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PHENOLOGY SATELLITE EXPERIMENT

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March 15, 1974
TYPE II PROGRESS REPORT
August 1973 - February 1974

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16. Abstract

Analysis of ERTS data for the 1973 Green Wave at 24 sites in the United States was completed and study of the 1973 Brown Wave was initiated. Ground observations from these sites were recorded and analyzed for the 1973 Brown Wave.

Procedures used during the period were as reported in detail in earlier reports.

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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 Brown Wave (1972), the Green Wave (1973), and the Brown Wave (1973) (p.5).

The type of work performed during this reporting period has been previously mentioned (1, 2). The final report was due at the end of this reporting period; however, the report has been delayed due to slow delivery of some necessary data.

All procedures in use and tentative results have been reported (3, 4) and presented to segments of the scientific community. When the late fall (1973) data is analyzed, it will be combined with the Brown Wave data for 1972 and 1973. This additional data will allow a comparison to be made between these two Brown Waves. The total growing season (Green Wave and Brown Wave) for 1973 will be analyzed using the completed study of ground observations and phenological data (3, 4).

MSS data from the 24 sites (p. 5) have been analyzed for 173 overpasses (pp. 7, 8, 10, 11).

A quideline for assessing vegetation changes using ERTS-1 Satellite Imagery was prepared at the University of Maine for an Imagery Interpretation Workshop at Montana State University.

Ground photography phase of the project was completed in November 1973.

ERTS (operational) data will provide the only reasonable means of making synoptic phenological measurements over interregional areas in a time frame required for assessing the complex soil-air environment to provide answers to management and planning questions.

These answers, obtained from phenology satellite data without the need for ground observations, become important in areas of political or economic sensitivity.

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1.0 Introduction

For the sake of information, continuity and economy, sections of previous reports are reproduced or referenced in this report.

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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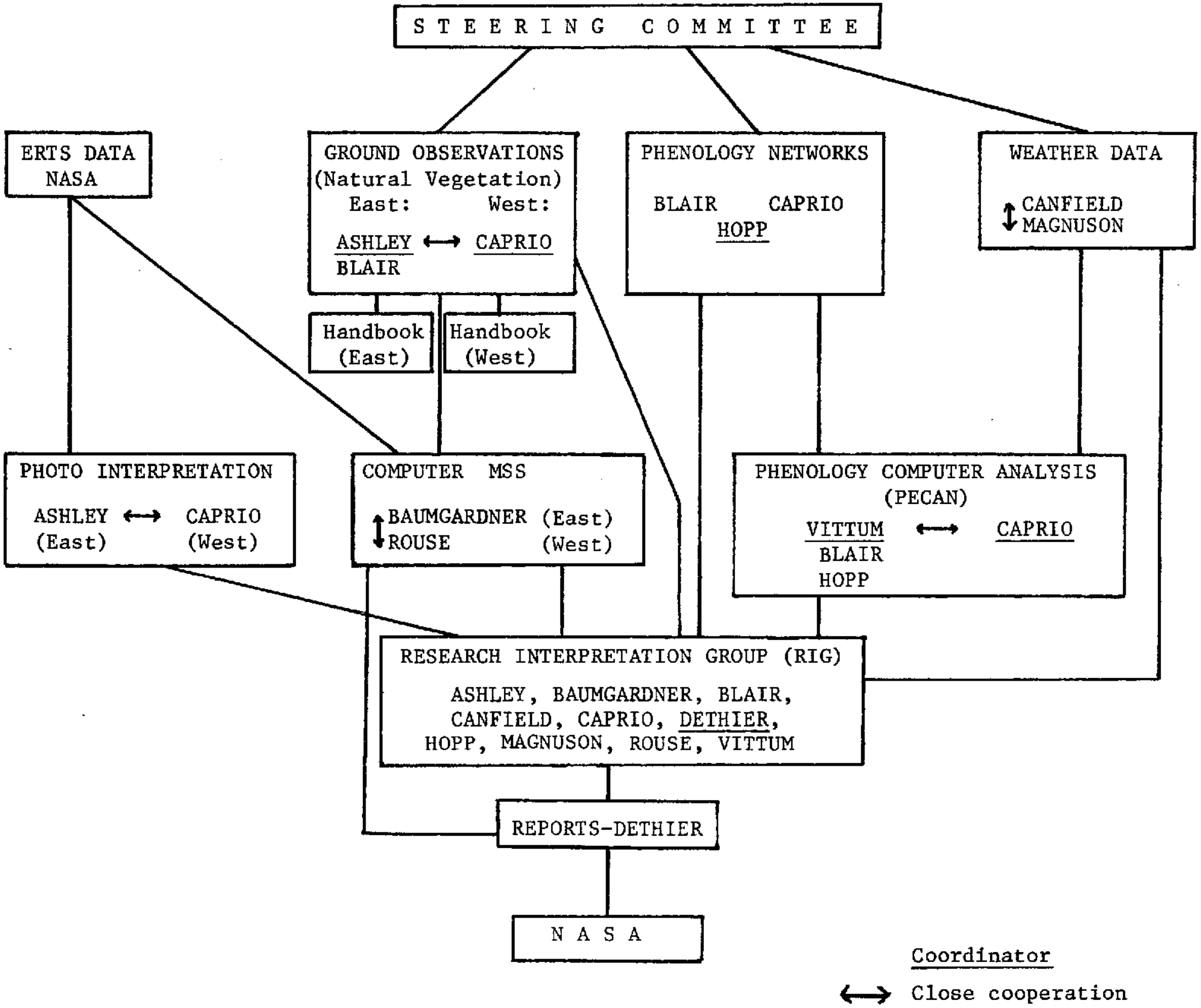
[1] Regional Research projects such as NE-69, Atmospheric Influences on Ecosystems and Satellite Sensing, and W-48, Climate and Phenological Patterns for Agriculture in the Western Region, are funded jointly by participating State Agricultural Experiment Stations and by federal regional research money 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 ⟷ CAPRIO
(East) (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
NASA
Coordinator
⟷ Close cooperation

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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.

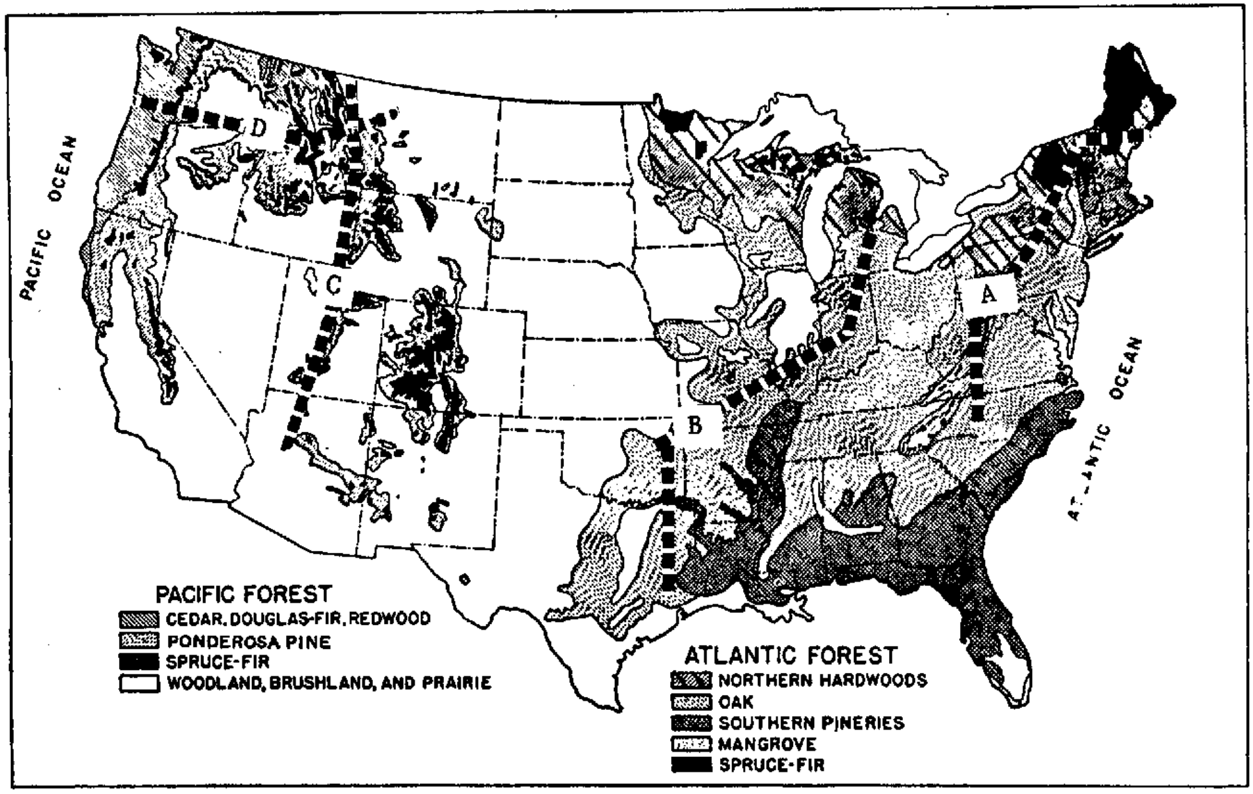

Figure 1. A - Appalachian Corridor, B - Mississippi Valley Corridor, C - Rocky Mountain Corridor, D - Columbia Valley Corridor.

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.

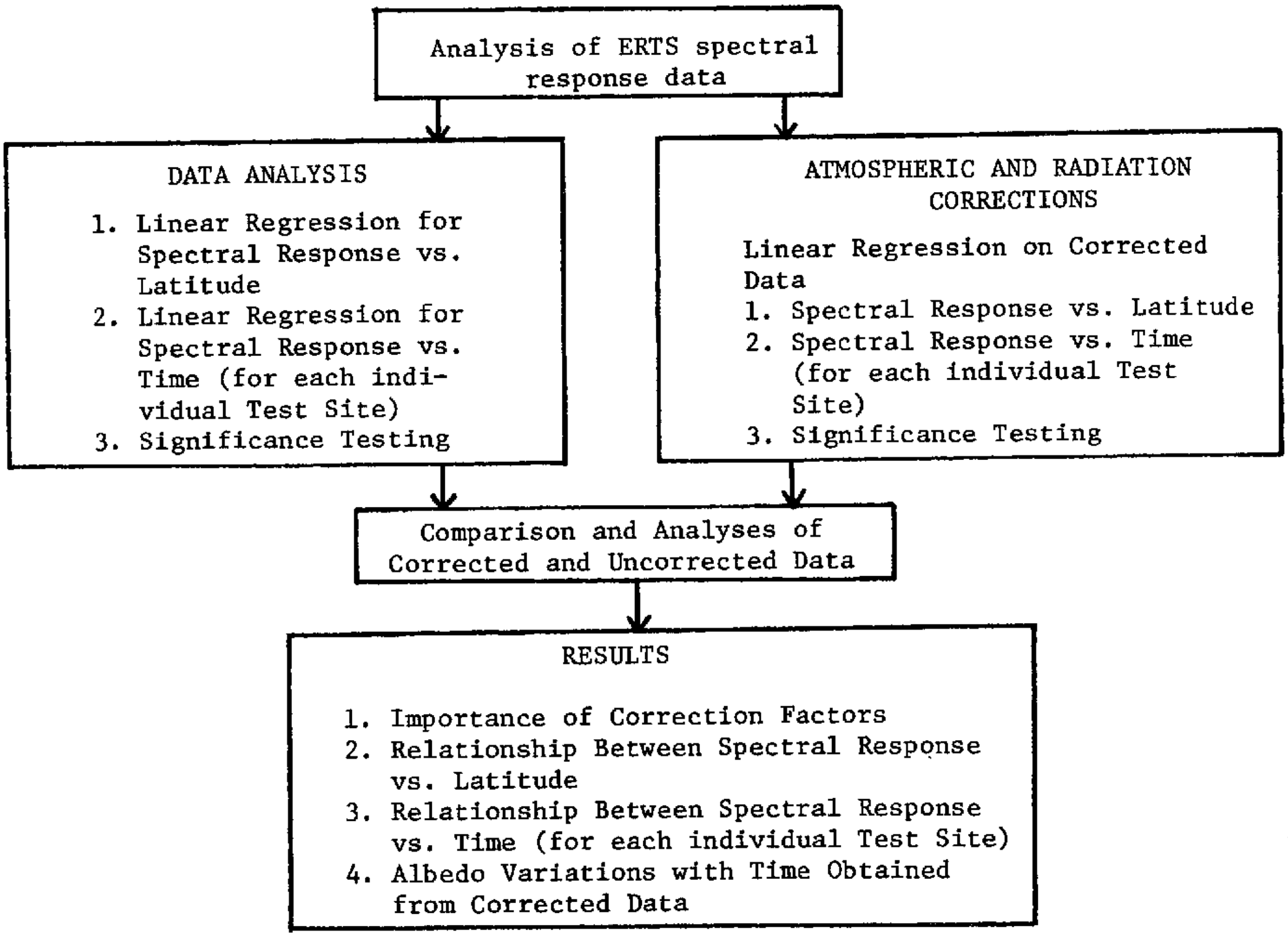

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Table 1 shows all the data received and analyzed for each test site.

TABLE 1

ANALYSIS SUMMARY

All Data According to Test Site

Orono Maine	Richmond Maine	Burlington Vermont	Ithaca New York
1 Sept. 1972	15 Aug. 1972	21 Sept. 1972	19 Aug. 1972
28 Feb. 1973	1 Sept. 1972	10 Oct. 1972	23 Sept. 1972
23 April 1973	28 Feb. 1973	27 Oct. 1972	11 Oct. 1972
22 July 1973		7 April 1973	2 June 1973
		25 April 1973	8 July 1973
		6 July 1973	

State College Pennsylvania	Morgantown West Virginia	North Carolina	Lansing Michigan
6 Sept. 1972	20 Aug. 1972	19 Aug. 1972	25 Aug. 1973
10 Jan. 1973	7 Sept. 1972	6 Sept. 1972	
23 March 1973	18 Nov. 1972	24 Sept. 1972	
16 May 1973	6 March 1973	11 Oct. 1972	
9 July 1973	24 March 1973	12 Oct. 1972	
	2 Sept. 1973	30 Oct. 1972	
		23 March 1973	
		10 April 1973	
		16 May 1973	
		2 June 1973	

Lafayette, Indiana		Southern Indiana	
30 Sept. 1972	4 May 1973	26 Aug. 1972	6 Nov. 1972
1 Oct. 1972	5 May 1973	12 Sept. 1972	16 Jan. 1973
19 Oct. 1972	9 June 1973	13 Sept. 1972	4 Feb. 1973
24 Nov. 1972	7 Sept. 1973	30 Sept. 1972	22 Feb. 1973
17 Jan. 1973	14 Oct. 1973	1 Oct. 1972	4 May 1973
4 Feb. 1973		19 Oct. 1972	9 June 1973
		5 Nov. 1972	3 Aug. 1973

Jefferson City Missouri	Barnsdall Oklahoma	Commerce Texas (North)	College Station Texas (Central)
11 Aug. 1972	13 Aug. 1972	16 March 1973	30 Aug. 1972
28 Aug. 1972	9 Feb. 1973	9 May 1973	23 Oct. 1972
29 Aug. 1972	17 March 1973	27 May 1973	16 Dec. 1972
8 Nov. 1972	22 April 1973	2 July 1973	3 Jan. 1973
14 March 1973	10 May 1973	7 Aug. 1973	16 March 1973
25 May 1973	3 July 1973	25 Aug. 1973	8 May 1973
18 July 1973	8 Aug. 1973		9 May 1973
5 Aug. 1973			27 May 1973
			2 July 1973
			19 July 1973
			24 Aug. 1973

A breakdown of analysis according to Brown and Green Waves by site is shown in Table 2 for Eastern Corridors.

TABLE 2

BREAKDOWN OF ANALYSIS ACCORDING TO TEST SITE

	Number of Dates Analyzed			
	BW '72	GW '73	BW '73	Total
APPALACHIAN CORRIDOR				
1. Orono, Maine	1	3		4
2. Richmond, Maine	2	1		3
3. Burlington, Vermont*	3	3		6
4. Ithaca, New York*	3	2		5
5. State College, Pennsylvania*	1	4		5
6. Morgantown, West Virginia*	3	2	1	6
7. Raleigh, North Carolina*	6	4		10
MISSISSIPPI CORRIDOR				
8. Lansing, Michigan	1			1
9. Lafayette, Indiana*	4	5	2	11
10. Southern Indiana*	8	5	1	14
11. Jefferson City, Missouri*	4	3	1	8
12. Barnsdall, Oklahoma*	1	5	1	7
13. Commerce, Texas (North)*		4	2	6
14. College Station, Texas (Central)*	3	7	1	11

*Curvilinear regressions performed for each individual site having five or more dates for analysis.

Table 3 shows the status of tapes ordered or received.

TABLE 3

DATA SUMMARY

BW '72	(11 August 1972 - 31 December 1972)
GW '73	(1 January 1973 - 31 July 1973)
BW '73	(1 August 1973 - 21 November 1973)

IMAGERY	BW '72	GW '73	BW '73	Total
Expected (approximate count):	192	288	144	624
Received by 15 December 1973:	131	150	19	300
TAPES				
Ordered:	58	75	18	151
Received in time for analysis:	40	48	9	97
Received but unuseable:	15	8	2	25
Total received:	55	56	11	122
Total not received	3	19	7	29

For examples and discussion of temporal analyses of Brown and Green Wave data see Type II Report, October 15, 1973, pp. 9-26.

A new format for displaying the results of the analysis has been adopted. The peak relative spectral response for a given channel is plotted against the date of overpass. The graphs show this temporal plot for each channel individually.

A linear regression analysis was then performed for all test sites having four or more analyzed fall dates. The following points were made:

1. Higher correlation coefficients were found in bands 6 and 7.
2. The slopes were negative in all four bands (channels). This suggests the possibility that the correction factor is important in that a decrease in actual albedo at all wavelengths is unlikely for the forested areas being studied.

A graphic and statistical comparison was also made between peak relative spectral response and latitude for given dates (1).

All statistics for the eastern corridors have been revised and, in some cases, enhanced using information provided by the imagery interpretation groups. The statistics charts contain the spectral response values and their standard deviations for each date as well as the solar elevation angle (to be used for atmospheric and solar angle corrections) and the Band Ratio Parameter (BRP) developed by the Remote Sensing Center, Texas A & M University.

Rocky Mountain and Columbia Valley Corridors

Table 4 shows all the data received and analyzed for each test site.

TABLE 4

ANALYSIS SUMMARY

All Data According to Test Site

Rocky Mountain Corridor

Browning Montana	Logan Montana	Camas Idaho
28 Aug. 1972	26 Aug. 1972	26 Aug. 1972
3 Oct. 1972	13 Sept. 1972	13 Sept. 1972
4 Aug. 1973	30 March 1973	1 Oct. 1972
	27 June 1973	16 July 1973
	15 July 1973	26 Sept. 1973
	16 July 1973	
	26 Sept. 1973	
	14 Oct. 1973	

Snowville Utah	Kanosh Utah	Colorado City Arizona
7 Aug. 1972	7 Aug. 1972	30 Sept. 1972
25 Aug. 1972	25 Aug. 1972	16 April 1973
26 Aug. 1972	12 Sept. 1972	22 May 1973
12 Sept. 1972	30 Sept. 1972	15 July 1973
30 Sept. 1972	14 April 1973	20 Aug. 1973
6 Nov. 1972	16 April 1973	7 Sept. 1973
22 May 1973	4 May 1973	
16 July 1973	22 May 1973	
20 Aug. 1973	8 June 1973	
1 Nov. 1973	27 June 1973	
	14 July 1973	
	15 July 1973	
	1 Aug. 1973	
	7 Sept. 1973	

Columbia Valley Corridor

Havre Montana	Charlo Montana	Helmer Idaho	Bickleton Washington
26 Aug. 1972	11 Aug. 1972	11 Aug. 1972	1 Sept. 1972
13 Sept. 1972	28 Aug. 1972	12 Aug. 1972	19 Sept. 1972
12 March 1973	29 Aug. 1972	30 Aug. 1972	7 Oct. 1972
30 March 1973	3 Oct. 1972	5 Oct. 1972	11 May 1973
5 May 1973	20 Jan. 1973	27 May 1973	29 May 1973
23 May 1973	18 July 1973	12 Sept. 1973	9 Aug. 1973
10 June 1973	11 Sept. 1973		27 Aug. 1973
16 July 1973			
3 Aug. 1973			

A breakdown of analysis according to Brown and Green Waves by site is shown in Table 5 for Western Corridors.

TABLE 5

BREAKDOWN OF ANALYSIS ACCORDING TO TEST SITE

	Number of Dates Analyzed			
	BW '72	GW '73	BW '73	Total
ROCKY MOUNTAIN CORRIDOR				
1. Browning, Montana	2		1	3
2. Logan, Montana	2	4	2	8
3. Camas, Idaho	3	1	1	5
4. Snowville, Utah	6	2	2	10
5. Kanosh, Utah	4	8	2	14
6. Colorado City, Arizona	1	3	2	6
COLUMBIA VALLEY CORRIDOR				
7. Havre, Montana	2	6	1	9
8. Charlo, Montana	4	2	1	7
9. Helmer, Idaho	4	2	1	7
10. Bickleton, Washington	3	2	2	7

For examples and discussion of data processed for these corridors, see Type II Report, October 15, 1973, pp. 27-35.

2.1.2 Radiation and Atmospheric Correction Factors

The factors applied to all ERTS data, when necessary, are described in Type II Report, October 15, 1973, pp. 35-43.

2.1.3 Photo Interpretation

A guideline for assessing vegetation changes using ERTS-1 Satellite Imagery was prepared at the University of Maine for an Imagery Interpretation Workshop at Montana State University. In this way, uniform work procedures were achieved for both the eastern and western corridors (Appendix).

The Welsh Densicron density analyzer was modified to make measurements on areas less than was possible using the standard aperture. In addition, regression equations were derived for calibration of the instrument and gray scale anomalies on the MSS imagery. Analysis indicates that density changes are directly related to phenological changes and these correlations are also evident using the

$$\text{band-to-band ratio} = \frac{\text{Density Band 5} - \text{Density Band 7}}{\text{Density Band 5} + \text{Density Band 7}}$$

A summary of forest phenological events observed on the ground observation photos has been compiled. Negatives of ERTS frames, bands 5 and 7 have been made showing the sites at all available dates. A set of prints have been made from these negatives with the exact forest sites located on them. A densitometry (involving bands 5 and 7) and band-to-band ratio analysis of available data for all sites over all dates has been finished.

Black and white 33mm pictures have been taken of the Brown and Green Wave data on hand from all corridors. Color 35mm slides were also taken of at least one good date for each site.

2.2 Ground Observations

2.2.1 Corridor Sites

Vertical shots of forest canopy taken at the 14 sites in the eastern corridors have been analyzed using Digicol Processor equipment in order to obtain quantified data. These ground observations for the Brown and Green Waves are being correlated with ERTS-1 imagery.

Photography at the 24 ground observation sites ceased in November after having documented the Brown Wave 1972, Green Wave 1973, and Brown Wave 1973. Data from the phenology networks have been analyzed for the Green Wave 1973 and for the Brown Wave 1973.

2.2.2 Phenological Networks

Phenological observations of the Brown Wave (fall 1973) have been analyzed and mapped. This phase of the project is complete.

3.0 FUTURE WORK

Study of the 1973 Brown Wave will be completed and 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

This phase has been completed.

3.2 Solar Thermal Units

Comparison of the solar thermal unit accumulations during the 1973 Green and Brown Waves with phenological development and satellite information will be completed.

3.3 Data Processing

Analysis of the 1973 Brown Wave will be completed upon receipt of the imagery and tapes. Comprehensive computer printed reports will be obtained for all 24 sites pending receipt of the final data for the fall of 1973.

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

3.4 Photo Interpretation

This phase has been completed.

3.5 Phenoclimatic Models

Due to delay in the receipt of daily temperature data from NOAA the necessary calculations were not completed until January 1974.

Growing degree days accumulated using the different formulas are being 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.

Phenoclimatic models are being used to draw preliminary world maps 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:

1. spectral curves,
2. imagery in the suitable band or bands, and
3. 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:

1. mean and standard deviation and covariance matrix of reflectance,
2. comparative spectral response,
3. change in forest canopy and plant cover, and
4. relationship between weather parameters and phenological events.

Maps will be prepared of the following:

1. Green Wave,
2. Brown Wave, and
3. 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 1973 - February 1974) has continued at a pace determined by the rate of receipt of ERTS-1 data.

To date our research leads to the following conclusions concerning the application of an ERTS system.

ERTS (operational) data will provide the only reasonable means of making synoptic phenological measurements over interregional areas in a time frame required for assessing the complex soil-air environment to provide answers to management and planning questions such as:

1. status of plant development,
2. plant management, including storage and transportation,
3. tentative yield comparisons between regions or countries,
4. feasibility of plant introduction.

These answers, obtained from phenology satellite data without the need for ground observations, become important in the following cases:

1. In less developed areas (those devoid of support data), ERTS data becomes a useful quantified data base which can be applied to existing models and those yet to be developed.
2. In areas of political or economic sensitivity.
3. In times of widespread ecological stress.
4. In remote areas of even the better developed regions.
5. Where areas of natural vegetation are to be converted to agricultural use.

APPENDIX

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GUIDELINES FOR ASSESSING VEGETATION CHANGES USING ERTS-1 SATELLITE IMAGERY

by

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Forest Resources Remote Sensing Laboratory
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Prepared for an
Imagery Interpretation Workshop
Montana State University
October 12-15, 1973

GUIDELINES FOR ASSESSING VEGETATION CHANGES USING ERTS-1 SATELLITE IMAGERY

Introduction

The analysis and evaluation of remote sensing imagery for most purposes follows well defined guidelines. This paper illustrates these guidelines by presenting an introduction to remote sensing principles and describing a system to assess seasonal vegetation changes using ground and Earth Resources Technology Satellite (ERTS-1) imagery. This system has been developed as part of a NASA funded project to study phenological changes over the United States. All of the interpretation, data handling and analysis procedures including darkroom methods are outlined.

Fundamentals of Imagery Interpretation

The term imagery as discussed here refers only to ERTS-1 multispectral scanner prints and transparencies. The methods used to interpret this imagery are very similar to those used for aerial photography. The appearance or change in appearance of any object on this imagery will be a function of the imagery's resolution, scale, recorded spectral sensitivity and of the interpreter's ability-training.

Resolution is a descriptor used to indicate the fineness of detail which can be seen on the imagery. The resolution of fields, forests, and other objects is dependent upon several factors such as the feature's shape, area, contrast with surroundings and the scale of the imagery.

Scale is the number of units distance on the ground equivalent to a unit distance on the imagery. The scale of the ERTS-1, 70 millimeter format products is 1:3,369,000 or a one inch measurement on the imagery is equivalent to fifty miles distance on the ground. The 9 x 9 inch products have a scale 1:1,000,000 or approximately sixteen miles on the ground per inch on the imagery. These relatively small scales indicate that to be seen or resolved an object must be relatively large in area or contrast greatly with its background. Experience with the ERTS-1 data indicates that crops or forests as small as ten acres in area can be identified when surrounded by other crop or forest species.

Sensor Sensitivity and Object Reflectivity

The spectral sensitivity of the remote sensors coupled with spectral reflectivity of an object are also partially determinant in whether or not or how an object will appear on the imagery. The ERTS-1 multispectral scanner has four sensors, each "looking" at a different part of the electromagnetic spectrum. These four sensitivities are expressed in terms of the wavelength response of the sensor and are 0.5-0.6 (green-band 4), 0.6-0.7 (red-band 5), 0.7-0.8 (near infrared-band 6), 0.8-1.1 (near infrared-band 7) micrometers. Whenever an object reflects those wavelengths to which a sensor responds, it will appear light in tone on that imagery band. Objects reflecting green wavelength radiation will appear light in tone on band 4 imagery while objects having high red reflectivity will appear light in tone on band 5 imagery. The near infrared bands record radiation not visible to the human eye. However, the conversion of the sensor's output onto film allows objects reflecting radiation in these wavelengths to be seen as lighter tones on the resultant imagery.

Green fields and forests will often appear much lighter in tone on the infrared bands than on band 4. A much greater reflectance of near infrared wavelengths by green vegetation in comparison with that of the green wave lengths produces this result. Vegetation appears green to the human eye only because green reflectance is dominant over the range of wavelengths to which the eye is sensitive (0.4-0.7 micrometers). Vegetation is usually darker in tone on the red band imagery because of the low reflectance of these wavelengths (chlorophyll absorption

Whichever band is used in interpretation, the density-vigor of the vegetation and the amount of soil or other background features greatly influence the interpreter's ability to discern specific crop or forest areas or phenological changes in this vegetation. The satellite has essentially a vertical view of all those features below it and an object's appearance results from an integration of all these features.

The ability-training of an interpreter to successfully evaluate ERTS imagery depends upon his understanding of the few concepts presented above. Implicit in these is the recognition of how interpretation factors such as shape, size, tone, pattern, texture and topographic position interact with object appearance.

Consideration must additionally be given the changing factors of atmospheric aerosol and solar illumination. Atmospheric aerosol, visible as haze, reduces the contrast between objects. Imagery obtained under these conditions will have a uniform grayish-white frosted appearance. Scattering of light by the aerosol (Rayleigh scattering) produces this effect and is more acute in shorter wavelength bands.

Solar elevation differences also influence object appearance. For a given latitude and time of day the solar elevation and illumination differs throughout the year. These factors cycle continuously, with summer highpoints and winter lows. There will be a general darkening of the imagery in all bands as solar elevation and illumination decreases.

Site Location On the ERTS Imagery

The forest and crop areas at each test site must be located accurately on the imagery for the interpretation studies. Comparisons of the same areas over different dates are necessary for continuity.

The general site area can be quickly located using a World Aeronautical Chart (WAC). These charts and the 9 x 9 inch ERTS products have the same scale. The latitude and longitude of the site should be marked on the map. Then the band 7 transparency covering the site is overlayed on the WAC by aligning rivers, lakes or other prominent features appearing on both. Placing the chart on a low intensity light table often highlights the map details and facilitates the alignment. The general site location (latitude-longitude mark) is then marked on the imagery with a grease pencil. This point is then transferred from the band 7 image to any other band by aligning the corner fiducial marks of the two images and with the alternate band on top, marking through the latitude-longitude mark from the band 7 imagery.

The specific forest or crop site is then located using larger scale charts and photographic enlargement of the imagery. The exact site is marked on a USGS quadrangle sheet (scales of 1:62,500 to 1:24,000). Then roads, forest boundaries or other features shown on the map, and visible on the imagery, are referenced on the imagery to close in on and exactly locate the study areas. Comparisons of map details with 7X photographic enlargements of the imagery usually make identification of the site much easier. Use of a 5-10X hand lens to study the ERTS transparencies also often facilitates this work.

Visual Correlations With Phenological Changes

Seasonal changes in vegetation can be correlated visually with tonal changes on the satellite imagery. Bands 5 and 7 provide a good basis for such studies. Forest stands usually lighten in tone on band 5 and darken in tone on band 7 as autumn leaf coloration and fall progresses. These tonal differences can be explained by considering the interpretation factors discussed above. Many crops follow this same pattern as they mature and are harvested. Spring-summer sequences give a reversal of these developments.

The correlations are made by comparing visually the imagery tonal changes of forest and crop areas with ground observation photography taken of the same area on the same dates. The ground photography consists of color slides taken by trained field personnel. These slides document the stage of phenological development of site vegetation at and between given dates.

Density Analysis of ERTS-1 Imagery

Visual interpretations of imagery and correlations with ground observations are subject to human judgment. An objective method of analyzing the imagery and verifying the interpretations would seem desirable. Film density measurements on the transparencies are one way to obtain objective data which will be indicative of tonal changes. Considering any given spectral band, the density of an area is inversely related to the reflectance for this area. Areas with high reflectance will have a low density and light tone. Image density is also relatively simple and inexpensive to measure with standard darkroom densitometers.

The site must be accurately located before density measurements can be made. This positioning is assured by the following procedure. Place a strip of clear film (acetate or mylar) over the imagery so that it covers the site and extends to the edge of the transparency. Securely tape the film to the outer edge of the imagery so as to prevent side movement, yet allow the clear strip to be lifted and folded back. Then place the transparency with the attached clear overlay on a light table and put an ink dot on the clear film, marking the exact location of the site. The site location is then transferred to the overlays for imagery on other bands and dates by aligning the original and new images using obvious common features such as lakes, rivers and highways and putting an ink dot on the overlay strip covering the second transparency. This procedure should give repeatable reference points.

The densitometer readings are now made using the ink dots as site references. The image with the ink-dotted film taped on is placed over the aperture and light source of the densitometer. The imagery is shifted until the dot blocks the light source, thus aligning the site directly under the measuring head. The transparency is taped in place, the overlay folded back and the densitometer head lowered to make the measurement.

Several adjustment functions have to be made to standardize the original densitometer measurements. An instrument calibration adjustment should be made on all densitometer readings. The data necessary to calculate this correction for densitometers such as those manufactured by the Welsh Scientific Company is obtained by comparing instrument readings with a density wedge standard made by Eastman Kodak. This data is plotted and a graphically plotted adjustment curve is constructed. A further refinement of this technique is suggested for use in adjusting ERTS imagery density readings. The densitometer readings and gray scale readings are run through a simple linear regression and a prediction equation for adjusting the instrument readings to calibrated readings is derived. This equation and others discussed below can be written into computer programs that will greatly reduce the workload in the correction of large numbers of density readings.

Further adjustment of the densitometer readings is required for possible differences in processing between different dates. This is accomplished by measuring the density at several known points on the imagery's fifteen wedge steps. A simple linear regression equation is then developed for each pair of dates so that the equation adjusts the readings at one date back to comparable readings at the base date.

A final adjustment for differences in solar elevation and atmospheric transmission between dates should then be made to each reading, after having gone through the two least squares adjustments. This adjustment is in ratio form and is calculated using solar radiometer readings. (The procedure is outlined in a recently written LARS-Purdue working paper). These corrections in total should give resultant densities indicative of actual vegetation reflectances over different times.

Band to Band density ratios can be used along with the density changes in individual bands to depict phenological changes. One ratio found to work well is: $R_{5-7} = \frac{\text{Density Band 5 - Density Band 7}}{\text{Density Band 5 + Density Band 7}}$. This ratio increases with vegetation development in the spring and decreases with the fall's seasonal changes.

Use of the Diazo Process for Making Color Transparencies

Sometimes a color infrared composite image is easier to interpret than the black and white imagery. However, the delivery of color products by NASA is often several weeks later than that for the other products. If one has an immediate need for color renditions of the ERTS imagery, they can be made using the Diazo process. Most visual-aids departments have the necessary equipment for this work.

The Diazo procedure is based on the Ozalid process. The Diazo film is exposed using ultraviolet light and developed in ammonia gas. The resulting image is identical to the one copied except for color. In other words, dense areas on the original are also dense on the Diazo product. The film used in the Diazo process comes in practically any color desired. Two types often used are Tecnifax Diazochrome color film by Scott Graphics and Spectra Diazo film by K & E. The University of Maine's processing machine is a Blu-Ray made in Essex, Connecticut.

The color composite process is started by making transparencies with different colors for black and white images of two or more of the four ERTS MSS bands. The black and white transparency and Diazo film of the desired color are placed in contact with each other and an ultraviolet light is shown through the imagery onto the emulsion side of the Diazo film. This is much like making a normal photographic contact print from a negative on a contact printer. After this the Diazo film is developed by exposure to ammonia gas. This process is repeated for each band and color combination that is required to make the final color image. To make a color infrared composite, three images are used (band 4, 5, and one of the infrared bands). The Diazo film colors to use for each band are:

Band	Diazo Film Color
4	Yellow
5	Magenta
6 or 7	Cyan

One other variable to consider in this process is the density of the Diazo image. It can be changed by varying exposure time. It has been found that trial and error is the best method of choosing the proper exposures. The composite image is formed by sandwiching together the color images in exact register using the corner fiducial marks for alignment. An overhead projector provides a good method to view the composite. This multi-layered affect can be distracting when the image is viewed directly without enlargement or a high intensity light source.

Darkroom Techniques for Processing ERTS-1 Imagery

The ERTS-1 black and white transparency images are not suitable for many investigator uses. Examples are publication purposes and enlargements needed in paper print form for interpretation studies. Standard darkroom procedures are used to make the necessary photographic transformations. The methods used are simple and permit the use of common dark room equipment and supplies.

To make a black and white positive print, a negative is needed. These negatives are obtained in one of two ways. For small scale prints, such as 1:1,000,000, the 70 mm transparency negatives supplied by NASA can be used. However, these can't be enlarged much more than three times without having exposure times in excess of that advisable for making prints with ordinary darkroom materials. NASA bulletin Vol. A, No. 13, 1/15/73, describes a recommended procedure to be used when printing with these negatives. This paper also lists recommended exposure settings for various papers, enlargers, and developers.

These negatives are very dense, making them difficult to use. By trial and error it has been found that for Band 5 imagery an exposure time of approximately 30 seconds with an 'f' stop of 8 (50 mm lens) on an Omega PRO-LAB D-6 enlarger set for a 3X enlargement will give a proper exposure on KODAK polycontrast rapid paper developed in Dektol (1:2) for 90 seconds. For a Band 7 negative the 'f' stop is 3.5 and the exposure time 20 seconds. These values will vary from frame to frame and the best method of determining the proper exposure for each new frame is to expose test strips.

New negatives must be made to produce enlarged prints at scales sufficient for detailed study of a site. The negative can be made on 35 mm Fine Grained Release Positive film, Eastman Kodak 5302. This film has nearly the same emulsion as print paper and can be handled under safe lights and developed in Dektol. The first step in making the negative is to place the ERTS 9 x 9 inch positive transparency on a contact printer after having noted the site location. To ensure making the negative so that it covers the site, the site area is masked using metal masking strips or by making a mask from any thin opaque material. The masks should be sized to allow the 35 mm film to fit in the mask opening with the opening placed over the site. The Fine Grained Release Positive film strip is then placed under the opening, on top of the transparency and exposed. Test strips should be made to determine the exposure times required to produce negatives of any desired density. These negatives are at a scale of 1:1,000,000 and can be enlarged quite easily because of their fine grain and relatively lower density. Also their larger scale as compared with the NASA 70 mm negatives gives less of an enlargement factor from which to make the larger scale prints.

One method of adjusting the enlarger to give a desired scale is to first trace details such as lakes, rivers and highways on a white sheet of paper from a map having the same scale as desired for the enlarged print. This paper is then placed in the enlarging easel and the enlarger with negative in place is raised or lowered until the image projection fits the outline traced off the map. If a print is made with an unknown enlargement factor, the scale can be determined by measuring known distances between land marks that appear on the print such as lakes, islands, major highway intersections and calculating the scale as a representative fraction: $\text{scale} = \frac{\text{photographic distance}}{\text{ground distance}}$. The ground distance is usually scaled off from map measurements.

Summary

These guidelines should give the interpreter interested in analyzing ERTS imagery some useful working methods. This discussion is certainly not all inclusive of the methods and problems encountered in working with multispectral satellite imagery. However, it should provide a good basis from which to start and have experience modify.

REFERENCES

1. Phenology Satellite Experiment, ERTS-1 Proposal No. MMC 159, Progress Report Type I, No. 6, for period 10/08/73 - 12/08/73.

2. Phenology Satellite Experiment, ERTS-1 Proposal No. MMC 159, Progress Report Type I, No. 5, for period 8/08/73 - 10/08/73.

3. Phenology Satellite Experiment Progress Report Type II, No. 2, for period February 1973 - August 1973, Report date October 15, 1973.

4. Phenology Satellite Experiment Progress Report Type II, No. 1, for period August 1972 - February 1973, Report date April 16, 1973.