UNMANNED SPACECRAFT FOR RESEARCH

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Introduction

The remarkable achievements of the Apollo Lunar Exploration Program have tended to overshadow unmanned automated satellite flights. It is not always realized that spacecraft operating in earth orbit have already revolutionized global communication, maritime navigation and worldwide weather forecasting. These satellites, the result of NASA's Space Applications Program, are now vital links in a global network providing worldwide services which would not have yet been economically or technically feasible prior to the advent of near-earth space operations.

The Space Applications Program of NASA's defers in a fundamental way from its manned and scientific program. This difference is best characterized by the fact that the Space Applications Program has users or "customers." The users cover an enormous spectrum of our society ranging from Federal Government departments such as Interior, Commerce, and Agriculture to individuals and groups. Both the private sector and public sector are represented, state and local governments as well as airlines and shipping companies. In the last decade we have barely begun to exploit the potential of space applications for our society. As you will hear in the later sessions of this conference, the next decade promises to be a rewarding one, and the returns from our space investment will be substantial.

Space Applications

The two major parts of NASA's Space Applications Program are Communication and Navigation (Comm/Nav) satellites, and Earth Observations satellites. Table 1 lists the seven major applications in each of these categories. The Comm/Nav applications are characterized by the transfer of information from earth to satellite or satellite to earth to be used for a variety of purposes ranging from transmission of telephone and television programs to the precise location of aircraft and ships. On the other hand, the earth observation applications all involve looking down at the earth with sensors onboard the satellite. The sensor data are then transmitted to earth where they are processed so as to obtain useful information. In both cases the customers shape both the character and goals of the applications indicated.

Interestingly, the two application categories besides having different objectives are characterized in general by two different types of satellite orbits. As illustrated in Figure 1, the Comm/Nav satellites are in what we call earth synchronous or geostationary orbits at an altitude of approximately 22 000 miles above the equator. In this particular orbit the satellite's period of rotation is identical to or synchronous with the period of the earth's rotation. Consequently, the same geographical part of the earth remains constantly in "view" of the satellite antennas. By virtue of this unique geometric relationship to the earth, a satellite in synchronous equatorial orbit has operational possibilities not easily realized by other means. It has a constant line of sight for communication to any point on the visible 43 percent of the earth's surface. The ability to connect a single point on the earth to myriads of others that can be simply equipped, and are not necessarily accessible by other means, has an unusual spectrum of applications. The inherent advantages of a satellite system are important for most communication activities and some navigational demands. On the other hand, the earth observation satellites generally have a requirement for observing the whole earth (including the polar regions) on a daily or weekly basis. Furthermore, the sensors onboard the spacecraft usually require a low altitude and a constant angle of sunlight reflected off the earth into the sensors so as to maximize their performance. Consequently most earth observation missions require a polar orbiting satellite so as to get repetitive coverage of the whole earth and to maintain a constant sun angle. This type of orbit is called "sun synchronous."

During the later sessions of this symposium you will hear many presentations on these applications satellites. By way of introduction to these later sessions I would like to give you an overview of these application missions with particular attention paid to how these satellites benefit you and some of the prospects for the future. Perhaps as I review these missions you will discover for yourselves other applications where data from these satellites would be of help to you or your profession or your community.

Comm/Nav Applications

The first application on our Comm/Nav list (Table 1) are point-to-point communications satellites. These satellites provide transmission links for terrestrial communication systems. As illustrated in Figure 2, these satellites provide communication between ground stations in various countries (International Telecommunications Satellite Consortium [INTELSAT I, II, III]) and will shortly provide communication between various cities within a country or between two adjoining countries. Figure 3 gives the projected growth of telephone voice channels during the next decade. This growth in communication needs is now economically satisfied by the use of satellite systems and will result in reduced telephone bills for you and me. Furthermore, television communication for specialized needs can be provided by these satellites. Organizations with major offices spread over a large country or over the globe could use such circuits for many purposes including, for example, management and engineering meetings, television tours of major projects, introduction of new products and services, and instruction of sales and maintenance personnel at field locations. Other potential applications include the rapidly growing field of point-to-point data transmission. Long-distance interconnection of computers and other data-processing equipment is being considered for such purposes as:

1. Information-retrieval systems
   - a. Travel reservations
   - b. Technical literature
   - c. Stock quotations
   - d. Medical information
2. Government administrative systems
   - a. Social Security system
   - b. Internal Revenue Service
   - c. Motor vehicle bureaus
3. Time-shared data-processing systems
   - a. Remote computing
   - b. Remote manipulation of text
4. Management information systems
   - a. Inventory control
   - b. Production control
5. Financial information systems
6. Consumer-data services
7. Remote typesetting

The above gives you a partial listing of the potential applications of this type of communication satellites. Perhaps you can see others.

Another major communication satellite application is the distribution and retrieval of information. Potential users of this type of application in the fields of education, health services, law enforcement and libraries have already been identified. Figure 4 illustrates a medical and health information network. Data from medical libraries, schools, and hospitals could be readily available to a medical center remote from these facilities thus bringing us better and cheaper health services. Another example can be found in the field of education. Education in the U.S. is approaching a crisis where the key issues are cost and equality of educational opportunity. In the past 10 years the cost of education in the U.S. has risen by 160 percent to $70 billion. The student population has grown by 129 percent to 59 million students. Labor costs for education are greater than for any other major U.S. economic sector, with over 60 percent of the total expenditures going for the salaries of the instructors. Furthermore, equality of educational opportunities demands a much more unified standard of teaching and information. These factors point to the need of a unified national or regional educational system. The possibility of implementing an educational communication-satellite system is an extremely promising approach to solving the problem of linking large numbers of widely separated schools, libraries, and information centers.

Another major application of communication satellites is the direct broadcasting television. A satellite system could offer services to areas not presently covered by existing television networks, could extend the number of programs offered (more choice), and could offer special programs of particular significance to various regions of the world. Where wide-area coverage is needed for common program material, a satellite is much more economical of spectrum space than is a terrestrial system. To cover the U.S., for example, with typical stations having only a 50-mile radius takes about 10 channels to avoid interference between contiguous stations. The satellite can accomplish the same task with only one channel. This is a frequently overlooked advantage of satellites, and one that is not trivial, with spectrum space so valuable (Fig. 5).

The average number of channels available to a home receiver in the U.S. is only three. A satellite could profitably add several to this, either nationally or sectionally.

Conventional television stations have difficulty running profitably if they are devoted to educational and instructional programming in the broadcast sense. By extending the coverage cheaply, and thereby expanding the audience to whom the program material is directed, a satellite system appears to be natural for the complex of programming called public television. Included within this elusively defined class would be public-interest broadcasting, cultural and educational material, and even instruction in the scholastic sense. Such a system is technically possible in a variety of realizations. The obstacles are largely social and political. The question as to who would originate and control program material is, therefore, a thorny point.

Figure 6 illustrates the use of educational broadcast television to a country such as India with its vast population and lack of trained teachers. An experiment such as this will be tried with India, using NASA's Applications Technology Satellite (ATS) to be launched in the near future.

Figure 7 illustrates the use of satellites to relay data from various collection stations or platforms to a central processing facility. This type of data relay is particularly important where the data being taken are perishable. A data collection satellite can serve the purpose of complete, real-time, synoptic reporting by transmitting such data to a national or a regional processing center. Environment forecasting services alone are expected, for example, by 1975 to encompass 4100 land stations, 885 marine vessels and weather ships, 500 buoys, one or more satellites, and 4500 balloons. Approximately 6000 platforms provide agriculture and seismic data and approximately 10 000 platforms are envisioned for marine oceanographic and hydrological data. This large volume of data traffic makes the use of a satellite economical and provides for a far faster, more efficient service to the users of these data.

Figure 7 also illustrates the use of a satellite for air traffic control, collision control and navigation. This also will be a very important use of satellites in the next decade.

Earth Observation Applications

The NASA Earth Observation Program is designed to improve methods of gathering data on our atmosphere and resources by remote sensing from automatic, earth-orbiting satellites. This program will deliver direct benefits to most Americans by improved weather forecasting and by helping to survey our limited natural resources, such as food, water, fish, minerals, and oil, and by contributing to their improved management. As a growing American population with greater expectations of a higher standard of living consumes more resources, occupies more living space, produces more waste, and puts more pressure on an already fragile earth environment, it becomes more important and finally crucial to manage the available resources effectively. The earth resources satellites are an essential tool, one of many in the national earth resources program whose objectives are to discover resources, improve the management of others, conserve those we have, and help to apply them for the public good.

The program is based upon several years of interagency cooperation. Many kinds of sensors for different users have been flown in aircraft over known test sites and their observations checked with the known surface vegetation and features. For several years, the Department of the Interior and the Department of Agriculture have been preparing requirements and testing applications. The Bureau of Land Management, custodian of the Nation's public domain, is interested in improved surveys of land use. The Bureau of Commercial Fisheries is measuring ocean color to find fish. The Forest Service wants better ways to survey forest infestations. The Bureau of Reclamation needs comprehensive water inventory data.

Visual photographic interpretation techniques are well established, although in photographs taken from aircraft the various species of flora tend to blend together. Crops and trees usually cannot be identified when viewed remotely in the visible portion of the spectrum. Tone and texture differences are revealed, however, when visual images are compared with images produced by sensors tuned to other wavelengths. Such multispectral sensing can identify and distinguish various species and varieties of plant life. Similar multispectral techniques may be used to distinguish healthy crops and trees from diseased or infected ones. Diseased or stressed plants reflect or emit different electromagnetic radiation than vigorous plants (Figs. 8 and 9).

When used together with visual imaging, data from new sensors, especially infrared, are expected to assist in a wide variety of interpretive studies, including identification of crop and timber species, analysis of crop vigor, estimation of crop production, and early detection of plant disease and stress over wide areas of farmland and forests. Remote sensing will simplify and make accurate the prediction of seasonal changes, and the assembling of statistical data on large-scale changes such as a function of planting, fertilization, and irrigation practices, and the gathering of inventory data.

Imagery from earth resources satellites can be used to construct land-use maps, make soil surveys, assess cropping practices and range conditions, and predict agricultural yields. Such crop information will become important as food production is increased to feed growing populations. Tomorrow's farm manager may be able to find out more about his operation from remote observations than by walking through his fields.

Similarly, public land managers can benefit from satellite observations of the public domain. Public lands and national parks and forests comprise 175 million acres in the U. S. and 289 million acres in Alaska. These lands are a resource base for the future. Today they are yielding income to the nation from oil, gas, forest products, and recreation. These lands also support about 7 million head of livestock and nearly 3 million big-game animals. Conservation of these resources helps support the $20 billion per year outdoor recreation industry.

The data-gathering potential of remote sensing from space will assist the Department of the Interior in administering these public lands and preserving their ecology. Studies of changing features or conditions such as grassland status and foraging patterns could be supported by synoptic observations from space. Environmental management can also benefit from timely and reliable, satellite-derived information on the distribution, health, and vigor of vegetation, and measurements of snow accumulation and glacier movement.

The geologists' chief information tool is the geological map which shows the distribution of rocks exposed at the earth's surface. Now, in addition to aerial photography, geologists will have available the big, synoptic view offered by remote sensing. These systematic space pictures will offer geologists a broad, integrating panorama from which they can select observables of interest for closeup looks by aircraft or ground parties. The advantage offered by observations from space is that aircraft or prospecting surveys can be directed to specific areas of interest.

Known relationships exist between concentrations of mineral and fuel resources and particular geologic features. Petroleum and metallic mineral deposits, for example, are frequently found near structural features such as folds or faults. In a space photograph, part of an entire mountain range could consist of a series of folded rocks, and in the series of folds might lie an anticline or dome which could yield oil. Aerial photographs have been used to identify such features, but pictures from orbital altitudes have proven superior for viewing the larger linear geologic features. A new fault system in southern California was first discovered in space photographs. Geologic features and faults are even more obvious in radar images than in visual pictures. Radar also penetrates clouds and haze, and can be used during nighttime (Figs. 10 and 11).

The conservation and utilization of water supplies is the responsibility of the Department of the Interior, of which the Survey is a part. No other resource commands a comparable percentage of departmental time, funds, and talents. Department water management activities include the mapping of water, studying its properties, predicting its behavior, impounding it, diverting it, desalinating it, and using it to create electricity, fish and wildlife habitats, and recreation areas. In addition, other agencies such as the National Weather Service also collect hydrological data.

Performance of these functions can be improved by the use of remote sensing. When earth resources satellites join this collection network, large-scale, repetitive imagery of water systems will supplement the point data already being taken. In addition, the network of automatic sensors in rivers and lakes will radio measurements to the satellites. The automatically repetitive feature alone is very valuable since hydrology is a data-dependent natural science, and its data are highly perishable. An operational system promises global, synoptic, repetitive, and real-time coverage of major aspects of the hydrologic cycle.

A new order of water resource inventory will be achievable. The available water in an entire river basin or lake system, for example, can be monitored repetitively. Repeated observations in the visual, infrared, and microwave regions of the spectrum can be made of snow, glaciers, and ice accumulations and melting patterns. These changes can be monitored during the seasons of the year over areas too large to survey by conventional means. More accurate predictions of runoff can be made. These forecasts, in turn, will enable hydrologists to better regulate the impounding and release of water in reservoirs. Programs such as flood control, irrigation, and power production, as well as water for urban and industrial consumption, can thus be better managed. Improving the basis for water management decisions will produce measurable economic benefits (Figs. 12 and 13).

In addition to reporting water inventories, remote sensing may help to reduce water losses. Underground fresh water is being lost to the sea. Aerial infrared detectors flown over the coast of Hawaii show 250 underground springs discharging fresh ground water into the ocean.

Cartographers are constantly searching for better, quicker, and more accurate ways to make maps. Of all the techniques at their disposal, aerial photography presently offers the best means of obtaining small-scale maps of large areas. Nevertheless, the U.S. Geological Survey reports that the complication of small-scale maps by current practices is a slow, laborious process of assembling thousands of observations, and scale maps available today are neither uniform nor timely. Fortunately, cartography is applying techniques developed in the space program which promise greater efficiencies. The process of assembling the thousands of aerial photographs into a mosaic of a large region is both long and costly. About 1 million such photographs would be required to make a photomosaic of an area the size of the U.S. From satellite altitudes, such a panorama of the U.S., would require only 400 pictures, could be assembled in a few weeks, and would cost only a fraction of the cost of aerial mosaics (Figs. 14 and 15).

Aerial photomosaics typically do not display uniform shadow patterns and texture. The sunlight angle is always changing throughout the duration of the aircraft's flight. Placed in an appropriate sun-synchronous orbit, a satellite is capable of producing pictures of the earth under virtually constant lighting conditions. In a sun-synchronous orbit, the satellite crosses the equator or any parallel of latitude at the same time each pass. Since the orbit plane of the satellite always maintains the same, fixed angle with respect to rays of sunlight, the illumination of ground features is consistent. Shadows in each adjacent satellite swath always point in the same direction. Images of large areas composed of pictures taken during many passes will display the same constant illumination. Satellite pictures are also geometrically superior to aircraft photographs of large areas because of the straight-down view. The distortions caused by oblique camera angles are eliminated. These features make possible automatic processing and interpretation techniques that are difficult or impossible to utilize working with aerial observations.

More than 70 percent of the earth's surface is covered by water. These broad expanses of the oceans, coupled with their dynamic nature, have made it impractical to undertake continuous broad-scale surveillance by conventional methods. Limited synoptic surveys have been conducted by Soviet, Japanese, and U.S. oceanographic vessels working in patterns over large areas, but their best efforts are necessarily limited to selected data points rather than the comprehensive coverage offered by satellite. Most of the world's oceans are never seen by man, while areas of special interest are checked only intermittently by ships or aircraft. Yet the oceans are the birthplace of the world's weather and must be monitored completely and repetitively before global weather forecasting can become a reality (Figs. 16 and 17).

Biological productivity of plankton and fish is perhaps the most important oceanic resource. In the years ahead, this resource must be monitored, conserved, and harvested with judgment. The oceans absorb surplus carbon dioxide in the atmosphere via phytoplankton which converts it to oxygen. The overload of industrially emitted carbon dioxide may already have saturated the ocean's capacity for conversion.

If enough of these planktonic resources are killed or their vigor impaired by spreading oil slicks or pollution films, world climate might be adversely affected. Our capacity for generating such slicks is increasing. If the Torrey Canyon tanker had been filled with herbicides instead of oil, all life in the North Sea would have been destroyed.

The temperature outlines of ocean currents and upwelling can be traced with infrared sensing. Since there is a correlation between ocean temperature and the location of large schools of fish, this type of data may prove valuable to the fishing industry. Satellite infrared imagery of the Gulf Stream has already confirmed the possibility of detecting differences in water temperature from space and of relating the temperature distributions to current patterns. Thermal mapping of ocean currents and sea ice, information vital to the future development of resources in Alaska and Northern Canada, has already been demonstrated. Surface temperature measurements help to identify locations of highest plankton concentration, the prime source of food for fish, suggesting preferred locations of the fish population.

Subtle gradations in ocean color which correlate with ocean flora may also indicate areas of high food content where fish are more likely to be found. Ocean color gradation in coastal areas may be used to produce updated hydrographic charts for use by navigators. Under the action of tides and currents, bottom contours are always changing faster than charts can record them. Depth contours in the mouth of the Colorado River have been prepared from color separations of space photography.

The sea state has been measured in experiments conducted from aircraft. Radar can illuminate the ocean's surface. The reflected energy produces different images corresponding to the height of the waves. Radar observations could be conducted on a 24-hour, all-weather basis since radar can penetrate clouds and storms, and does not depend upon sunlight. By measuring sea state, locating ice areas, and mapping favorable currents, remote sensing can help to reroute ships at sea to reduce time at sea and improve efficiencies and profits.

Since the environment is a major resource, it should be treated and managed as the essential life-support resource which it is. More often, the environment has been relegated to the role of dump for the residues left over from conventional resource extraction and consumption operations. These residues pollute both water and air.

Water is polluted by oil, runoff from farmlands sprayed with chemical fertilizers and pesticides, effluent wastes, algae blooms fed by oversupplies of nutrients in organic wastes dumped into the water, and by heat. Many forms of water pollution can be monitored by satellite. The advantage offered by satellite sensing is that large areas of water or many small rivers or lakes, such as Minnesota's 10 000, can be monitored quickly, repetitively, and automatically. Water polluted by contact with polluted air, by the introduction of chemical fertilizers and pesticides, and the byproducts of domestic and industrial wastes will continue to pose serious problems.

Lake Erie, for example, receives 2.5 million tons of silt, sewage, and industrial effluents such as pickling acids from the steel mills and phosphate-based detergents each year. The biochemical oxygen demand of this overload has exhausted the supply of dissolved oxygen and the lake is now biologically dead. Other lakes are going the same way. Algae infestations which turn fresh water into green, sludgy soup, have occurred in such sewage basins as Lake Washington, Seattle, and Lake Tahoe, Nevada. Steam generating and nuclear power plants heat large volumes of water. Frequently, different pollutants are mixed together in one body of water.

To effectively monitor water pollution, a variety of hydrological characteristics must be measured: surface temperature gradients in lakes and streams, sedimentation dynamics, precipitation, lake and reservoir levels, and tonal colors (Fig. 18). Differences in water color may correlate with chemistry and vegetation such as plankton bloom and algae, thereby contributing to pollution studies. Polluted water may be warmer than adjacent unpolluted water and may be detected by infrared scanners.

Patterns of water flow are visible in aerial and space photography. By revealing flow features invisible from the ground, such pictures can be used to map and compute large-scale mixing patterns in bodies of water. Such patterns establish the basis for tracking and controlling pollutants.

Air pollution consists of toxic gases introduced into the atmosphere, carbon dioxide, particles such as fly ash, volcanic or radioactive dust, and aerosols used to disseminate pesticides. Distribution is more or less worldwide. These toxic gases attack the lungs and crops; pesticides attack reproduction. Combustion products from industrial processes and operation of aircraft and automotive engines introduce carbon monoxide, hydrocarbons, lead compounds, sulfur dioxide, and nitrogen oxides. Sufficient quantities of these gases can alter the chemical composition of localized atmospheres. Chemical changes alter the path through which sunlight falls to the surface and is reflected up to spaceborne sensors. The altered nature of the reflected sunlight may be the signature of such concentrations. The shape of this altered signal may also indicate the degree of toxicity.

Although local sources such as industrial plants and cities can probably be monitored adequately with ground detectors or aircraft, large regional distributions and cross-country movements of polluted air may best be monitored by satellites. What was a local problem until recently is fast becoming a regional problem. Now that Los Angeles smog is appearing over Arizona, perhaps Japanese pollution, notoriously heavy, may carry to our West Coast, or east-coast pollution may carry to Europe. Here again, the quick, repetitive, large-scale pictures from satellites can supplement data gathered by aircraft and ground detectors.

One of the most important long-range environmental tasks for remote sensing is to monitor the composition of the upper atmosphere worldwide. This thin film functions as a two-way value. It protects life on earth by filtering solar energy, allowing only enough to enter to nourish life. This film also passes heat radiated by the earth to space. Otherwise, the surface would heat up. Life exists and thrives because this global thermostat has been balanced for centuries. Now, however, since the industrial age has been converting fossil fuels to carbon dioxide, evidence is accumulating that the environmental balance is being altered by the changed composition of the upper atmosphere.

The effects of weather on human activities are so important that a national meteorological service is one of the first functional organizations established in every developing country. And because weather systems do not recognize national boundaries, there is a high degree of international cooperation in meteorological activities, even between nations which are otherwise less-than-friendly.

It is the large-scale nature of weather phenomena which has made the satellite such an important tool for meteorologists. Earth-orbiting satellites are able to observe weather systems, regularly, over oceans, deserts, the Arctic and other regions which are otherwise inaccessible to long-term human observations. Since man's ability to predict weather (wind, rain, etc.) is based on how well the initial state of the atmosphere is known, it follows that the large-scale observations available only from satellites should enhance the length and quality of weather forecasts. The close relationship between predictions and atmospheric observations is shown in Figure 19, which relates the increase in our predictive ability to the observational tools which made the predictions possible. Electronic computers are included to indicate that the meteorologist's ability to assimilate and understand great numbers of observations has been greatly increased at a very propitious time in meteorological history.

Since Napoleon's scientists first discovered the relationship between atmospheric pressure and the weather, meteorologists have sought better tools for measuring the characteristics of the atmosphere. The meteorological satellite has provided an unprecendented ability to observe the parameters on which accurate weather predictions can be based, and now there is a strong hope for a predictive ability for 14 days or longer. The advantages to the general public far exceed the cost of the satellites and their related systems. These satellites initially took pictures of clouds over the globe, and are now measuring the world's temperature distribution (at the surface and through the atmosphere to a height of more than 100 000 ft), snow distribution and ice distribution plus cloud-height patterns over the whole world. In addition they have provided a tremendous ability to relay weather information between observers and users of weather information between distant locations.

In a more specialized application, satellites are proving invaluable in monitoring severe storms, such as hurricanes. In the past, hurricanes often appeared on the horizon with little warning. Later, expensive aircraft reconnaissance was used to patrol areas of frequent hurricane occurrence, but often these patrols failed to locate storms which later caused great damage. With the advent of satellite observations came a capability to observe the hurricane belts of the tropics on a daily basis, and today the meteorologist is routinely aware of hurricane activities.

An example of satellite observations of hurricanes and tropical storms on September 14, 1967, is shown in Figure 20. This composite view of global weather was prepared from data gathered by the Environmental Science Services Administration (ESSA), a weather satellite operated by the Department of Commerce. Six hurricanes and two tropical storms can be identified and with this identification available it becomes possible to alert surface installations and aircraft operators in order to make precise measurements of the hurricane's movement and intensity.

Hurricane Beulah, located in the Caribbean at the time shown in Figure 20, was tracked by satellite on a daily basis until landfall at the Rio Grande Delta on September 20, 1967. Although this storm spawned over a hundred tornadoes and caused severe flooding, damage and loss of life were minimized because of the advance warning provided to inhabitants of the area.

Besides providing information for use in hurricane advisories for the general public, satellites are helping meteorologists understand the dynamics of these storms. There is now more confidence in man's ability to eventually dissipate these storms before they become dangerous.

TABLE 1. EARTH-ORIENTED APPLICATIONS

Communication and Navigation	Earth Observations
• Point to Point Communication	• Agriculture and Forestry
• Information Networking	• Geology and Mineral Resources
• Broadcasting	• Hydrology and Water Resources
• Data Relay	• Geography, Cartography and Cultural Resources
• Air Traffic Control	• Oceanography and Marine Resources
• Aircraft Collision Avoidance	• Environmental Quality
• Marine and Air Navigation	• Meteorology and Weather Prediction

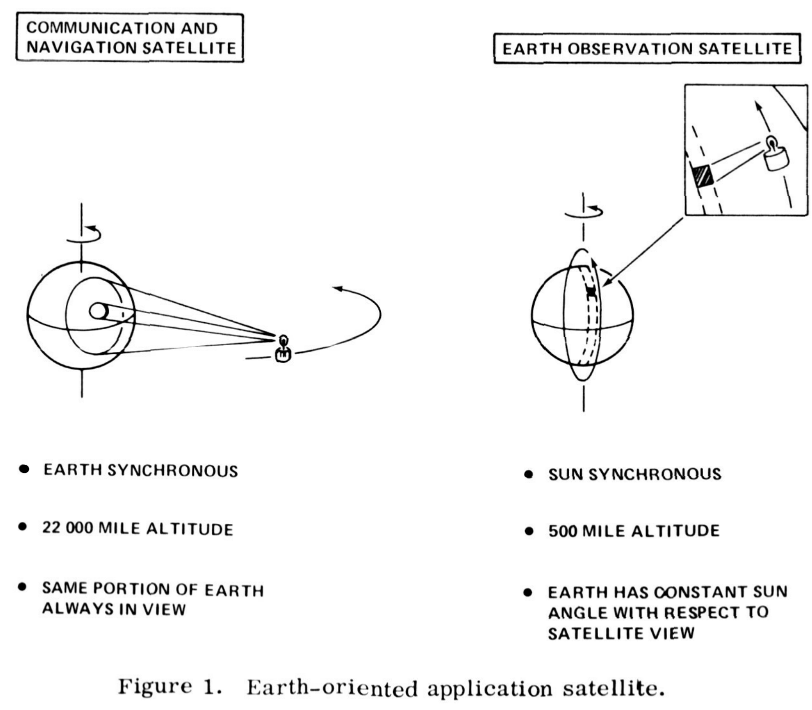

Figure 1. Earth-oriented application satellite.

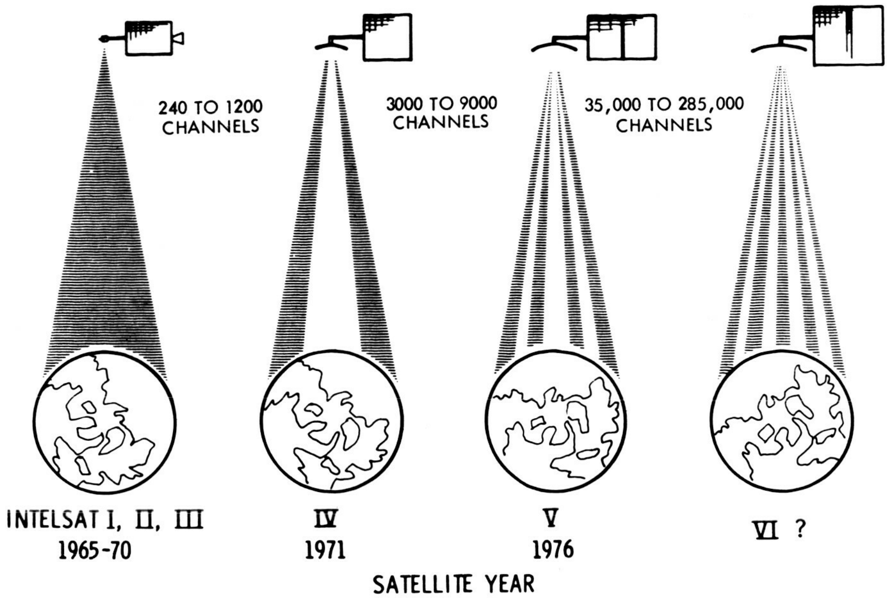

Figure 2. Point-to-point communication satellites.

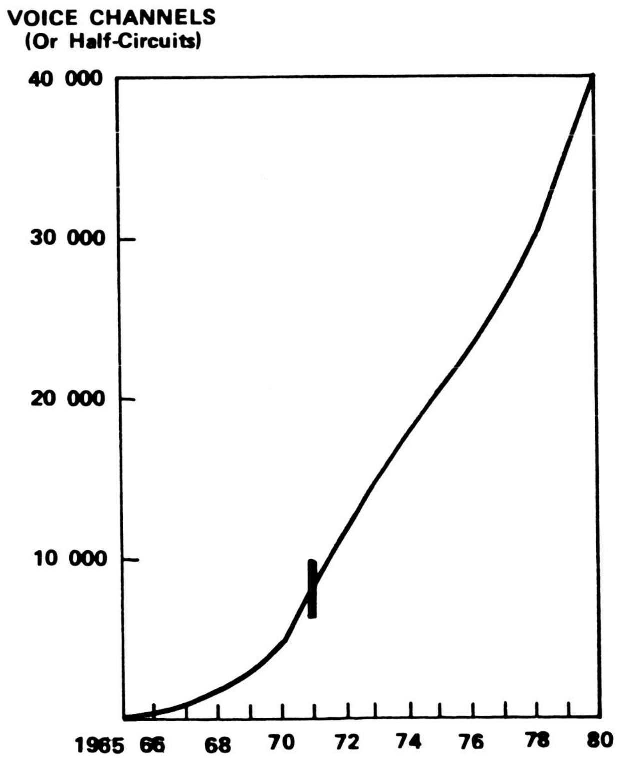

Figure 3. Projected growth of INTELSAT traffic.

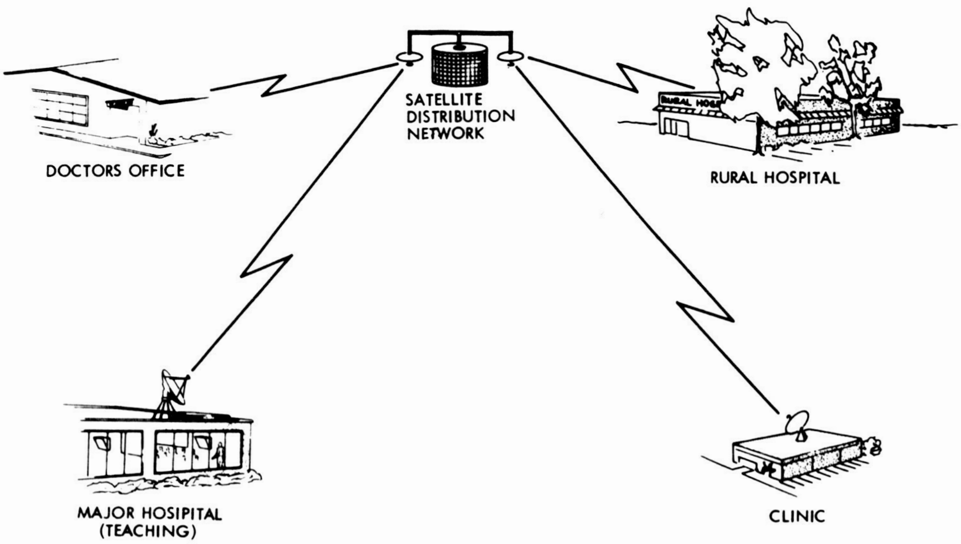

Figure 4. Conceptual medical and health information network.

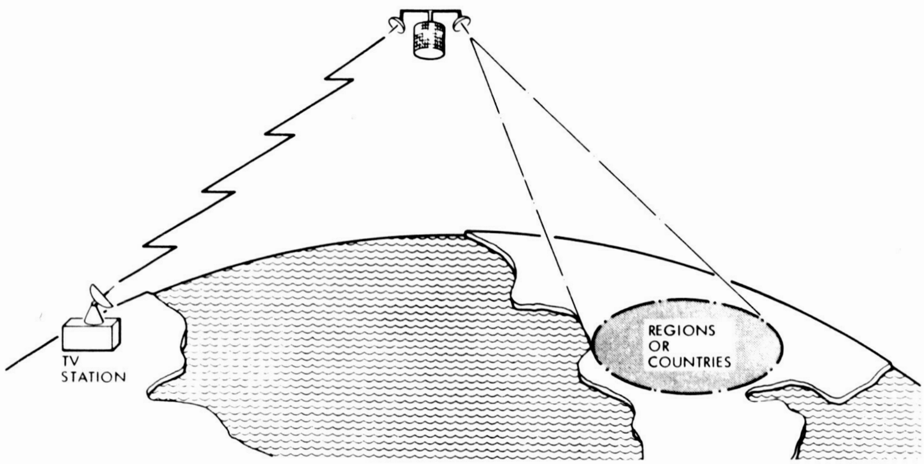

Figure 5. Direct broadcast television.

Figure 6. Educational broadcast television to India.

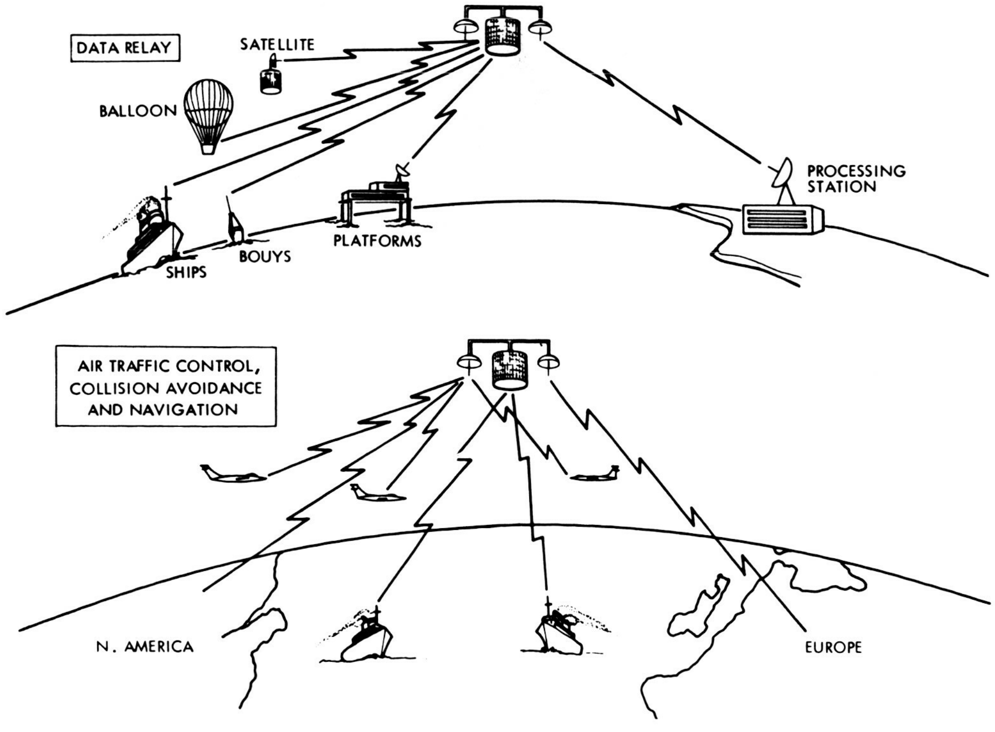

Figure 7. Satellite systems for data relay and navigation.

Agriculture & Forestry

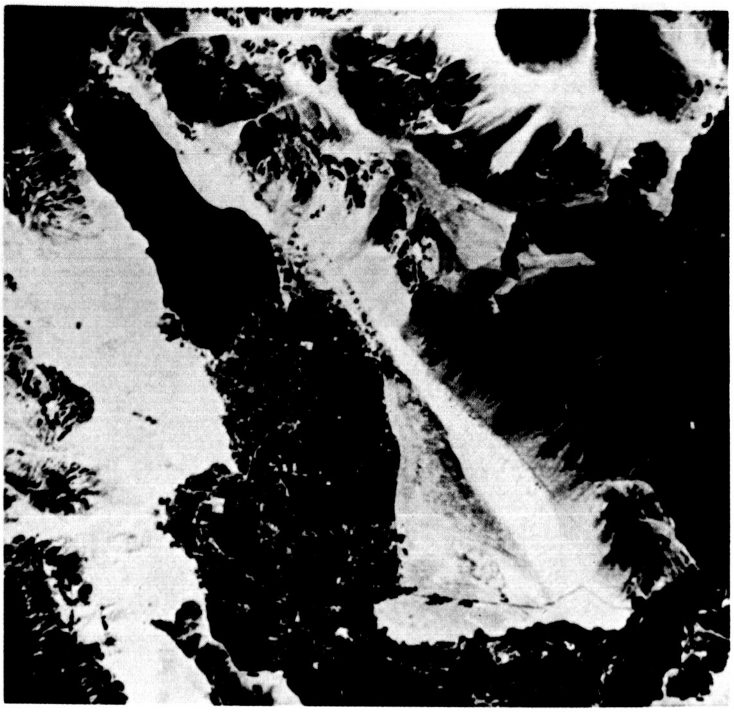

Figure 8. False-color photograph of Salton Sea (Apollo IX, March 1969) showing healthy vegetation in the Imperial Valley farmlands as red objects.

- Land use planning
- Crop irrigation
- Regional development
- Crop yield
- Grazing range management

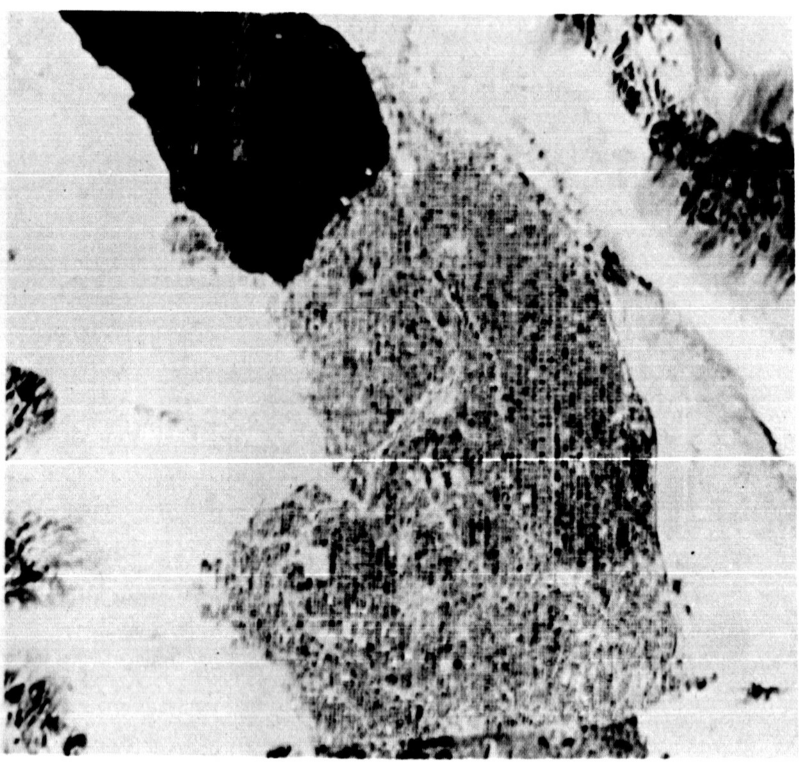

Figure 9. Apollo IX photograph of Salton Sea area used for construction of agricultural land-use map.

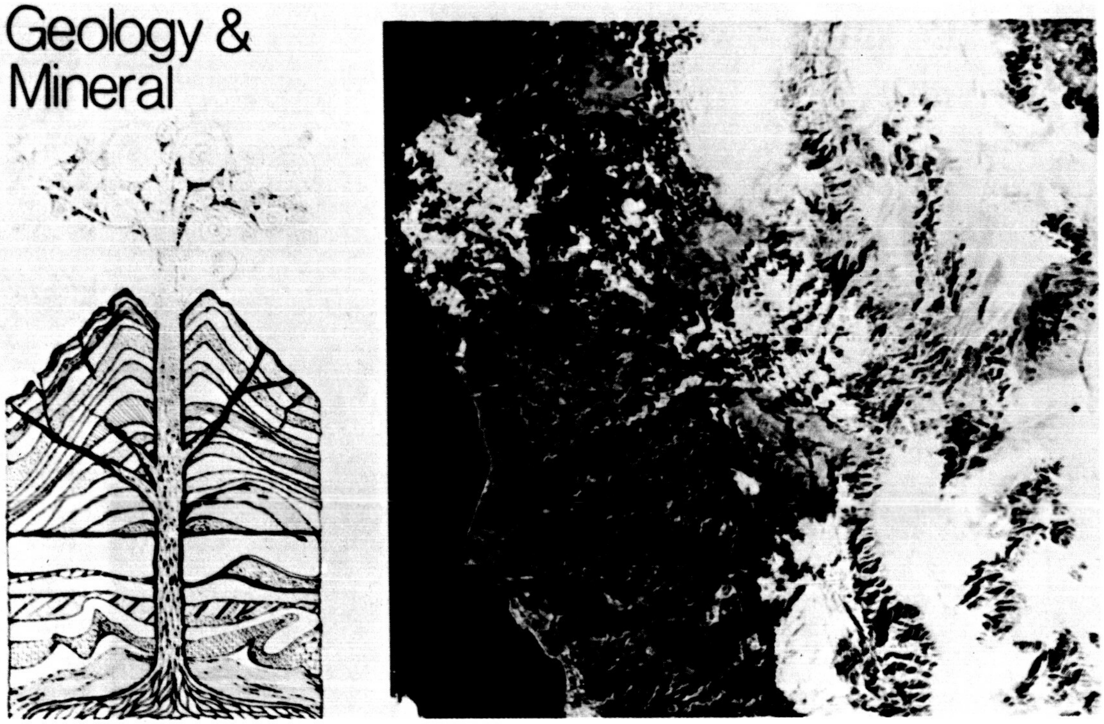

Figure 10. Apollo X photograph of Baja Peninsula area of California.

- Geologic mapping
- Geothermal & volcanic observation
- Fault & playa location

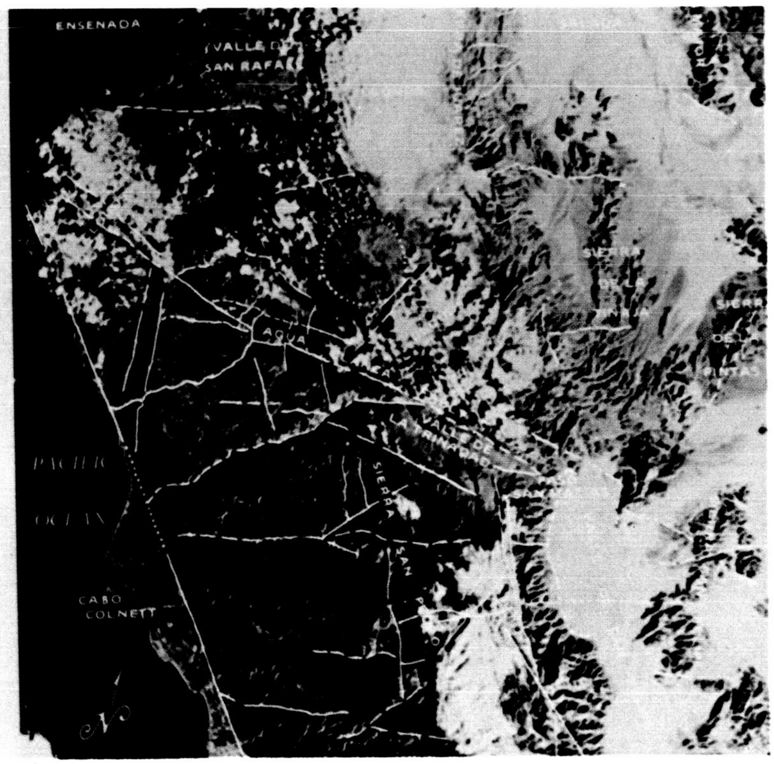

Figure 11. Photo interpretation showing faults, lineaments, and playas.

Hydrology & Water

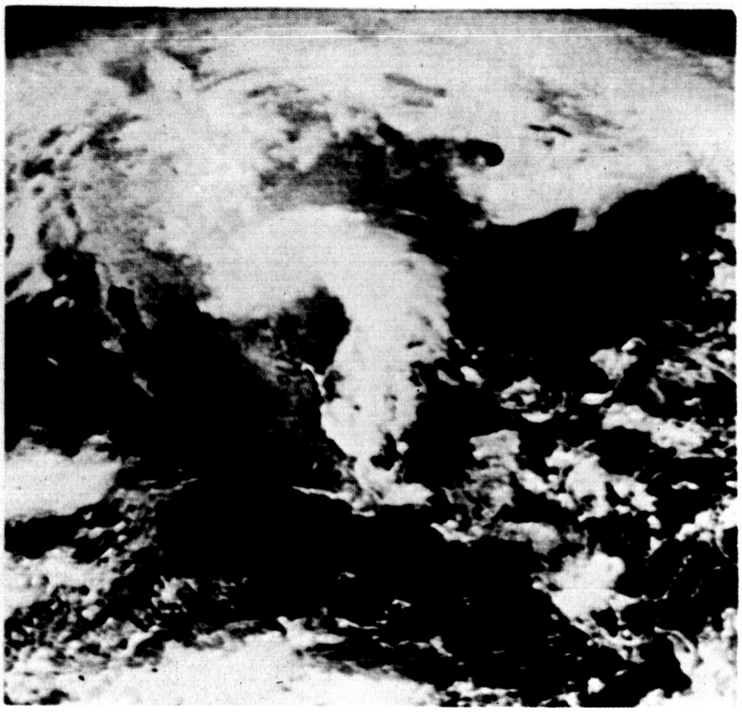

Figure 12. ATS-III photograph of California Sierras showing clouds and snow.

- Surface water mapping
- Watercourse location
- Drainage patterns
- Flood monitoring & prediction

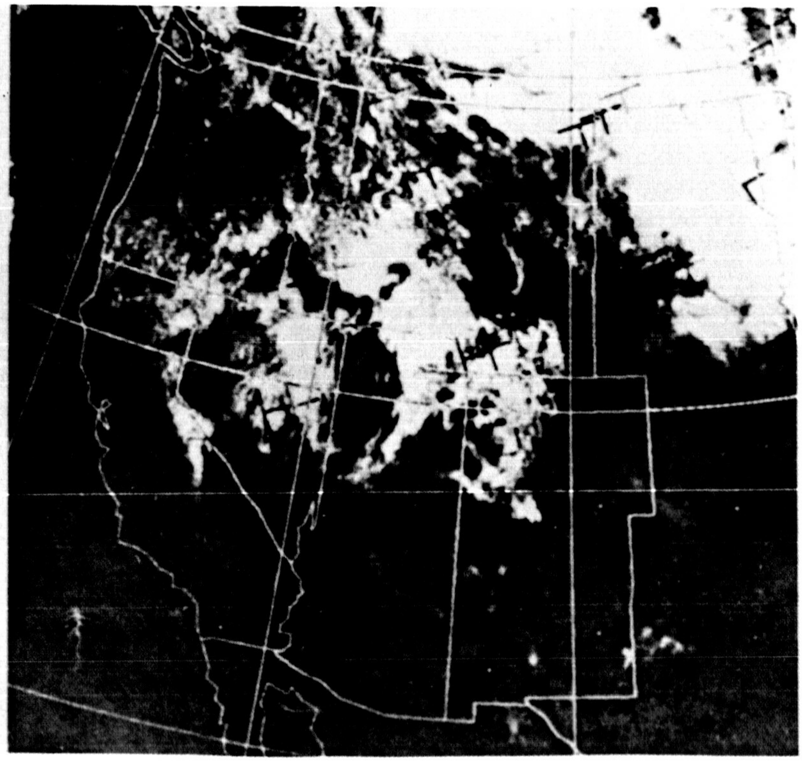

Figure 13. Map showing snow coverage, generated by ESSA from NASA photograph.

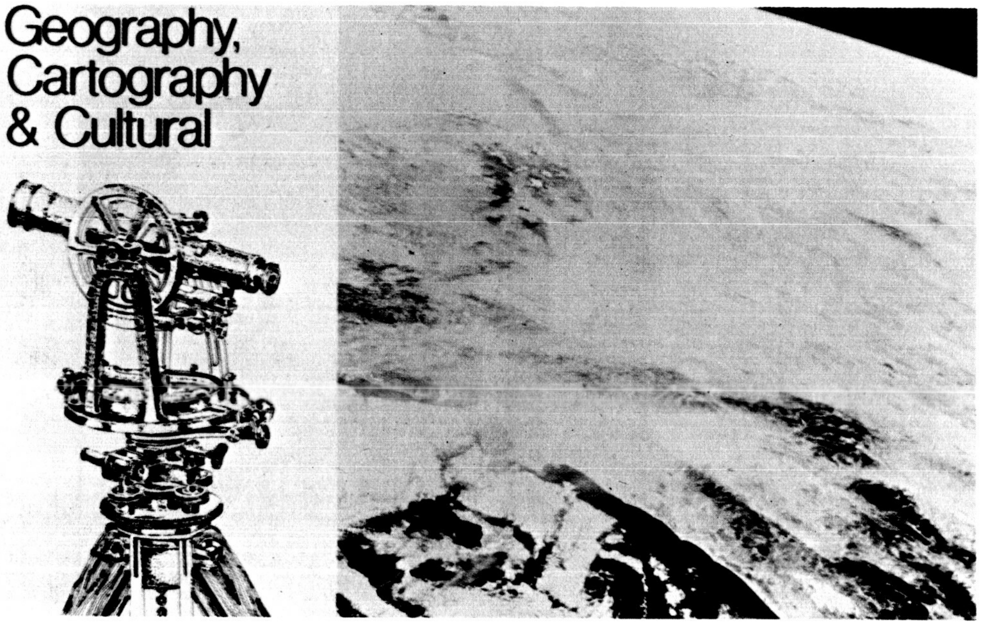

Figure 14. Apollo VII photograph of southern California showing smog plumes over the Los Angeles region.

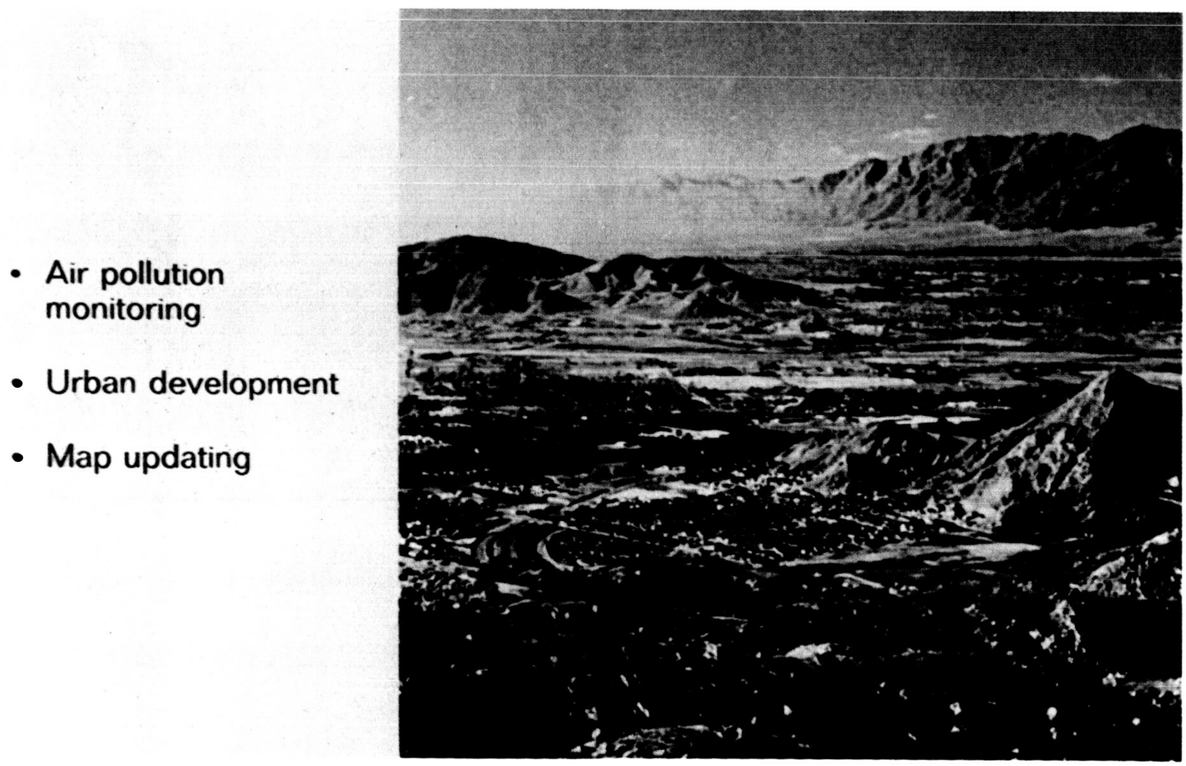

Figure 15. Multispectral photograph for pollution detection.

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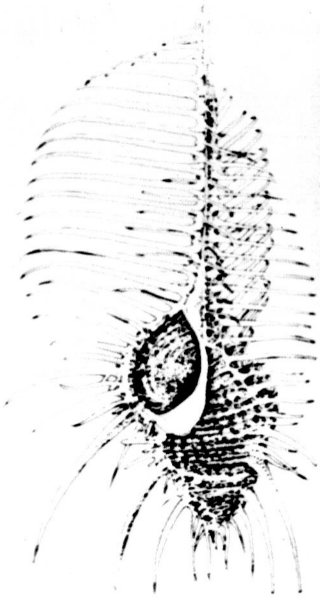

Figure 16. Apollo IX photograph of West Florida keys in natural color.

- Updated hydrographic charts
- Location of shipping hazards
- Location of fish feeding areas
- Monitoring of shoals and sandbanks

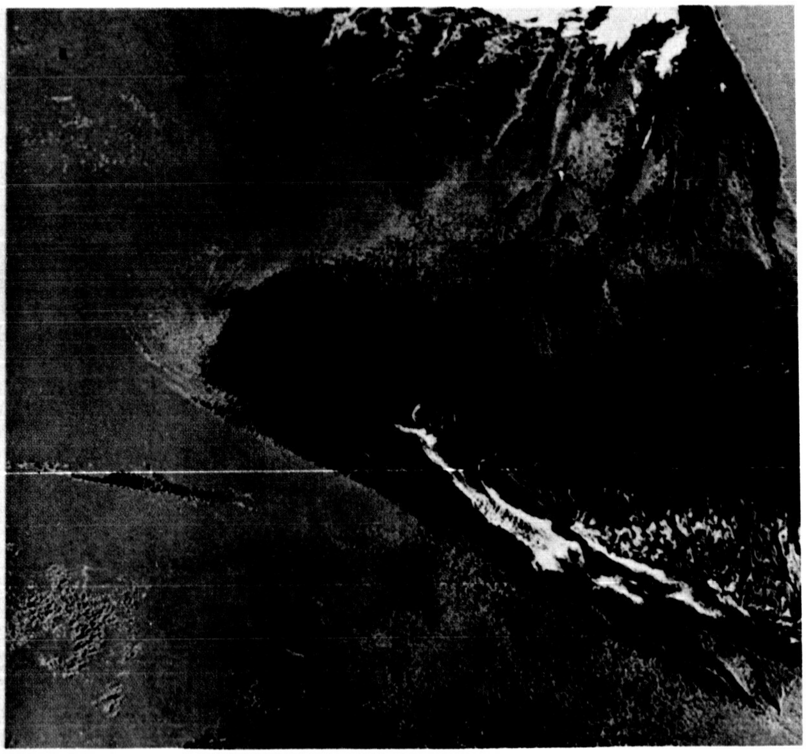

Figure 17. Interpretation of Figure 16 by NASA/Navoceano showing relative water depth to 10 fathoms in false color.

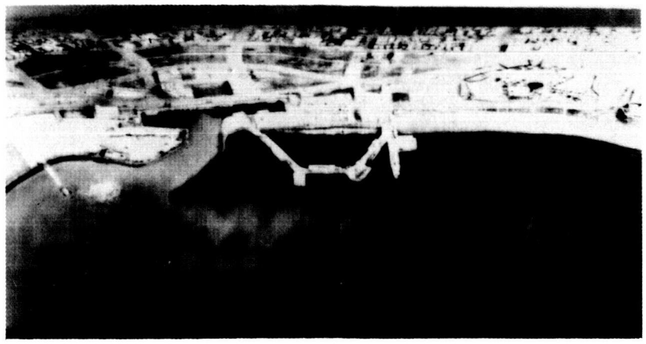

Figure 18. Thermal pollution monitoring.

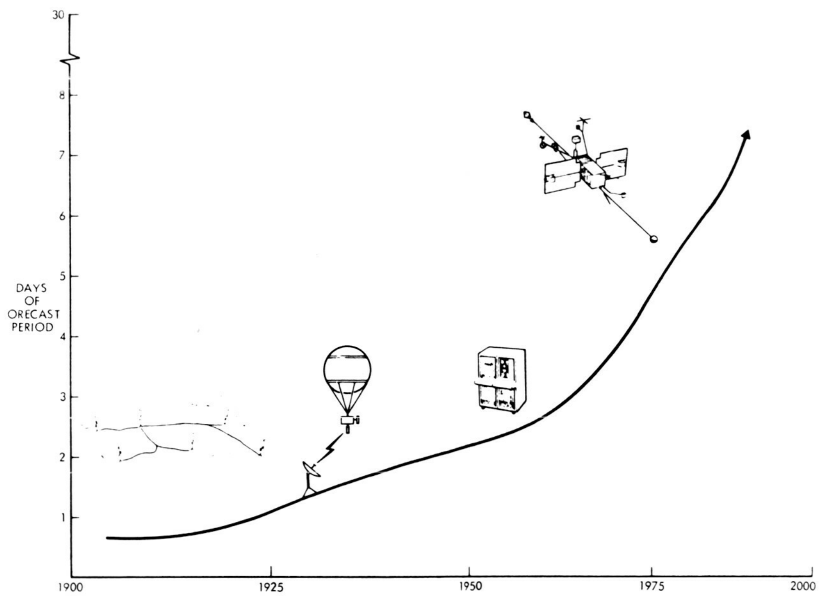

Figure 19. Progress in prediction of weather events.

Figure 20. ESSA V tracks eight major storms on September 14, 1967.