The Role of Terrestrial Vegetation in the Global Carbon Cycle:
Measurement by Remote Sensing
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CHAPTER 7
Coupling Remotely Sensed Data to Ground Observations

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ABSTRACT

Remote sensing is increasingly employed by those interested in mapping landscapes. Data received by the remote sensor, in this case LANDSAT, are not perfectly correlated with the land. No map is 100 per cent accurate. Sequential imagery and use of ratios of one band to another have been shown to improve accuracy greatly. An example is offered of an approach that might be used to examine changes in vegetation globally.

7.1 INTRODUCTION

Colwell (1956) published the first reports of an important non-military use of colour infra-red film, he found that black stem rust of wheat and yellow dwarf virus disease ih oats could be detected before symptoms were visible to the unaided eye. One might have expected this report to have caused rejoicing among phytopathologists, but initial pleasure yielded to a decade of debate on why the technique worked. No satisfactory explanation based on a biotic mechanism was offered. The scientific community was reluctant to accept without further evidence that the correlation between the image and the disease constituted effective prediction. However, the popular press and semi-technical journals published many articles on the identification of disease using remotely sensed imagery.

More than 10 years later Gausman and others (1969, 1971) explained the phenomenon. They showed that differences in intracellular water pressure and intercellular air spaces were responsible for near infra-red reflectance; rather than identifying disease *per se*, Colwell's film had detected loss of cell turgor. The coupling of the imagery to the disease required another, more difficult step based on additional information. The correlation between the observation and the cause in this case proved to be correct, but such inferences based on data from remote sensing may be misleading.

After 1956 there was a gradual evolution in remote sensing from qualitative recognition to what might be called an enumeration phase of measuring features of the landscape. One can think of the former phase as exploration, the latter as mapping.

7.2 THE MAPPING PHASE

However, mapping is not a simple transformation of data from remote sensing. Clients of photogrammetry frequently expect, unrealistically, a perfect correlation between the data derived from remote sensing and ground observations. Several factors complicate this correlation:

(1) Measurements made remotely are by definition the response of the target through the atmosphere.
(2) Precision is limited by the accuracy of the instrument and its resolving power.
(3) In most situations it is not possible to resolve pure target material, i.e., one can not see plants in a garden without seeing the soil.
(4) The time of day and season influence the target and the radiant energy directed twoards the sensor.

These general limitations govern remote sensing analyses as follows:

1. The difference between the identification of features and the discrimination of features is of paramount importance. Given the current state of technology, the identification of features is not performed by an objective analysis of the measurements made by the sensor. Rather, the identification process occurs either because the shape of the feature, or the 'colour' of the feature, or both, are unique and within the experience of the image analyst. (The term 'colour' includes the spectral response of the feature whether or not it is in the visible portion of the electromagnetic spectrum.) Discrimination, on the other hand, occurs solely because the 'colour' of different features is, in fact, different. For this case the analyst may not and usually does not know the identity of the discriminant. Identification occurs only after a field survey. Conventionally, this survey is done by the analyst but in some cases it may be provided as collateral data in the form of reports and/or photographic interpretation keys.

2. Once the identification process has been accepted, the matter of accuracy remains. If the parameters involved in the acquisition phase are examined, it becomes clear that 100 per cent accuracy is never achievable. Although there are some features for which remote sensing technology can approach 100 per cent (i.e., bare soil, green vegetation, water) within these classes there will be a

finite range of values for each class and a probability for error associated with each range of values.

These comments apply to all maps. No map is 100 per cent accurate, and no inventory or survey or even sample taken during the course of a survey is free of error. Remote sensing has one important advantage over every other survey technique; it can and does enumerate the entire population. This enumeration merely reduces the errors, it does not eliminate them. The limitation is caused by the heterogeneous nature of those features that we consider to be members of the same population. There is, for example, a large but finite range of sizes and shapes and colours of those species of trees we class as deciduous or coniferous. Even if we only include a single species in our class, for example, wheat, the statement is still true. In fact, if one examines a taxonomic text from the statistical point of view, one finds that the descriptive approach follows the familiar bell-shaped Gaussian curve.

Fortunately, the data behave according to conventional statistical principles and the accuracy of the survey or inventory with and without field work can be determined. In addition, one can employ statistical methods to calculate the improvements one can derive from additional sampling (i.e., field verification) versus the cost of the improvement. It must be remembered that the potential accuracy can only be estimated from experience with data drawn from similar populations. For example, if an analysis of LANDSAT data has been performed in one portion of a large ecosystem (the grasslands) one can reasonably expect to get similar results in another part of the same ecosystem providing the analysis is performed at the same time.

7.3 INTERPRETATION OF IMAGERY

Two simple rules help in interpreting remotely sensed imagery: (1) work with ecosystems, and (2) recognize the importance of the date of the image and the possibility of comparing images from different times. The utility of these rules becomes apparent from a consideration of the radiometric properties of the LANDSAT-D Thematic Mapper (Table 7.1) and the response of the mapper to vegetation (Table 7.2).

Different species of plants vary little in responses and the possibilities for separating species in one image seem limited. But when images at different times are available, considerably more information can be used. Band ratios when compared over time give information descriptive of the age, condition, health of the plant, or of canopy density relative to the background from soils, become useful in identifying species or communities. Interpretation of the data in the context of a phenological model is thus critical in the process of interpretation.

For most crop plants, three observations at different times are usually required to identify the species; a fourth may be required to make some of the

Table 7.1 Radiometer characteristics for the thematic mapper

Band	Spectral width (μm)	Dynamic range (mw/cm^2-ster)	Low level input (mw/cm^2-ster)	S/N′
1	0.45–0.52	0–1.00	0.28	32
2	0.52–0.60	0–2.33	0.24	35
3	0.63–0.69	0–1.35	0.13	26
4	0.76–0.90	0–3.00	0.16	32
5	1.55–1.75	0–0.60	0.08	13
6	2.08–2.35	0–0.43	0.03	5
7	10.40–12.50	260 °K–320 °K	300 °K	0.5 °K (Net D)

Absolute chennel accuracy < 10 per cent of full scale.
Band to band relative accuracy < 2 per cent of full scale.
Channel to channel accuracy < 0.25 per cent rms of specified noise levels.
S/N′ = signal to noise ratio.

Table 7.2 Thematic mapper spectral and radiometric characteristics

Band	Wavelength	NE$\Delta\rho$	Basic primary rationale for vegetation
TM 1	0.45–0.52	0.008	Sensitivity to chlorophyll and carotenoid concentrations
TM 2	0.52–0.60	0.005	Slight sensitivity to chlorophyll plus green region characteristics
TM 3	0.63–0.69	0.005	Sensitivity to chlorophyll
TM 4	0.76–0.90	0.005	Sensitivity to vegetational density or biomass
TM 5	1.55–1.75	0.01	Sensitivity to water in plant leaves
TM 6	2.08–2.35	0.024	Sensitivity to water in plant leaves
TM 7	10.4–12.5	0.5 °K	Thermal properties

NE$\Delta\rho$ = noise equivalent reflectance difference.

more difficult separations. In the LACIE project (see Erickson, this volume), which developed techniques for predicting world wheat production, there was an absolute requirement of a series of three or four observations over the season.

Recent studies by Park have shown that information on the stage of growth of crops can be derived from repetitive observations using ratios of one band to another. The bands are plotted as vectors (Figure 7.1(a)–(f)). Results showed that the ratios of bands 4/5 compared with 6/5 crossed very shortly after emergence of the crop. At harvest there was another cross over. Careful use of the ratios with knowledge of the phenology enabled identification of the following stages of growth in corn on the satellite imagery:

(1) Preplanting (bare soil)
(2) Emergence

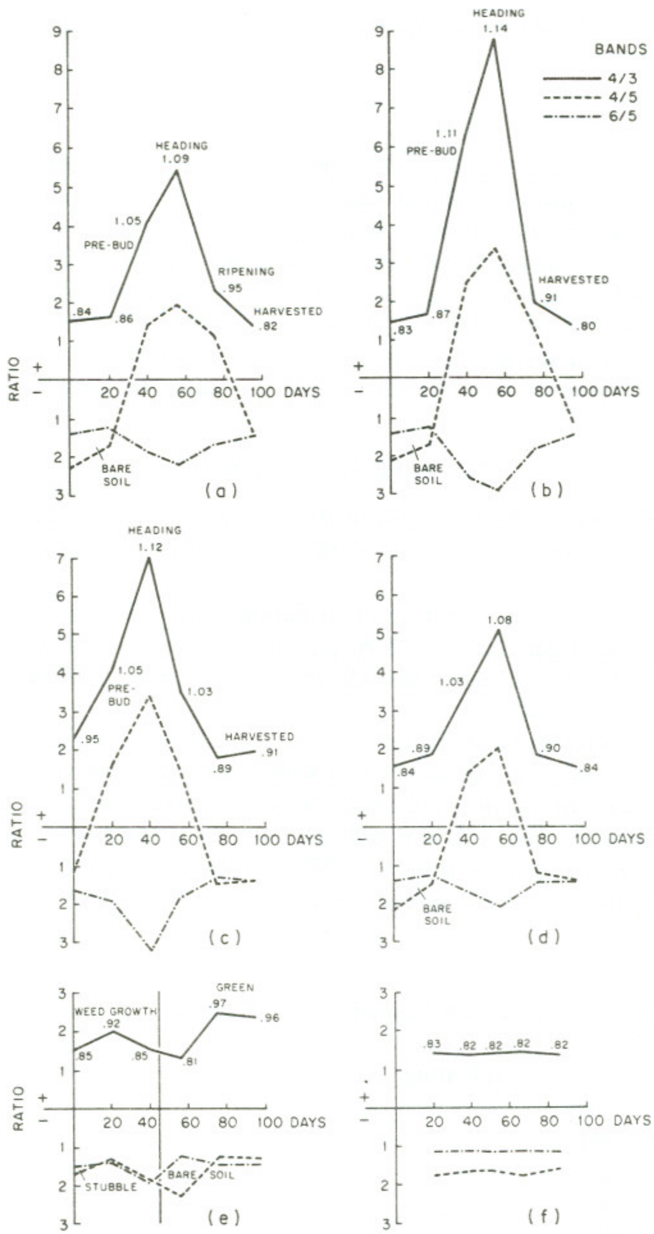

Figure 7.1 Ratios of airborne spectrometer measurements, simulating multispectral scanner (MSS) bands from LANDSAT 4 (thematic mapper), plotted as vectors over time: (a) spring wheat; (b) barley; (c) alfalfa; (d) oats; (e) corn; (f) bare soil ((a)–(e) Hand County, South Dakota; (f) Williston County, North Dakota). These ratios may be used to identify stages of plant development

(3) Booting or prebud (preheading)
(4) Heading
(5) Ripening
(6) Harvest (post-harvest)

Knowledge of phenology is vitally important in interpretation, and use of the knowledge requires sequential imagery. The most important advantage that LANDSAT and other satellite imagery offers over other types of remote sensing is that global measurements can be made repetitively. Most of the experience with vegetation has been developed in attempts to estimate agricultural productivity. In this work the satellite imagery is used in conjunction with a model that estimates yield of the crop on the basis of meteorological data, information from the satellite and other sources.

7.4 SITE SELECTION

The first consideration in the design of the programme is the selection of the area to be represented by each cell of the grid. There are several important criteria.

First, the scale must be determined. If national statistics are required, the grid cells can be larger than would be possible if regional or provincial data are sought. Reducing the size of the cells increases the number of cells and the homogeneity among cells.

Second, the complexity of the terrain must be estimated. If the crop grows under a wide range of conditions and is widespread, cell size can be large. If the crop grows only under a narrow range of conditions or is managed intensively, as is the case with rice, cell size must be reduced. The decision on cell size can be made readily from a LANDSAT mosaic of the country.

After a decision is made on size, each cell must contain the following descriptors:

(1) Area of the crop
(2) Number of crops harvested and rotation practices
(3) Crop calendar
    (a) Planting or transplanting
    (b) Emergence
    (c) Flowering
    (d) Heading
    (e) Ripening
    (f) Harvest
(4) Crop varieties
(5) Potential yield

    Because it is possible to model the potential yield in more than one way, it is useful to store historical yield data as follows:

(a) Minimum
(b) Maximum
(c) Mean

(6) Cultivation practices
(7) Fertilizer
(8) Plant pests

Commonly, a visual report will be used to start a review of remotely sensed imagery to:

(a) Confirm the event
(b) Determine the area affected
(c) Note the presence of additional susceptible species
(d) Confirm the stage of growth predicted by the yield model, and
(e) Estimate the effects

(9) Soil
(10) Meteorological data
(11) Terrain model

7.5 APPLICATION OF LANDSAT DATA

The design of the data base for a field crop is shown in Figure 7.2 in graphic form. This model, with its global data base and emphasis on crops, is an example of one potential approach to monitoring the role of vegetation in the carbon cycle. Important work is also possible at the other end of the scale; the desertification process. A number of researchers are using LANDSAT data to study local effects. Robinove and Chavez (1978) have developed an important process of coupling vegetated areas of the earth with adequate spatial resolution. With Robinove and Chavez's approach, atmospheric and sun elevation corrections are applied with no ancillary data required. Trends in the change of albedo (indications of the darkening or lightening of the terrain) form the basis of a monitoring scheme in arid and semi-arid regions. Such variations can be the result of changes in the density or type of vegetation, changes in the area of bare ground, or changes in the distribution of wind-blown material. Slight snow or cloud cover in a full scene does not significantly affect the mean albedo of large areas. The ease of the method recommends it for widespread use and further experimentation.

Robinove and Chavez's work is a good example of the modelling required to couple LANDSAT data to a very slowly changing surface phenomenon. The coupling involved the calibration of the albedo measurements in terms of vegetation trends. Their work is also a good example of a principle now accepted by the various disciplines; ground observation programmes suffer without LANDSAT data to show investigators where to make surface observations and measurements.

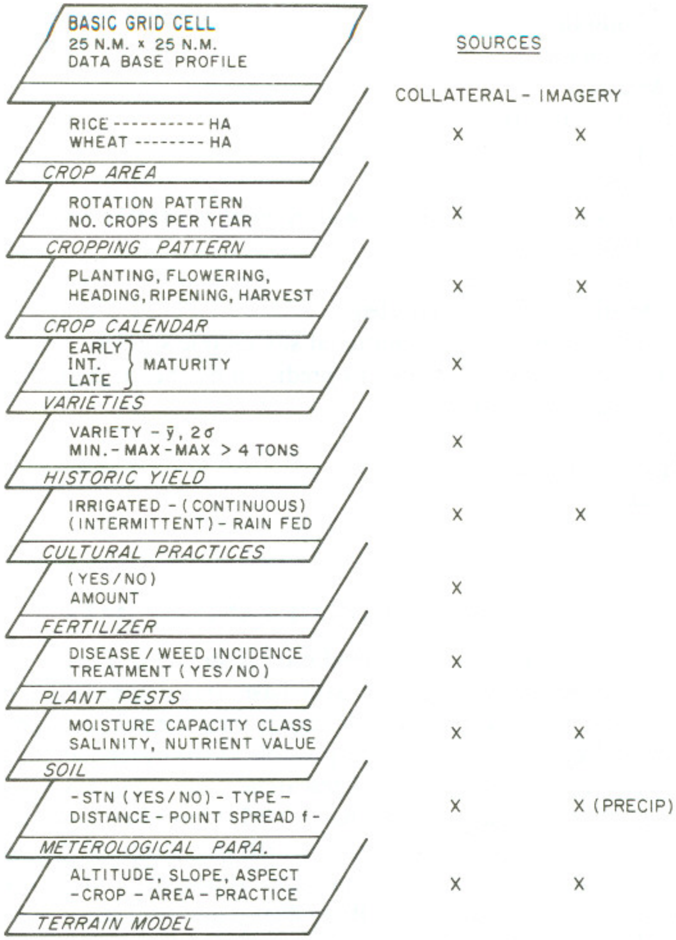

Figure 7.2 Data-base designed for on-line support of phenology and yield models of field crops

7.6 SUMMARY

The coupling of remote sensing data with ground observations is accomplished by an appropriately trained scientist. This is particularly true for the enumerative mapping function, in which the image is transformed into a map of the terrain. Field trips may or may not be required. As one proceeds from mapping to monitoring dynamic features of the terrain, such as vegetation and water resources, extensive use is made of models. In most cases the pixel radiance values become coefficients in an equation which measures some attribute of plant condition other than the area it covers. Most applications which are operationally oriented are supported by a geo-referenced data base. Here, however, the data are transformed into resource management decisions.

7.7 REFERENCES

Colwell, R. N. (1956) Determining the prevalence of certain cereal crop diseases by means of aerial photography. *Hilgardia*, **26**, 223–286.

Gausman, H. W., Allen, W. A., and Cardenas, R. (1969) Reflectance of cotton leaves and their structure. *Remote Sensing of Environment*, **1**, 19–22.

Gausman, H. W., Allen, W. A., Wiegand, C. L., Escobar, D. E., Rodriquez, R. R., and Richardson, A. J. (1971b) The leaf mesophylls of twenty crops, their eight spectra, and optical and geometrical parameters. *SW C Res. Report 423*. 88 pp.

Keegan, H. J., Schleter, J. C., Hall, Jr., W. A., and Haas, G. M. (1956) Spectrophotometric and colorimetric study of diseased and rust resisting cereal crops. *National Bureau of Standards Report 4591*.

Park, A. B. (1978) Multispectral temporal analyses. *IR&D Report*. 54 pp.

Robinove, C. J., and Chavez, Jr., P. S. (1978) LANDSAT albedo monitoring method for an arid region. AAAS International Arid Lands Conference on Plant Resources, Lubbock, Texas.

Tucker, C. J. (1978) A comparison of satellite sensor bands for vegetation monitoring. *Photogrammetric Engineering and Remote Sensing*, **44**(11), 1369–1380.

Wiegand, C. L., Gausman, H. W., and Allen, W. A. (1972) Physiological factors and optical parameters as bases of vegetation discrimination and stress analysis. *Proceedings, Seminar on Operational Remote Sensing*, American Society of Photogrammetry. 341 pp.