ENVIRONMENTAL MONITORING

FROM AIRCRAFT AND SPACECRAFT

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INTRODUCTION

The problem of pollution and the need for preventive methods on a global scale is fast becoming one of the greatest problems man has had to face on this planet.

President Nixon in his 1970 Environmental Message to the Congress of the United States summarized the situation as follows:

> "The basic causes of our environmental troubles are complex and deeply imbedded. They include: our past tendency to emphasize quantitative growth at the expense of qualitative growth; the failure of our economy to provide full accounting for the social costs of environmental pollution; the failure to take environmental factors into account as a normal and necessary part of our planning and decision making; the inadequacy of our institutions for dealing with problems that cut across traditional political boundaries; our dependence on conveniences, without regard for their impact on the environment; and more fundamentally, our failure to perceive the environment as a totality and to understand and to recognize the fundamental interdependence of all its parts, including man himself."

Today we hear such key words as pollution, environment, environmental quality, natural resources, endangered species, etc. Quite often these words are all combined under the term ecology, meaning the science of the relationships of a living organism and his living and non-living environment. The real key word that should concern us, however, is change for this is what one is really trying to determine in any ecological or environmental study. The same, of course, is true for remote sensing studies of the environment. Be it positive or negative, we are trying to assess and monitor the changes brought about within various ecological cycles and determine what factors change or upset these natural balances. We are beginning to see that man has a tremendous impact on his environment, and we sometimes learn too late, some of the consequences of our actions.

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In the Nile River Valley, man built a large dam for economic and industrial reasons and soon found that the fish population in the Mediterranean Sea decreased; that the number of disease bearing aquatic snails increased; and that the fertility of the valley itself was diminished. Closer to the site of this conference, we can examine the results of the construction of the Welland Canal connecting Lakes Erie and Ontario. The completion of the canal allowed the predatory sea lamprey eel to enter the interior lakes and quickly reduce the fisheries of trout and other commerical species. Soon the smaller alewife flourished since they had always served as food for the commercial fisheries. The sudden increase in these fish has often resulted in massive kills, quite common along the shores of Lake Michigan. In recent years ecologists have introduced the coho salmon which has thrived and cut back on the alewife population. These fish, however, have had to be removed from commercial markets from time to time because of high DDT concentrations in their bodies.

These two cases are significant examples of how fragile the environment is and how careful one must be when he deals with it. Impact on the environment can also be measured simply in terms of the ever increasing number of people that must interact with it. For example, in the past forty years the National Parks of the United States have had to accept a number of visitors that has ranged from 3 million in 1940 up to 150 million in 1970. How man plans for and copes with changes such as these will, to a great extent, determine the quality of our environment in the years to come.

Alvin Toffler in the introduction of his book Future Shock discussed change in this manner:

> "... I gradually came to be appalled by how little is actually known about adaptivity, either by those who call for and create vast changes in our society, or by those who supposedly prepare us to cope with those changes. Earnest intellectuals talk bravely about 'educating for change' or 'preparing people for the future.' But we know virtually nothing about how to do it. In the most rapidly changing environment to which man has ever been exposed, we remain pitifully ignorant of how the human animal copes."

THE PROBLEM

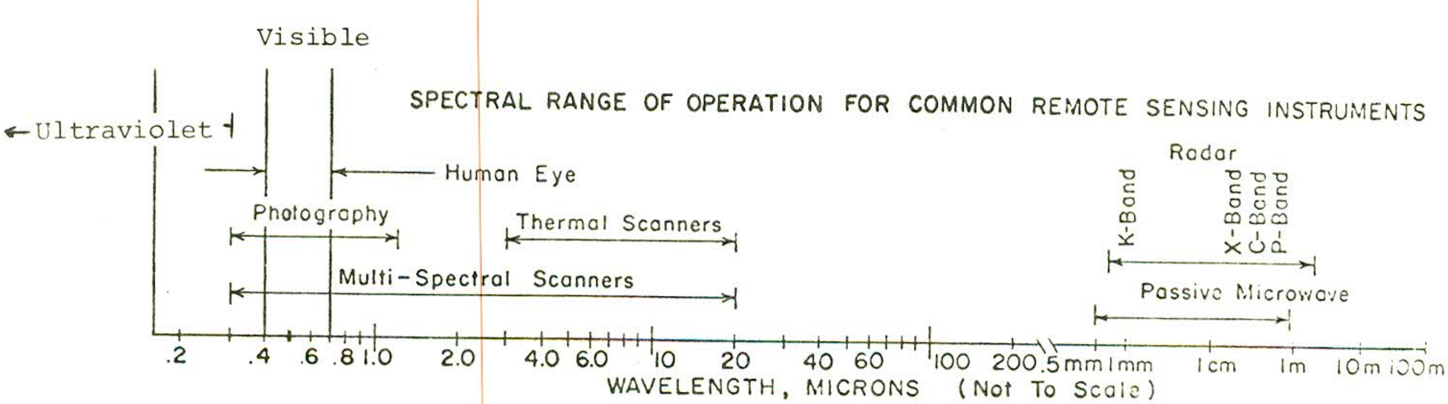
To see how the human animal copes and how the environment fares with his coping, man has begun to employ remote sensing devices to provide him with environmental data. These sensors have many limitations but may prove to be the key to global pollution monitoring in the years to come. To say that they are capable of detecting or "controlling" pollution is often not true and many times unfair to the sensor for we have yet to define what pollution is. Definitions will vary from nation to nation, province to province, or person to person. The man dependent on soft coal to heat his house or run his factory will have a much higher tolerance of sulfur dioxide fumes and acid mine wastes than the person trying to live and raise fish downstream from the mine. There have always been elements in the environment which were undesirable to us and beyond our control, such as specific occurrences of algae, salty water, acid water, volcanic dust, smoke, and silt. These cannot be categorically classified as pollution because they are products of natural processes--but, on the other hand, we must be capable of coping with these by-products of nature. Our society has removed, or greatly modified, certain aspects of the natural environment and ignored many others. By stimulating or restricting natural processes and increasing our consumption rates, modern man is locally overburdening his environment, and, in so doing, is causing pollution and degradation of environmental quality. The reason for this is simply that the problem is multifaceted; and, to properly study it, one must consider a variety of factors such as: numbers of people, land use, misplaced economic incentives, value systems, technology, mobility, limits of government units, depletion of resources, health, aesthetics, costs, effects on natural systems, and many others. Remote sensing devices cannot provide answers for each of these categories, but they can provide data on which decisions in these categories can be based. They sometimes make it possible to: detect alien substances in the environment; identify specific pollutants and classes of pollutants; measure varying concentrations of pollutants through time; monitor the source, movement, and fate of pollutants; determine the effects of pollutants on the environment; assist in determining environmental quality; determine the susceptibility of the environment to degradation; and provide data for comprehensive environmental planning and modeling. Data obtained by remote sensing must be understood, interpreted, and carefully used before it can provide many of the answers that users desire of it. In a remedial context, its role is direct, for it consists of locating and monitoring, while in a preventative context it is indirect, for it can only point out potential problems on the basis of previous detections.

REMOTE SENSING AND ENVIRONMENTAL MONITORING SYSTEMS

Remote sensing is a term used to describe a series of activities relating to the use of airborne or spaceborne instruments that measure properties of objects, generally at or near the Earth's surface, without coming into direct contact with them. Most often the properties being measured are either absorbed, emitted, scattered, transmitted, or reflected electromagnetic energy. This energy is generated by the sun and travels in harmonic waves toward the Earth at the speed of light. The wavelengths of this energy range from very short to very long, but human senses perceive only a small amount of this energy as sight or temperature. Remote sensing devices, however, can be built to detect specific wavelengths, or parts of this electromagnetic spectrum, beyond the range of the eye; thus expanding man's range of sensory perception.

Electromagnetic energy is continuous from one end of the spectrum to the other, but for convenience purposes it is divided into spectral regions. Table I indicates the regions in which most remote sensing devices are capable of operating at the present time. Note that the human eye only perceives energy in the 0.4 to 0.7 micron range.

Table I[1]



Each object on the Earth's surface emits, absorbs, or reflects energy differently. By determining the values of reflectivity and emissivity, one can predict how an object should appear in each region and thus establish its unique spectral characteristics. For example, coolant effluents from power plants can best be recorded in the thermal infrared portion of the spectrum because in this region temperature differences are easily discernible. Shape, color, or texture may also be important keys to identifying an object. These characteristics can easily be recorded on photographs taken in the visible portion of the spectrum. Thus, by knowing something about the spectral characteristics of an object, a remote sensing device can be built to discriminate those objects that can best be recorded in each spectral region.

Research is now underway to determine the spectral characteristics of various pollutants. The slides accompanying the Ottawa presentation of this paper will present examples of how different pollutants, or pollution processes, appear in various spectral regions and will illustrate which regions are best for recording information relative to particular environmental problems.

In defining "remote sensing" it should be noted that the term applies to a series of activities. It includes not only the selection of an appropriate instrument but data acquisition, collection, processing, distribution, and analysis. Furthermore, remote sensing can be said to be based on inference, i.e., "if cause C_1 exists, then effect E_1 will be observed, and if effect E_1 is observed, then cause C_1 must exist."[2] The science of remote sensing is rapidly advancing to a point where it could become the most important data source for environmental studies and management problems. The remainder of this section will briefly describe many of the sensor systems that can provide such data.

Photographic Systems

The oldest, best known, and most widely used remote sensing device is the camera. Cameras have long been used in aircraft, and more recently in spacecraft, to collect photographs of the earth below. Cameras, for example, have been successfully employed on Gemini and Apollo spacecraft; and, many examples appear in various reports. Aerial photography is an effective medium for storing environmental information; for photographs can be enlarged, enhanced, and taken with sufficient overlap to yield stereographic coverage of the area of concern. By combining various film and filter combinations, it is also possible to record selected spectral regions from the ultraviolet to the near infrared.

Basically, all cameras operate on the same principle--reflected visible light is allowed to pass through a lens and is then recorded on a piece of film which is sensitive to the visible light. The film is then processed, and the resulting photograph becomes a piece of remotely sensed data. Various modifications, or changes, can be made to camera systems. Lenses are made to be interchangeable so that varying scale images can be produced, and so that area coverage can be enlarged or reduced. Film too can be changed, thus allowing the use of particular types that are sensitive to portions of the spectrum, outside that recorded by the human eye. An example of one of these special films is color infrared, which records reflected energy in the near infrared portion of the spectrum. On this film green vegetation appears bright red if it is in leaf and healthy, or bluish-grey if it is dormant, diseased, or dying.

The following is a list of the more common film types and some of their special characteristics:

A. Panchromatic Film

Panchromatic film is the msot economical and widely used film for aerial mapping throughout the world. This black and white film has approximately the same sensitivity to reflected light as the human eye. It has a wide exposure latitude and provides reasonably good tonal contrast. On this film the light-sensitive silver salts are contained in one layer affixed to a stable base material.

B. Black and White Infrared Film

By extending the sensitivity of panchromatic film to include the near infrared region of the spectrum (0.7-1.2 microns), black and white infrared film is produced. This film is identical to the panchromatic except that some of the grey where it could become the most important data source for environmental studies and management problems. The remainder of this section will briefly describe many of the sensor systems that can provide such data.

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C. Color Film

Color film is similar to panchromatic except that its sensitive silver salts are arranged in three layers, each sensitive to different wavelengths of visible light. The top layer is sensitive to blue light, the middle layer to green and blue, and the bottom layer to red and blue. It has a more limited exposure latitude than panchromatic and a slower speed, but presents each scene almost exactly as the eye sees it. A haze filter should be used when the film is exposed from aircraft or spacecraft altitudes because of its high sensitivity to blue light. Color film is a valuable aid in water-quality studies involving wave and current patterns, sediment patterns, and discoloration due to agricultural, municipal, and industrial discharges.

D. Color Infrared Film

Like color film, color infrared film has three layers of silver salts sensitive to light from different parts of the spectrum. The significant feature of this film is that its range is increased from below 0.3 microns to above 0.9 microns. Thus any object reflecting ultraviolet, long-wave red, or infrared light will appear red on the photograph. The other two sensitive layers image green light as blue and red light as green, causing the film to be referred to as "false color" film. This film is insensitive to the blue portion of the spectrum, and thus has greater haze penetration capability than other film. The use of a yellow filter is required to guarantee that no blue wavelengths are recorded. The Apollo 9 S065 photography experiment produced some spectacular results with this film, and overall it can be said that it is perhaps the most useful film for recording environmental and resource information.

E. Aero-Neg Color Film

The Kodak Aero-Neg is a "true" color film that produces a negative from which color prints, black and white prints, color diapositives, black and white diapositives, or color transparencies can be made. This allows the user to choose the most useful type of film output to meet his particular needs. It has the same spectral characteristics as color film, but the greater variety of film output gives it an added advantage.

In addition to film and lens changes, the use of a variety of special filters on a camera allows only selected wavelengths of energy to pass through to the film; thus, it is possible to record only red light, or blue light, etc. An example of a special sensing system employing this technique is the multiband camera. When this system is used, several cameras or a multiple-lens camera record several pictures of the same scene at the same time. Each photograph records the maximum information in a particular spectral band. Data from these systems may be useful in helping to establish a data bank of specific spectral characteristics for various environmental pollutants.

Perhaps the most useful airborne camera system is one employing metric cameras. These instruments produce large scale data on 9 inch x 9 inch film of excellent geometric fidelity. Precise locations, accurate measurements, and controlled mosaics can be made from metric camera photography.

There are several problems involved in using camera systems for remote sensing from aircraft or spacecraft: 1) camera systems are restricted in normal use to daytime and virtually cloud-free conditions; 2) the lenses must be color corrected so that they record an accurate picture of the scene; 3) lenses must be free of geometric distortion, so that the resulting photograph is an accurate map-like representation of the scene; and 4) in order to record particular items such as junkyards, industrial pollutants, and crops, long focal length lenses are required for use from spacecraft and high-altitude aircraft.

<u>Radiometer</u>

A radiometer is a non-imaging sensor which measures emitted or reflected electromagnetic energy. It can detect energy from the ultraviolet to the infrared region of the spectrum, depending upon its detector. It converts incoming radiation into an electrical impulse which, in this case, is recorded on a gauge, or as a line trace on a strip chart recorder. These instruments have been extremely useful in laboratories and in the field for recording spectral characteristics of various objects.

<u>Infrared Scanners</u>

The infrared scanner, or scanning radiometer, is a sensor specially built to detect the thermal infrared energy emitted by objects. The sensor can be used day or night as it records energy emittance, as well as the sun's reflected energy. This device is sometimes referred to as an optical-mechanical scanner, or line scanner. The word scanner is used in connection with this sensor because the detection system involves the use of a rotating or scanning mirror, which directs the emitted energy from the ground to a detector in the system onboard the aircraft or spacecraft, translates that energy into an electrical signal and then records each scan on a piece of unexposed film or magnetic tape for computer processing.

The detector contains an infrared or heat sensitive material such as indium antimonide or copper-doped geranium, which is kept at temperatures approaching 0° Kelvin by either liquid helium or nitrogen. Infrared photons reflected off the scanning mirror strike the detector, generating an electrical impulse which varies in intensity according to the amount of infrared energy emitted from the object on the ground. This impulse is then recorded on black and white film as a shade of grey: the more energy, the stronger the impulse and the darker the shade of grey on the negative film. In this manner a thermal picture of the ground is pieced together, line by line, as the mirror spins at rates proportional to the forward speed of the aircraft or spacecraft.

Multispectral Scanners

Multispectral scanners operate on the same principle as the infrared scanners except that, by adding additional detectors and a special defraction grating to separate the energy coming from the scanning mirror, information in the ultraviolet and visible portions of the spectrum can also be recorded. By recording the impulses coming from each detector on a separate piece of film or magnetic tape, the same ground scene can be recorded in several so-called channels. Scanners are now capable of dividing the spectrum into as many as 24 channels. This allows analysts the opportunity to determine which part of the spectrum is best for recording each type of environmental data. The use of this instrument also allows the researcher to compare and/or combine several channels to determine more precisely the spectral characteristics of an object.

Side-Looking Airborne Radar (SLAR)

Side-looking airborne radar is an all weather, day or night sensor which is particularly effective in imaging large areas of terrain. It is called an active sensor because it generates its own energy, which it sends out in short pulses from a transmitter on the side of the aircraft. This energy travels to the Earth, bounces off the ground or objects on the ground, and is returned to the aircraft where a receiving antenna collects it, converts it into an electronic impulse, and displays it on a cathode ray or television tube. The cathode ray tube is then photographed, and a permanent record of the illuminated terrain is made. The imagery resulting from this sensor is similar in appearance to a black and white photograph, but contains much less detail than a camera produced picture. The black areas on the imagery represent either radar shadows or voids created when the energy leaving the aircraft strikes a smooth surface such as a body of water, and "skips" off at the same angle at which it arrived. If the energy strikes a large object, however, a bright or white return will be recorded because a large part of the energy is reflected back from the object to the receiving antenna.

The principal advantages of using SLAR are speed and scope of areal coverage, enhancement of the Earth's physical features, and the fact that it can be flown day or night in any type of weather. In addition, some SLAR systems can penetrate certain types of vegetation, thus providing a picture of the surface below the trees or bushes.

The scale at which SLAR imagery is usually collected is approximately 1:240,000. Thus, the scale is too small to record most types of environmental pollution. It can be used, however, to detect disturbed ground associated with mining and quarrying activities, or to detect large oil spills, since these spills tend to subdue wave action and consequently image darker than the surrounding waters.

Correlation Spectrometers

The correlation spectrometer is a device built to detect gases in the atmosphere from spacecraft, aircraft, or ground-based platforms. It is capable of detecting sulfur dioxide and nitrogen dioxide, two air pollutants which are major components of smog.

The operation of a spectrometer depends upon reflected or scattered energy, which is collected by a telescope on the imaging platform and passed through a special grating or prism. This spectrum of incoming radiation is then projected onto an optical mask, which contains a photographic replica of the spectrum of gas that is being sought. By vibrating the incoming spectrum across this mask, a correlation can (or cannot) be established. If the gas sought is present, the two spectra will match and a so-called beat signal will be generated. By recording the amplitude of these signals, a quantitative measurement of the amount of gas in the analyzed air column below the aircraft or spacecraft can be made. The more gas present, the better the match and the stronger the signal. This signal intensity is recorded on a strip chart recorder; and, thus, by plotting these readings along the line of flight, a profile of gas concentrations can be made.

Correlation spectrometers have been used mostly in aircraft, but they may also be placed in balloons or in mobile vans for use on the ground. They could also be placed in a spacecraft for experimental purposes at some time in the future.

Fraunhofer Line Discriminator (FLD)

The Fraunhofer line discriminator is an experimental remote sensor built to detect and measure fluorescence. The prototype instrument was built to detect solar-stimulated, yellow fluorescence emitted by Rhodamine WT dye. This dye is widely used as a trace element in current and flow studies of harbors, lakes, and rivers. In recent tests in San Francisco Bay, for example, dye concentrations as small as 5 parts per billion were recorded from both helicopter and ship platforms.[3]

The FLD operates on the principle that sunlight stimulates certain substances in the natural environment to fluoresce. This means that, while each substance reflects solar radiation, it also emits some of its own energy at a specific point or line on the electromagnetic spectrum. Fluorescence is very difficult to see with the naked eye because sunlight is so bright; but, by designing the sensor to record energy only at a particular line, one can detect the presence of the substance emitting the energy. Preliminary research indicates that additional FLD's can be built to detect such substances as crude oil, fish oil, the pulp mill pollutant called lignin sulfonate, and other natural and man-made substances that fluoresce. One limiting factor in the use of FLD's is that they can only be used when the sun is shining.

Scintillation Detectors

A scintillation detector is a special device built to detect gamma radiation with energy levels greater than 50 Kev (kilo electron volts). These devices are usually referred to as aeroradioactivity equipment and are mounted in low-flying aircraft to detect and monitor nuclear radiation including cosmic radiation, radionuclides in the air, and radionuclides in the surficial layer of the Earth. The sensors are internally calibrated in cycles per second (cps) and use a series of thallium-activated sodium iodide crystals to detect energy pulses greater than 50 Kev. Once an incoming signal is detected, it is then split and channeled through two rate meters. One meter is designed to measure total radiation, and the other is designed to subtract cosmic and aircraft background radiation which may be contributing to the incoming energy signal. Once this is done, a correction is made for the altitude of the aircraft and a net radiation signal is recorded. These data are then collected and compared with similar flight data. The resulting changes are plotted on maps, and individual ranges or radioactivity levels are assigned to each area.

CONCLUSIONS

Environmental monitoring programs using remote sensing systems in spacecraft and aircraft have been conducted sporadically across the United States by universities, research groups, government agencies, and private industry. Examples of data from these efforts can be seen in various scientific journals, professional reports, technical papers, etc. For the most part, these studies demonstrate that remote sensors do possess unique capabilities which make them valuable for environmental monitoring. Some specific advantages are:

1. They provide a synoptic or small scale view of a region, thus making it possible to study the whole area as the sum of its parts.

2. They provide a permanent record of a situation at a particular location and point in time. Then when a second record has been collected, a comparison can be made to determine change. In this fashion many significant seasonal, cause and effect, or time lapse factors can be determined.

3. In providing certain kinds of environmental data, this type of approach is inexpensive if one wishes to survey large areas of terrain. In fact, a natural fallout of any regional land use study will be the identification of critical environmental zones and many evidences of pollution.

4. The employment of remote sensing devices allows scientists and planners the opportunity to study pollution by monitoring it in different parts of the electromagnetic spectrum: thus, expanding the users' range of sensory perception.

5. Data produced by remote sensors can be analyzed and enhanced using special equipment, thus providing supplementary information in addition to the original record.

Since remote sensing should not be considered a panacea for every type of environmental study, certain disadvantages should be pointed out.

1. The determination of whether something is a pollutant or not usually is based on a subjective analysis of the data rather than a quantitative one. This is true since most of the presently available sensors only record color or temperature differences.

2. The identification and time lapse monitoring of most effluents, or pollution sources, requires large scale data. Currently scheduled satellite systems and high altitude small scale data will not allow monitoring of many types of pollutants.

3. The cost of using remote sensing systems is very high if one is only interested in covering a small area or identifying a few sources of pollution.

4. In order to correctly use and understand remote sensing systems and derived data products, education and training programs need to be established. This applies not only for scientists and other users but for judges and lawyers who may have to accept these data as evidence in court cases.

RECOMMENDATIONS

Concern for environmental problems appears to be increasing throughout the world. This, of course, has led many people to expect a global solution to many problems. While this is a worthy goal to pursue, it does not appear that we can find a global solution for each problem or even that we know now what each solution might require. National and/or regional programs will probably have to take the first steps.

Recommendations have been made by many groups and individuals within the remote sensing community concerning needs in the environmental monitoring area. Perhaps the most critical need at the present time is the lack of adequate information on the physical, chemical, and ecological aspects of the environment. In 1970 the report of the study of critical environmental problems entitled Man's Impact on the Global Environment, the following set of recommendations were made.

1. We recommend the development of new methods for gathering and compiling global economic and statistical information, which organize data across traditional areas of environmental responsibility, such as air and water pollution. We further recommend the propagation of uniform data-collection standards to ensure, for example, that industrial production data collection across the world will be of comparable precision and focus.

2. We recommend a study of the possibility of setting up international physical, chemical, and ecological measurement standards, to be administered through a monitoring standards center with a "real time" data analysis capability, allowing for prompt feedback to monitoring units in terms of monitoring or measurement parameters, levels of accuracy, frequency of observation, and other factors.

3. We recommend an immediate study of global monitoring to examine the scientific and political feasibility of integration of existing and planned monitoring programs and to set out steps necessary to establish an optimal system.

In 1971 a 50-man team of the leading United States authorities in the field of remote sensing of pollution published a summary of work and recommendations entitled Remote Measurement of Pollution (NASA-SP-285). In addition to many recommendations for monitoring specific land, air and water pollutants, the report suggested establishing a Prototype Operational Environmental Monitoring System (POEMS) for use on both a local and regional basis to solve specific environmental problems.

In general, it can be said that more research and development for environmental monitoring is required especially in the development of quantitative sensors; that training courses need to be established so that a wider range of users can learn to use remote sensing; and that more emphasis needs to be placed on the international exchange of data/information and the establishment of global monitoring programs.

FOOTNOTES

[1]Scherz, James P. and Stevens, Alan R.: 1970, An Introduction to Remote Sensing for Environmental Monitoring: University of Wisconsin, Institute for Environmental Studies, Report 1, p. 5.

[2]Michigan, University, Willow Run Labs.: 1966, NASA/MSC Training Course in Remote Sensing: Ann Arbor, Michigan, Section 2, p. 2.

[3]Stoertz, George E., Hemphill, William R. and Markle, David A.: 1969, Airborne Fluorometer Applicable to Marine and Estaurine Studies: Marine Technology Society Journal, v. 3, no. 6, p. 11.