Technical Keynote Address on Remote Sensing

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INTRODUCTION

This paper will review briefly what remote sensing is, what it can do and problems presently being studied. Remote sensing refers primarily to sensors of electromagnetic radiation, i.e., the ultraviolet, visible, infrared and microwave regions. There are many other sensors that could be called remote sensors. But for one reason or another, usually very short range of operation or low geometric resolution, sensing from aircraft or spacecraft primarily means sensors of electromagnetic radiation. The time available does not permit explanation of all remote sensors; so most of the examples shown will be of ultraviolet, visible and infrared radiation, but the fact that radar pictures will not be included in this paper does not mean that they are not useful or important.

In environmental affairs there are three major classes of activity:

(1) Obtaining data on the environment

(2) Using the data to predict what is going to happen and to make recommendations for action on the environment

(3) Taking action on the environment based on (1) and (2)

Remote sensing is usually construed to be concerned with the first two of these activities. Also, for the most part, the activities of NASA are concerned with the data acquisition and the utiliziation of the data to reach certain conclusions and recommendations for action with regard to the environment. It is more often the responsibility of other agencies to actually take action with regard to the environment, so I will concentrate on the first two major classes of activities.

There is some tendency to regard remote sensing as being a matter of having a few new eyes, but remote sensing is far more. In fact, it is the joint effect of employing, with proper coordination, a variety of distinct technologies. Figure 1 is a representation of this definition of remote sensing.[1] Within the first sector (upper right) are a group of technologies concerned with obtaining data. This activity requires platforms, communications, navigation devices, and sensors. Within the next area (remainder of illustration) are a number of technologies concerned with utilizing the data to reach conclusions. It is a large activity and requires management of large programs. It is interesting that NASA is relatively strong in the technologies required for the two major classes of activities, with one exception. The construction of environmental models and knowledge of common practices are areas where, quite clearly, the relevent technical experience resides primarily in other places. But remote sensing is defined as the proper utilization of all of these technologies *in conjunction* with each other.

From the standpoint of NASA we regard our objectives in the remote sensing activity as contributing to man's ability to manage and use his terrestrial environment:

(1) By improving environmental data types, quality, and timeliness

(2) By improving systems for employing data to derive and communicate decisions for action (it is not a primary function of NASA Earth observations activities to improve the means of implementing the decisions for action beyond the informational - decision making aspects of the overall problem).

Figure 2 shows the Manned Spacecraft Center (MSC) at Houston. The technical activities that we engage in are given in the areas of data utilization and data acquisition. This organization is typical for any NASA center engaged in remote sensing activity.

[1] Copies of these and other charts and photographs are available upon request from Marvin R. Holter, Chief, Earth Observations Division, National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas 77058.

Figures 3 and 4 show the component activities of data acquisition and data utilization, respectively. Data acquisition (fig. 3) involves development, implementation, and generation of sensors and data sources. Presently, we operate several aircraft that generate data. In about a year the ERTS satellite will go into operation and the Skylab satellite, equipped with sensors to obtain data, will follow a year later. Data utilization (fig. 4) requires:

(1) Data must be stored, indexed, and retrieved to make it available to users (We have such a research data facility at MSC and it seems certain that other centers of the agency will establish similar data operations as they become involved in remote sensing activities.)

(2) Data must be applied. (We are beginning to work very closely with user agencies in the Texas area to employ data we have obtained in real application to problems.)

SYSTEM PROBLEM AREAS

Figure 5 illustrates some of the "pacing" problems in this business by following the life history of a piece of information. We begin by sensing some data. The next step is to translate the sensor outputs into reflectivities and emissivities of the objects under observation. Signatures and data processing represent an area of ignorance in which we must do some research. To proceed from the radiation properties to the identity of species or the condition of the species, whether the corn is deseased or not, for example, requires another transit through this circular area. It is an area of some considerable ignorance, a pacing technical problem if you will, on which we must do research. Having the identity of the species and the conditions, then the thing that is of most interest in this crop yield example is to make some predictions.

Whenever we attempt to make predictions with regard to the environment, we need environmental models. The people in NASA do not have the principal skills to develop such models. We must depend on other agencies, e.g., universities, the Departments of Agriculture and Interior, or certain international programs such as the International Biological Program or the International Hydrological Program.

Remote sensing techniques do not provide sufficient data on which to base recommendations for action on the environment. Rather, remotely sensed data must be used in conjunction with climatic data, knowledge of cropping processes, existing maps, planting records, political considerations such as acreage allotments, input from agricultural county agents and all sorts of other information. This necessity presents a technical systems problem, i.e., how to bring many disparate sources of data together so they can be applied to the same problem. Figure 6 illustrates this specific system problem. We must learn how to accept spacecraft data, aircraft data, data from ground instrumentation, weather data, verbal data from county agents, stored data and other different types of data and coordinate them for application to an environmental problem. Figure 7 gives an estimate of our progress in dealing with such system problems. We are learning to make observations. Ultimately, we hope to be able to monitor, understand, and modify the environment for our own purposes. Achieving this goal will be a matter of one or two decades.

Figure 8(A) shows a conventional aerial photograph. Examine this picture carefully and compare it with figure 8(B). It is the next picture on the same roll of film, made with the same camera, the same filter, and the same lens only 20 seconds later. The aircraft moved perhaps one mile. The appearance of this picture is radically different, not only in the middle but also in the appearance of the tones in the corner. I don't know why. I think I do, but I cannot yet prove it. I merely show it to illustrate that the question of signatures–what are the relationships between the materials on the surface that we want to observe and the radiation that we do observe–is something where we need a good deal more understanding, even with the oldest sensor that we have at the present time.

REMOTE SENSING APPLICATIONS

Figure 9 shows the relationship of Earth observations to other national programs within the space agency. The Earth observations remote sensing program draws data from past space missions, from presently operating aircraft and from the projected ERTS and Skylab satellites. These data are channeled to workers in the remote sensing community by means of our research data facility. Finally, we work with a number of national and international agencies and universities.

I frequently get asked why we need to improve on aerial photography, the present classic means of doing surveys. Present survey techniques produce simultaneously too little information in one sense and too much information in another sense. Air photography, including color photography, does not produce very strong contrasts between some pairs of features that we would like to discriminate more exactly, while other kinds of sensors–ultraviolet sensors, infrared sensors or radar sensors–indicate strong differences. Thus the problem of too little information can be remedied by adding more wavelengths to the sensors.

The second problem with aerial photography is too much information. Any camera, if operated continuously, will produce more pictures than any reasonable number of human beings using ordinary methods can intensively interpret. This problem can be remedied by two means. First, sensors in other parts of the spectrum can be used to enhance the contrast between features so that human interpretation becomes easier and more rapid. The principal solution, however, centers around the attempt, already partially successful, to automate significant parts of the interpretation; i.e., to use computers to make certain classes of decisions. We will show some examples of those kinds of results later.

Figure 10 shows the aspects of the radiation that are remotely sensed that can be used to do the discrimination among the various materials and conditions of interest: The wavelength distribution or spectral discrimination, the shapes, spatial discrimination, polarization, and the prime effects that are really of two types, depending on speed of movement. If things are moving rapidly, Doppler shifts from the objects occur. The frequency of the radiation is changed. The only place outside of the Defense Department that Doppler radar is being used at the moment is for police radar used to determine whether cars are speeding. It has to my knowledge not yet been explored for environmental applications. The slow prime effect is that obtained with ordinary time-lapsed photography or time-lapsed observations with any sensor at intervals of hours, days, weeks, or months. With regard to automating the interpretation, we can today at least partially automate spectral discrimination based on wavelength. We are not in a very good position to automate shape or spatial discrimination, polarization, or Doppler effects at the present time. Therefore, the research work that goes on with regard to the last three here is an exploratory effort to develop methods. Much of the research in spectral discrimination is concerned with application since workable methods are available now.

Figure 11 shows a panchromatic mosaic of an agricultural area in California. This is ordinary photography. Some of the things that can be done with more modern instrumentation will now be illustrated.

Figure 12 shows 18 views of the same region. The view in the upper left is an ultraviolet image. The following 10 are narrow bands within the visible region and the remaining are reflected infrared except the last two. They are emitted infrared. Several interesting features of the imagery are shown here. Let us just consider one of them. Many people claim that there is no information in the ultraviolet that does not exist elsewhere in the optical spectrum. The ultraviolet photography shows marked difference between two fields that are the same crops: safflower. The marked difference shows up nowhere so strongly in any of the rest of the 18 bands in the visible and the ultraviolet and the infrared.

Uses of Color

Plate 1 shows one of three uses of color as a display means. Color is used in the assignment of the color of the dye in the photograph to the wavelength used in the sensors. We have assigned a blue dye in the photograph to an ultraviolet sensor band, a green dye to a blue visible-region sensor band, and a red dye to a green visible band of the sensor. A difference between the two safflower fields shows because the ultraviolet information is sensed.

Plate 2 shows what the world looks like through infrared eyes. I have assigned the three dyes to three infrared wavelengths: the blue dye to the very near infrared; the green dye to a reflected infrared band at about 2.5 microns; the red dye to a thermally emitted infrared band. Note the two fields of the same crop: Rice at 10 centimeters tall of the same degree of health. They look quite different in this photograph only because the emitted infrared radiation band is present. The one field had been drained, and at 11:00 in the morning in the bright sunshine, the temperature in the field is much higher than in the other field which is still flooded with water. So here is another kind of information one can get and display in this fashion.

Plate 3 shows a different use of color. This is a single band in the sensor, the thermal band. It can be related directly to temperature and the colors have been assigned to temperature. In this case, the violet color is assigned to the highest temperature. The drained rice field is much higher in temperature than the flooded field and the other fields with more luxurious foliage. This is a second use of color that is different from the first one. The color here is assigned to amplitude of the signal within a single band rather than being assigned to wavelengths.

Figure 13 shows the result of having used a computer to decide what materials were present. A computer was asked in the uppermost strip to determine the 20-centimeter rice and nothing else. It did. In the second strip it printed out the 10-centimeter rice and nothing else, the process being sensitive enough to distinguish between the same crop at two different stages of growth. In the third instance it was asked to print out the safflower, and it did. In the fourth instance, the computer interpreted and printed out the bare soil.

Now it is not necessary to look at four photographs. Plate 4 shows exactly the same data; however, all are placed on the same chart with the third use of color. In this case, the colors have been assigned to the computer decision: red to 20-centimeter rice; blue, 10-centimeter rice; green, safflower; black, bare earth. That is an intriguing picture because it is my observation that most people who work with geographically distributed data very laboriously accummulate data, use many draftsmen to finally make, as the most useful output product, a chart or map with either cross hatching or coloring to code the different materials. What we have instead is a means of bypassing much of that labor. Almost directly from the sensor through a computer we produce a kind of a presentation which must be useful because so many people in so many groups who work with geographically distributed data spend much labor producing just this sort of display. One could carry the process at least one step further in the computer. The statistical recording service of the Department of Agriculture usually does not want to look at pictures at all. It wants tabulations.

Table 1 shows this kind of result. If the computer can recognize the materials, it is a fairly easy job to ask the computer to sum the areas, and this is what is done: The computer responds with totals– bare soil, 190 acres; safflower plants, 290 acres; etc. This is a typical sequence of the types of results that we are beginning to learn how to get in remote sensing applications.

TABLE 1.–Crop Acreage for Davis, Calif., Area Obtained by Digital Processing

Crop	Symbol	Acres
Bare soil	•	190
Safflower	(	290
Immature rice	⌿	410
Mature rice	X–X	270
Other		440

Other Types of Results

Here are some sequences of other kinds of results. Figure 14 is a panchromatic photograph of all of that immoral oil out in the Santa Barbara Channel a couple of years ago. You can see the drill platform. Barely visible is a boat that is spreading detergent or some sort of dispersent. In this panchromatic photograph the oil slick is not visible.

Plate 5 shows an infrared photograph over an ultraviolet one. In this case, the thickness of the oil is such that it does not show in the infrared. In the ultraviolet it appears lighter in tone than does the surrounding water. But that is not all we have to do in this case because kelp beds in the area can be confused for oil. Recall the configuration here; oil shows nothing on infrared, shows light on the ultraviolet.

Plate 6 shows kelp which is brighter than the water in the infrared where the oil did not show at all. It is darker than the water in the ultraviolet where the oil was brighter than the water. So in this example we need no special data processing. All we need to do is look at a couple of special bands and we get an unequivocal distinction between the materials.

Plate 7 shows another kind of an example. This is an area of the Everglades. Colors represent the computer-assigned decisions with regard to the types of plant communities that are present in the area. Remote sensing has the obvious advantage that, in an area where it is difficult to gain access on foot, we can fly over the area with these multiband, multispectral sensors and reach decisions regarding the types of vegetation.

Figure 15 is an ordinary panchromatic photograph taken in Florida in an area characterized by subsurface voids, whose presence many times is not known. When houses, roads, and other structures get built over them at subsequent dates, subsidence occurs, as happened with this house.

Plate 8 shows an infrared photograph in which the intensity of the radiation, the apparent temperature, has been indicated by color. At the time the flight was made, this was a known area of crass feature. With a little imagination, a more or less concentric pattern of changing temperatures can be seen. At the time that flight was made there were no known crass features in the vicinity of the road junction. However, it was conjectured that there were subsurface voids there. Inspection was made on the surface, without any indication of voids. Drilling, however, indicated some voids down 40 to 60 feet. Four months later some subsidence began to occur here. I do not want to imply that we know how to do this every time. We don't yet. But, it is certainly intriguing that, in at least one place, we have demonstrated that we could get an indication of the subsurface void before any other obvious manifestations were present.

Plate 9 contains three photographs. Part (A) is an ordinary color photograph of the shoreline of Lake Michigan. Part(B) is another color photograph. Air pollution over the city is evident in the lower left. An effluent being discharged into the small body of water does not show up very clearly in the ordinary color photograph. In the infrared Ektachrome photograph, part (C), it shows up somewhat more clearly. That is the effluent from a paper mill. An infrared scanner photograph, plate 10, shows the signal levels coded in color where the red area is the discharge of warm water from an electric power generating plant into the lake; the orange area is the coastline of Lake Michigan; the blue area, the water. The highest temperature, in this case, is indicated by the red, and lower temperatures fade off into the yellow, the light blue and the dark blue. All is not simple, however; that is the flow pattern at just one time of the year.

Figure 16 shows, in black and white, the same area but at some different times of the year—the flow considerably varying seasonally. So it is not enough to get one look at where this hot water is going. It will shift, sometimes with the wind velocity, sometimes with the current, sometimes seasonally.

The upper part of plate 11 is an infrared photograph of Hilo, Hawaii. The dark strips are cooler fresh ground water seeping out into the bay. This water is of much interest in that region of volcanic soil where the water leaches through the soil very rapidly. The agriculture in the area is, in fact, limited pretty much by available water supply. Water wells suitably located could tap this valuable resource. The lower part of the illustration is the result of having done some density work on the upper part and coding the densities in color.

Plate 12 shows an urban problem. The black-and-white photograph is of a segment of Ann Arbor, Michigan. The question addressed here was as follows: As areas become urbanized, larger fractions of the surface become covered with materials through which the water cannot drain. The fraction of those materials present in the area determines how many, the size, and spacing of soil-water drain tiles. It is a laborious task to determine the fraction of the area that is impervious to water. Also shown is the result of having used a multiband sensor and a computer to very rapidly map the areas that will not leach water into the subsurface, the red area. The blue areas are those areas of soil where the water can leach. This demonstrates another kind of result we are getting from remote sensing. Table 2 shows, again in this application, where the computer was asked to just add the acreage because that is the relevent information with regard to the drain tiles.

Figure 17 is a chart of some crops in the Mesa area near Phoenix, Arizona. Shown along the bottom are several crops of hay grown each year. The light-green areas occur where it is cut, the dark-green areas where it is growing. Near the top, cereal grains are green in spring and ripen along about May (tan). They are harvested then, and only stubble remains (brown). This type of crop calendar is useful for making more intelligent choices about the frequency of observation, if one is interested in using what I would call time-distributed signature.

Plate 13 shows some infrared Ektachrome photographs at the major time intervals indicated in the crop calendar for March, April, May, and August. Note that the patterns of these fields change. The colors change from time to time. The pattern that they exhibit is a result of the variations in the plant growth and planting, cropping, and harvesting processes illustrated in the previous crop calendar.

TABLE 2.—Acreage Estimates of Impervious Materials from Digital Computer Recognition Map

Category	Number of points	Acreage
Bare soil	654	0.86
Field	1196	1.56
Gravel	7567	9.85
Water	6411	8.35
Tree	10246	13.34
Lawn	3503	4.57
Light roof	2055	3.13
New roof	1354	1.76
Perpendicular roof	231	0.30
Parallel roof	460	0.60
Asphalt	630	0.82
Cement 1	507	0.66
Not classified	3241	4.22

Plate 14 shows another kind of an example. The fish and wildlife people are interested in the duck carrying capacities of certain regions in South Dakota where much duck breeding occurs. This is a function of the number of ponds, the length of the shoreline and shoreline convolution. There has been some preliminary success in surveying these regions with a multiband sensor and automatically determining the area of the ponds, the perimeter of the ponds, the degree of convoluting of the shorelines, and making estimates of the duck carrying capacities. Several kinds of results are indicated. Part (A) is an ordinary picture of the area. Part (B) is a photograph processed to show only the water, with all of the vegetation suppressed. Part (C) is processed to show the vegetation type with the water suppressed, showing it as black. Part (D) is a digital picture; I do not have the final computations but one can carry the process to the point where he can calculate the duck breeding capacities of the region.

Figure 18 shows two infrared photographs of interest to anyone concerned with aquatic affairs. This is part of the Tennessee Valley Authority's system 20 miles below Norris Dam and site of an electric-power generating plant. The dark tones are coal. An area can be seen in (A) where the warmer surface water has been skimmed off so only the cooler subsurface water is admitted to the turbines in the generator. The warmer water discharges from the other end of the turbines. At the time this photograph was made on September 3rd, the gates at Norris Dam, 20 miles upstream, were open and a slug of cold water was admitted to the stream. Just about 24 hours later on September 4th (we had been making observations in 2- or 3-hour intervals), we saw the slug of cold water advancing down the river and photographed it (B). Surprisingly, there was very little mixing at the interface after having been flowing down the river for 24 hours. Here is another kind of result with obvious applications to studying flow in streams. Figure 19 shows a densitometer trace across the river, indicating where the skimmer was at the input to the power plant at the main river. The hot plates and cold plates are calibration sources in the sensor.

PLATFORMS

At the present time NASA has a number of aircraft (fig. 20) for the use of all the people involved in remote sensing. The Convair 240 has now been retired from the program, but we do have a P-3, a C-130, and an RB-57.[2]

[2]Editorial Note: At the conference, it was announced that two instrumented U-2s, having higher altitude capability, will be scheduled for flights from Wallops Station, Virigina.

Figure 21 shows the various sensors aboard the C-130 aircraft and, very roughly, the areas they cover on the ground underneath the aircraft. Sensors include a 13.3 GHz scatterometer, a 24-channel multispectral scanner, a Reconofax 4 infrared scanner, six Hasselblad cameras, two RC-8 cameras, and the side-looking airborne radar that looks out considerably to the side of the aircraft. This is representative of the instrumentation aboard that aircraft.

Figure 22 shows instrument coverage of the P-3, with a similar set of instruments, that are not identical in ground coverage.

Figure 23 shows the high-altitude B-57 aircraft, with its compliment of sensors that change from time to time, as we do update them; if one wants to know for certain what the sensors are today, he should not rely entirely of this chart; note the various cameras, scanners, a calibrated radiometer with a very small field of view in the center, and a spectrometer.

Figure 24 shows the planned instrumentation and ground coverage for the Skylab Earth Resources Experiment Package. It is planned that in early 1973 this will be in orbit and, of course, in 1972 the ERTS Satellite will be in orbit.

We have covered the sorts of data sources that exist at the present time that NASA is using for the benefit of all the investigators in these programs. Figure 25 illustrates, in one sense, the scope of the activities that we believe are necessary in Earth observations: the theoretical analysis of various sorts; lab measurements we must have for signatures; *measurements in the field; aircraft at several altitudes; and spacecraft.*

I hope that this presentation informs you of the kinds of results available today and the kinds of instrumentation that are available in the remote sensing program.

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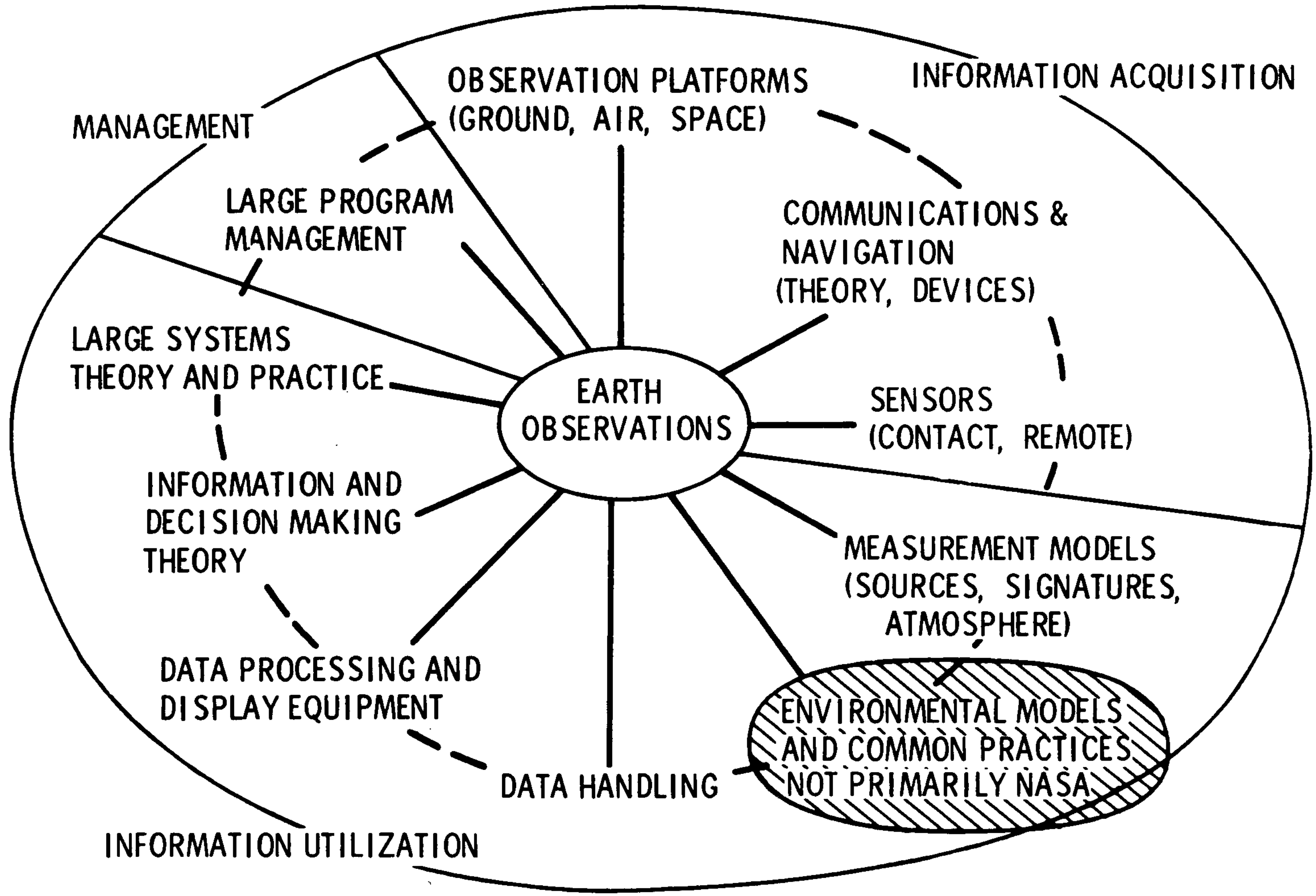


Figure 1.–Areas of NASA competence.

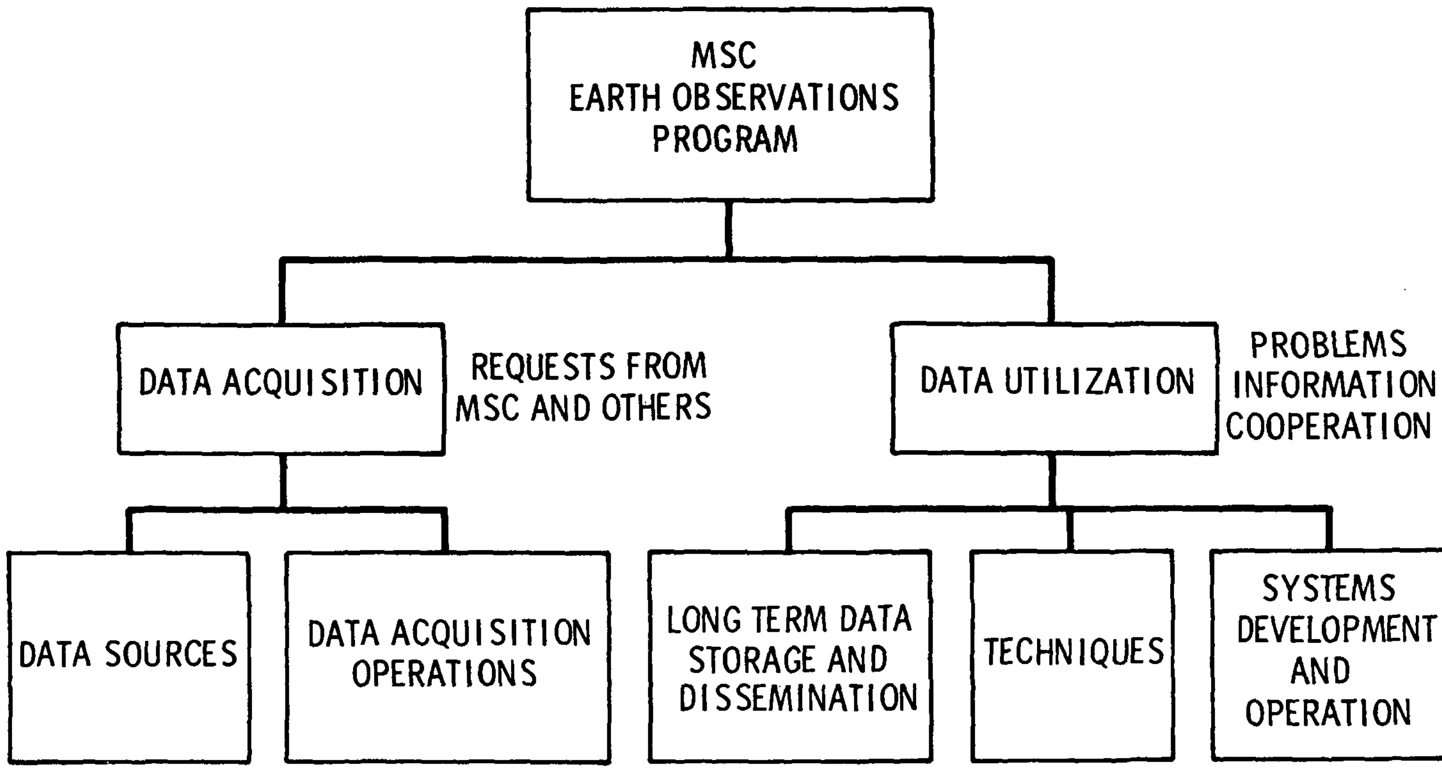


Figure 2.–Earth observations management responsibilities.

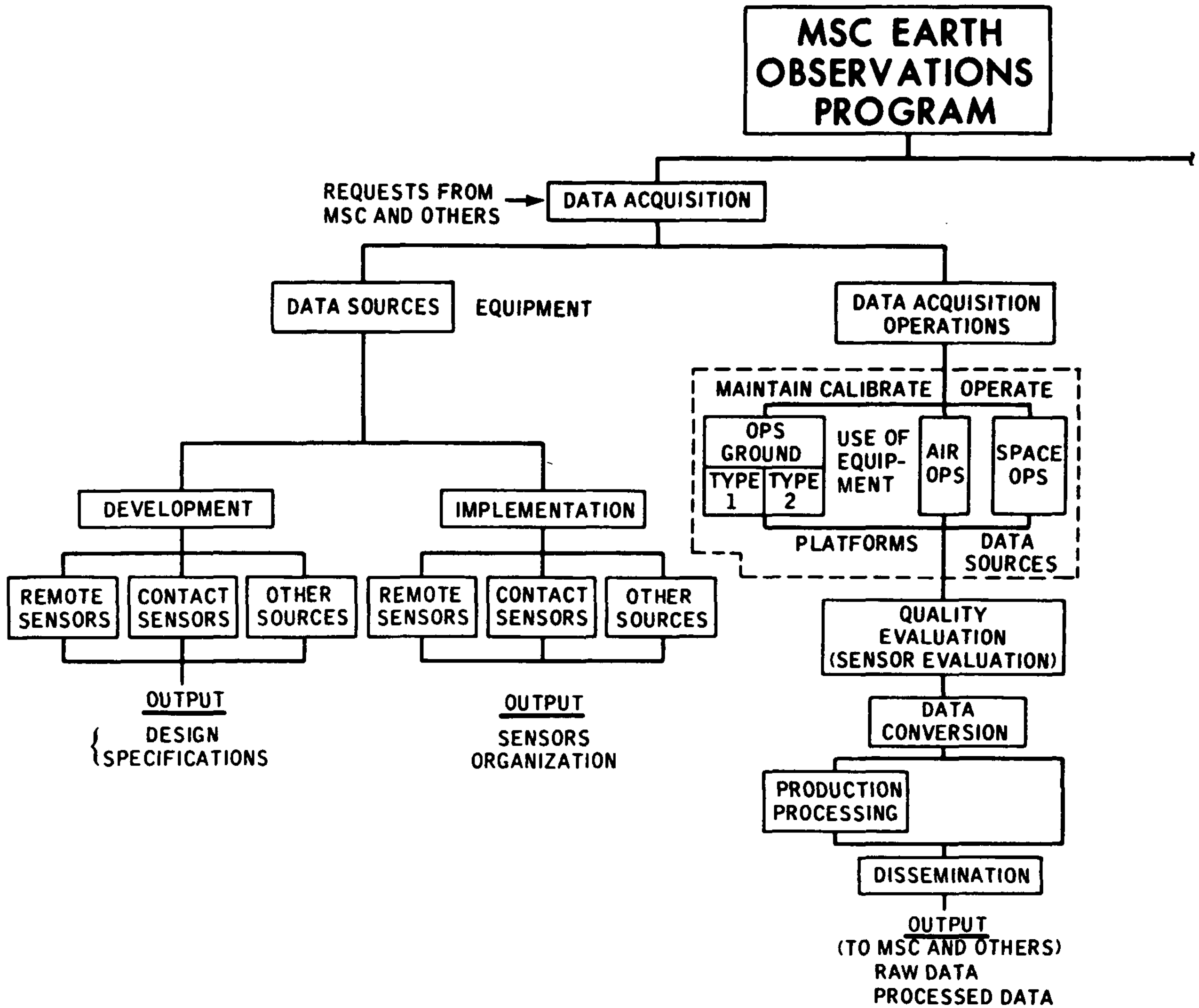


Figure 3.–Data acquisition activities.

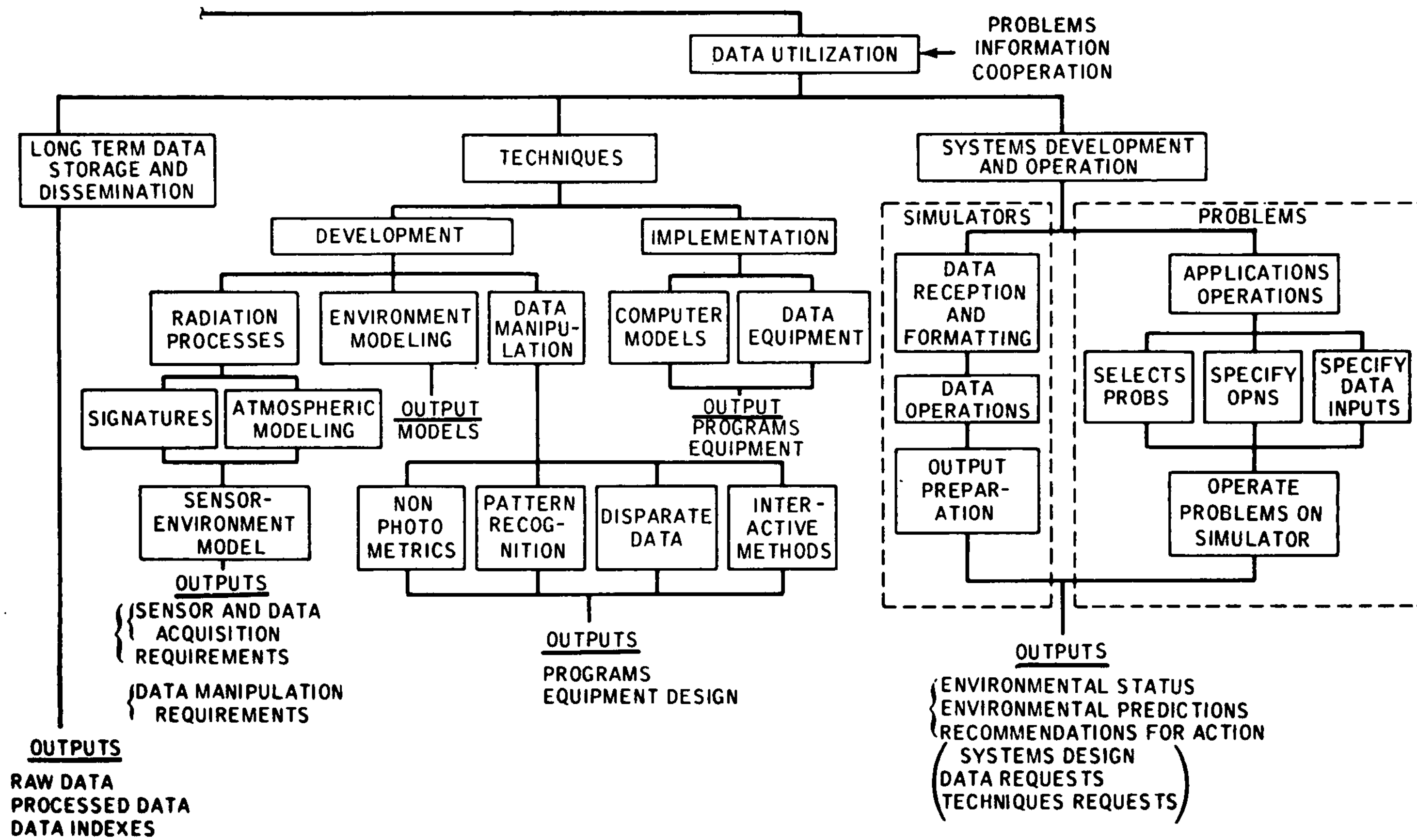


Figure 4.–Data utilization activities.

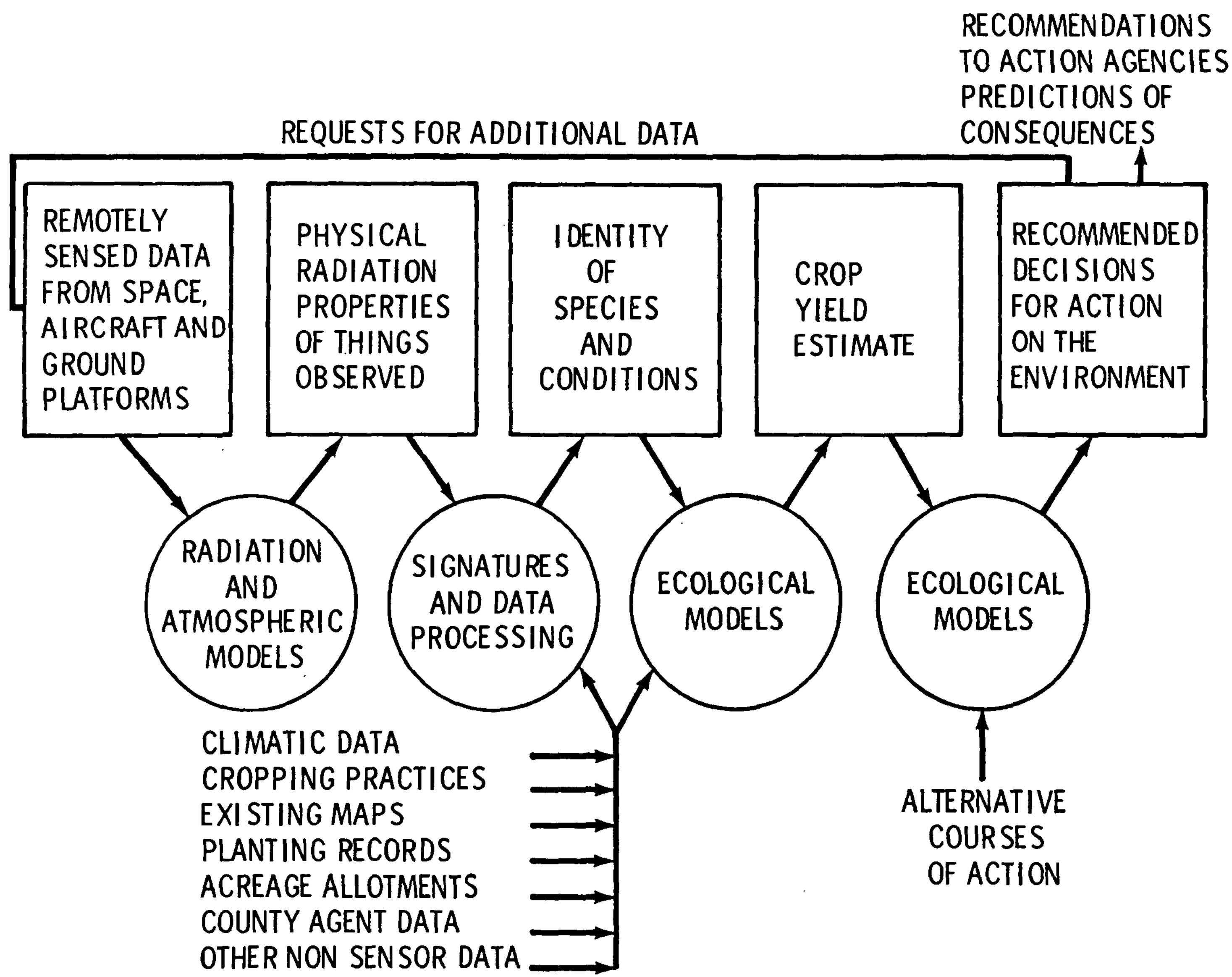


Figure 5.–Earth observations system (crop yield example).

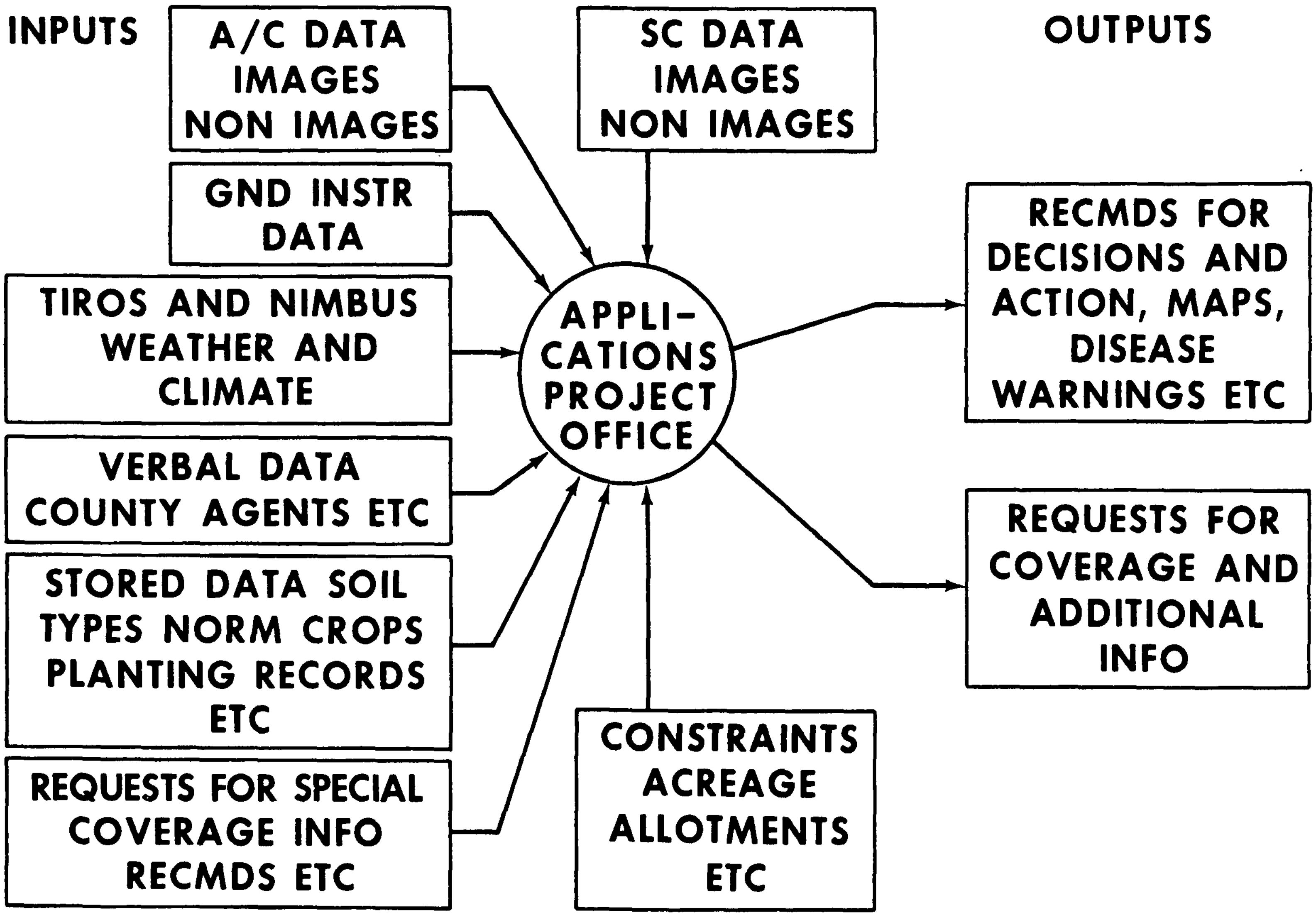


Figure 6.—Disparate sources must be coordinated for meaningful application.

	SHORT RANGE	MID RANGE	LONG RANGE
OBSERVATION	THEMATIC MONITORING OF LAND AND SEA		
UNDERSTANDING	IMPROVED WORLD REFERENCE SYSTEM		
		COMPREHENSIVE MODELS FOR ATMOSPHERE, DYNAMIC EARTH, OCEANS, AND LAND	
PREDICTION		PREDICTIONS FOR FOOD PRODUCTION, POLLUTION, NATURAL DISASTERS, RESOURCES, AND TRANSPORTATION	
MANAGEMENT MODIFICATION		REGIONAL EXPERIMENTS IN MANAGEMENT OF NATURAL RESOURCES SUCH AS WATER	
			EXPERIMENTS IN ENVIRONMENTAL MODIFICATION

Figure 7.–Evolution of capability (typical examples.)

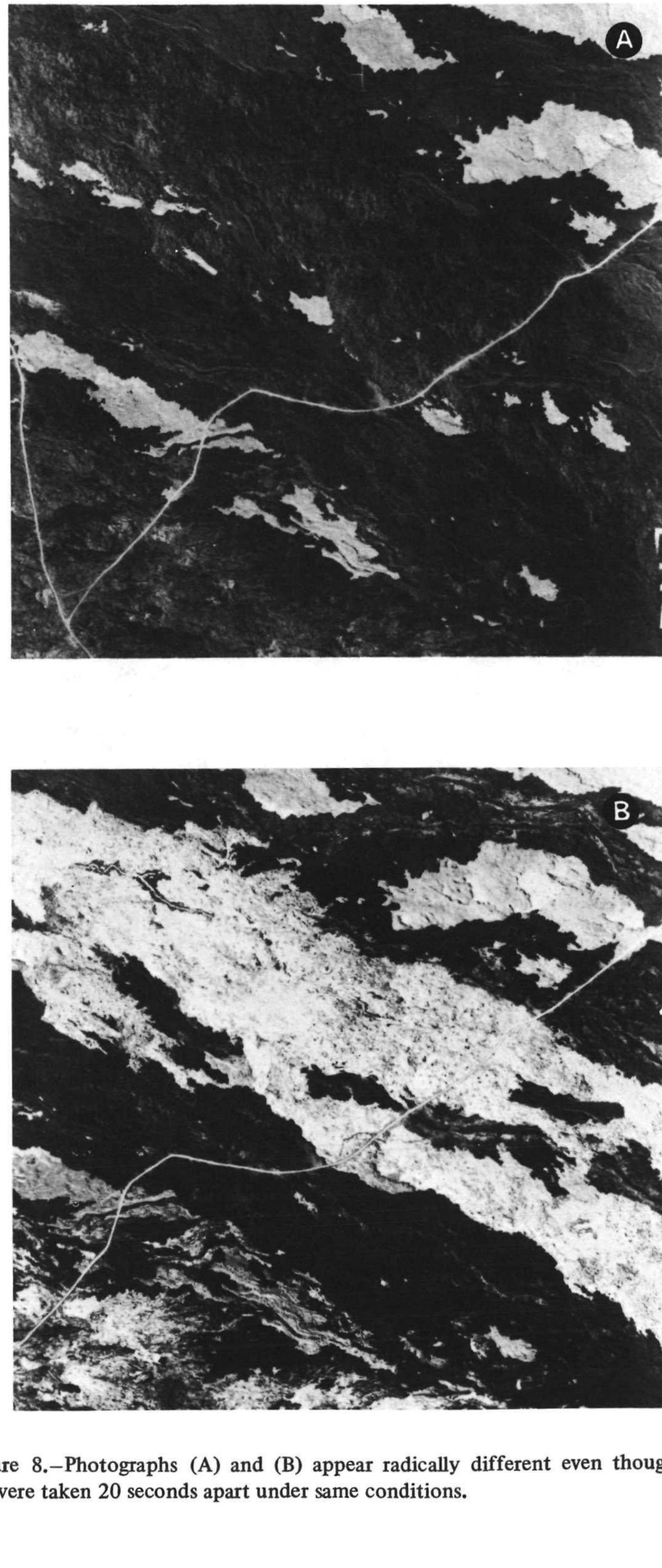


Figure 8.–Photographs (A) and (B) appear radically different even though they were taken 20 seconds apart under same conditions.

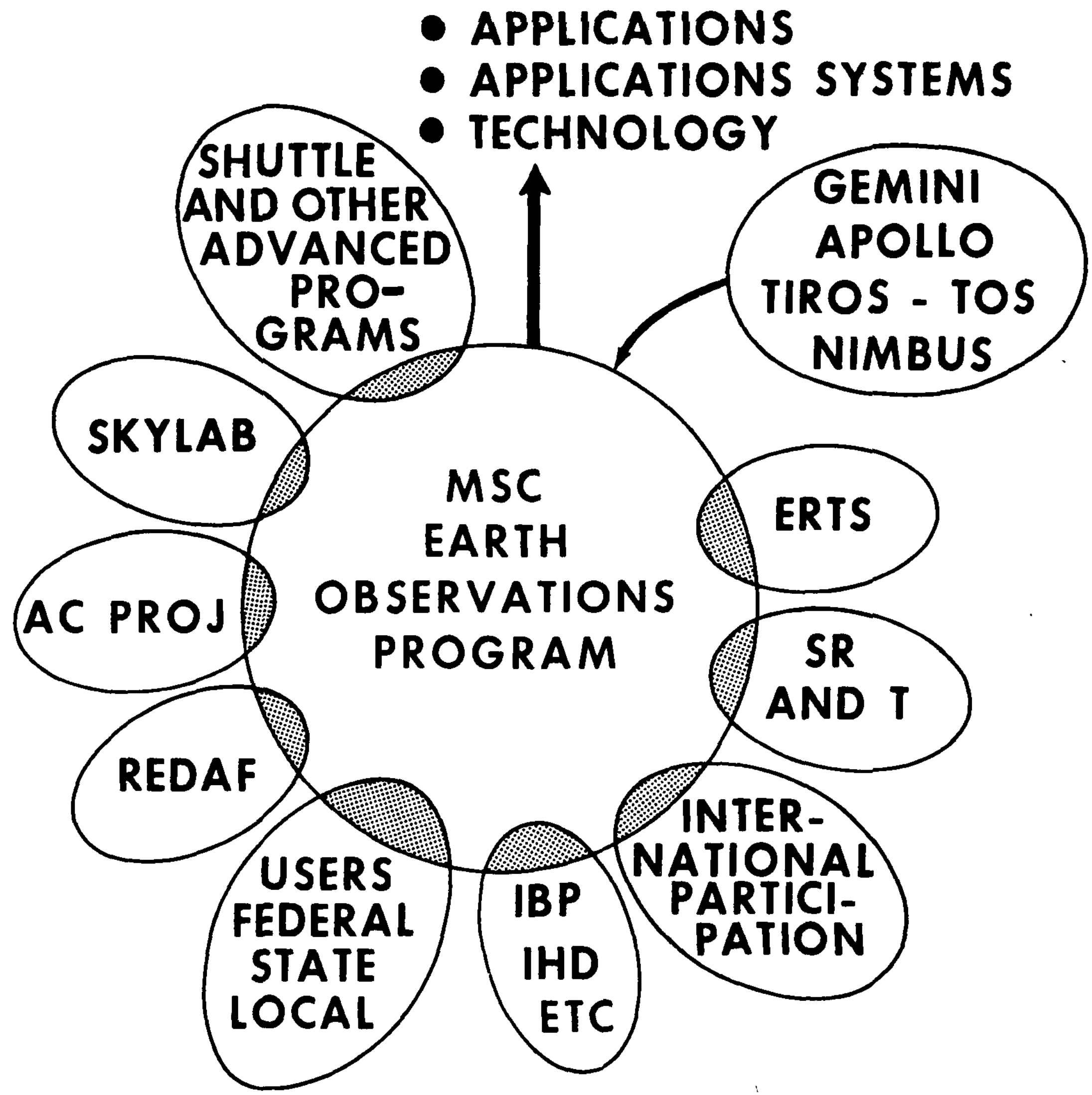


Figure 9.–Other programs impacted.

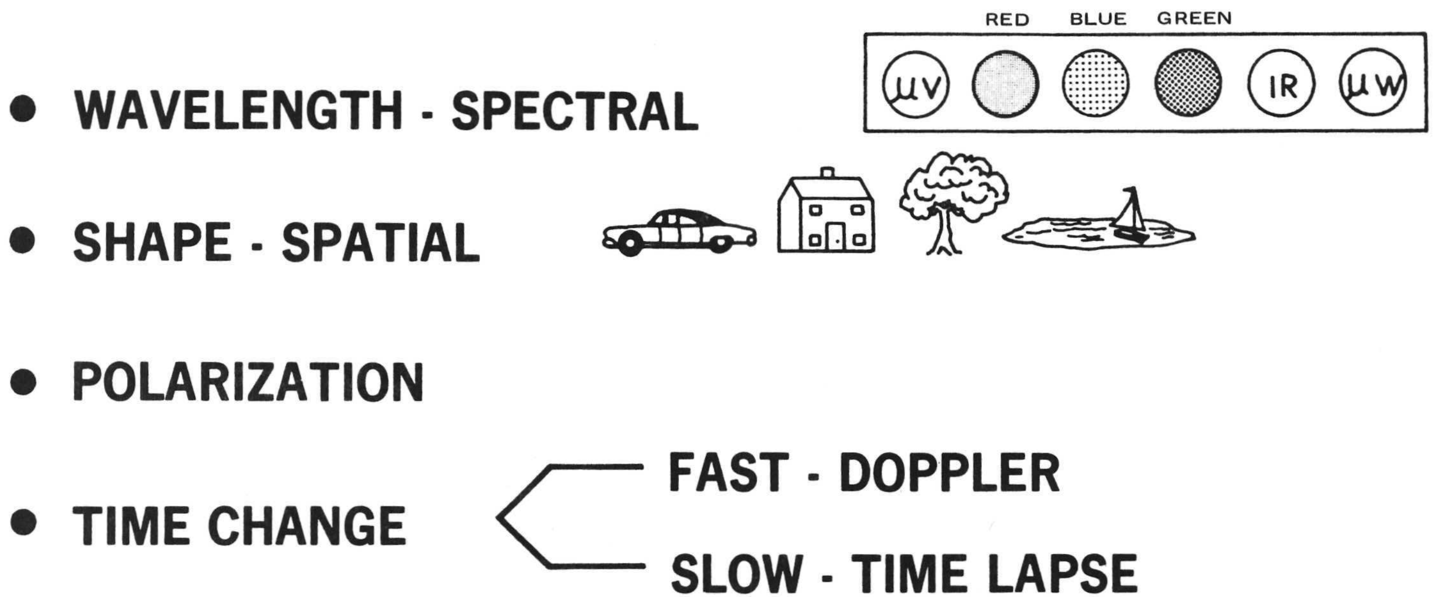


Figure 10.–Information in radiation.

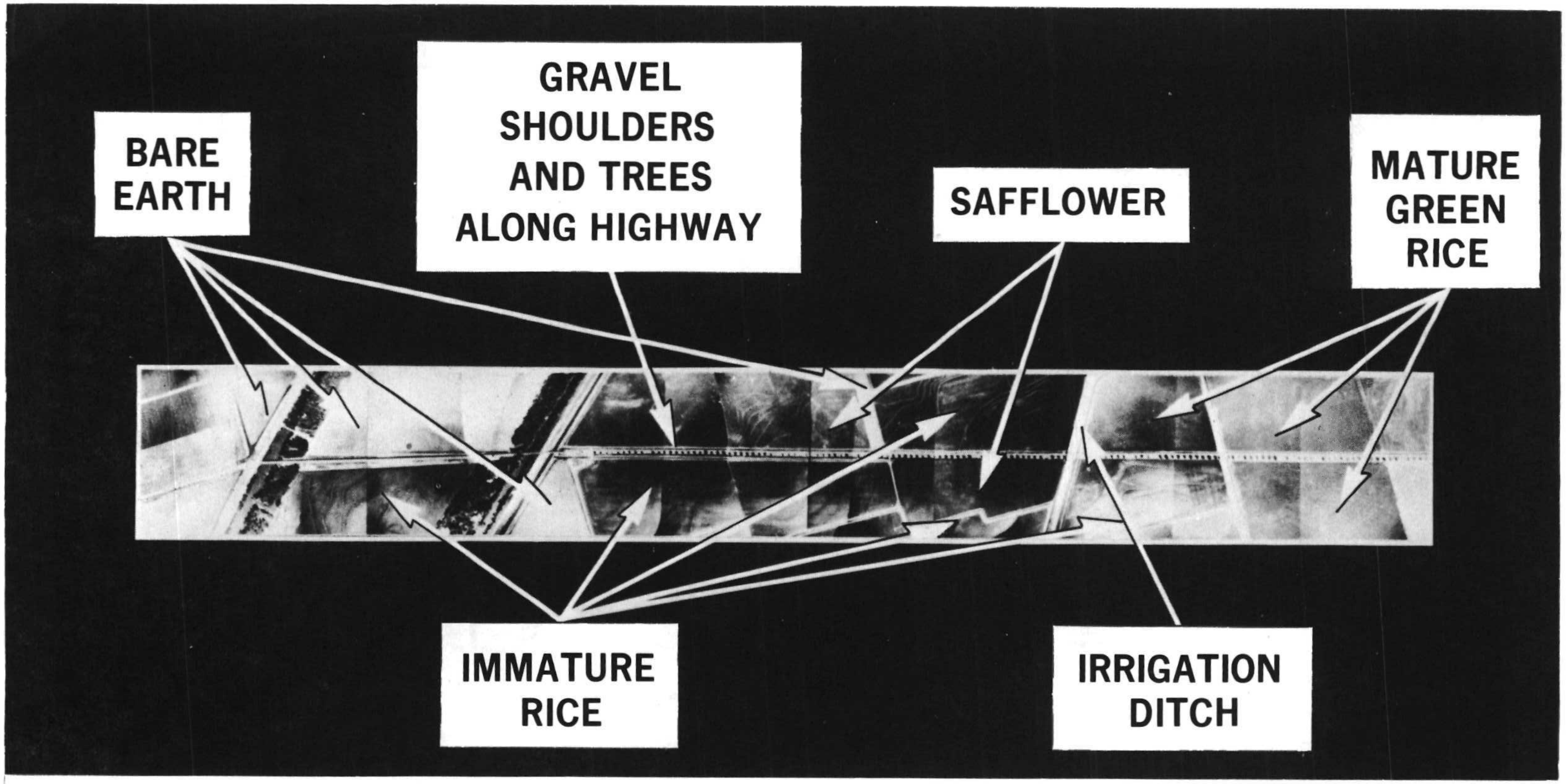


Figure 11.–Panchromatic mosaic of California farming area; May 26, 1966; 1600 hours; altitude, 2000 ft; sky condition, clear and bright, 10 percent cloud cover at 30 000 ft; surface temperature, 27° C; University of Michigan photograph.

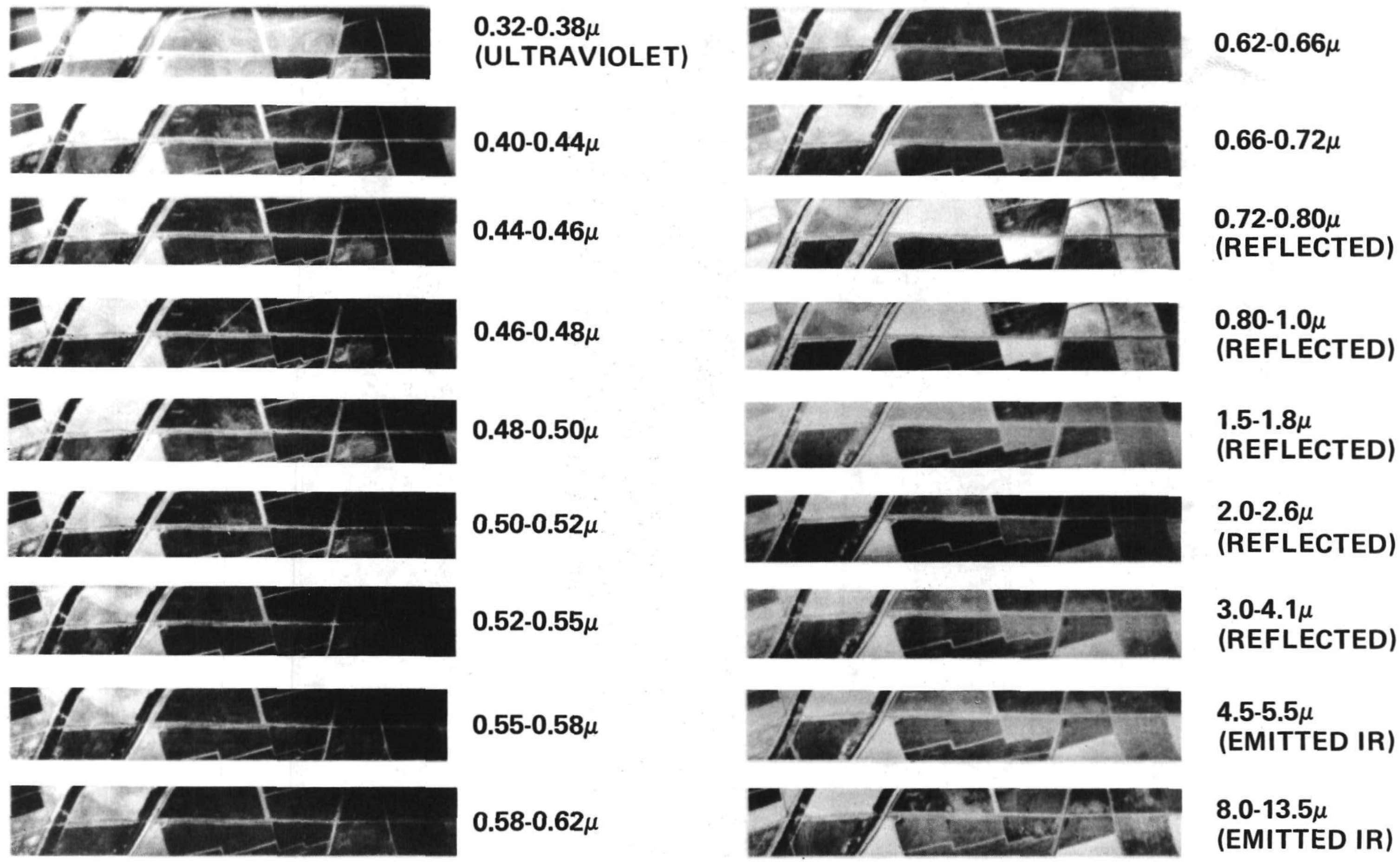
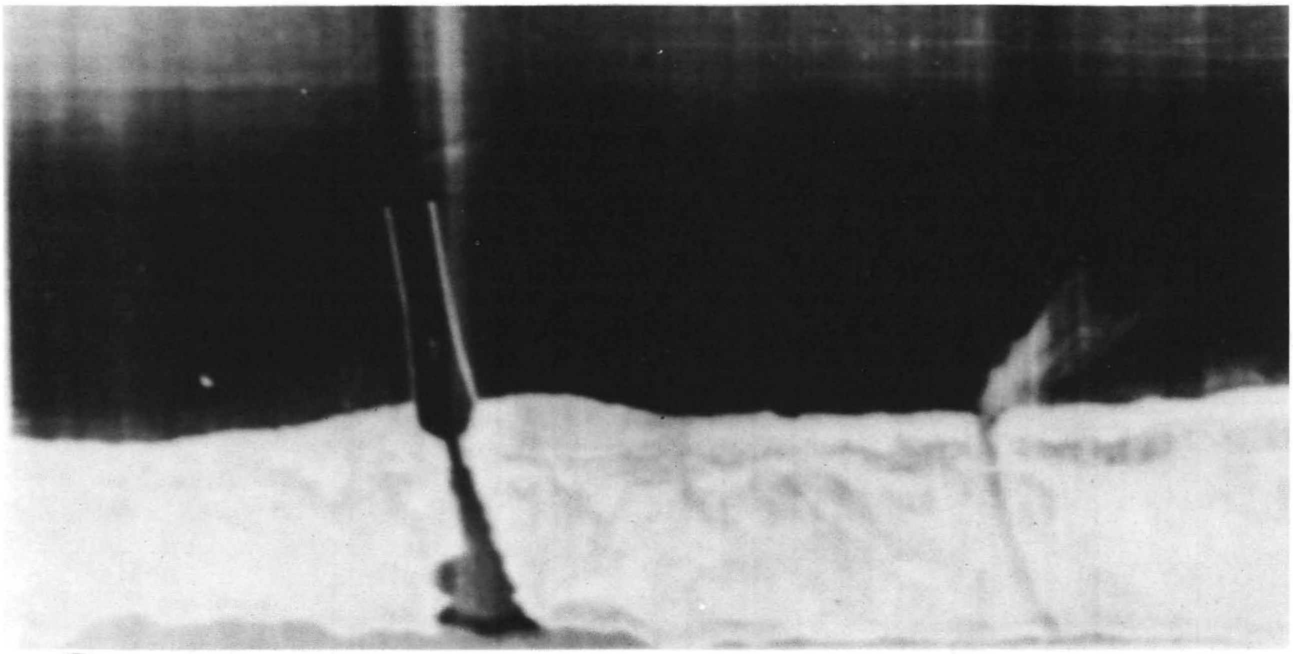


Figure 12.–Multispectral imagery of Davis, Calif., agricultural area. Same conditions as for figure 11.

Figure 13.–Agricultural area, Davis, Calif., recognition pictures; (A) mature green rice, channels 0.46 to 0.48μ and 0.58 to 0.62μ; (B) immature rice, channels 0.48 to 0.50μ and 0.62 to 0.66μ; (C) safflower, channels 0.72 to 0.80 and 0.80 to 1.0; (D) bare soil, channels 0.46 to 0.48μ and 0.62 to 0.66μ.

Figure 14.–Panchromatic photograph (K-2 filter) of Santa Barbara oil slick (University of Michigan photograph).

Figure 15.–Panchromatic photograph of area in Florida where subsurface voids led to subsidence.



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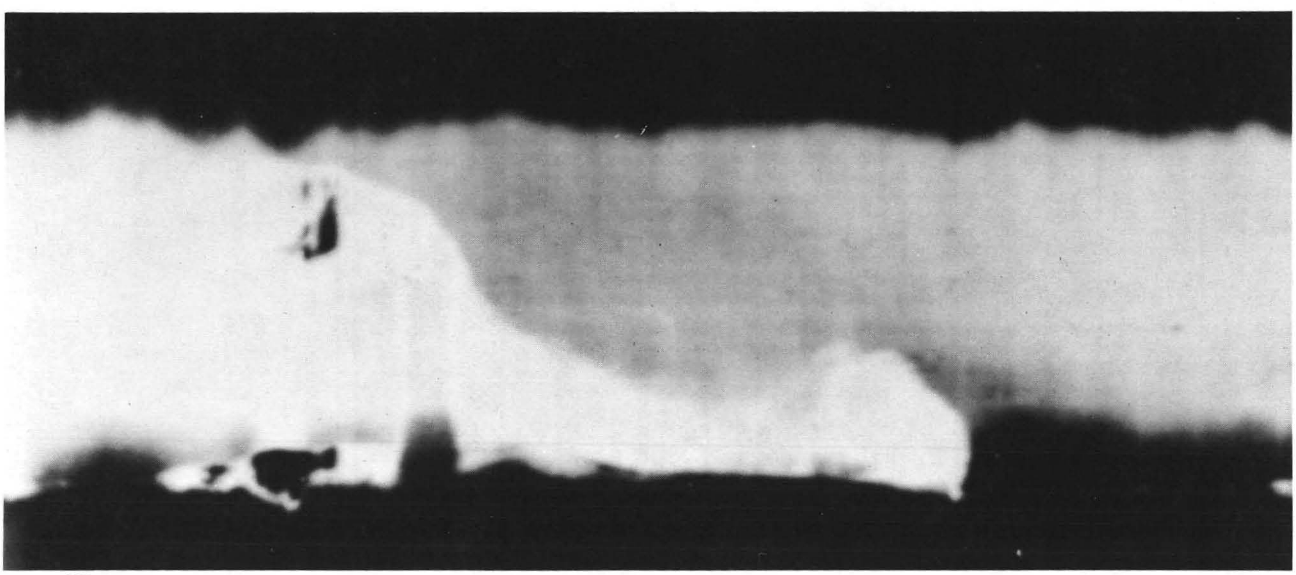

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Figure 16.–Seasonal current reversal detected in Lake Michigan via infrared imagery of warm water discharge. (A) Spring; (B) Autumn.

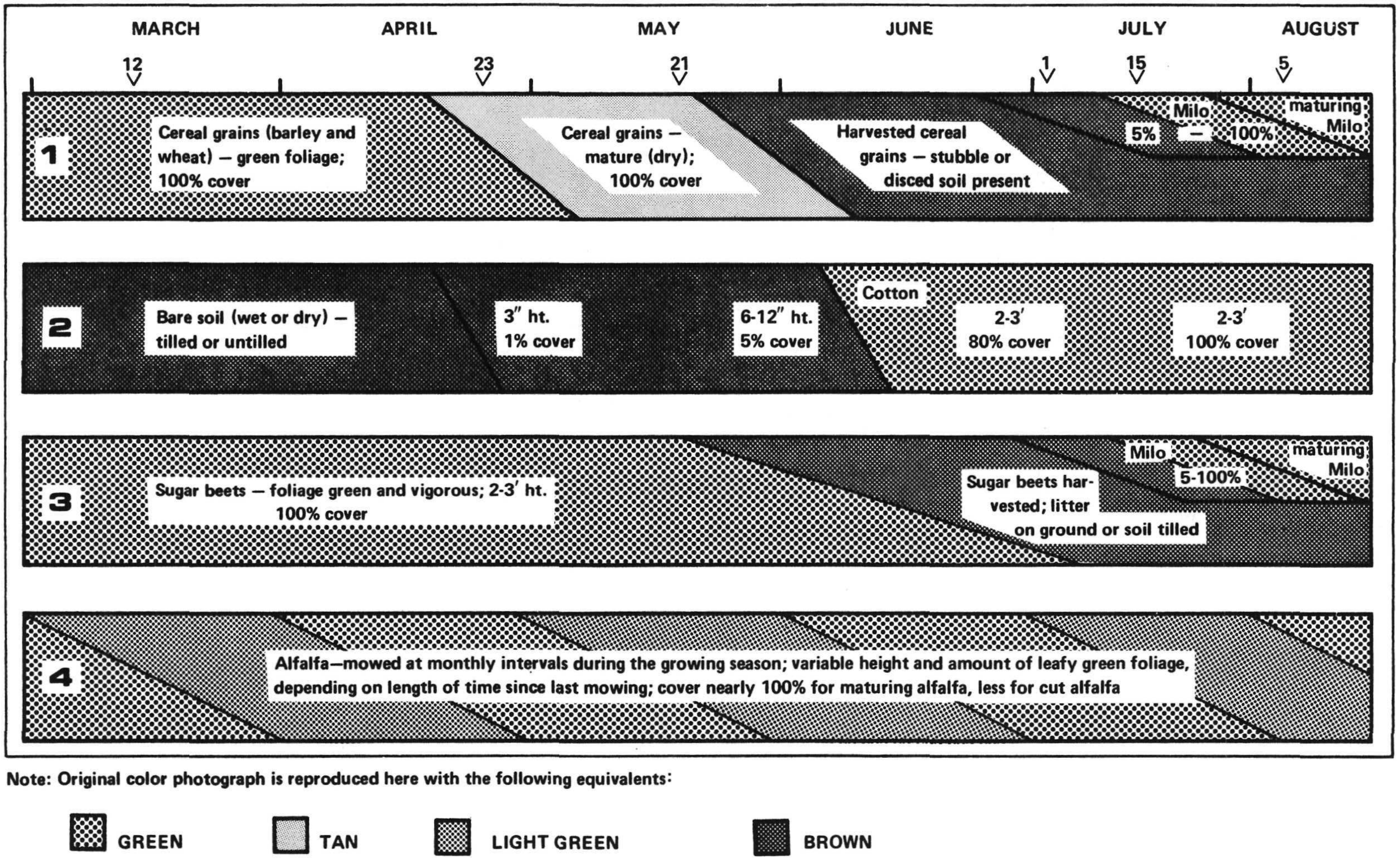


Figure 17.–Mesa test site crop calendar–1969 sequential shading.

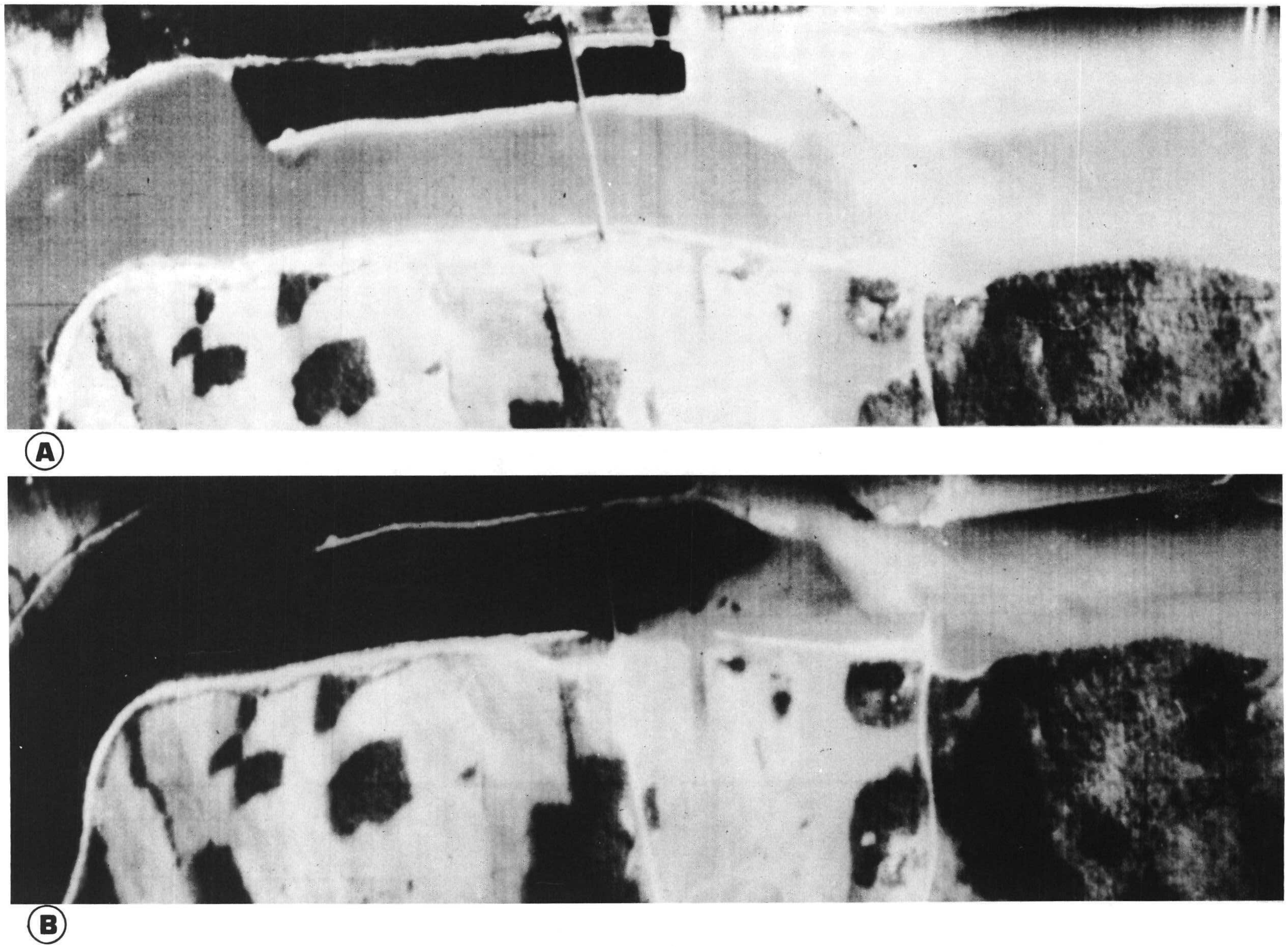


Figure 18.–Power plant site showing advance of upstream cold-water release into river. (A) Sept. 3, 11:15 a.m.; (B) Sept. 4, 10:18 a.m. (8 to 14μ imagery).

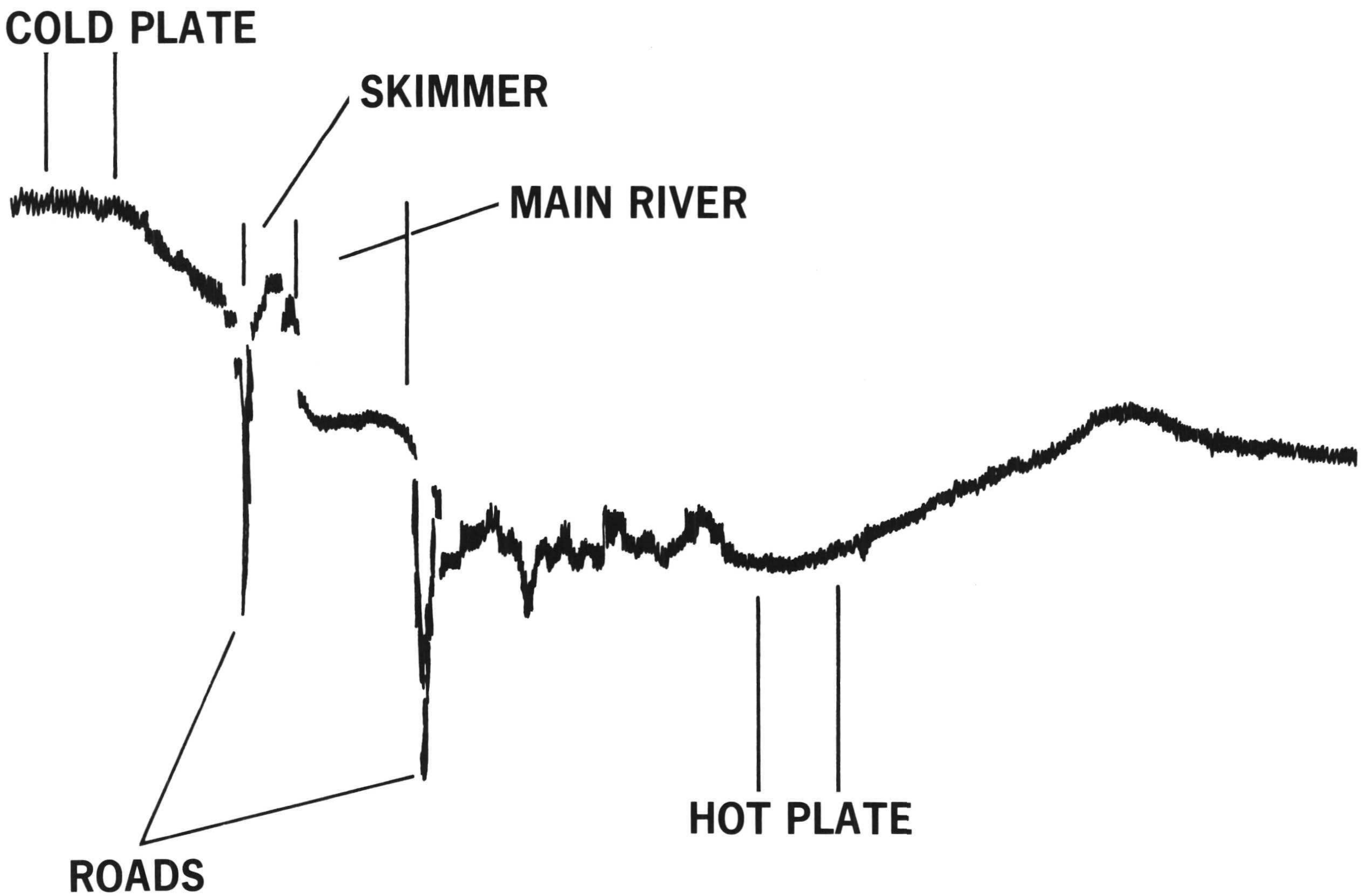


Figure 19.–Densitometer trace across river; see figure 18.

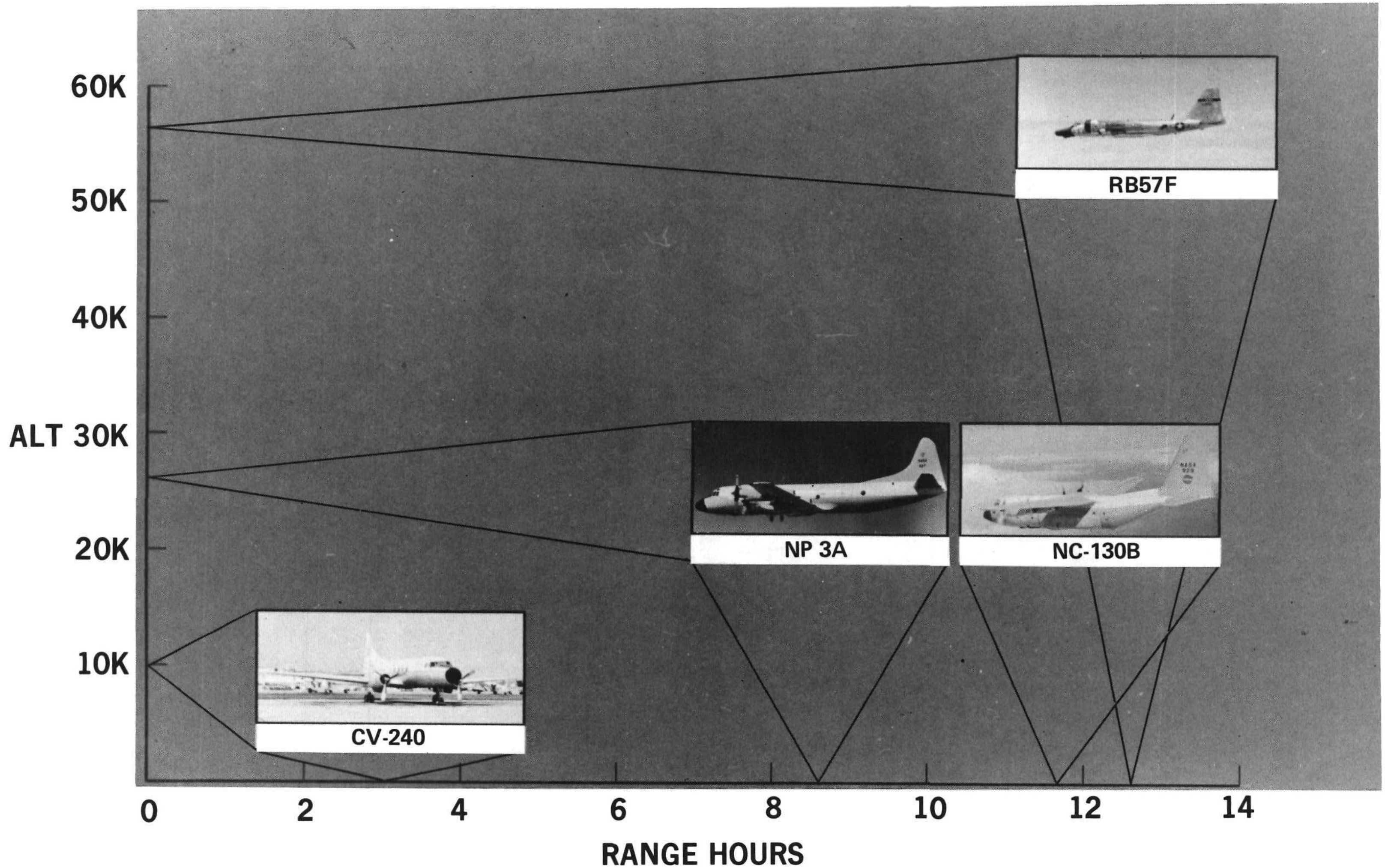


Figure 20.–Aircraft capabilities.

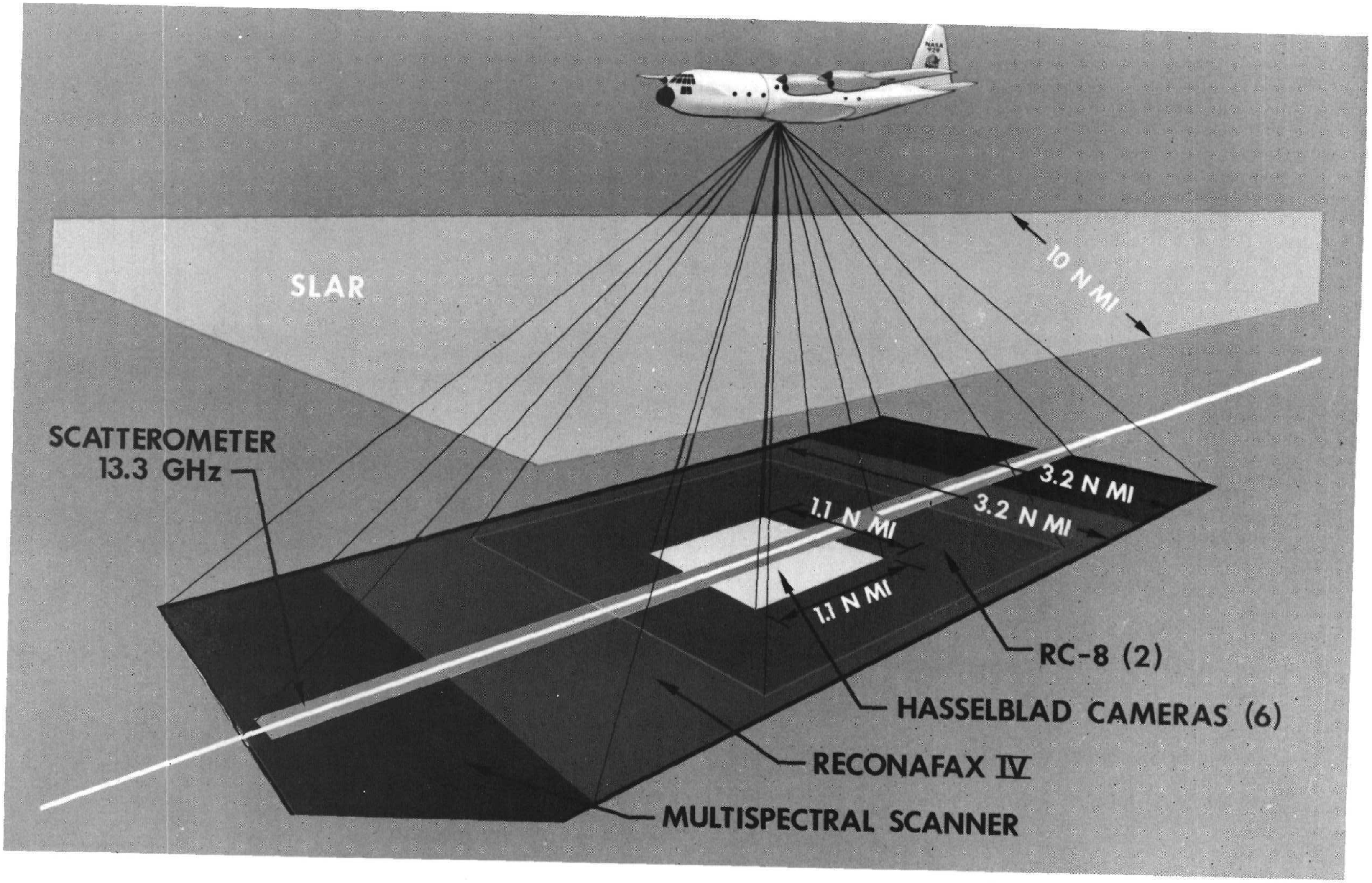


Figure 21.–Lockheed Hercules C-130 coverage at 10 000 ft.

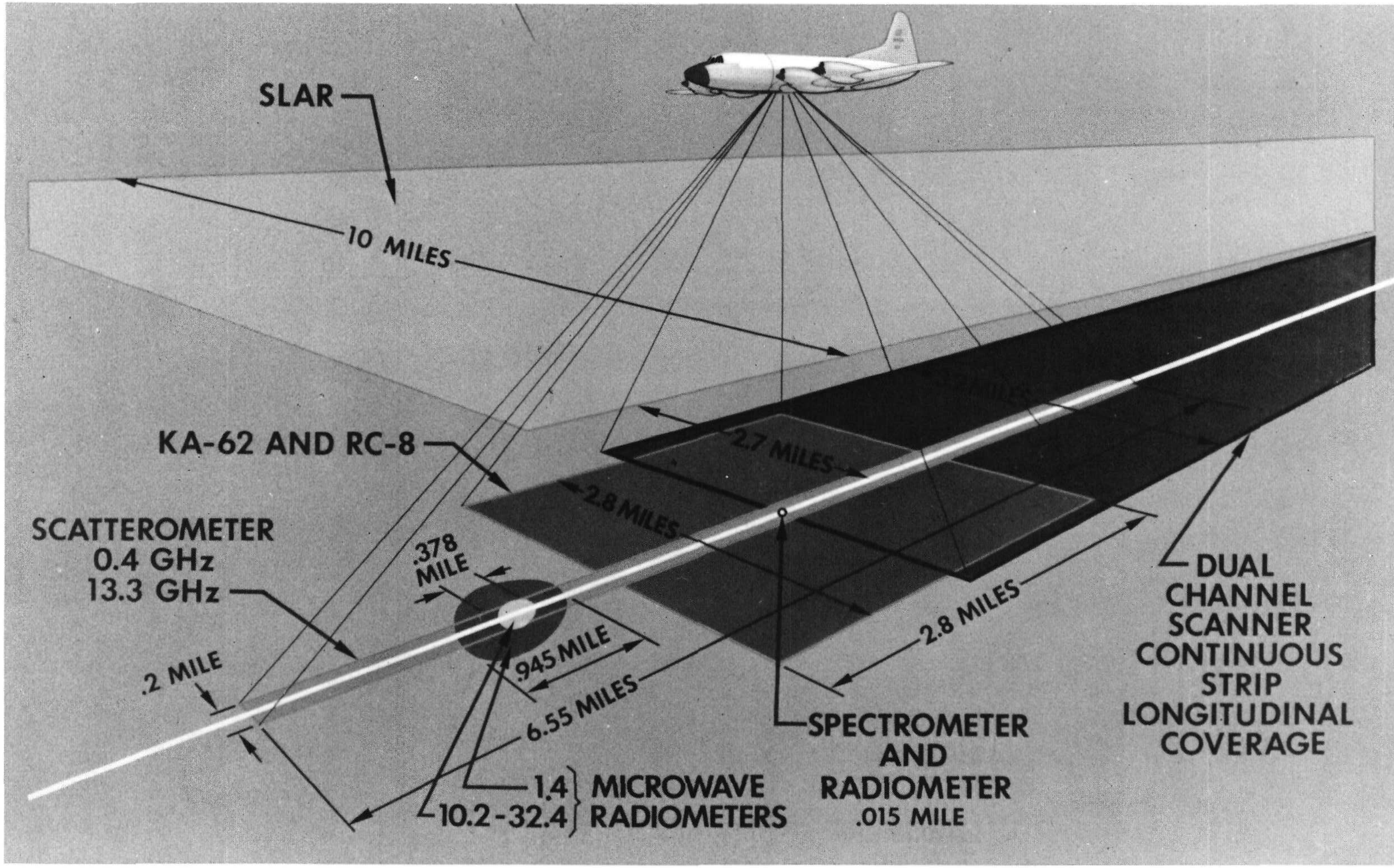


Figure 22.–Lockheed Electra P-3A coverage at 10 000 ft.

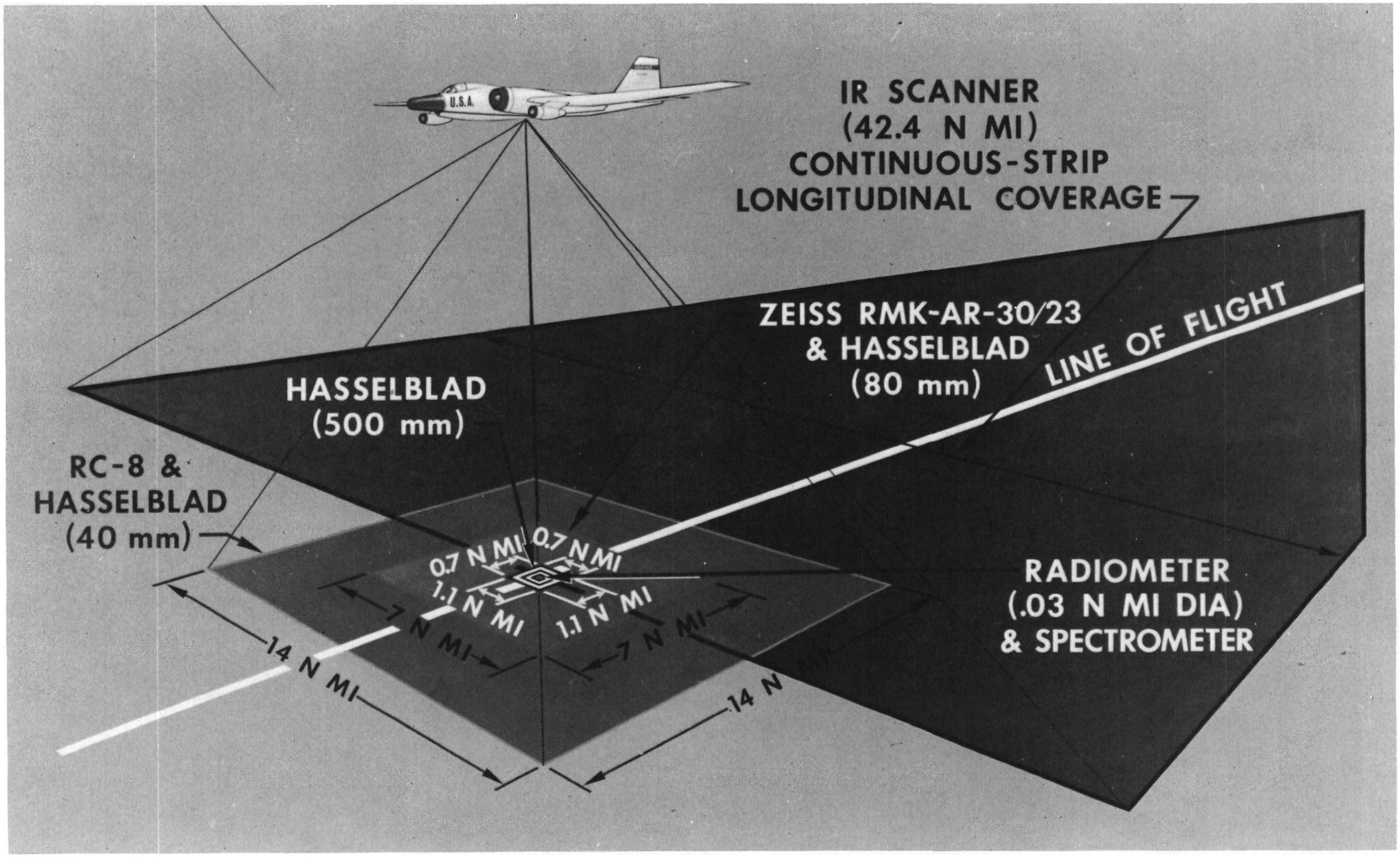


Figure 23.–RB57F coverage at 60 000 ft.

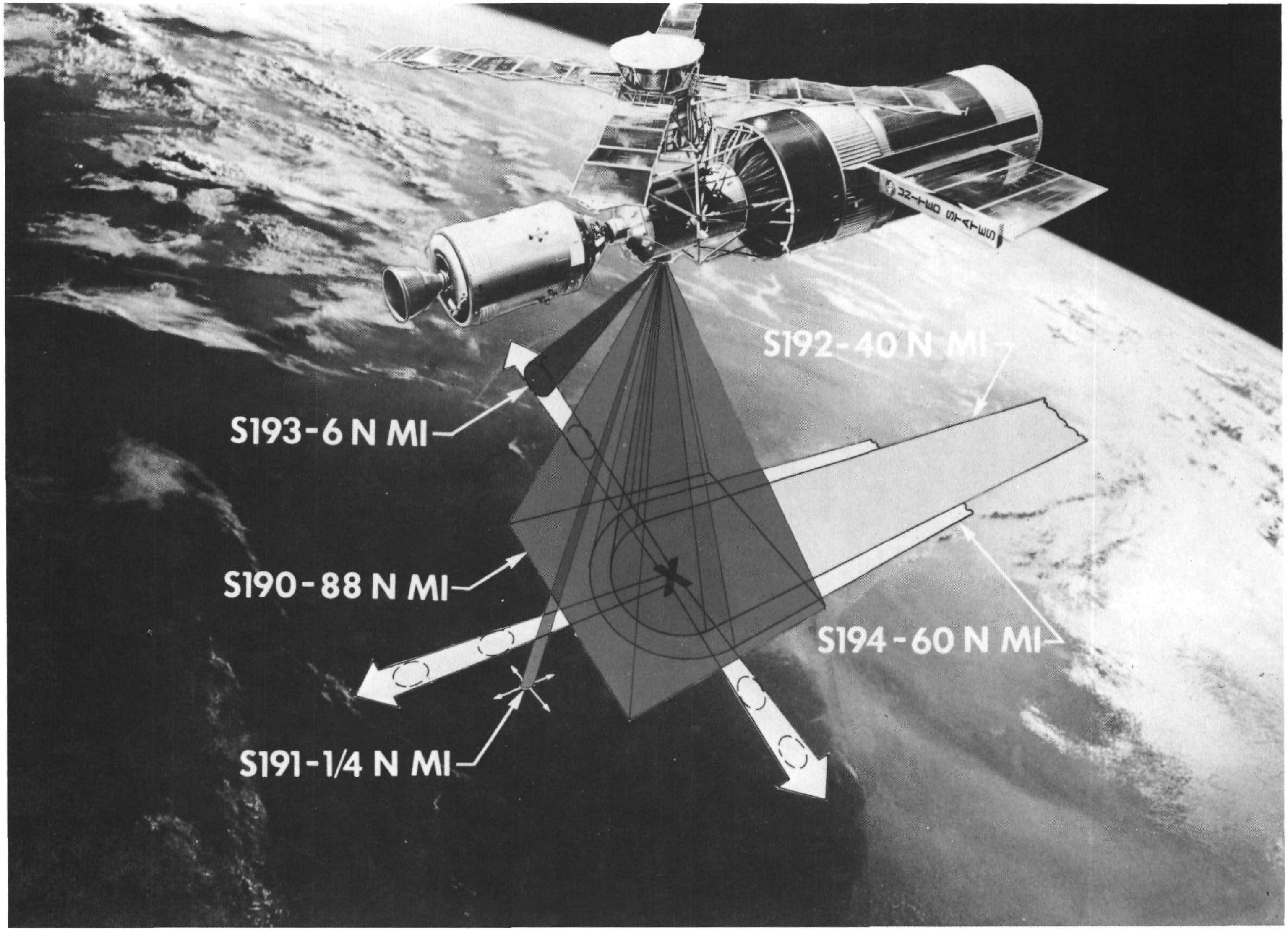


Figure 24.–EREP ground coverage.

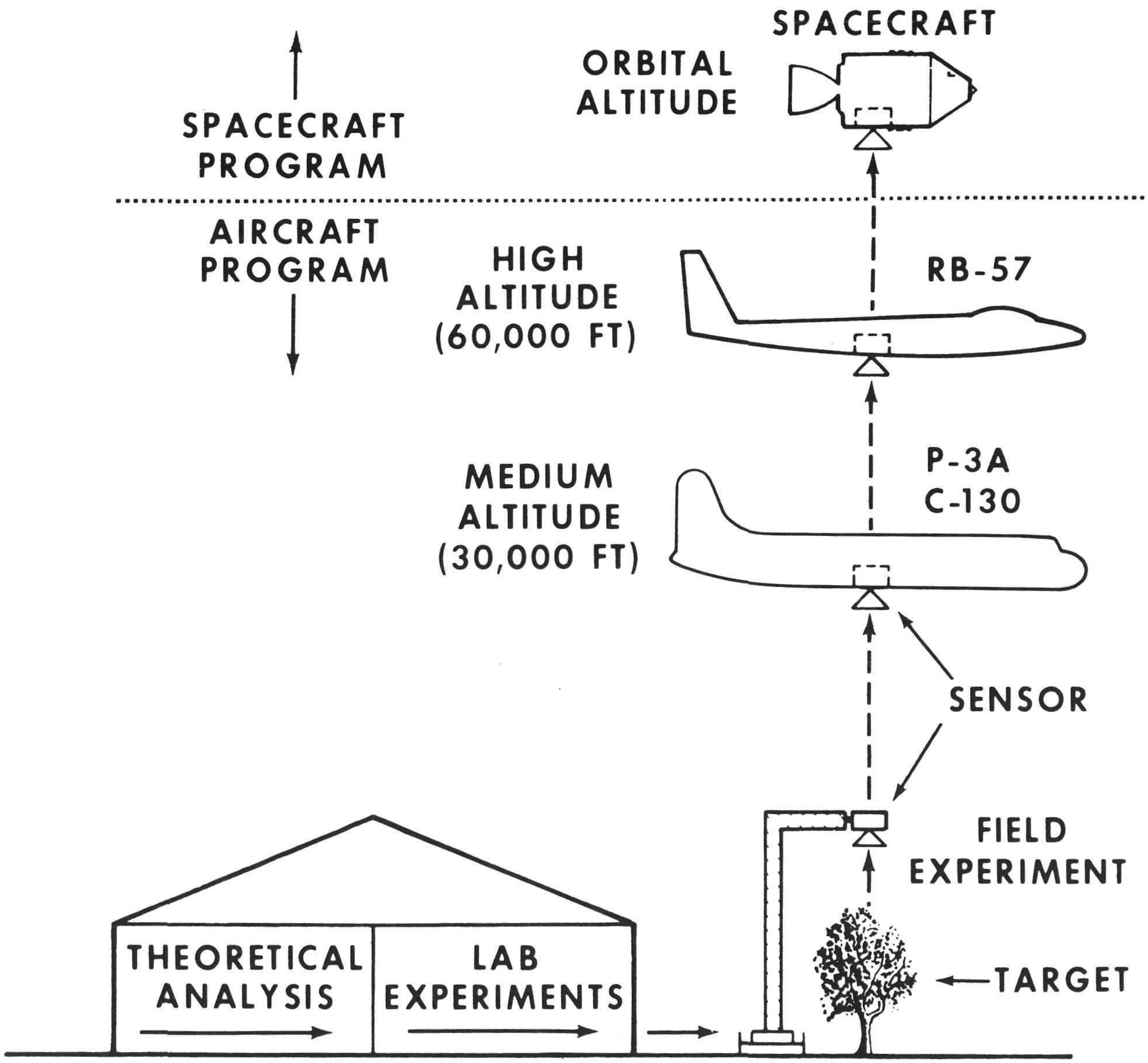


Figure 25.—Development of remote sensor techniques.

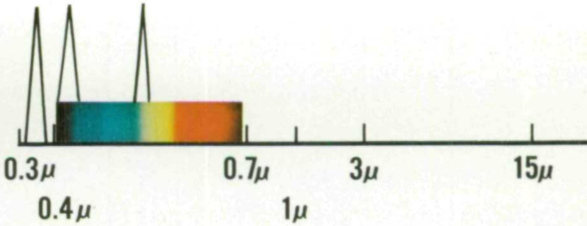


Plate 1.–Agricultural area, Davis, Calif., color-wavelength translation, ultraviolet, visible; blue, 0.32 to 0.38μ; green, 0.40 to 0.44μ; red, 0.52 to 0.55μ.

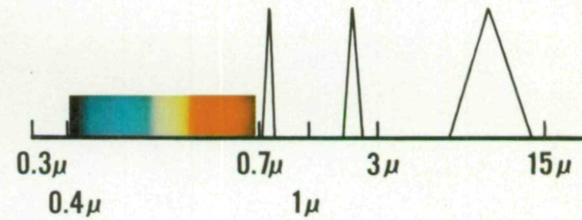
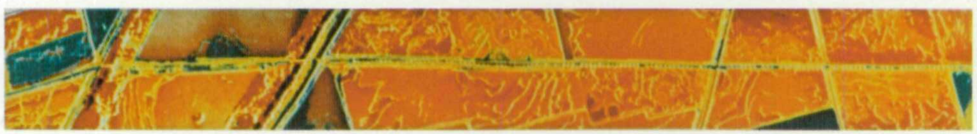


Plate 2.–Same area as in plate 1, color-wavelength translation, infrared; blue, 0.72 to 0.80μ; green, 2.0 to 2.6μ; red, 8.0 to 14.0μ.



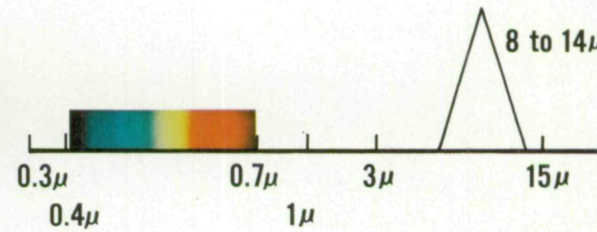
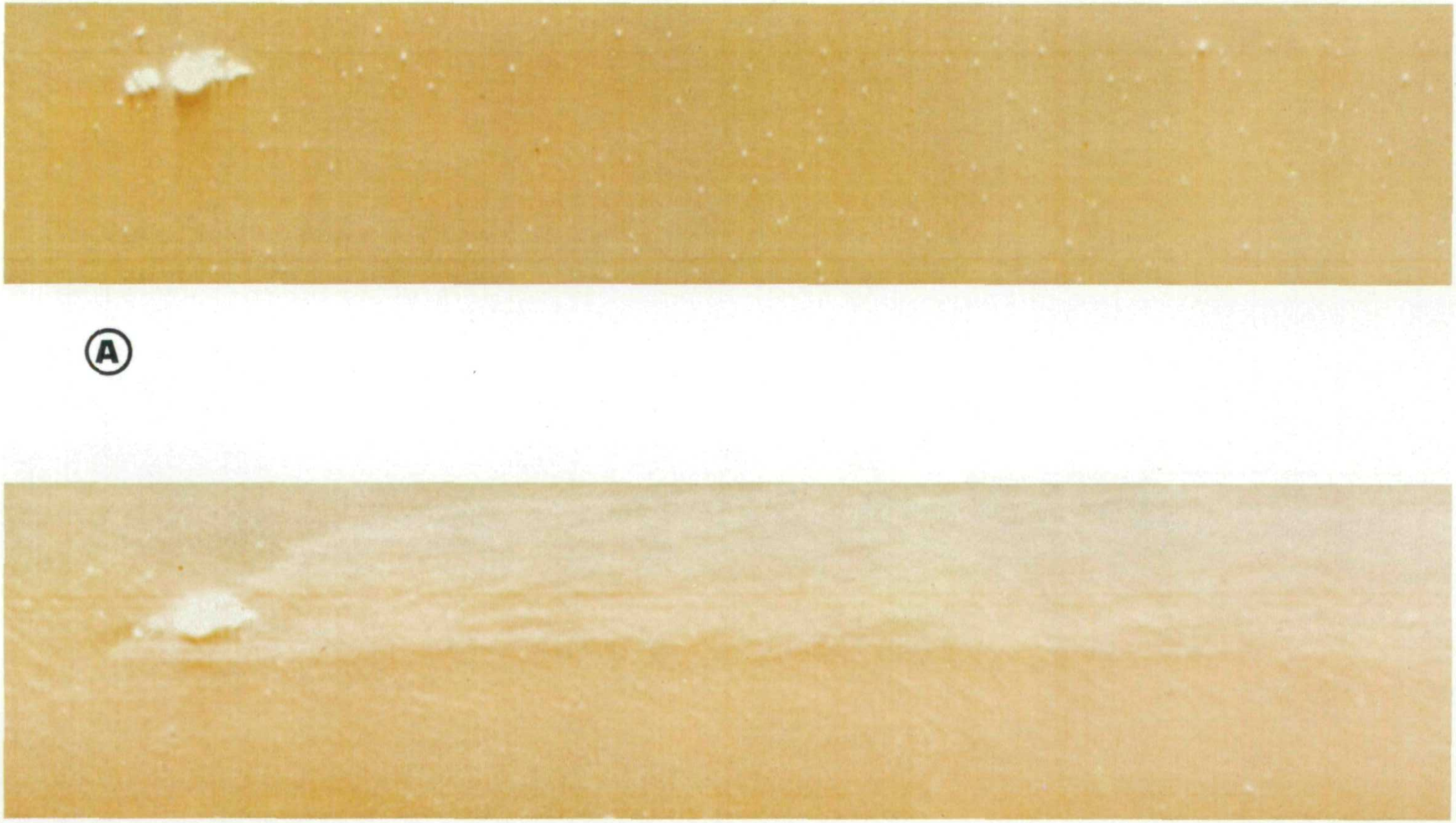


Plate 3.–Same area as in plate 1, apparent temperature is color-coded. Highest temperature is violet. Temperature decreases through the sequence violet, blue, green, yellow, orange, red (wine), brown, black. Black is lowest temperature.

Plate 4.–Same area as in plates 1 to 3 and figure 13; red, relatively mature green rice; blue, immature rice; green, safflower; black, bare Earth.



(A)

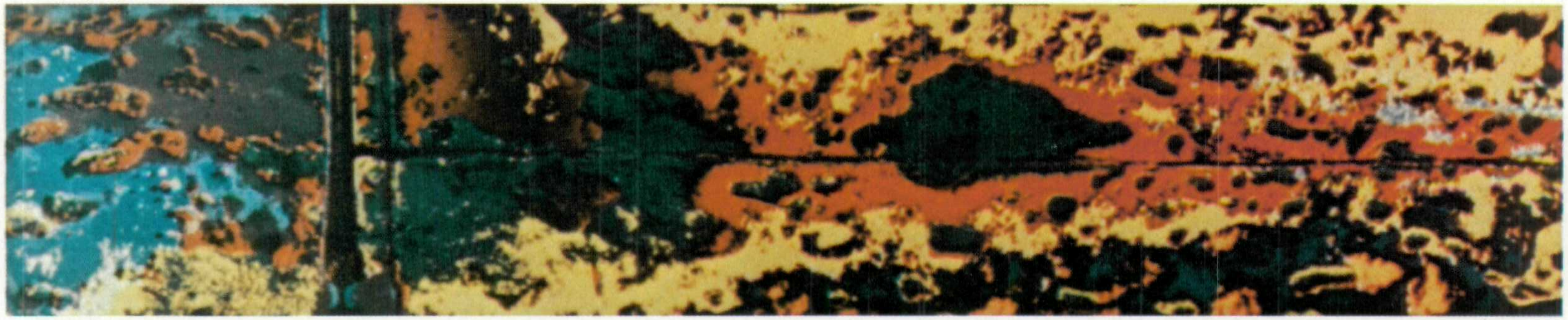
(B)

Plate 5.–Oil does not show in infrared but in ultraviolet is lighter than surrounding water. (A)0.8 to 1.0μ; (B) 0.32 to 0.38μ.

(A)

(B)

Plate 6.–Kelp is brighter than the water in the infrared where oil did not show at all. Kelp is darker than the water in the ultraviolet, in contrast to oil which was brighter. (A) 0.8 to 1.0μ; (B) 0.32 to 0.38μ.



(A)

(B)

Plate 7.–(A)Everglades color recognition map used to determine types of vegetation; (B) Map units 3 and 4 of same area.

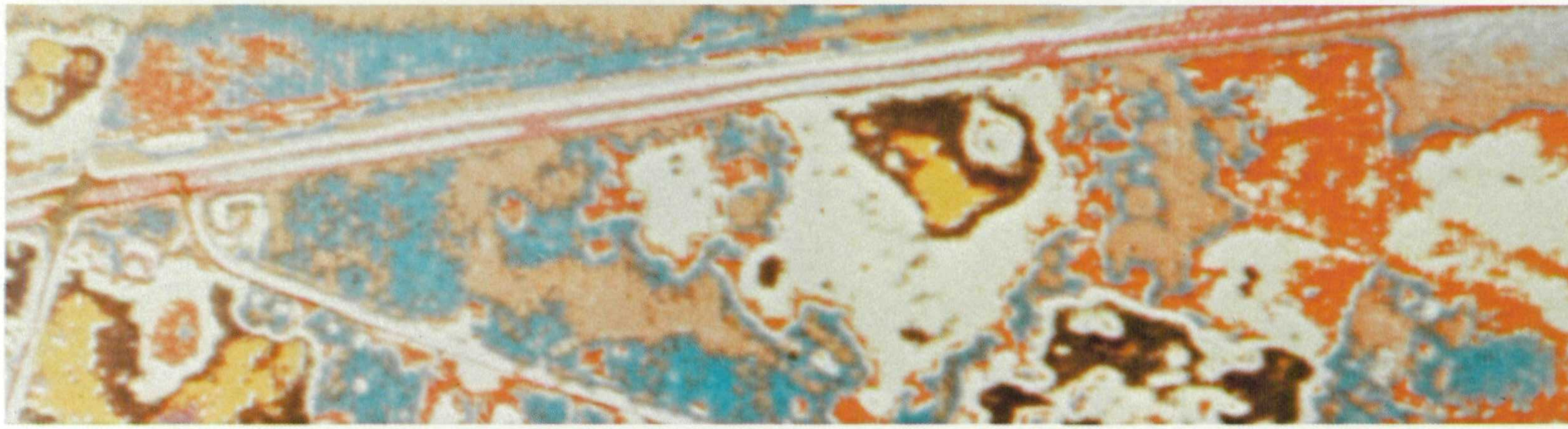


Plate 8.–Infrared photograph showing concentric pattern of changing temperature indicated by color.

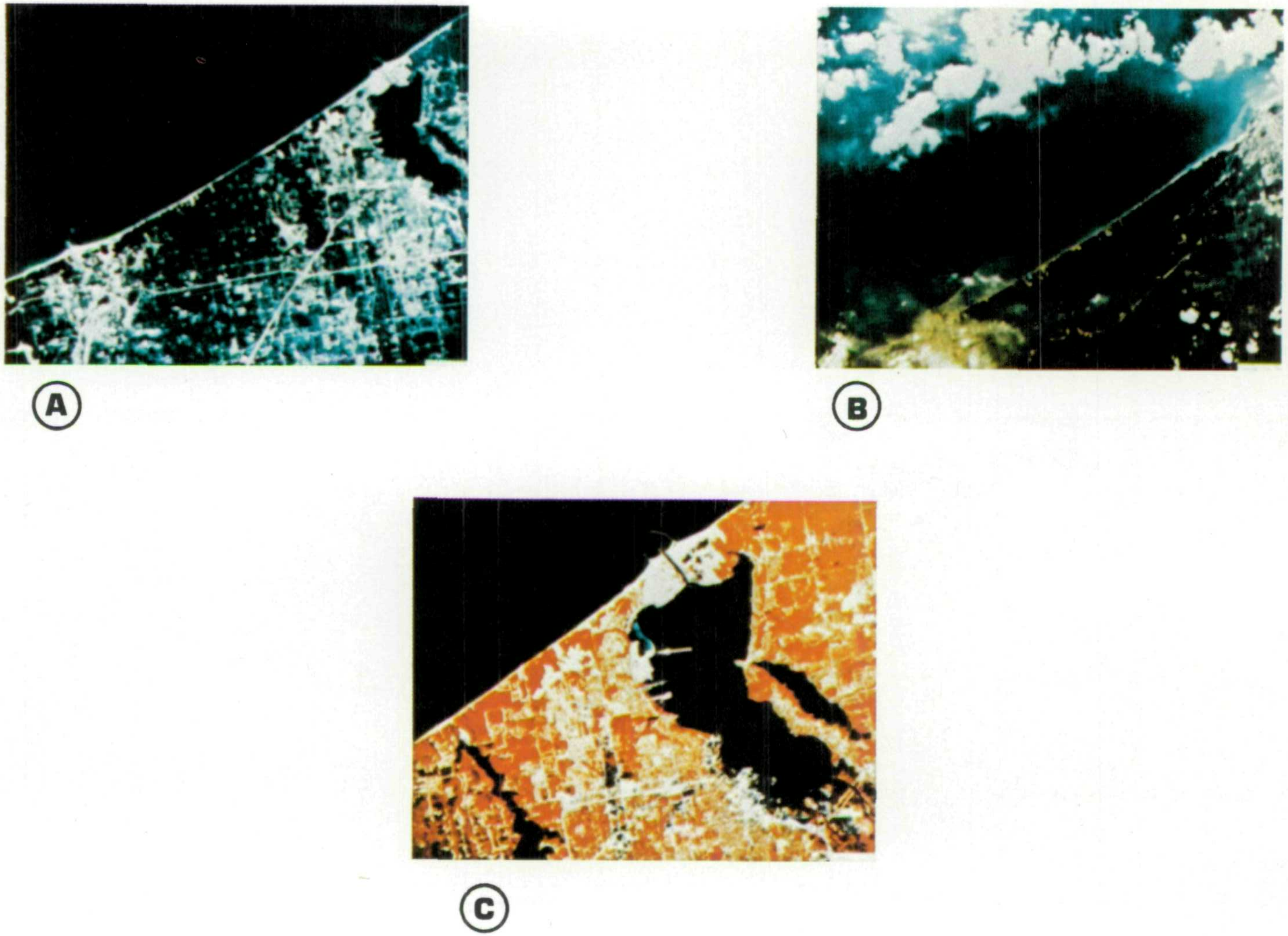


Plate 9.–Lake Michigan pollution patterns. (A) Pollution from urban areas; (B) Southern end of lake showing air pollution and near-shore industrial effluent; (C) Dominant source of pollution due to outfall of papers plant. See also plate 10.

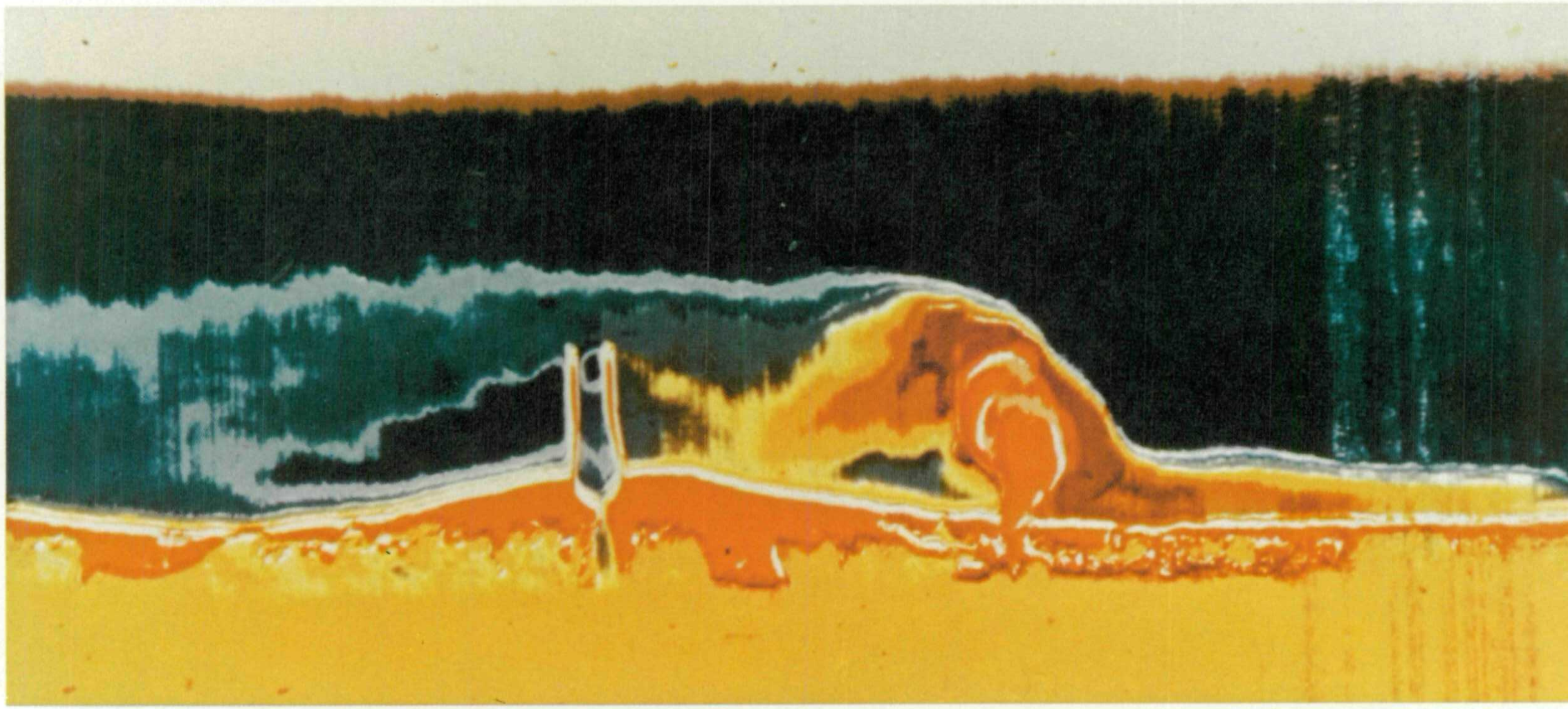


Plate 10.–Thermal enrichment from power plant on shore of Lake Michigan. Color-coded temperature shows mixing zones: Red, 78.7° F; pastel red, 78.2° F; magenta, 77.6° F; sepia, 77.0° F; tan, 76.4° F; orange, 75.8° F; yellow, 75.3° F; blue-green, 74.8° F; cyan, 74.2° F; pastel blue, 73.6° F; dark blue, 73.0° F; violet, 72.4° F.

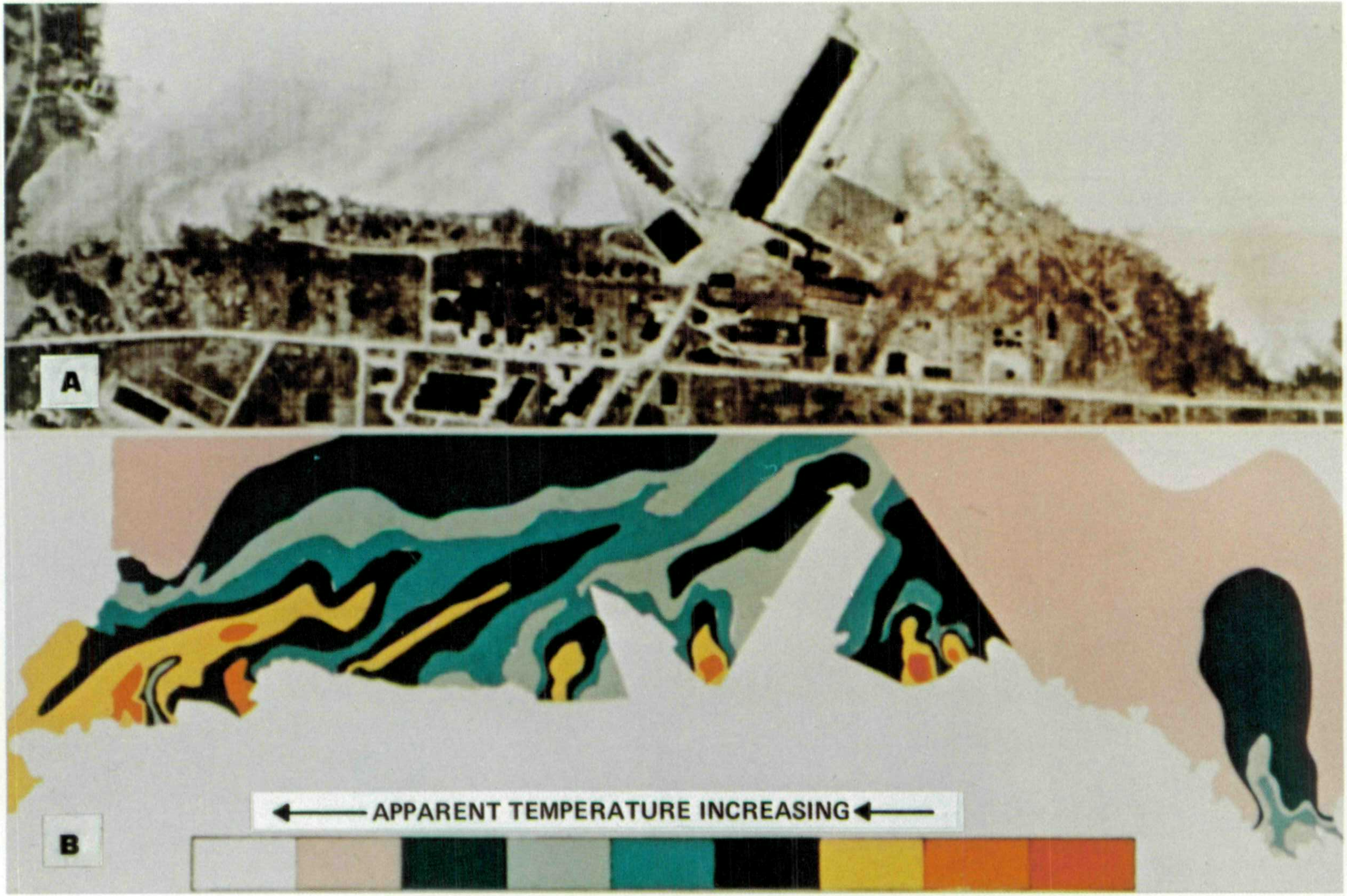


Plate 11.–(A) Infrared image (in the 4.5 to 5.5μ range) of Hilo, Hawaii, showing escape of fresh water (cold) into the ocean. (B) Map showing distribution of film density (apparent temperature), Hilo, Hawaii. Cool water discharge in red, orange, and yellow.

A B C

Plate 12.–Watershed characteristics as affected by urban growth. (A) Photograph of suburban area under study; (B) Recognition map identifying the vegetative, nonvegetative, and water areas; (C) Recognition map identifying important materials.

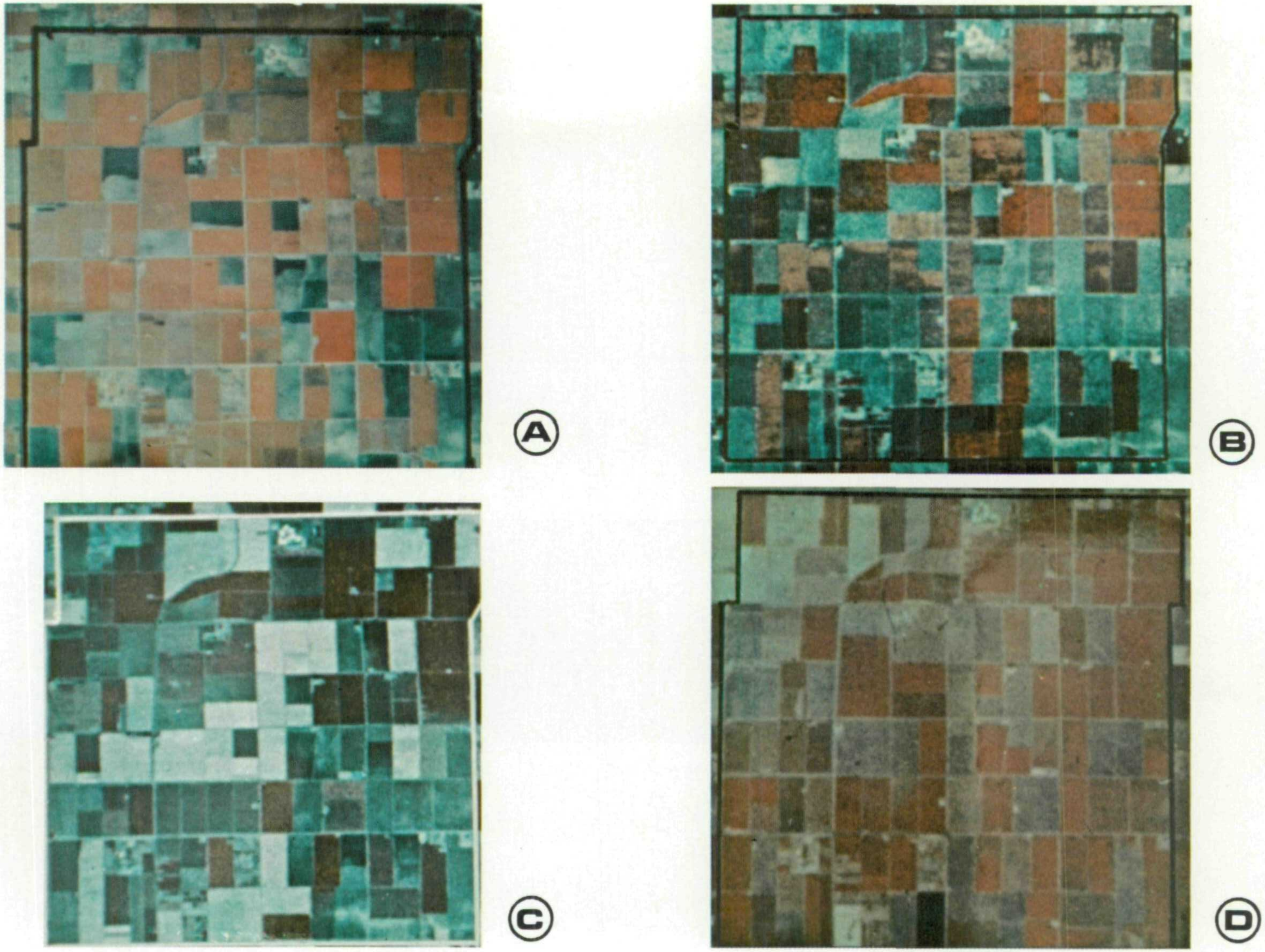


Plate 13.–Infrared Ektachrome sequential photography of Mesa, Arizona, agricultural study area. (A) March 1969; (B) April 1969; (C) May 1969; (D) August 1969.

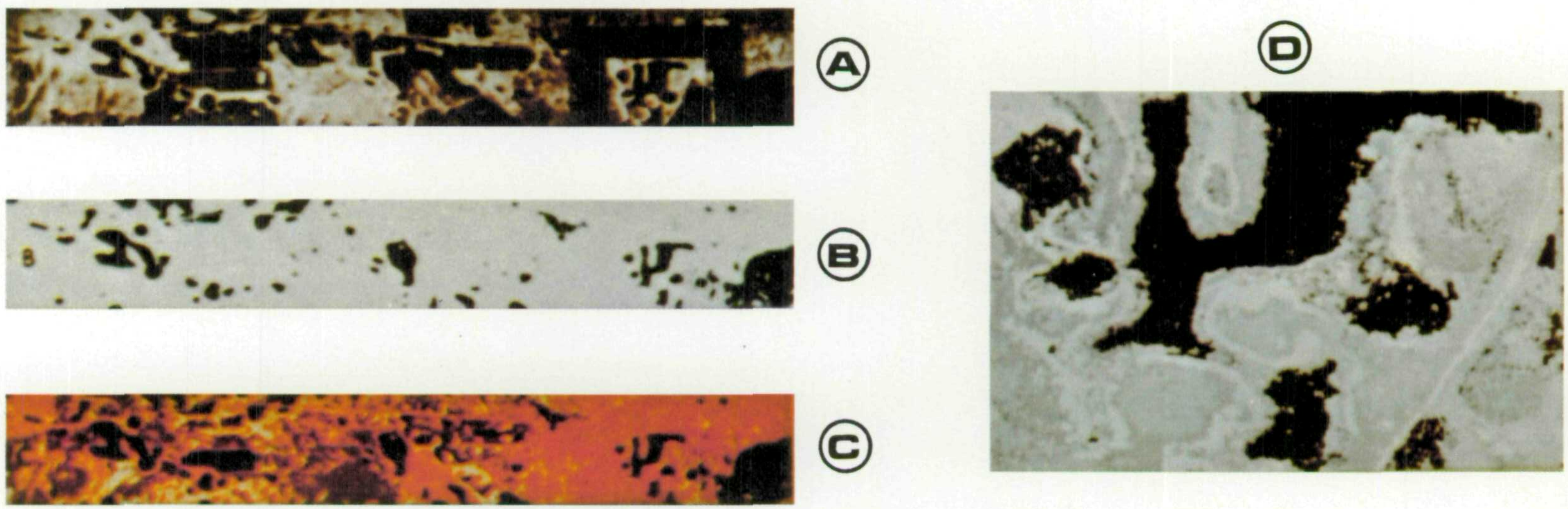


Plate 14.–Wildlife study. (A) 0.8 to 1.0μm imagery; (B) Analog computer recognition map for water; (C) Recognition map for various land-use features; (D) Digital map of water area.