Plant phenology in the western United States using the ERTS-1 satellite

by Charles Moncur Jones

A thesis submitted in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY in Crop and Soil Science
Montana State University

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Algorithms were developed to use the ERTS-1 data in specifying , greenness, foliage height or biomass, and species for certain crops (especially irrigated alfalfa, dryland winter wheat, and nonirrigated rangeland) in the test plots. Methods are presented to indicate feasibility of computer-assisted crop identification and inventory over broad areas by using satellite data.

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ABSTRACT

Methods are described for the detection of phenological events in Western United States (especially vegetation development - green wave, and vegetation senescence - brown wave) for certain crops using ERTS-1 data during 1972 and 1973. Multispectral scanner satellite data were used in conjunction with ground data collected at more than 30 test areas consisting of 3 subsites at each of the 10 main test sites.

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INTRODUCTION

As we continue to place greater demands on the earth's resources, it becomes increasingly important to inventory and understand the available plant resources. This investigation is mainly concerned with the productive cycle and time-distribution of plant life in the Western United States. However, the techniques described herein are readily adaptable for investigation of other earth resources.

The Earth Resources Technology Satellite (ERTS-1) data and some of the ground data for this investigation were collected in conjunction with the NASA-funded Phenology Satellite Experiment. Under contract number NAS5-21781, NASA funded the experiment to investigate the timing of the green wave's northward movement across the United States in springtime and the brown wave's southward movement in autumn. Also, techniques to monitor the general phenological status of the earth's surface on a broad scale were to be developed if possible.

A coordinated network of 24 ground observations sites was established to collect appropriate ground-truth data for comparison with the satellite data. Fourteen of these sites were in two "corridors" in the Eastern United States and ten sites (each having 3 sub-sites) were in two corridors in the Western United States.

Most of the information contained herein is related to the investigations in Western United States where information was collected for irrigated alfalfa, nonirrigated winter wheat, and nonirrigated rangeland. A few test plots also covered spring planted barley, conifer forests, and an irrigated range plot, but due to insufficient replication of these test plots the data were not analyzed as were the data from alfalfa, wheat, and range plots. The eastern corridors provided information mostly on deciduous forests.

As funded by NASA, the Phenology Satellite Experiment was a temporal study of plant properties and their associated spectral emissions. The broad aim of this investigation was to observe the temporal and geographical progression of the plant life cycle during the annual seasons in the United States by using ERTS-1 data.

Also reported herein are the efforts and results of attempts to use satellite data for the computer-assisted identification of crop species, inventory of crops by area, and determination of plant height or biomass.

REVIEW OF LITERATURE

Charles Morren, a Belgian botanist, appears to be one of the first to use the term "phenology". In 1853 he applied the term to that branch of science which studies the periodic phenomena in the plant and animal world insofar as they depend upon the climate of any locality. A complete definition of phenology may be hard to find, but W. P. Lowry (1972) calls it "the study of the time patterns associated with the developmental sequences of organisms". Daubenmire (1959) says "phenology embraces all studies of the relationships between climatic factors and periodic phenomena in organisms".

Phenological studies seemed to be popular in Europe before they became popular in the United States. Pioneering work in phenology was done by the Swedish naturalist, Carolus Linnaeus. His famous book Philosophia Botanica (Linnaeus 1751) suggested local phenological calendars and phenological networks in Sweden. F. Schnelle (1948) studied phenological records from a network located in Germany from 1936 to 1939 using rye as the principal indicator species.

One of the most notorious early American phenologists was A. D. Hopkins who published his famous Bioclimatic Law in 1918 and extended it in 1938 (Hopkins 1918, 1938). By the mid-1950's, J. M. Caprio had established an extensive phenological network in Western United States (Caprio 1966) which provided the impetus for new and expanded networks in the western, northcentral, and northeastern regions using clonally propagated plant material. These networks now cover 40 states and 5 Canadian Provinces with several thousand observation sites (Detheir, 1974, page 5).

In recent years the study of plant related phenological events has been done from several types of aircraft. By far the most popular means of recording these data has been by photographic methods. The most used forms have progressed through black and white film, color film, black and white infrared film, and color infrared film. Now the practice of recording these data via a multispectral scanner (MSS) has become popular and useful. Baumgardner (1970) explains the operation of multispectral scanners (MSS) from aircraft and spacecraft.

A four-channel multispectral recording system is described by Johnson, et. al. (1969) using four cameras, sensitive to blue, red, green, and infrared light. This instrumentation is roughly equivalent to a MSS system and is relatively inexpensive. For the cameras operating in the visible spectrum, a simple filter over the lens specifies the band of wavelengths being recorded.

More complicated and powerful MSS systems using various types of electronic and color enhancement on digitally recorded data are presented in Purdue University Research Bulletin 873 (Anonymous 1970). This publication also describes evaluations of data and computerized analysis techniques.

It has been difficult for many people to realize that MSS can provide information within the visible spectrum which the human eye can not detect. This stems from the separation of that spectrum into several discrete bands by MSS. In general, the more bands, the more information that can be detected. This approaches the principles of analytical spectroscopy.

The Phenology Satellite Experiment (sponsored by NASA) using ERTS-1 data was probably the first significant attempt at monitoring earth's plant phenology from a satellite (Dethier 1974). However, tremendous amounts of remote sensing data were available to indicate feasibility of the experiment before the satellite was lauched.

Immediately prior to the time ERTS-1 data became available for phenological studies and research, a comprehensive compilation of state-of-the-art remote sensing techniques was published in conjunction with a symposium presented by Forestry Remote Sensing Laboratory personnel from the University of California, Berkeley (Anonymous 1972a). Within this publication are "Basic Considerations of Remote Sensing" by R. N. Colwell, "Agricultural Land Use, Stereoscopy, and Manual Image Interpretation Techniques" by D. T. Lauer, and discussions of crop inventory, vigor, and yield analysis by W. C. Draeger. Colwell's paper (pages 17 and 19) suggests the use of multispectral tone signatures on photographic film for monitoring crop features:

Two-Band Signatures

Crop	Pan-25A Film (.58 to .72 microns)	IR-89B Film (.72 to .89 microns)
Hardwood trees	Dark	Light
Conifers	Dark	Dark

Four-Band Signatures

Crop	Pan-47B Film (.40 to .48)	Pan-61 Film (.47 to .61)	Pan-25A Film (.58 to .72)	IR-89B Film (.72 to .89)
Alfalfa:				
Healthy	Dark	Dark	Dark	Light
Unhealthy	Dark	Light	Very Light	Dark

Haas and Watson (1971) indicate applications of color IR for distinguishing species of woody plants. Their data were taken by aircraft flying at 4000 feet.

Prior to launch of the ERTS-1 from Lompoc, California on July 23, 1972, extensive plans were made for agricultural studies using satellite data (Anonymous 1972). Applegate (1972) indicates that some of the studies planned were the use of the satellite data to determine kinds of vegetables (by C. L. Wiegand, Weslaco, Texas) and yields of corn, milo, alfalfa and wheat (by V. I. Meyers, Remote Sensing Institute, Brookings, South Dakota).

Unfortunately, the three-channel "TV system" malfunctioned and only four bands of the multispectral scanner system were available for research.

Before the ERTS-1 was launched, about the only opportunity to remotely study the earth's surface from spacecraft was with data from weather satellites. Ormsby and Dethier (1970) published a bibliography mainly concerned with interpretation of clouds, but most of the satellite data and associated research done prior to 1970 are referenced therein.

Now that data from ERTS-1, ERTS-2, and Skylab are available, much agricultural research is being conducted with satellite data and related ground truth information. Some recent ground based investigations have provided information which should be valuable in making use of satellite data. Kanemasu (1974) agrees with Bowers and Hanks (1965) that longer wavelengths are more strongly reflected from green foliage. Kanemasu further reports % cover equations developed from his studies of reflectance at a height of 1.5 to 2 meters above a wheat test plot:

	R
% Cover = 109.88 x (ratio) - 63.71	.87
% Cover = 2.85 x (NIR) -19.24	.72

where (ratio) is approximately equivalent to the ratio of ERTS-1 $\frac{\text{Band 4}}{\text{Band 5}}$ and (NIR) represents near infrared reflectance. R is the correlation coefficient. He concluded that "reflectance ratio alone does not discriminate between crop species, but should be a valuable parameter when used with other recognition processes".

Gausman, Allen, Cardenas, and Richardson (1973) found that "increasing leaf age of corn within four growth stages had little effect on near infrared (.75 to 1.35 microns) reflectance whereas mature leaves of cotton had higher near IR light reflectance than young leaves".

Caprio (1973) published a preliminary model of the green wave timing for the world by using meteorological data and his Solar Thermal Unit Theory. This and his other worldwide maps (Caprio 1974) should be valuable in correlating specific satellite phenology studies with good truth for use on a worldwide basis.

Since ERTS-1 data have become available, several publications have appeared which actually make satellite data useful for phenological observations. The most comprehensive of these is the Phenology Satellite Experiment Final Report (Dethier 1974) which includes studies in Eastern and Western United States. Carlson and Fenton (1975) have shown how ERTS-1 data have been useful in determining Iowa's agricultural resources. Carneggie, Degloria, and Colwell (1974) have indicated usefulness of ERTS-1 and aircraft data to monitor California's pasturelands. Wiegand, Richardson, Gerbermann, Gausman, and Cuellar (1975) have developed a reflectance model relating reflectance to proportions of ground area covered by vegetation, exposed to sun, and occupied by plant shadows, for use with ERTS data.

Some of the studies referenced above have described how ERTS data can provide practical information. Hopefully, this study will make a significant contribution to encourage practical applications of phenology using satellite data.

MATERIALS AND DATA ACQUISITION

Satellite Data

The ERTS-1 satellite data available for use in accomplishing the objectives stated previously were as follows:

> Four discrete bands of electromagnetic radiation within the visible and near infrared spectrum were collected by the satellite's multispectral scanner (MSS) and relayed via the data distribution system to various users (Anonymous 1971).
>
> Band 4: .5 to .6 microns wavelength - covers most greens and all yellows
>
> Band 5: .6 to .7 microns wavelength - covers most oranges, all reds, and some very near infra-reds
>
> Band 6: .7 to .8 microns wavelength - covers near infrareds
>
> Band 7: .8 to 1.1 microns wavelength - covers near infrareds
>
> (Bands coded 1, 2, and 3 were assigned to a system which malfunctioned on ERTS-1).

The data from the four bands is first recorded in digital form (discrete steps) on a magnetic tape aboard the satellite. At appropriate intervals the data are then transmitted to earth stations and recorded on computer compatible tapes (still in digital form) for distribution to users.

Each of the sensors for the four bands provides a maximum of 128 voltage levels to represent the full range of reflected energy in each band. Therefore, users of the data cannot expect to receive smooth (analog) transitions from one intensity level to another, such as the eye or a photograph might simulate. However, the discrete intensity levels are displayed and distributed in a simulated analog system as photo transparencies.

This simulated photographic image is created by causing a computer to provide the appropriate intensity levels to a cathode ray tube (like a black and white television tube) as its control circuits scanned rapidly across the face of the tube. (This method of display might be called "digital TV".) A photograph is taken of each displayed image for distribution to users. Figures 1, 2, 3, and 4 are prints of typical transparencies from bands 4, 5, 6, and 7 of the satellite, respectively.

Thus, all data recorded by the satellite multispectral scanner (MSS) are available from NASA as either magnetic tape recorded digital data or as photo transparencies of those data displayed to form an "apparent" photo-image. Each transparency (available in 70 mm or 9.5 inch size) of the data from a single MSS sensor covers an earth area approximately 100 nautical miles square. In addition to the above output products, the NASA Data Processing Facility (NDPF) also