N73-28226

Paper A 19

PHENOLOGY SATELLITE EXPERIMENT[1]

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ABSTRACT

The detection of a phenological event (the brown wave-vegetation senescence) for specific forest and crop types using ERTS-1 imagery is described. Data handling techniques included computer analysis and photo interpretation procedures. Computer analysis of ERTS-1 multispectral scanner digital tapes in all bands was used to give the relative changes of spectral reflectance with time of forests and specified crops. These data were obtained for a number of the study's twenty-four sites located within four north-south corridors across the Unites States.

Analysis of ground observation photography and ERTS-1 imagery for sites in the Appalachian Corridor and Mississippi Valley Corridor indicates that the recession of vegetation development can be detected very well. Tentative conclusions are that specific phenological events such as crop maturity or leaf fall can be mapped for specific sites and possibly for entire regions.

Preliminary analysis based on a number of samples in mixed deciduous hardwood stands indicate that as senescence proceeds both the rate of change and differences in color among species can be detected. This will permit timber surveys by species over large areas and the determination of conditions of wildlife habitats.

The roles of the State Agricultural Experiment Station and the cooperative state extension agent and specialist in disseminating methods of applying ERTS data to agricultural, forestry and wildlife management practices are also discussed.

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I. INTRODUCTION

The term "phenology" appears to have been first applied in 1853 by the Belgian botanist, Charles Morren, to that branch of science which studies periodic phenomena in the plant and animal world insofar as they depend upon the climate of any locality. The word phenology itself is derived from the Greek word "phaino", meaning to show. Plants can be used as indicators of climatic differences because the times of occurrence of phenological events of many plants is to a large degree controlled by the weather. Thus, phenology represents a merging of the meteorological and biological sciences, each contributing something to the other.

Scientists have known for many decades that plant species are excellent indicators of environmental conditions. Some phenological indicator plants reflect climatic contrasts between locations through their differential rate of seasonal development; other species indicate soil moisture conditions, depth to water table, and nutrient status of soils. Two phenological sequences are observed in the Phenology Satellite Experiment:

1. The Green Wave: A record of the geographical progression with time of foliage development over wide areas. This is the first step that must be taken toward a real time inventory of the yield potential, yield realization and crop management over extended crop and timber producing areas of the nation.

2. The Brown Wave: A record of the geographical progression with time of vegetation senescence (maturation of crops, leaf coloration, and leaf abscission). It plays the analogous role in the autumn as the Green Wave phenomenon does in the spring in terms of phenological predictors for vegetation management.

This report describes the phenological changes during the fall season (Brown Wave) detectable through satellite scanner systems.

The research was conducted at 24 sites within four corridors: (1) the Appalachian Corridor from Maine to North Carolina, (2) the Mississippi Valley Corridor from Michigan to Texas, (3) the Rocky Mountain Corridor from Montana to Arizona, and (4) the Columbia Valley Corridor in Washington and Oregon (Fig. 1). Multispectral scanner data from selected segments in each corridor were analyzed and correlated with ground site photography from corresponding segments.

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

The photographic analysis of the Rocky Mountain and Columbia Valley Corridors is being performed by Dr. Joseph Caprio, Montana State University. Dr. John Rouse, Texas A & M, is processing the MSS data for these corridors and correlating similar data from 10 sites in a Great Plains Corridor for an associated ERTS-1 project.

The ERTS satellite provides the only reasonable means of making synoptic phenological measurements over the interregional areas described in a time frame which will allow operational use of the results. The results described here are derived from analysis of MSS data from the Appalachian and Mississippi Corridors.

II. DATA SOURCES AND METHODS OF ANALYSIS

Imagery from all four multispectral scanner (MSS) bands is being evaluated. Standard products used are 70 millimeter and 9x9 inch positive transparencies, 9x9 inch color infrared composite transparencies from bands 4, 5, and 7, and computer compatible tapes from all bands. On-site photographs of the forest, crop, and range sites is being taken on a six day cycle at each site so that the date of every third set of photos coincides with an ERTS overpass. This photography provides a basis for comparison in the ERTS data analysis.

Computer analysis and photo interpretation procedures are being used to determine phenological changes. Computer programs have been written by the Laboratory for Applications of Remote Sensing (LARS), Purdue University, and the Remote Sensing Center (RSC), Texas A & M University, to express the relative reflectance in each band.

Analysis of data from all 34 sites (Phenology Satellite Experiment project and 10 sites Great Plains Corridor project) for the fall season is continuing. At the present time, sequential analysis of data from the Vermont, North Carolina, and Indiana sites is complete. The average and distribution of the reflectance in each band for a given date have been plotted graphically to show the spectral changes with time.

Photo interpretation methods are used to construct similar time sequences. Gray tone changes on the black and white products are being evaluated as an indicator of phenological change. ERTS imagery of the Vermont test site was examined for this part of the study. As more data becomes available, time lapse sequences showing the coincident changes in vegetation on the imagery and the ground observation photography will be assembled.

Another type of phenological time lapse sequence is currently being collected. This sequence consists of the changes in the amount of forest cover as measured from the ground photography, using a Digicol model 4010-3? density slicer. The Digicol has an electronic planimeter attachment which evaluates the percent area of different density levels (e.g. sky versus foliage) within a photo. The changing percentages between sets of photography of the same scene result from foliage development or recession.

III. RESULTS AND DISCUSSION

The relative differences in reflectances for an Indiana forest site are illustrated in Figure 2A. Reflectance in both bands 6 and 7 decreased with each succeeding overpass. The ground observation photography also shows a significant change during this eight week period. The leaves in mid-September were fully developed and green while by the October 19 overpass fall coloration was well under way. Leaf fall was complete by November 24. A similar analysis for two successive passes over the North Carolina site before leaf senescence had started shows, as would be expected, little change in reflectance (Fig.2B). These correlations indicate that phenological changes (Brown Wave) can be readily detected from ERTS-1 data.

The photo interpretation analysis also has shown substantive results. On site photography has documented the fall phenological changes at the cooperators' sites. By evaluating the complete sets of photos, the time of crop development and maturity, leaf coloration, and leaf fall can be determined for the different geographical locations. Digicol measurements quantify these events.

The timing of vegetation senescence is not strictly a function of latitude. In the Appalachian corridor the northern hardwood leaves at the Vermont site, 44°25'N lat. (Nov. 4) fell before those at the Orono,

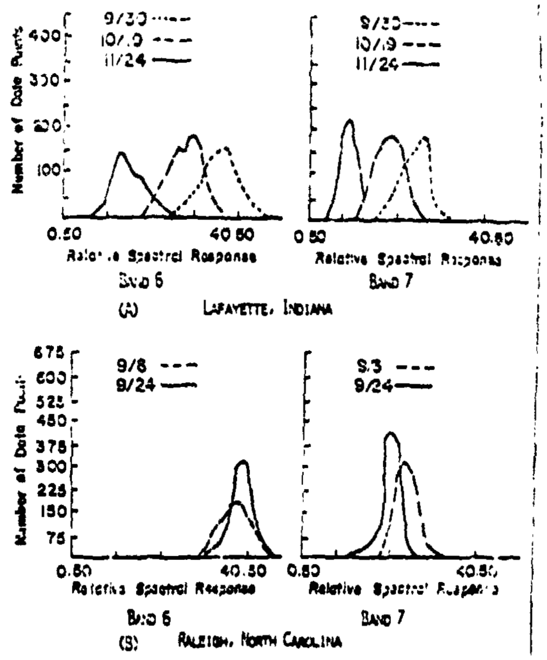

Figure 2. Histograms of the comparative spectral response of forest test sites, (A) Lafayette, Indiana; (B) Raleigh, North Carolina.

Maine site, 44°55'N lat. (Nov. 12). In the Mississippi Corridor, oak leaves in Missouri, 38°46'N lat. completed coloration (Nov. 15) before those at Lafayette, Indiana, 40°26'N lat. (Nov. 24). Elevation, soil type, moisture, and other environmental factors also influence the timing of phenological events.

ERTS-1 imagery used in conjunction with the ground observation photography sequences provides evidence of the geographical progression of vegetation development. Figures 3 and 4 show how some phenological changes in crops and forest appear when correlated in this way. ERTS frames E-1079-15063 (October 10) and E-1096-15115 (October 27) in bands 5 and 7 are presented along with ground observation photography of the test site near Richmond, Vermont. The ground photos were taken on October 10 and November 4, 1972, the dates nearest ERTS-1 overpasses. The terrestrial photos on October 10 are of standing mature corn and a forested area containing northern hardwood species. The forest leaves were near the height of fall coloration. The later set of ground photos shows that the corn has been harvested with only stubble remaining in the fields and the leaves at the forest site have nearly all fallen. Examination of the corn field and the forested site on the imagery verifies these events.

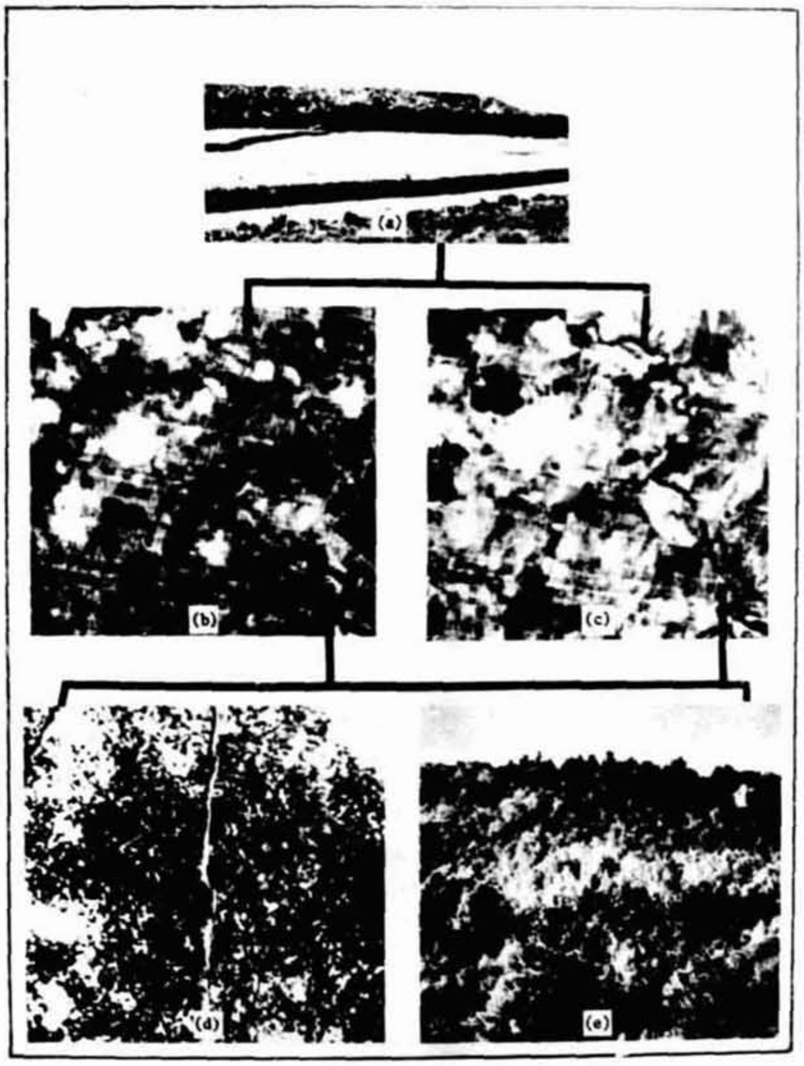

Figure 3. Ground observation photography and ERTS-1 imagery showing stages of vegetational development on 10 Oct 1972 at the Vermont Test Site: a) partially harvested corn, b) MSS Band 5 (scale 1: 125000), c) MSS Band 7 (scale 1:125000), d) forest canopy, and e) forest site.

The phenological progression can be detected using either band 5 or 7. When compared with the October 10 imagery (Fig. 3) the corn field appears lighter in tone on the October 27 (Fig. 4) imagery in the red band and about the same tone or a little darker in the infrared band. Perhaps this can be explained by the soil and stubble having relatively higher reflectance in the red wavelength than standing mature corn, while the infrared reflectance remained about the same or was slightly less for the stubble and soil. The red band also shows a general increase in reflectance throughout the Winooski River Valley and hardwood forest areas. The change is not as pronounced in band 7 imagery.

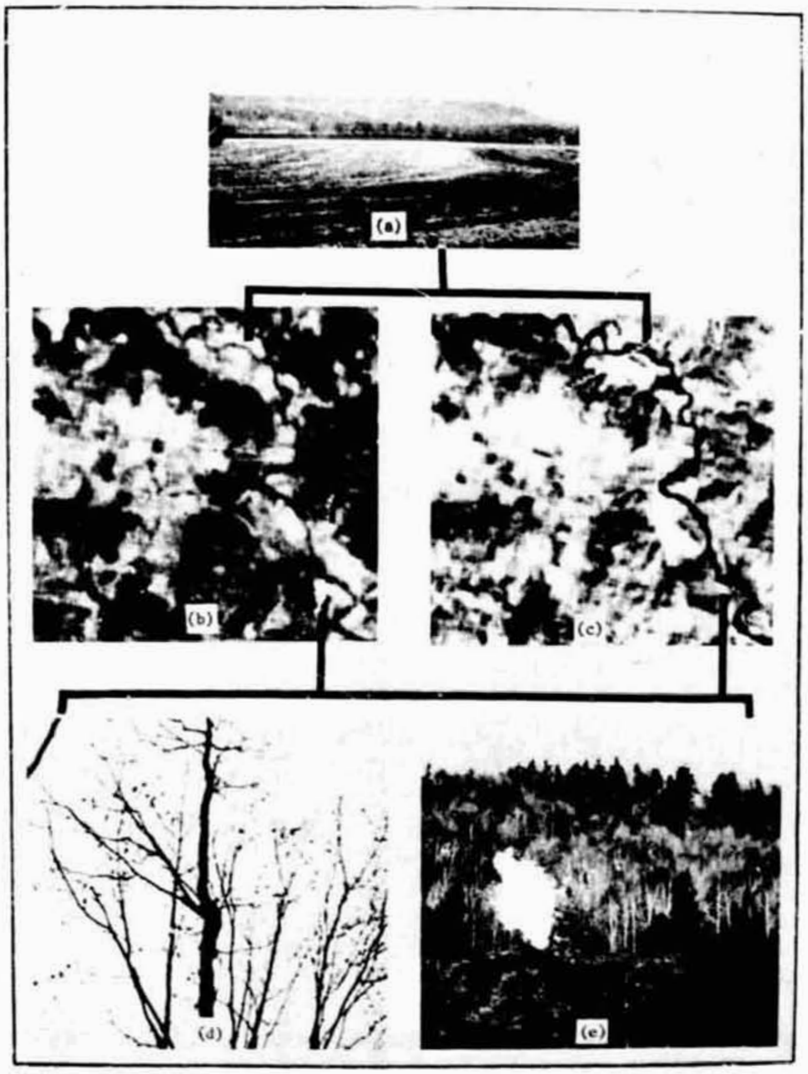

Figure 4 Ground observation photography (4 Nov 1972) and ERTS-1 imagery (27 Oct 1972) showing stage of vegetational development at the Vermont Test Site: a) corn stubble, b) MSS Band 5 (scale 1:125000), c) MSS Band 7 (scale 1:125000), d) forest canopy, and e) forest site.

While the evidence from analysis of band 7 is not conclusive, the analysis of band 5 does indicate a relationship between vegetative cover, reflectance, and phenological change. The depletion of chlorophyll in the vegetative cover due to leaf fall and senescence of lower vegetation results in a higher reflectance of solar energy in the red wave lengths. The potential for mapping such changes over large areas is evident.

IV. APPLICATIONS

Preliminary computer tests and a photo interpretation study of imagery in bands 5 and 7 for October 10 and 27 indicate that such events as crop harvest and leaf fall can be mapped for specific areas and possibly for entire regions. Comparison imagery taken before and after leaf fall can be used to map softwood and hardwood areas. For example, a land use and forest classification study was made using the October 27 MSS-5 imagery of the area around the Richmond, Vermont test site. Only that area which could be compared with a USGS topographic sheet was mapped. The resulting data is shown in Table 1.

Table 1. Forest and Land Use Classification
Richmond, Vermont test site.

Forest	Area (Acres)	Percent of Total
Softwood	1883	34
Mixedwood	415	7
Hardwood	532	10
Other		
Fields, farms, urban	2483	45
Water	210	4
	5523 Acres	100 Percent

These figures were obtained by tracing the gray tone boundaries of the land uses as seen from a projection of the ERTS frame onto a base map (scale 1:125,000) and then using a dot grid to get the areas in each class. Only 20 to 30 minutes were required to classify the 5500 acres. This time can be considerably reduced through the use of computer techniques.

Another application of the Brown Wave (leaf fall) is in the study of wildlife habitat conditions and availability.

Results to date from the Phenology Satellite Experiment shows the feasibility of the development and refinement of phenoclimatic models similar to the one illustrated in Figure 5.

The model presented is a world map showing isolines for the greening of grass in spring in the northern hemisphere. The lines are based on a number of reference points and data calculated from a mathematical model.

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

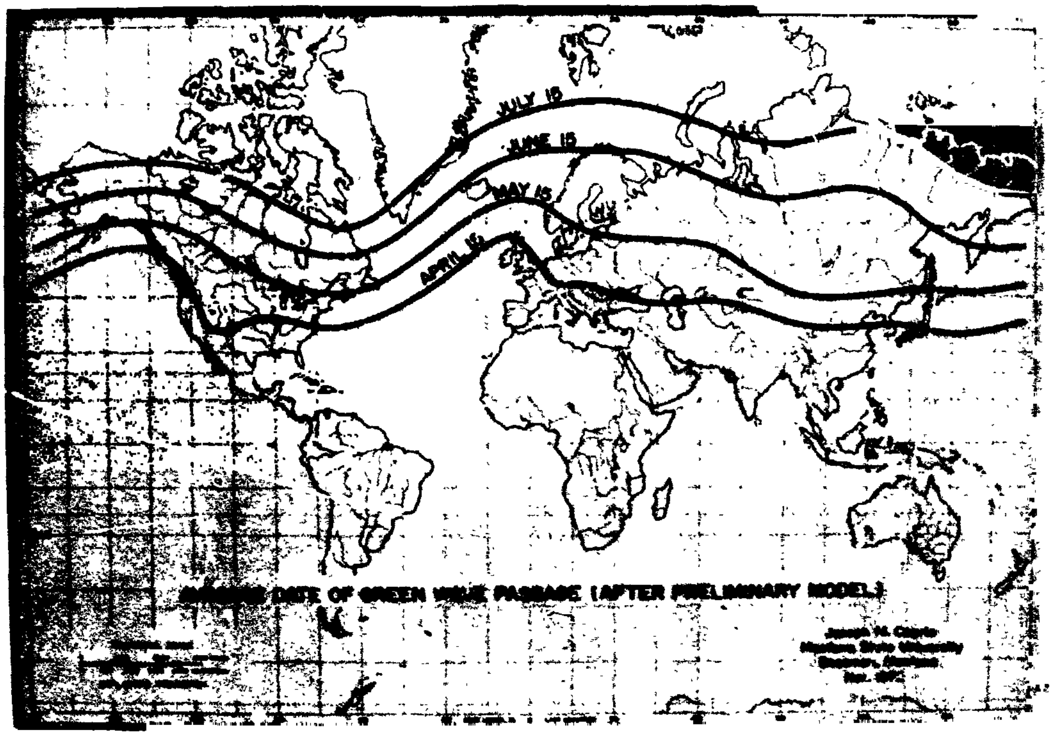

Figure 5. Average date of the Green Wave (greening of grass) passage in the northern hemosphere.

For countries with highly developed agriculture, such information would be useful in characterization of crop status, 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 accurate estimates of acreage and yield forecasts of many commodities. The means of disseminating the interpreted data 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.