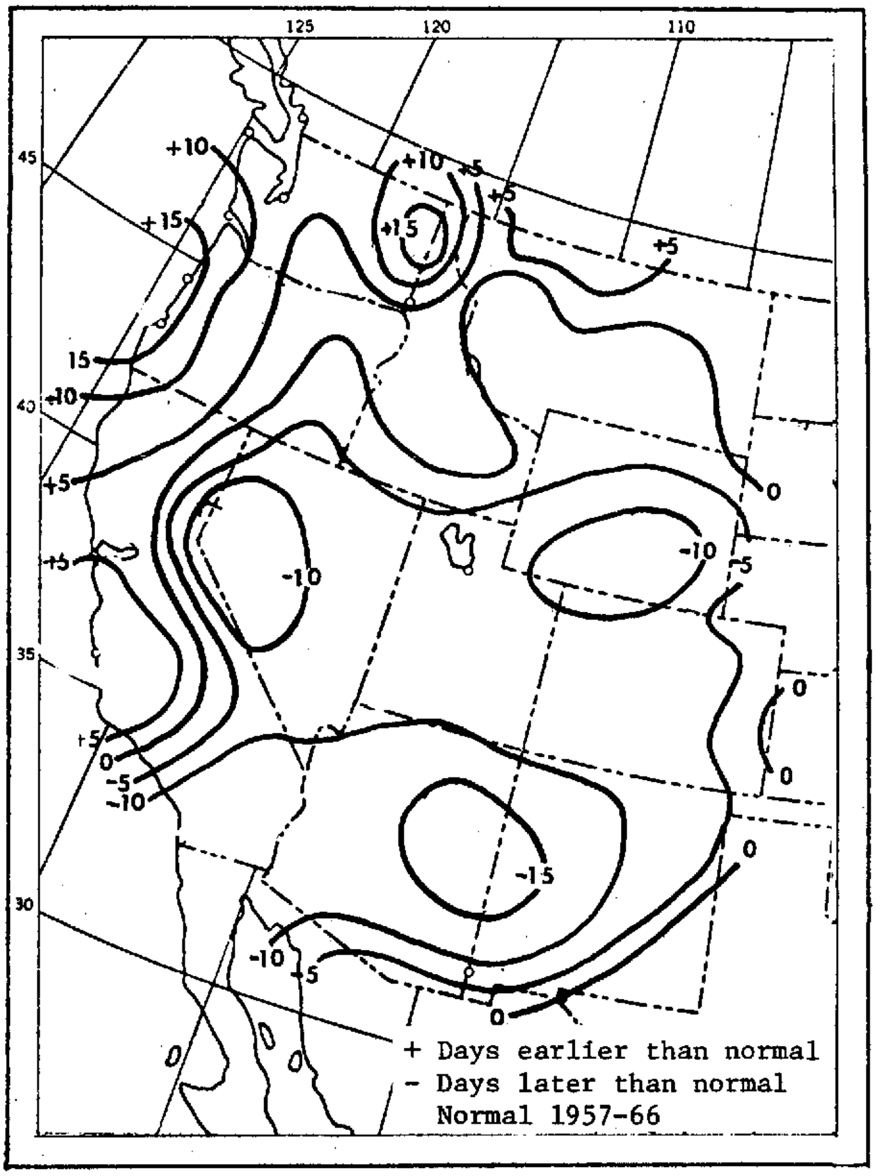


Figure 34. Lilac begin bloom date anomoly map for spring 1973.

regression equations. Latitude, longitude and elevation of the observation sites were used to estimate the dates of first leaf and first flowers. In Table 6 the regression equations for 1973 are compared with the equations for average dates (4). While normally the northerly advance of first leaf in the east is at the rate of about four days for each degree of latitude, the rate in 1973 was over six days. Thus, the two to three week earliness in the southern part of the corridor was reduced to about one week in the north.

Time lapse photographs document the development of a "Red Rothomagensis" indicator plant. The pictures (Figure 35) were taken at the NE-69 phenological site near Richmond, Vermont, between 19 April and 6 July. The rapid developmental changes that occurred during the interval between two successive ERTS-1 overpasses are obvious from the photographs, particularly during the end of May and early June. The dates of the overpasses at this time were 14 May, 1 June, and 19 June.

Computer programs have been written for calculating daily and cumulative growing degree days (GDD) using base temperatures of 30, 32, 36, 40, 45, and 50 degrees F. Programs are likewise being prepared for the Weather Bureau 50-86 and 40-86 and the Newman-Purdue and Brown-Ontario methods as described by Lytle (5).

The 1973 minimum and maximum temperature data from those locations in New England, New York, and New Jersey where lilac phenology data are available this year are presently being punched on cards in preparation for the development of phenoclimatic models.

Table 6. Multiple Regression Equations for Predicting 1973 Date and Average Date of First Leaf and First Flowers on 'Red Rothomagensis' Lilac in the NE-69 Study Area

		n	R^2	Stand. error of estimate	
First Leaf					
	West				
1973	Y = −196.3 + 4.46 lat. + 0.41 long. + 0.0088 elev. (m)	66	0.73	10.1	(1)
*Avg	Y = − 99.8 + 4.56 lat. − 0.61 long. + 0.0133 elev. (m)	45	0.91	5.0	(2)
	East				
1973	Y = −125.9 + 6.14 lat. − 1.37 long. + 0.0272 elev. (m)	207	0.77	9.3	(3)
*Avg	Y = + 1.9 + 4.15 lat. − 1.79 long. + 0.0300 elev. (m)	129	0.84	4.9	(4)
First Flowers					
	West				
1973	Y = − 57.7 + 4.72 lat. − 0.88 long. + 0.0276 elev. (m)	40	0.89	6.3	(5)
*Avg	Y = − 50.9 + 4.51 lat. − 0.80 long. + 0.0138 elev. (m)	45	0.96	3.3	(6)
	East				
1973	Y = − 51.0 + 4.97 lat. − 1.22 long. + 0.0342 elev. (m)	137	0.85	5.4	(7)
*Avg	Y = − 15.0 + 4.30 lat. − 1.21 long. + 0.0178 elev. (m)	106	0.85	3.9	(8)

Y = coded date of phenological event where March 1 = 1, etc.

* Equations (2), (4), (6), and (8) from Hopp and Blair (1973).

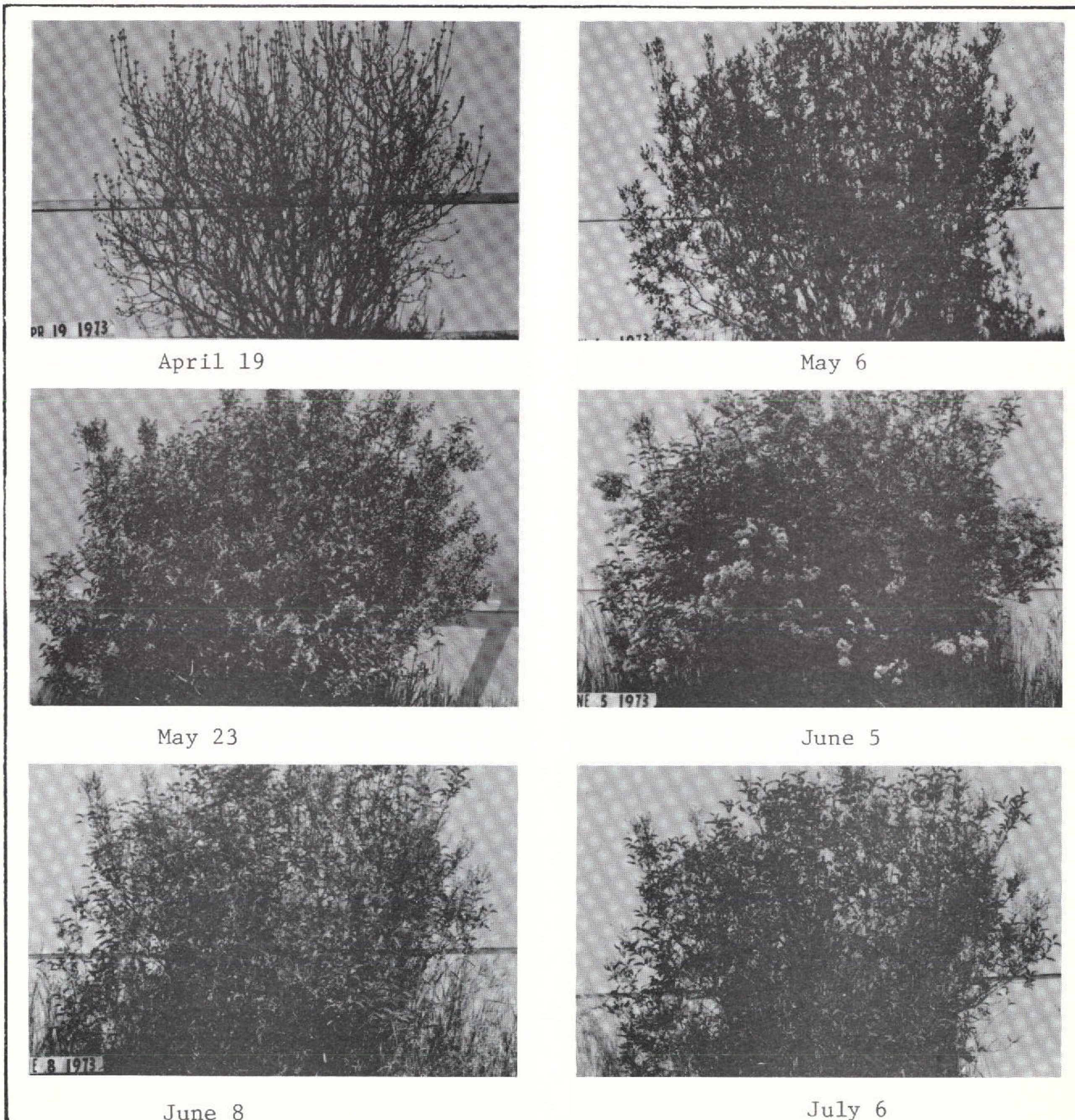


Figure 35. Green Wave (lilac development with time) at Burlington, Vermont, 1973.

3.0 FUTURE WORK

Study of the 1973 Green Wave will be completed; and, if data are received in time, the study of the 1973 Brown Wave will also be completed. If time and data permit, the 1973 Brown Wave will be compared with the 1972 Brown Wave. Such a study would give the first definitive information on annual variation of this phenological event.

3.1 Ground Observations

Computer mapping of the 1973 Green Wave and the 1973 Brown Wave will be completed. Data input for these maps will come from the phenological networks shown in Figures 27 and 28.

3.2 Solar Thermal Units

Comparison of the solar thermal unit (6) accumulations during the 1973 growing season with phenological development and satellite information will be completed.

3.3 Data Processing

Upon receipt of the other spring tapes, the study of the 1973 Green Wave will be completed. Analysis of the 1973 Brown Wave will be initiated upon receipt of the imagery and tapes. It is hoped that all the required data can be obtained before the November 11 cutoff date.

A standard method of correcting for changing atmospheric and illumination conditions will be decided upon. Comprehensive computer printed reports will be obtained for all 24 sites.

These reports will summarize the calculated data and present it graphically with both time and latitude on the abscissa.

3.4 Photo Interpretation

Ground observation photography documenting the 1973 Green and Brown Waves will be completed. Density sliced and color enhanced imagery will be obtained to qualify the phenological changes.

A densitometry study will be continued quantifying the phenological changes as recorded on the MSS imagery. Recently developed regression corrections for instrument calibration and gray scale standardization along with a sun elevation-atmospheric correction ratio will be applied to the densities so that the results will reflect actual changes in the albedo of forest canopy. The corrected densities will be used to calculate band to band ratios using the previously discussed formula. These ratios will be correlated in a time-lapse format with the observed phenological changes.

Aircraft underflight imagery will be used to verify alternate site selections. These alternate forest areas will be chosen to provide larger sample sizes and more cloud-free coverage at each of the sites. The aircraft imagery will also be used to see that the alternate forest areas are comparable to the area where the ground truth photography is taken.

3.5 Phenoclimatic Models

Growing degree days accumulated when using the different formulas will be compared with dates of phenological development of the lilac to determine which can be used to give the best prediction of the event. After these data have been completely analyzed, they will be compared with the progress of the Green Wave as revealed by the ERTS-1 imagery, although it will be difficult to make some of these comparisons because, on many of the passes of the satellite, clouds obscured much of the Northeastern United States.

Some of the daily temperature data will not be obtained from the

National Weather Records Center at Asheville, North Carolina, until October, so it will be impossible to complete the calculations for the more northern locations until that time.

Phenoclimatic models will be developed and preliminary world maps (7) drawn for the following events:

1. the Green Wave,
2. begin bloom of lilac,
3. yearly total evapotranspiration,
4. number of alfalfa cuttings per year, and
5. the Brown Wave.

3.6 Final Report

The most concentrated effort will occur during the final phase of the project and will be directed toward the writing of the final report.

Data presented in the final report will be in the form of photographs as well as statistics.

Time-lapse photos will be produced showing temporal and geographic changes. The products to be presented in this form will be:

a. spectral curves
b. imagery in the suitable band or bands,
c. density sliced representations of changes in vegetation on ground observation photos.

The statistical results will be presented in the form of tables and graphs and will include:

a. mean and standard deviation and covariance matrix of reflectance,
b. comparative spectral response,

c. change in forest canopy and plant cover, and

d. relationship between weather parameters and phenological events.

Maps will be prepared of the following:

a. Green Wave,

b. Brown Wave, and

c. other seasonal phenological events.

The mathematical relationships between temporal vegetation changes and atmospheric parameters will be expressed in phenoclimatic models.

4.0 Conclusions

The program of work outlined in the Type II Progress Report (August 1972 - February 1973) has continued at a pace determined by the rate of receipt of ERTS-1 data.

Preliminary regression analysis results for relative spectral response versus latitude show:

a) Correlation coefficients seem to be somewhat higher in bands 4 and 5.

b) Significance of the correlation coefficients is easier to obtain in bands 4 and 5.

c) Regression slopes are consistently negative for bands 4 and 5 and positive for bands 6 and 7.

d) The regression slopes tend to become consistently "flatter" as the Brown Wave progresses. This effect is observed in all four bands. Perhaps this reflects the fact that differences in spectral response with latitude are decreasing in that the vegetative condition becomes more uniform over the U.S. towards the end of the Brown Wave.

Regression analysis for a site with eight data points indicates:

a) Higher correlation coefficients are found in bands 6 and 7 (in contrast to the findings for spectral response versus latitude).

b) The slopes are negative in <u>all</u> four channels. This fact suggests the possibility that the correction factor is important (in that a decrease in actual albedo at all wavelengths is unlikely for the vegetation being studied).

The data available from Rocky Mountain and Columbia Valley corridors show evidence that vegetation conditions strongly effect radiance values. This is especially true of the measurements of alfalfa fields. In addition, the BRP appears to provide a responsive indicator of greenness. It appears that vegetative scene inhomogenieties are the major contributor to data variance, and that variance produced as a result of atmospheric variation in nonindustrial regions from some nominal value is small in comparison. Direct application of ERTS data to the problems addressed in this study is not dependent upon precise atmospheric correction, and it appears from the data considered that sun angle correction will provide adequate reduction of multitemporal data variance.

Corrections to ERTS data for the Eastern Corridors are found necessary due to variations of water vapor and particulate matter in the atmosphere. In the clearer atmosphere over the Western Corridors, correction for sun angle change is the only correction necessary.

The preliminary density analysis of Lafayette, Indiana and Vermont imagery has given results consistent with those found in the image interpretation study. Phenological changes have been correlated with density differences within each band and with the BRP.

This ratio continuously decreased with the progression of fall phenological changes in field crops and forests.

A preliminary study conducted in the spring of 1972 indicated that the "Green Wave" and "95% leaf phase" of purple common lilac occur on about the same date. Observations were also recorded for the first time throughout the West on the dates of the Brown Wave (the change from predominant green to non-green).

ERTS-1 imagery also shows the initiation of the drought-caused Brown Wave. As the natural vegetation begins to dry, the circular irrigated fields remain green. The resulting difference in radiance can be correlated to the onset of the dry period.

Observations from the phenological networks of the phenophases selected to document the Green Wave showed the following:

a) The spring progression of first leaf of "Red Rothomagensis" lilac in 1973 was characterized by initial earliness followed by considerable delays in certain areas.

b) First flowers followed a more normal pattern of development.

c) While normally the northerly advance of first leaf in the east is at the rate of about four days for each degree of latitude, the rate in 1973 was over six days. Thus, the two to three week earliness in the southern part of the corridor was reduced to about one week in the north.

The findings of the second six months of research reinforces our previous conclusions concerning the benefits to be derived from an operational ERTS system.

"Satellite data, such as that received from ERTS-1, will make worldwide phenological monitoring possible. This is necessary to develop universally applicable phenoclimatic models.

For countries with highly developed agriculture, such information would be useful in characterization of crop status and an aid to yield prediction and management planning. Phenological data in less-developed countries could be useful for agricultural land use planning and for determining site suitability.

In the final analysis, the success of Earth Resources Technology

Satellites will depend on the ultimate use of interpreted data. In the agricultural, forestry, and related segments of the economy these data will contribute to decision making of economic significance in management, provide more accutate estimates of acreage and yield forecasts of many commodities. The means of disseminating the interpreted date to the user is available through Cooperative State Extension Service. Working with the Scientists from the State Agricultural Experiment Stations, extension specialists could be trained to incorporate satellite derived information into their state advisory programs."

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