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CURRENT PROGRAM AND CONSIDERATIONS OF THE FUTURE FOR EARTH RESOURCES SURVEY

by

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Address by Homer Newell, April 16, 1968

Fifth Symposium on Remote Sensing of Environment -

"Current Program and Considerations of

the Future for Earth Resources Survey"

It is now six years since the first symposium on Remote Sensing of the Environment was held here at Michigan in mid-February of 1962. That symposium offered much hope of things to come. Today it is helpful in gaining perspective, to look back over the past six years to note our progress and find where we now stand.

Meteorological data from satellites is now being supplied to many countries on a routine basis and satellite communication links are commonplace. Photographs of the entire Earth from synchronous orbit and communications from aircraft via satellite to Earth have been demonstrated with the ATS-1 satellite. Ships navigate with the help of the Navy's Transit satellites, and geodesy measurements are underway using the Geos and Pageos satellites. The Gemini color photographs of the Earth have indicated a variety of uses for satellite photography.

Encouraged by these developments we are beginning to explore the possibility of using spacecraft for Earth resources sensing purposes. This may be an opportune point to explain what we mean by the expression "Earth Resources." It is much broader than just the valuable minerals and other sought after deposits. It covers all the conditions on the Earth's surface which are of economic or cultural interest to humanity.

A survey of the impressive volume of work during the past six years documented in the proceedings of the intervening symposia indicates that a long road existed between the early hopes for remote sensing of the Earth resources as expressed in 1962 and operational space systems to achieve this. A great amount of data has been taken during the past six years in the laboratory and from aircraft over ground truth sites. The effort has been to determine just how great the potential for remote sensing of resources really is, and what techniques merit earliest trials.

Today I will summarize some of the progress made, assess current needs and problem areas, and then sketch some of the most promising methods for future consideration.

(ADVANCES IN SATELLITE SENSING PROGRAMS IN LAST SIX YEARS)

(Meteorology)

First let us consider meteorology.

Here, progress in establishing an operational satellite program has been rapid.

Some of the highlights of this advance since 1962 have been automatic picture transmission systems initiated with Tiros VIII in 1963, high resolution infrared imagery allowing nighttime cloud cover mapping introduced with Nimbus I in 1964, and spin stabilization in sun synchronous orbit achieved with Tiros X in 1965. These advances led to the operational satellites ESSA II, which in the same year used the first operational advanced vidicon camera system. The experimental synchronous orbital satellite ATS-1 which since December 1966 has mapped the cloud cover over almost the entire hemisphere on a continuous basis.

These accomplishments in meteorology are impressive, particularly when one considers the long lead time between the inception and flight of a new system. The year 1966 was a particularly eventful year.

As another successful example, let us look at geodesy. Here systematic research and development have made progress since NASA's Geodetic Satellite Program was established in 1962. Two years later, operations were initiated with Beacon B and followed up by Beacon C in 1965, which carried geodetic quality Doppler transmitters and laser ranging corner reflectors. These were followed by Geos I in late 1965, and Pageos I in 1966, and Geos II early this year designed for high-precision geodesy.

These satellites have been tracked by over 100 ground stations, and the data will be used to establish a worldwide reference network with an accuracy of ± 10 meters. The Earth's gravitational field and its anomalies are also being defined with high-precision using these same observations.

Compared to meteorology and geodesy, where operational satellite programs have been producing results for several years, the field of Earth resources sensing from space is still in its infancy. No satellites have yet been launched, addressed to remote sensing for oceanography, forestry, agriculture, hydrology, or geology. Why, we must ask ourselves, has remote sensing in these areas not developed as fast, and where do we stand today?

There are basically two reasons why meteorology and geodesy led the other disciplines.

First, the space experiments which had to be performed in meteorology and geodesy were simpler, in that fewer variables had to be coped with than in the solid Earth disciplines.

Second, organizations were ready to put space experiments into orbit. The Weather Bureau had conducted tests with balloons and rockets, as had the Navy Department and other organizations interested in the atmosphere. The opportunity for advancement by satellite was quickly recognized and used.

In the Earth sensing areas, by contrast, definition of requirements, development of essential technology and organizational backing has come more slowly.

The only data we now possess from satellite altitudes relevant to resource sensing in these other fields have come indirectly from color photography of the Earth in the Gemini program and from photography and infrared imagery of the Earth from Nimbus II. Photography from the ATS-I satellite in synchronous orbit and recently from the Apollo 501 mission at 9000 miles, has provided useful oceanographic as well as meteorological information.

The Gemini photographs, taken with a hand-held Hasselbladt 70 mm camera through the windows of the Gemini spacecraft - not an ideal photographic procedure - display the enormous potential of systematic satellite color photography of the Earth's surface. With resolution down to about 200 feet, these photographs prove that many uses in agriculture, forestry, oceanography, geology, and cartography are possible using straightforward photography of reasonable quality.

Despite the lack of on-going Earth resources satellite programs, very considerable research and development work has been conducted and is underway now with help of ground-based facilities and aircraft.

(ADVANCES IN LAST SIX YEARS IN GROUND AND AIRCRAFT PROGRAMS)

(Oceanography)

Let us briefly review the field of oceanography. The large scale features of the oceans are dynamic and can only be monitored adequately with frequent repetitive measurements over wide areas. Because most of the oceans are never seen by man, oceanography should lend itself ideally to remote sensing by satellites. The oceanographic features studied and developed to the point of satellite applicability are sea surface temperature and currents, sea state, sea ice, and marine life detection. It would be most desirable to make these observations at frequencies which can penetrate the Earth's incessant cloud cover.

Sea surface temperature gradients and discontinuities have been studied from aircraft in the visible, infrared and microwave regions of the spectrum. The visible and infrared regions are available for sensing only during cloud-free conditions, the infrared is useful at night as well as day, and microwave is useful under all conditions, including cloud cover.

Nimbus II high resolution IR images of sea state from 1150 km altitude have been obtained, and computer gray scale plots of temperature contrasts have been made. Sea surface temperatures have also been inferred from cloud patterns in high altitude (22,000 miles) ATS-1 imagery. The recent color photographs of the Earth taken in the Apollo 501 mission, near apogee of 9,000 miles, are of particular use for sea surface study and have been interpreted successfully, largely due to their quality which is superior to that of the imagery from the meteorological satellites.

Scientists have long been searching for a method to measure sea state in all kinds of weather on an ocean-wide basis as an aid to the shipping industry and for weather forecasting. It is common practice to infer sea state conditions from wind reports. One method of measuring sea state is the analysis of wave patterns and sun glitter in aircraft photographs of the sea surface. New techniques utilizing passive microwave and radar reflectance measurements are currently the most promising for sea state determination from high altitude since they are sensitive to wave characteristics and can be made with no appreciable attenuation in the presence of storms and clouds. Investigators have shown recently that by plotting reflected radar energy against the angle of incidence at the sea surface, one obtains well separated signatures for various states of sea roughness. The data were substantiated by MSC aircraft measurements in late 1967 off New Foundland, and further tests are currently in progress off the coast of Iceland.

Adequate knowledge of the distribution of ice in the Arctic and Antarctic is lacking. All-weather information on ice and icebergs has applications for meteorological services, ice patrols, and the shipping industry. Television and IR sea ice data obtained with the poloar-orbiting meteorological satellites TIROS, ESSA, and NIMBUS have been used to support shipping activities.

Looking back into history we recall that ever since the Titanic disaster in 1912, the U. S. Coast Guard has carried out ice patrol surveys. These patrols were initially conducted by eye from shipboard and later from aircraft, which often meant flying at 50 feet above sea level below the clouds. Several planes were lost in collisions with icebergs. After World War II, radar was used, again first from low altitude and as a safeguard for the ice survey plane. Since 1962, the Coast Guard flies huge microwave scanning systems installed in C-130 planes. We must investigate the possibility that this difficult operation could be conducted from space. However, before recommending such an approach, it is our duty to verify that the satellite will produce data of adequate quality and that such a space operation will be cost-effective.

Photographs from aircraft of schools of fish are well known. Small spotter planes have been used by commercial fishing fleets for several years. Aside from surface temperature measurements, which provide important evidence for preferred fish locations, other applications are in the R&D stage, such as IR and narrow-band visible region spectrometry and photography. We are thus investigating the possibility that detection of fish could take place from higher altitudes.

All in all, the field of oceanography shows considerable progress in the application of remote sensing techniques. Technologies for surveying the ocean temperature and sea state condition are probably the nearest at hand of all the Earth resources observations. Consequently we may expect that these will be the first to reach operational status.

(Forestry, Agriculture, and Geography)

In turning from oceanography to forestry and agriculture, we are faced with a different set of data requirements. The identification of individual forest species or crops requires different types of sensors. The fact that there are seasonal and even diurnal changes in spectral signatures introduces new complications.

Operational techniques in agriculture, forestry and geography include photography in the visible and IR region of the spectrum. Aerial photographs and maps are the proven basis for land use, soil surveys, forest inventories, and engineering plans. As indicated at the outset, Gemini photographs have contributed already to the improvement of these records, and we hope to get additional photographs from appropriate future missions of the Apollo program.

There is now considerable evidence that infrared photography permits early detection of diseased crops or trees. A recent example of this has been the use of Ektachrome IR photography for early determination of brown soft-scale and black-fly infestation on citrus trees in Weslaco, Texas.

Another operational remote sensing application operated in the western mountain states is infrared forest fire monitoring from aircraft, performed by the Department of Agriculture. This function may be convertable to satellite application, including a volcano watch.

Perhaps the most significant innovation in remote sensing in agriculture is the use of IR and visible region imagery in several wavelengths from aircraft to determine crop species and variety, relative size and maturity of crops, and relative amounts of vegetation observed. Of particular significance is the fact that a large number of spectral bands - up to 18 - are being used, and that the multiplicity of channels provides a much greater degree of reliability than the use of a single band.

The same principle has been applied in the passive and active microwave regions using multifrequency, dual polarization for soil analysis. Computer maps of soil and rock types have been generated. It remains to be seen whether it is feasible to generate such maps from space or whether one should restrict the capability to aircraft altitudes. This will depend on future sensor development and data handling capability. But the progress is encouraging.

(Hydrology and Geology)

Operational programs in hydrology and geology remote sensing are still all from aircraft. Aside from the demonstrated potential of color photography it appears that it will take some time to sort out and develop other promising remote sensing techniques in these fields. During the past six years, it has been recognized that a definite effort is necessary to relate the complex spectra observed at aircraft altitude to the multitude of variables on the ground. A "ground truth" program has been initiated, with the objective of measuring accurately the parameters of grain size, ground temperature, soil moisture, rock composition, air temperature and other ambient conditions, then assessing the degree to which these parameters are reflected in the signal recorded from the aircraft. One can identify over 100 individual ground truth parameters. The objective is then to associate an identifiable spectral signature, or other distinctive reflective/emissive characteristic with each surface condition. This effort has been particularly active in geology and agriculture, but is also being advanced by other disciplines. There is no doubt that it is highly desired in geology and hydrology where the significant parameters are harder to identify.

At this point in time NASA has some 150 aircraft test sites spread all over the U. S. Most of these are of interest to geology and hydrology, some were selected for geography, agriculture, and oceanography. We have now two aircraft with operating remote sensors and we are planning to add both low and high flying aircraft to the program. For the first time, we have a data handling capability which allows us to process recorded data, and to incorporate ground truth and meteorological information. In the past this program had to be operated on a minimum budget. However, increased funding allocations this year will permit us to procure specially developed sensors for our aircraft. This new impetus in the program will particularly intensify the progress in hydrology and geology.

Aircraft sensing in hydrology has been used to trace fresh water discharge in salt water and pollution discharge into fresh water, largely on the bais of temperature differences identifiable by IR imagery. Similarly, IR imagery has been used to identify hot springs. Penetrating microwave sensing and remote sensing of fumarole (hot spring) activity by absorption techniques may help in detection of geothermal power sources. But this has not yet been demonstrated conclusively.

Snow and water surveys are being carried out from aircraft, and all-weather microwave sensing even of subsurface water (soil moisture) is being carried out using multiple frequency polarized systems.

In general, multiple-parameter, multichannel polarized sensing is being explored for geological application. This holds particularly for radar, microwave, and to some extent for IR. We are still awaiting firm results in this area.

Side-looking radar operated from aircraft has recently met with considerable interest. A well known industrial organization has offered to provide service in commercial terrain imaging. Similar efforts are being proposed in passive microwave technology. The objective of these surveys is to bring out topographic, tectonic, hydrologic and geomorphic features more clearly than is possible by photography.

In view of these promising results, we are giving some thought to the initiation of an Earth Resources Technology Satellite Program. To this end we have recently completed a preliminary study of sensors and spacecraft that would be suitable for such a program during the next three to four years. Our conclusions are that such a vehicle should be relatively small and be equipped with a limited number of sensors capable of serving most of the Earth resources disciplines. Certainly a TV camera system would be highly desired. However, before plunging into an expensive program of this nature, we must establish that such an effort would be consistent with our national economic objectives. We therefore plan to conduct an economic benefit study during the next few months which will help resolve this question.

(NEEDS AND FUTURE PLANS)

(Meteorology)

In meteorology, despite our operational satellite system, we still lack much of the data essential for world-wide long-range weather forecasting. Currently we get good global cloud-cover pictures, cloud motion and some ocean surface temperatures. We do not get three dimensional fields of density, wind velocity, temperature and water vapor content within the atmosphere itself. Yet these are required before realistic weather models can be constructed and tested.

Promising techniques to meet these needs are:

1) Measurement of atmospheric temperature profiles by radiance inversion techniques.

2) Atmospheric radio occultation between a satellite and a set of "slave" satellites to measure atmospheric density.

3) Auto-correlation of radar, microwave, or optical signals in two crossed beams. This method may be useful for measuring temperature, wind movement, clouds, rainfall and drop size.

Until methods such as these can be proven and made operational, high pressure weather balloons at various altitudes may have to be used for interrogation by satellites to supply the data needed for weather prediction to provide the state parameters in the atmosphere essential for long-range weather prediction.

As for eventual benefits, we can consult the 1967 Summer Study report of the National Academy of Sciences. The Study expects large annual economic benefits from the availability of a five-to-ten day reliable weather forecast for a variety of weather-sensitive activities, such as the construction industry and agriculture. The Academy believes that annual benefits will exceed annual costs by a very large factor.

(Geodesy)

In geodesy, completion of the current programs will enable us to find the relative positions of any two points on Earth with an accuracy somewhat better than that of conventional first-order triangulation. But geodetic science will not come to an end because of this. Far from it: just because space technology has so greatly increased the resources of geodesy, the imaginations of geodesists have leaped ahead to correspondingly ambitious new goals.

Key elements in new geodetic technology may be highly precise laser ranging devices, optical systems of very high resolution, atomic clocks, and a variety of sophisticated special instruments such as gravity gradiometers. Geodesists hope to use their new techniques to make direct measurements of the rates of continental deift and uplift, monitor the geometry of the ocean surfaces, keep track of the total water content of the polar ice caps and the world's glaciers, probe the interior of the Earth by exploring its gravity anomalies, and measure the tidal and other mass motions of the atmosphere.

(Oceanography)

There are three areas of oceanography where we may look for major contributions from space in the future.

1) Sea surface state on all shipping lanes

2) Marine biological resources

3) The science of oceanography

As for the first, we have mentioned that monitoring of ocean wave conditions and sea-ice has now been demonstrated by radar and microwave techniques from aircraft. It should be possible to extend this technique to satellites if the few technical difficulties can be overcome. Large economic benefits are predicted for the shipping industry from this program.

As for marine biological resources, we have not yet demonstrated any techniques of direct usefulness, except surface temperature determination and color photography. To produce data of significance to the fishing industry we will need something like weekly global maps of surface temperature and chlorophylll concentraction in gms/cm^3 by remote sensing. Color photography or spectroscopic determination of reflected light from a satellite may be effective for measuring surface chlorophyll levels.

Further possible information on marine life resources may come from oil slicks appearing near schools of fish. These might either be detected by detailed color photography, or, possibly, by absorption spectroscopy highly sensitive to fish oil vapors above the slicks.

Research is needed to find what overall contributions to the science of oceanography can be made through surface observations. Classically, oceanographers have been interested in many properties far below the surface and many of these will probably never be accessible from space. However, satellite interrogation of ocean buoys, designed to supply depth measurements of temperature, salinity, and currents may become useful.

If satellite altimeters can be developed to give accuracies of ± 10 cm, oceanographers can gradually determine the true shape of the geoid, and ocean height deviations from this level will be extremely useful in determining the dynamics of ocean movement on both local and global scales.

In the long term, benefits from satellite oceanographic techniques can be expected to result in many large sectors of the economy, such as fisheries, industrial applications as coastal engineering, and ocean transportation. A few examples cited by the Academy of Sciences Study of 1967 include world freight shipping and world fishing industries. The Academy finds it safe to assume that any small-percentage savings accruing to industries would quickly give benefits many times greater than the cost of a satellite program.

(Agriculture, Forestry and Geology)

In the areas of agriculture, forestry and geology the principal need now is for improved identification of the signature of various species. We have described recent advances showing that several techniques appear to be practical enough to be used with automated signature identification from aircraft altitudes. However, extension of this capability to satellite levels will require a great amount of basic research effort and experimentation.

In general when we plan to move from laboratory and aircraft testing of sensors to the spacecraft level we are faced with many serious problems. These are associated with energy absorption by the atmosphere, as well as emission/scattering by the atmosphere and other sources of noise. In addition, the engineering problems should not be overlooked. Included are such requirements as much lower volume and weight for the instruments, higher reliability and lower power levels usually available. Consequently, our high altitude aircraft project can be regarded as moving one step closer in developing an Earth resources surveying capability from space.

(SUMMARY AND CONCLUSIONS)

In summary then, we have touched upon the technical progress of the past and tentative plans for the future. We have not mentioned the very great problems of providing a data handling and distribution network and of organizing it into an overall workable system. Yet these must be faced before we can begin to realize the potentials of remote sensing. It is our hope that if we push on vigorously and demonstrate workable technologies, others will find ways to solve management and organizational problems.

It is reassuring to find that the National Academy of Sciences report from last summer's study on Space Applications has endorsed the future potential of remote sensing of resources so enthusiastically. I should like to quote from the report:

> "Useful applications of space are unquestionably real, substantial, and potentially close at hand. A turning point has been reached, at which we can now describe with conviction and in some detail the many specific ways in which space vehicles and space technology will become important elements in our economic, industrial, and social world. Applications that were speculative and vague only a few years ago now appear credible and attractive to the potential users. The space program has broken the plausibility barrier."

And later it states:

> "Our first general conclusion is that the potential economic benefits to our society from space systems are enormous. They may amount to billions of dollars per year to many diverse elements of our industry and commerce and thus to the public."

The prospects are promising. We must set our sights, however, on those observations and services which can only be obtained using space, in a conclusive manner, or which can be better or more economically produced using space. Our goal is a balanced program which explores as rapidly as resources permit the technical possibilities while constantly weighing the economic worth of the various uses.