LARS Print 120371

NTIS HC $3.00

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(NASA-CR-130020) THE IMPORTANCE OF GROUND TRUTH DATA IN REMOTE SENSING (Purdue Univ.) 13 p HC $3.00 CSCL 14E
N73-16495
Unclas
G3/14 53823

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THE IMPORTANCE OF "GROUND TRUTH" DATA IN REMOTE SENSING[1]

by

Roger M. Hoffer[2]

With the advent of satellites and the opportunity to obtain synoptic data at frequent intervals, there had been tremendous interest in a new technology called "remote sensing." Remote sensing is concerned with the acquisition of information about a portion of the earth's surface by using sensing devices operated from a remote location. A more complete definition could describe remote sensing as "the science involved with the gathering of data about the earth's surface or near surface environment, through the use of a variety of sensor systems that are usually borne by aircraft or spacecraft, and the processing of these data into information useful for the understanding and managing of man's environment." (Hoffer, 1971). Remote sensing is, in part, an extension of aerial photo interpretation, but can also involve many different instrument systems and analysis techniques, many of which are much more quantitative than past capabilities would allow.

The most common technique for gathering remote sensing data involves photographic systems, which can be used with many combinations of films and filters. Photographic systems have many advantages, but photographic films are sensitive only to energy from a limited portion of the electromagnetic spectrum (Fig. 1). It is known that valuable information concerning the thermal characteristics (temperature and emissivity) and the reflectance characteristics of vegetation, soil, and water can be obtained in the longer wavelengths, or lower frequencies. To obtain data in these wavelengths, optical-mechanical scanners and radar are the systems most frequently utilized.

In order to properly interpret data from scanner or radar systems, or even some of the photographic systems available, the user

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[1] Paper presented at the "United Nations Panel Meeting on the Establishment and Implementation of Research Programs in Remote Sensing," held at the National Institute for Space Research, São José dos Campos, S. P., Brazil, from Nov. 29-Dec. 10, 1971; printed in *Aerofotogeografia*, No. 7, Instituto de Geografia, Universidade de São Paulo, São Paulo, Brazil.

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must be knowledgeable about the energy - matter interactions taking place between (1) the vegetation, soil, water, or other material on the surface of the earth, and (2) the energy being reflected, absorbed, transmitted, scattered, or emitted by those materials. Knowledge of these energy - matter interactions allow the spectral characteristics of the materials to be predicted and the remote sensor imagery to be accurately interpreted.

Much of the data collected by various remote sensor systems is dependent upon spectral variations to delineate the features of interest. Differences in color on color infrared photography, for example, is an indication of spectral differences among the cover types of interest. Such spectral variations become extremely important in nearly every type of remote sensing research. In remote sensing research involving vegetation, we are frequently interested in one or more of three problem areas:

1. To delineate, identify, and map various species (i.e. floristic mapping).
2. To delineate, identify, and map vegetative groupings having different physical characteristics (i.e. physiognomic mapping).
3. To detect, identify, and map various types of vegetative stress conditions (e.g. stress caused by diseases, insects, lack of available soil moisture, fertility, pollutants in the air or water, etc.).

No matter which of these problems is involved, one finds that there is frequently a great deal of spectral variability within the vegetative group of interest. For example, if you are working on species mapping involving corn, you will find that not all fields of corn have the same spectral response. Consequently, the researcher must become knowledgeable about these causes for spectral variability within the species or condition of interest, so that the data can be more accurately interpreted. This type of study, as well as many others, will therefore require that detailed "ground truth" data be obtained.

"Ground truth" involves the collection of measurements and observations about the type, size, condition and any other physical or chemical properties believed to be of importance concerning the materials on the earth's surface that are being sensed remotely. Lately the term "ground truth" has fallen into disfavor, for several reasons. Sometimes, errors in data collection have caused "ground truth" to be false data, and also there are often so many variables involved that one wonders what the "truth" of the situation really is. Also, if you are obtaining data through interpretation of large scale photos collected from the air, or if you are obtaining measurements

measurements of the temperature of a water body, should such data really be referred to as "ground truth"? Therefore, it seems more logicial to call such procedures "surface observations", or some similar term to refer to the collection of data about the materials on or near the earth's surface.

Regardless of the name used, the type of data collected and the procedures involved in the collection of "surface observations" must be carefully defined in order to meet the objectives of the project. For example, if one is interested in identification of crop species, detailed information concerning the micrometeorological conditions within the crop canopy are not needed. However, if one was interested in the use of thermal infrared systems for disease detection, such data could be essential. If one is working with remote sensing instruments such as photographic systems that operate only in the reflective portion of the spectrum, soil moisture information might be required for the soil surface, but soil moisture measurements throughout the profile would be of much less importance (except as they influenced the surface soil situation). Thus, there does not appear to be a single answer to the question as to exactly what type of surface observations are required. We can only say that the type of ground observation data required must be closely related to the objectives of the research and the problems involved.

In our work at the Laboratory for Applications of Remote Sensing (LARS), at Purdue University, we found that one approach which seemed quite effective in determining the types of surface observations required was to obtain remote sensor data over areas where complete and detailed records concerning the vegetative characteristics and conditions were available, such as an agricultural experiment station. In much of the work at LARS, we have been involved with the mapping of agricultural species. Yet we have found great variation in spectral response within many species, as well as between species. It became apparent that we need to become more knowledgeable about the causes of spectral variability within the various species so that we could be more certain of the capability to reliably separate the different species.

Photographic and multispectral scanner data were obtained at different altitudes over the Purdue Agronomy Farm and also over selected test sites near Lafayette. We identified the various species and collected additional data on easily observed physical parameters, such as row width, row direction, height of the crop, as well as a general description of crop appearance and condition. Complete descriptions and data records were also obtained from a selected group of agronomists who had experimental plots of particular interest on the Agronomy Farm. With this data available, we proceeded to interpret the remote sensor data, and to identify those parameters which caused spectral variations within species, as well as to assess the reliability of differentiation between species. When we found spectral variations within a species, we would form a hypothesis as to probable cause, and then check with the agronomists in charge of those plots to be sure there were no other probable explanations for such differences. Frequently, because our own ground observations had been minimal, we would see distinct spectral differences on the imagery but had no data with which to explain such variations, so we would have to obtain data and records for those particular plots from the appropriate agronomist or farmer. This procedure proved quite efficient, in that we could confine our collection of detailed data to those particular areas of interest. Of course, if we had not been working primarily on the Agronomy Farm, where very detailed and precise records were available, this procedure of collection of ground data after the flight mission would not have been successful.

Our results indicated a large number of causes for spectral variation within species, as well as between species. I have summarized these causes of spectral differences as follows:

1. Variations in the amount of ground cover, caused by differences in soil type, soil moisture, planting date, uneven germination, and disease or insect conditions which resulted in small, stunted plants. Of course data collected at different times during the growing season often had differences in the amount of ground cover.

2. Variations in maturity, caused by differences in variety, planting date, soil types, or soil moisture conditions.

3. Differences in cultural practices, such as variations in amount and type of fertilizer (particularly at the low fertility levels), harvesting date and method, and planting procedures which caused differences in crop geometry.

4. Diseases, moisture stress, and insect infestations which would cause changes in the reflection and emission characteristics of the plants. Such stress conditions also can cause distinct variations in the amount of ground cover and crop geometry, thereby accentuating the changes in reflection and emission from the plants themselves.

5. Geometric configuration of the crop, such as differences in row width, row direction, and lodging (blowing down) of the plants.

6. Environmental variables, such as atmospheric conditions, wind, angle of reflection in relation to the angle of solar incidence, and soil moisture conditions as affected by the amount of previous rainfall, as well as the length of time and weather conditions since the last rainfall.

Since we were able to define the causes of spectral variations as a result of this study, we could then determine the parameters of most importance to consider in collecting surface observation data. We found that two major categories of surface observation could be defined:

A. Those data obtainable by looking at or measuring the parameter of interest (e.g. row direction, row width, wind conditions, insect infestations, dieseases, etc.).

B. Those data which could only be obtained through direct contact with the farmer or agronomist, to identify those causes of spectral variations which could not be directly observed or measured (e.g. variety of seed planted, date of planting, harvesting date, fertilization practices, etc.).

It was found that some of the data that could be obtained directly by observation or measurement (such as row direction or row width), and nearly all of the data obtained indirectly from the agronomist or farmer could be obtained most any time, and such data did not have to be obtained at the time of overflights by the aircraft. However, other types of data (such as crop or soil moisture and temperature measurements, observations on condition of the crop, etc.) had to be obtained as close to the time of overflight as possible. In many cases, a delay in data collection of a day or two could cause serious errors in interpretation of the imagery. In some of our more recent work involving temperature studies of water bodies, differences in time of even two hours between collection of temperature data on the surface of the water and the overflight with the thermal infrared scanner were critical. Thus, again, the type of ground observation data to be collected and the methodology used is heavily dependent upon the specific objectives of that research project, as well as the conditions or situation involved.

I firmly believe that one of the most important aspects of remote sensing research involves the planning and determination of the type of surface observation data to be obtained, when the data is to be obtained, and the method of obtaining these data. This phase of planning for a remote sensing mission is extremely critical. The time during the growing season when the flight mission is conducted is very important since the spectral characteristics of the materials of interest change as a function of time. Such changes, either diurnal or seasonal, are often referred to as "temporal" changes.

The three primary types of measurements which one can obtain with remote sensor systems involve

.spectral,
.spatial, and
.temporal data.

Because the temporal aspects of data collection are of such great importance, information concerning the annual growing cycle of the various crops or cover types of interest and the appearance of these crops at each phase of this growing cycle is essential. Such information will allow the user of remote sensor data to schedule flight missions much more effectively than might otherwise be the case. There may be certain times during the year when it would be rather easy to identify a certain crop species, and other times when identification of the same species would be extremely difficult. For example, we found that even though corn and soybeans are completely different in appearance, they are spectrally quite similar at some times of the year, but different at other times. Thus, there are periods of several weeks early in the growing season when it is difficult to reliably separate these crops, using very small scale photography or scanner data where only spectral differences are utilized. Later in the season after the corn has tassled or when differences in the condition of senescence have appeared, the species can be readily separated. It becomes very important for people working in remote sensing to be knowledgeable about these seasonal changes and the spectral response associated with such changes. It is also apparent that one must be familiar not only with the particular crop species of interest, but also with the phenology of other associated crops that could be confused with the species of interest.

Another aspect of remote sensing research that should be stressed is that a variety of sensor systems should be utilized, and at various altitudes above the ground. Different sensor systems such as photographic, scanner, or radar each have certain advantages as well as disadvantages. We should not let ourselves be overly concerned with which systems is "best", but rather we should strive to determine how to utilize the various systems in combination so as to optimize the advantages of each instrument system involved.

Similarly, remote sensing data should be collected from a variety of altitudes above the ground (Fig. 2). Satellites and aircraft systems both have certain advantages of each system, both in our research efforts and as operational systems are developed. In addition, remote sensing research can somtimes be carried out very effectively and economically at altitudes below those of an aircraft. At LARS, we have found that portable lift trucks as illustrated in Fig. 2 can be utilized extremely effectively to collect surface observation data and to study small, well-known situations on a frequent time interval, whereas aircraft would be rather expensive and somewhat ineffective in these situations. For example, such studies could involve the effect of a certain plant disease on the change in reflectance of the crop over time, or the effect of changes in soil moisture on soil plant reflectance or emittance. Such field studies might ideally involve field spectrophotometers capable of rapidly obtaining accurate measurements of the spectral characteristics of the materials of interest, but experience has shown that few such instruments exist and they are relatively expensive. However, many very worthwhile studies can and should be carried out from low altitudes with simple camera systems, such as 35 mm cameras and a variety of film-filter combinations similar to those planned for aircraft flights. For example, using the plant disease situation again, one could conduct some preliminary studies at a very low cost to determine which film-filter combination seemed to be best to detect the diseased plants. This information could then be applied to the aircraft data collection.

Since we often utilize rather complex instrument systems in obtaining our surface observation data and in conducting many other aspects of our remote sensing research, we have found that a strong team of scientists and engineers is essential. There must be people who can work closely together with mutual respect and understanding. For example, a life scientist may be very knowledgeable about the pigmentation characteristics of plants, but might not be familiar with the field instrumentation with which to examine the spectral reflectance of the plants, while an electrical engineer might be just the reverse. Together, they could make the type of powerful, dynamic team that is required in remote sensing research - a team that can effectively utilize various instrumentation systems to examine the biological and physical components of our environment, and relate such studies to remotely sensed measurements.

Summary and Conclusions

Experience has shown that the collection of "ground truth" or surface observation data is an essential part of remote sensing research. The exact type of ground observation data collected depends upon the objectives of the particular research problem involved. In some cases large scale, good quality aerial photographs might be the optimal type of surface observation data, whereas other situations might require large quantitites of detailed field measurements utilizing a variety of instrument systems. One of the most important aspects of remote sensing research takes place prior to a flight mission, and involves the planning to determine the type of surface observations to be obtained, when they are to be obtained, and the methods to be used in collecting the data.

Temporal information, involving changes in spectral responses as a function of time, is an extremely valuable type of surface observation data, in addition to the many other surface observations which are also necessary. Temporal data is particularly important in effective planning for flight missions.

Observations and data collection, utilizing various sensor systems, can be obtained at different altitudes above the ground. We have found that a portable lift truck allows the researcher to effectively observe and measure the ground cover from above, using the same viewing angle as the aircraft instrumentation, but from only 17 meters above the ground. This has proven to be a very effective method for collecting various types of data about the characteristics and conditions of the ground cover.

It has also been the experience of LARS that because we are working on remote sensing research involving the natural environment--vegetation, soils, water, weather, etc.--and since we are utilizing a variety of rather complex instrumentation in obtaining our surface observations and conducting our data analyses, it has been essential that our research be conducted jointly by a team of biological and physical scientists and electrical engineers. This team approach allows us to effectively study the energy - matter interactions taking place in the natural environment, thereby enabling us to more accurately interpret remote sensor data.

Although there is much to be learned concerning remote sensing systems and techniques for effectively utilizing these systems, great progress has been achieved during the past decade. There are various remote sensing systems being utilized on an operational basis in several locations around the world today, and the potential for remote sensing in the future appears to be almost unlimited.

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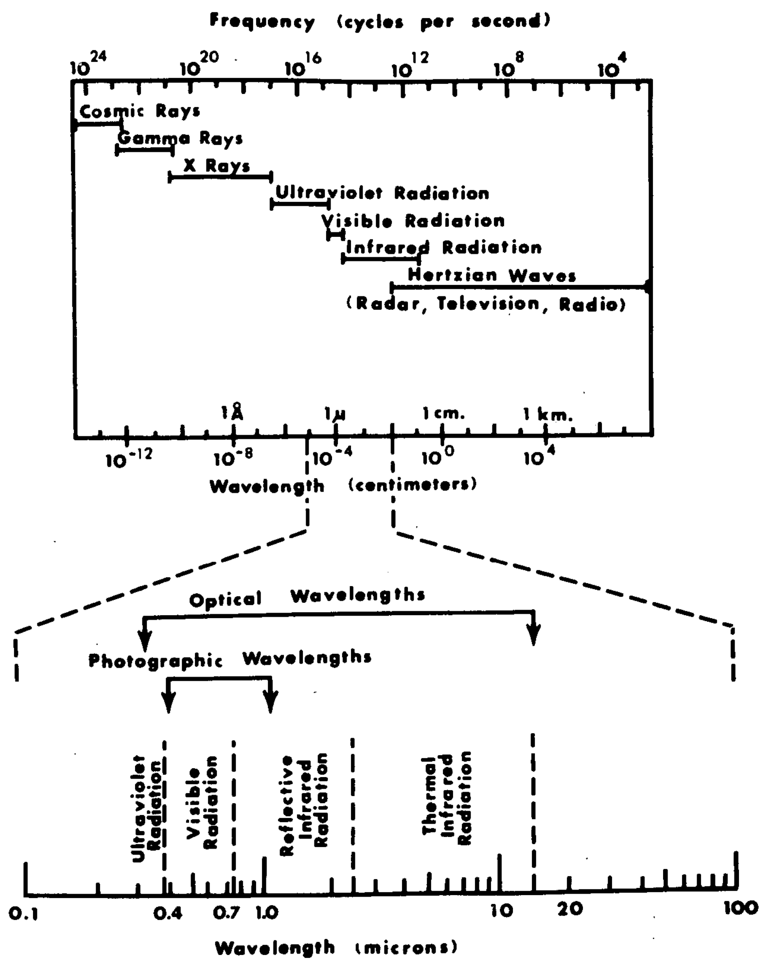

Figure 1. The electromagnetic spectrum. Note the relatively small range of wavelengths to which our eyes are sensitive.

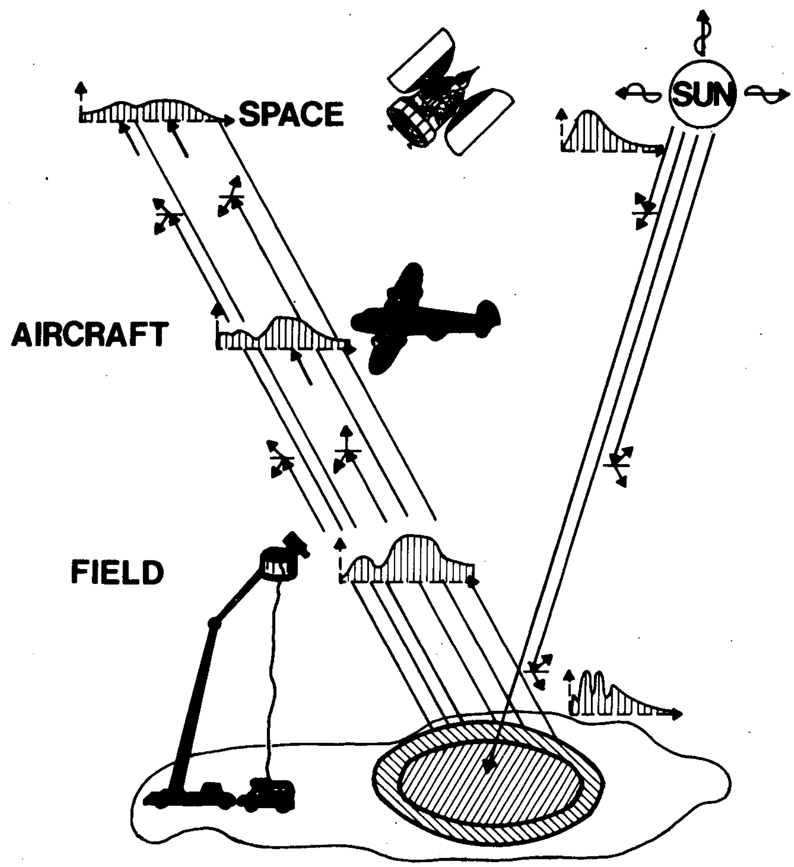

Figure 2. Multiple Levels of Research in Remote Sensing. Detailed field and laboratory studies on the spectral characteristics of materials of interest is extremely important in order to more accurately interpret the remote sensor imagery from aircraft and spacecraft.