Impact of Space Research on Science and Technology

Space techniques have provided new tools for science and applications.

Homer E. Newell and Leonard Jaffe

Today is rich with challenge and opportunity. Political, social, and economic problems of the most vexing nature confront the peoples of the world. Progress during the last century has been tremendous, but that very progress has contributed difficulties that beset humanity today. Industrial and urban wastes pollute our rivers and streams at the very time when the limited supply of fresh water is recognized as a serious problem. We look to the oceans as one of the most likely sources of increased food supply for the future; at the same time we pour tons of detergents into them, thereby running the risk of harmfully —perhaps irreversibly—upsetting the very ecology on which we base our hopes. The industrial furnace, the smelter, the hearth fire, and the automobile pour forth contaminants into our atmosphere, with short-term effects that are typified by the smogs of London and Los Angeles and with long-term effects that have yet to be assessed.

How do we attack these problems and the many others like them, such as the dwindling farm population, increased urbanization, transportation, production and distribution of food and other supplies, protection against the rigors of nature, and the preservation of health? Certainly we cannot solve them by inattention or by any laissez-faire approach. Progress is born of experience, but some experiences completely undo the steps of progress. We must not let such experiences come to pass; the world must learn to handle its resources wisely. Population growth must be controlled; food production must be expanded, and food distribution must be matched to the need. We must heed what we are doing to our atmosphere, rivers, and oceans; if necessary, we must change our ways, lest we irreparably damage ourselves through misuse of our environment.

Various tools must be shaped and applied by the human intellect to the solution of these problems. Some of these tools are political, some sociological and economic, and some scientific and technical. Mankind must fully develop all these tools in order to solve the problems that lie ahead.

Important among these tools are those of science and technology. They provide the basis for understanding the consequences of what we do to, and with, our natural environment, and they also furnish us with the technical ability to achieve our objectives. Moreover, modern developments in science and technology have produced the capability for large-systems management, undoubtedly one of the most important new tools for better control of man's environment and for the solution of many of our other large-scale problems.

In the present climate, science faces a double challenge. On the one hand, there are the problems of understanding and interpreting nature and of extending the frontier of knowledge. On the other hand, there is the challenge, more clearly defined than ever before, to scientists to apply the results of science and technology for the benefit of mankind.

The Challenge of Science

At the frontiers of science today lie some of the most fundamental problems that have ever challenged or excited the human intellect. In the biosciences, the structures of giant molecules involved in life and life processes are becoming known and understood. The genetic code, the fundamental roles of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), the mechanisms of information storage and retrieval in memory processes, and the fundamental significance of chemistry to all phases of life, including perhaps those of mental behavior, occupy the attention of competent researchers all over the world.

Astronomers are trying to probe the mysteries of the quasars and the radio galaxies. If the red shifts in these bodies are interpreted in the usual manner, then these objects must be billions of light years away, and they must be of galactic size; moreover, they must be pouring forth energy at a prodigious rate, equivalent to the consumption of a dozen suns per year. What these objects are, whether they are as far distant as they appear to be, whether they are really pouring forth such great quantities of energy and, if so, how, remain exceedingly challenging and perhaps very fundamental problems. At the same time, the astronomer has another new object to deal with, namely, the celestial source of x-rays. Quite unexpectedly, rocket observations have revealed some dozens of appreciable sources of x-rays on the celestial sphere. The exact identification of these sources and their explanation remain unsolved at the present time.

Only decades ago, the discovery of a number of new elementary particles gave some expectation that the fundamental nature of matter would soon be explained. Today, the plethora of such particles leaves the question of the ultimate nature of matter completely open. The proton, neutron, and electron, once regarded as ultimate units, appear to have further detailed structure. The electronic charge itself may be further divisible. Quarks, particle triplets which may prove to be fundamental building blocks of matter, are now being sought. For this purpose, higher-energy particles, similar to those found in the natural cosmic rays at the top of the atmosphere, must be used or must be generated with larger and more powerful accelerators than those previously available.

The progress of the past decade has completely revolutionized geophysics. The nature and behavior of the iono-

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sphere, the aurora, the geomagnetic field, and the upper atmosphere have been revealed in a series of brilliant discoveries. The present opportunity for direct observations of other bodies of the solar system makes possible fuller study of the earth by direct comparison with the moon and the planets.

The problems in each discipline are stimulating, frequently broad in scope, and fundamental in character. The time is rich with opportunity to increase our understanding of nature and man and to increase the store of knowledge with which man turns the forces and substance of nature to his own advantage.

Since World War II, science has enjoyed generous and, to a considerable extent, unquestioning support from the various government agencies and the Congress. But this golden age of largess to science is ending. Science may indeed receive ample support in the future, but it will not be unquestioning support. Science must compete with other demands on the national pocketbook, and scientists must present their cause in an effective and understandable way. The case is a good one; it is in the national interest to present that case as vigorously and as effectively as possible, to show how and why government support of basic research is a national investment from which full return can be expected.

Over the past decade, space research has become an important segment of modern science and technology. In a remarkably short period of time, space techniques have had a sizable impact on numerous scientific disciplines and on the development of valuable practical applications.

Space Science

The rocket, satellite, and space probe are powerful tools for scientific research. With them, the investigator has been able to tackle many important and fundamental problems that previously could not be attacked effectively. Observations that are impossible on the surface of the earth at the bottom of our obscuring and distorting atmosphere can now be made with space techniques.

With the Space Age, a new phrase came into use—*space science*, meaning basic scientific research in or directly related to space. In broad perspective, space science includes two major areas of research—exploration of the solar system and investigation of the universe. The first category includes the scientific investigation of our earth and its atmosphere, the moon and planets, and the interplanetary medium. The nature and behavior of the sun and its influence on the solar system, especially on the earth, are of prime importance. With the availability of space techniques, we are no longer limited, in direct observations, to a single body of the solar system; we may now send our instruments and men to explore and investigate other objects in the solar system. The possibility of comparing in detail the properties of the planets adds greatly to our power to investigate our own planet. Potentially far-reaching in its philosophical implications is the search for life on other planets.

The fundamental laws of the universe in which we live are the most important objects of scientific search. Space techniques provide a powerful means of probing the nature of the universe by furnishing the opportunity to observe and measure from above the earth's atmosphere in wavelengths that cannot penetrate to the ground. It is also possible to perform experiments on the scale of the solar system by the use of satellites and space probes to study relativity; we can delve into the nature of gravitation and search for the existence of gravitational waves.

Space science is, however, not a new science or even a new scientific discipline. Rather, it is the extension of numerous classical disciplines by the application of space techniques to the solution of important scientific problems. The vitality of space science lies in its great contribution to the broadening and strengthening of science right here on Earth.

Four major disciplines—geoscience, physics, astronomy, and bioscience—supply us with several examples. All these disciplines are thoroughly involved in exploring the solar system and investigating the universe.

Geoscience

The space approach has strengthened and extended geoscience in four significant ways: (i) by providing powerful new tools; (ii) by opening up new areas of geoscience; (iii) by extending geoscience to other planets; and (iv) by drawing geoscience, astronomy, and physics closer together.

New tools for geoscience. Sounding rockets and satellites have furnished a powerful new attack on old problems. One of these problems is the investigation of the earth's upper atmosphere beyond the reach of aircraft and balloons. Those familiar with this field are keenly aware of the struggles, starting in the early 1900's and extending over nearly half a century, to glean information from various indirect sources about the properties and behavior of the high atmosphere. Some remarkably good detective work was done, but progress was slow and very uncertain. There were simply too many parameters, not subject to direct measurement, to achieve unambiguous answers.

With the sounding rocket, and later the artificial earth satellite, the pace of definitive observation and measurement increased by orders of magnitude. The pressure and density of the atmosphere were determined to heights of over 1500 kilometers. Molecules and ions in the upper atmosphere were identified. It was found that there are ionized oxygen atoms in the middle ionosphere instead of the neutral oxygen molecules found at sea level. Still higher is a region dominated by helium, and even farther out there is a region predominantly of hydrogen. Atmospheric motions, the aurora, and other high-altitude phenomena have come under the revealing scrutiny of space-borne instrumentation.

It was possible to observe the solar spectrum at various altitudes, thereby determining where the different solar wavelengths are absorbed in the atmosphere. These data are critical to understanding the influence of the sun upon our atmospheric environment.

The word "environment" is the key to the practical importance of much of space science. Through space research we understand better the nature and behavior of our environment and its influence upon our lives. With such knowledge we are better able to cope with the problems of living in our environment and of using the earth and space environment to full advantage.

For example, understanding the lower atmosphere and its behavior is especially significant at this time when we are wrestling with the possibilities of actually modifying weather to serve practical needs, such as enhancing water supplies, decreasing lightning hazard, protecting crops from storm damage, and perhaps, in the more distant future, even taming the hurricane and the tornado. The atmosphere affects the design of airplanes, missiles, and satellites; it has a major influence on various forms of radio communication, including the guidance and control of our own rockets and the detection and interception of enemy missiles. Knowledge of the atmosphere is also important in the monitoring of nuclear tests and in the development of applications that depend upon atmospheric behavior, such as transhorizon radar.

The problem of atmospheric pollution, which affects us all, needs thoughtful and searching attention. Urban smog is no longer an occasional phenomenon, but is a threat to most large cities. The frequency of smog in the Los Angeles area is well known. Smogs of London, New York City, and Pittsburgh have been highly distressing—even fatal to some. One solution to this problem would be to cease burning fuels for home and industry, stop driving automobiles, and forego those activities that inject contaminants into the atmosphere. A better approach is to understand thoroughly the behavior of our atmosphere, and what our activities do to it, so that we may devise ways of living and working that leave our environment unharmed. The ability of an instrument on a polar satellite to observe the entire earth each day, coupled with the ability of modern computers to analyze vast amounts of data rapidly, gives the space scientist not only a global view of terrestrial phenomena, but also the tools to begin to understand the behavior of our atmosphere.

These are examples of the direct practical application of knowledge about our environment; but there are aspects that may escape attention until too late if we do not press for a clear perception of man's environment and his role in it. Let us cite two examples.

The amount of carbon dioxide in the atmosphere has increased 8 percent in the last 60 or 70 years. Over this period there has been a great growth in industrial activity and in the use of the internal combustion engine. Because carbon dioxide in the atmosphere absorbs heat radiated from the ground, increasing carbon dioxide content implies a gradually increasing temperature at the earth's surface. It would take only a rise of a few degrees in the average temperature of the atmosphere to cause profound changes in climate, the melting of the polar ice caps, with sufficient changes in sea level to inundate low-lying land masses such as Florida. It has been suggested that the melting of Arctic and Antarctic ice would soon lead to an increase in the earth's cloud cover followed by increased and widespread snowfall, initiating a trend toward another ice age.

Even more subtle is the influence we may be exerting on the ultimate sources of life-giving oxygen in our atmosphere. Science teachers used to point out that, although the atmosphere is not a chemical compound, the proportions of the major constituents like nitrogen and oxygen are absolutely unchanging. This point of view, however, is an illusion fostered by the vastness of the atmosphere and the extreme slowness of changes. But changes do occur, as illustrated by the previous example of the carbon dioxide content of the air.

The fact is that oxygen is constantly being removed from the air, for example, by oxidation of the rocks of the earth's crust. This loss is offset by the escape to the atmosphere of oxygen from the oceans where oxygen is continually being released by photosynthesis in marine plants. There are indications that marine life is absorbing and being affected by pesticides and herbicides that are being washed into the oceans. In view of the fact that there is no known buffer or stabilizer for the equilibrium of oxygen in the photosynthesis-atmosphere cycle, the amount of oxygen in the atmosphere may be expected to decrease if the balance of the plant and animal ecology of the oceans is drastically disturbed. Because there are now about a half million metric tons of oxygen per inhabitant on Earth, and because any changes will appear to be quite slow, harmful long-term effects will not be easily perceptible in the critical early stages. The concern is that by the time significant changes are evident, it may be too late to remedy the situation. The consequences of ignorance are potentially so drastic that the investment in knowledge becomes necessary.

The significance of the atmosphere in our lives is clear. The interplanetary medium and the sun have a related importance. The sun literally controls the state and behavior of the earth's atmosphere by transmitting prodigious quantities of energy to Earth through the interplanetary medium. Thus, from the practical importance of scientific research on our *local* environment, we are inevitably led to the importance of investigating our *space* environment.

Land and water, too, are important parts of our environment that space techniques are helping us to investigate. By observing the effect of the earth's gravitational field on the orbits of artificial earth satellites, it has been possible to analyze the gravitational field to a high degree of accuracy, to deduce the strength of the earth's upper mantle, to describe in considerable detail the true shape of the earth, and hence to improve our mapping capabilities. Earth photography, such as that from the various Gemini missions, adds new power and perspective to the study of geography, geology, hydrology, glaciology, oceanography, forestry, and agriculture. The potential of these areas of science for practical returns is tremendous.

New areas of geoscience. The second impact of space research upon geoscience is in the opening up of new, unsuspected areas in the discipline. Investigation of the earth's magnetosphere is an entirely new aspect of geoscience, which began with James Van Allen's discovery of the radiation belts. Indeed, the term magnetosphere is new; it was coined to designate that region of the interplanetary medium over which the earth's magnetic field has a dominating influence.

In retrospect, it is somewhat surprising that the magnetosphere took so long to be discovered. At the beginning of the 20th century Størmer began developing the theory of orbits of charged particles in the earth's magnetic field as a basis for his theory of the aurora. He showed that particles coming from great distances such as from the sun would be excluded from certain regions in the vicinity of the earth because of the earth's magnetic field, and that those which did reach the top of the atmosphere would be guided by the field into the auroral zones. Later extensions of the Størmer theory to relativistic particles explain the shielding effect of the earth's field on cosmic radiation. The Chapman-Ferraro theory of the earth's magnetic field fully predicted the generation of a cavity in the solar plasma sweeping by the earth. Nevertheless, it was not until a decade ago that this theoretical concept was experimentally confirmed, and the fullblown concept of an earth's magnetosphere began to take shape.

Occupying a cavity carved out of the solar wind by the earth's magnetic field, the magnetosphere (Fig. 1) is enveloped on the sunward side by an immense shock wave that sweeps around the earth in much the same way that an aerodynamic shock wave accompanies a supersonic aircraft. The magnetopause, or boundary of the magnetosphere, lies behind the shock wave, while within the magnetosphere itself are the trapped radiations that comprise the Van Allen belts. These radiation belts are a sort of no-man's-land where radiation intensities are too high to permit any prolonged manned operations.

While the magnetosphere extends 10 or 15 earth radii from the sunlit side of the earth, in the antisolar direction the earth's field lines are swept out by the solar wind to great distances. The total extent of this magnetospheric tail, which some have likened to that of a comet, is still not known, although it clearly reaches well beyond the distance of the moon's orbit. Explorer XXXIII has provided data on the magnetospheric tail from a distance of 120,000 kilometers beyond the moon's orbit. Moreover, instruments in the deep space probe Pioneer VII have detected what may be effects of the earth on the solar wind at more than 6,000,000 kilometers beyond the earth.

The study of the magnetosphere is interwoven with investigations of the aurora, magnetic storms, magnetic fluctuations, disturbances in communications, and weather anomalies, on the one hand, and of the interplanetary medium and solar activity on the other. To understand the important relations among these various phenomena, we are now investigating the dynamics of the magnetosphere. With such studies we expect to learn about the detailed mechanisms by which the sun exerts its control on the earth's atmosphere.

Geoscience and the other planets. The third profound impact that space activities have on geoscience involves the planets. The domain of geoscience has grown to include many bodies of the solar system. No longer must the geoscientist be content with only one sample of the solar system, namely, the earth. Now automated instruments —and later on, men—can go to the moon and planets to ask of those other bodies the same questions that the scientist has long been asking about the earth. The theories, instruments, and skills needed and developed to study the earth can now be applied to investigating the moon and planets firsthand. Conversely, improvements in instrumentation achieved to further the study of the planets directly benefit the investigation of the earth.

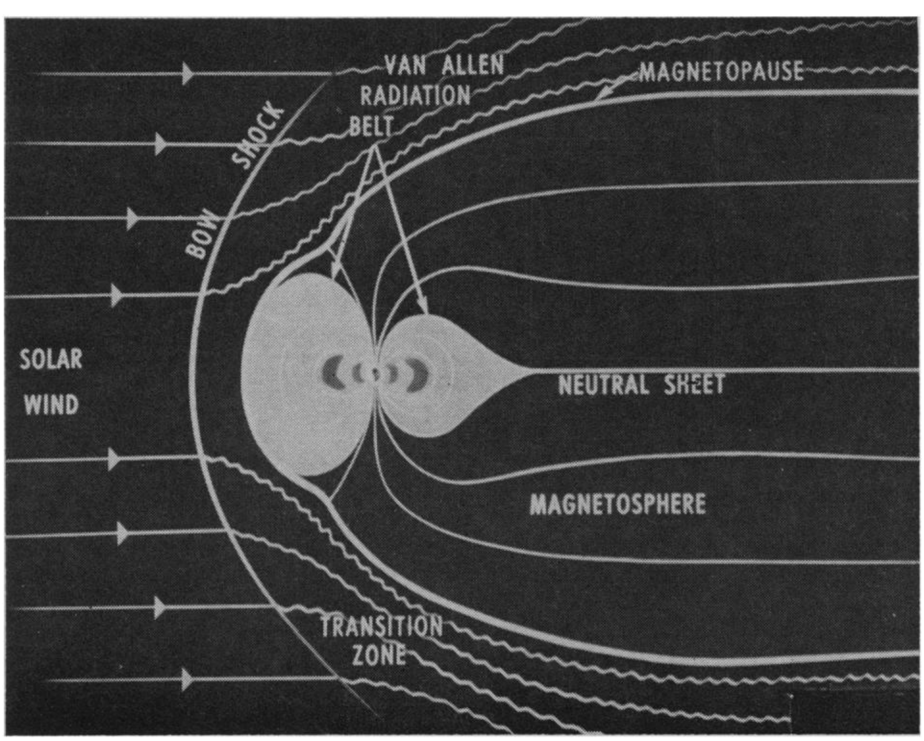

Fig. 1. Magnetosphere of the earth.

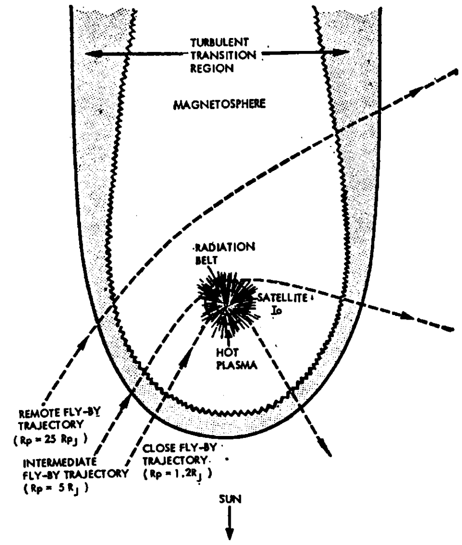

Fig. 2. Jupiter fly-by trajectories.

Comparative studies of the planets and their atmospheres, ionospheres, and magnetospheres promise increased understanding of our own planet. The investigation of solar-terrestrial relationships can now become the study of solar-planetary relationships. If it is true, as has been suggested, that the composition of Jupiter is essentially that of the primordial material from which the solar system formed, the study of Jupiter, fascinating and important in itself, should also assist in probing into the origins of the solar system and our earth.

The existence of an earth's magnetosphere immediately suggests the possibility of other planetary magnetospheres, the study of which may shed still further light on solar-planetary relationships. The instruments on Mariner II and Mariner IV, however, did not detect any planetary magnetic field, which shows that Venus and Mars have very weak magnetic fields, if any. Further evidence for the lack of magnetic fields was the absence of any detectable magnetospheres like that of the earth. On the other hand, radio wavelength emissions from Jupiter indicate that this planet has an extensive magnetosphere, reaching to millions of kilometers from the planet itself (Fig. 2). From the intensity of these radio emissions, it is clear that the Jupiter radiation belts are at least a thousand times more intense than those of the earth.

It may even be correct to think of our earth as revolving within a solar magnetosphere. Perhaps interplanetary space divides into two regions: a solar magnetosphere region enveloping the nearer planets, and the remote reaches of the solar system where galactic space conditions prevail. A challenging problem of space research is to find and probe the boundary between these two regions and to enter and study the true interstellar medium.

Partnership among geoscience, astronomy, and physics. The fourth impact of space research on geoscience is the drawing together of physics, astronomy, and the geosciences in the study of solar-terrestrial relationships and in the comparative study of the earth, moon, and planets. The investigation of the moon and planets has long been in the domain of astronomy. Now, as instruments reach these other bodies of the solar system, the investigation of them extends into the geosciences.

Modern earth-based telescopes have made it possible to view the moon in great detail. However, the best photographic resolutions have been on the order of a kilometer, and visual resolutions have been only a little better. When Ranger took its pictures of the moon, it figuratively provided the astronomer with a telescope a thousand times as powerful as any previously available. Objects about 0.5 meter in size could be resolved in the best of the Ranger and Lunar Orbiter pictures (Fig. 3). In addition, a new perspective could be obtained (Fig. 4). When Surveyor landed, it provided the astronomer with further improvement in resolution by another factor of 1000 (Fig. 5). But at that point, because the spacecraft actually landed on the lunar surface and demonstrated the ability to place equipment and instruments on the moon itself, it brought about the fusion of astronomic and geoscience interests in lunar geologic investigations.

In a similar way, studies of cosmic rays, plasmas, and magnetic fields in space and studies of their relationship to the earth's magnetosphere have brought physics and geoscience into a close partnership. The physicist finds in the magnetosphere and interplanetary space a gigantic laboratory in which he can study plasma and magnetohydrodynamics under conditions not afforded to him on the ground. He is even able to conduct some controlled experiments by flying high-energy particle accelerators and then to measure their effects on the magnetosphere and upper atmosphere with satellite instrumentation. Barium and sodium releases in the upper atmosphere and the more distant space can be used to make observations on the photochemistry of the atmosphere and to study magnetic and electric fields in space. But in pursuing these studies, the physicist is, at the same time, tackling problems of great interest to geoscience.

Physics

The principal importance of space to the field of physics is in providing a gigantic new "laboratory" for the conduct of research. The vacuum and the absence of surface effects in the space laboratory are not attainable in the earth-based laboratory. In space, the

Fig. 3. Orbiter III P-12a-H. rim of Flamsteed Crater around Surveyor I site; 43°00′W, 2°75′S.

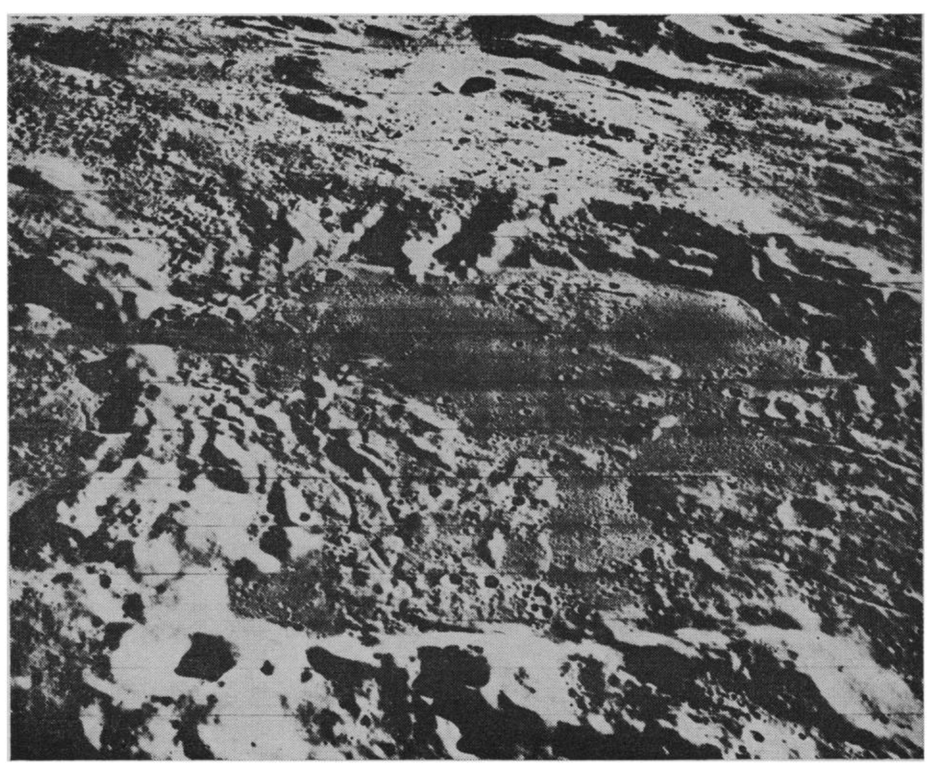

Fig. 4. Orbiter III, craters Murchison and Pallas; 0°30′W, 5°00′N.

plasmas and magnetic fields furnished by the sun can be used to investigate magnetohydrodynamics, collisionless shock waves, and other phenomena that are impossible to investigate on the ground. Also, streaming through interplanetary space are galactic cosmic rays of far greater energy than can be generated on Earth in any accelerator now in existence or contemplated. These particles are available as research tools to the physicist working on problems of high energy and the ultimate structure of matter.

With satellites and space probes, experiments can be conducted on the scale of the solar system. With our developing capability in manned spaceflights, even those experiments requiring the presence of man can be undertaken. Artificial satellites carrying accurate nuclear clocks or precision gyroscopes can be used to check various aspects of the theory of relativity which cannot be checked on the surface of the earth.

The fundamental nature of gravitation is still not understood. The emplacement of high-precision corner reflectors on the moon, to be used with lasers on the earth to obtain a very accurate determination of the relative positions of Earth and Moon, may permit us to use the earth-moon system to determine whether the expansion of the universe has an effect on the value of Newton's gravitational constant.

Astronomy

One can predict an impact of space techniques upon astronomy as profound as that upon geoscience. Throughout most of its past, astronomy was confined to observations in the narrow visible window, augmented in the last few decades by observations in some of the radio wavelengths. A truly remarkable astronomical theory has been built upon these results. But that very theory emphasizes that some of the most important information about the galactic medium and processes, such as the birth, evolution, and demise of celestial objects, is contained in the x-ray, ultraviolet, and infrared wavelengths that are prevented by the atmosphere from reaching the ground. This is not idle speculation. Already, rocket observations have revealed dozens of x-ray sources on the celestial sphere. Such intense x-ray sources were not predicted by astronomical theory, and their discovery has raised numerous difficult questions. The explanation of these sources is one of the major astronomical problems of the day.

The discovery of x-ray sources by space techniques and the finding of the very puzzling radio galaxies and quasars by ground-based techniques underscore a very important point. In the future development of astronomy, both ground-based and space techniques must and will become close partners in extending the frontiers of knowledge about the cosmos. Peering some distance into the future, one can visualize an astronomical facility in orbit about the earth. Like its ground-based counterparts, such as the Mt. Wilson or Mt. Palomar observatories, such an astronomical facility, once established, could remain one of the basic tools of astronomical research for a long time to come.

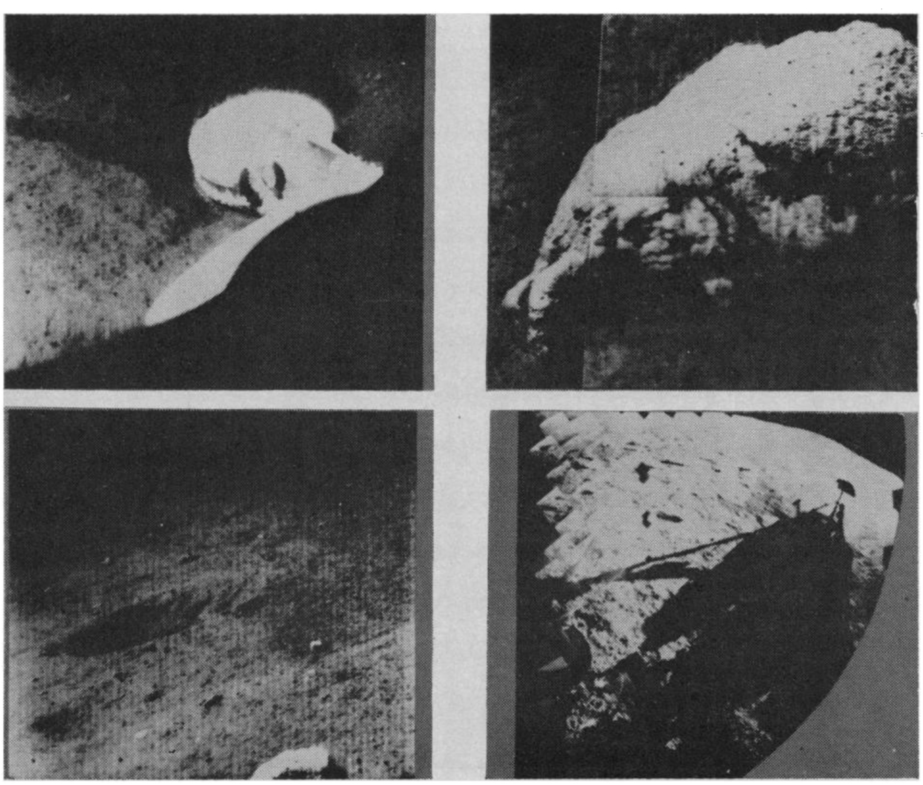

Fig. 5. Surveyor I lunar photos.

Bioscience

The last of the disciplines that we shall use to illustrate the impact of space research on science is in the life sciences. Space science enters upon the scene at a time when some of the most fundamental questions about the physics and chemistry of life are yielding to the penetrating researches of modern biology. The fundamental roles of the proteins and nucleic acids in biological materials and processes, the genetic code, and the chemical basis for memory processes are becoming understood. The discovery of life on another planet of the solar system would illuminate terrestrial bioscience researches, in addition to having a tremendous philosophical impact.

Life on Earth is ubiquitous. Virtually everywhere we search for it, we find it, often in microbial form. It shows up in the driest of deserts and in the hottest and coldest of climes. There are even worms that live in glaciers.

Life has existed on Earth for aeons of time. Fossils of bacteria have been discovered in specimens of chert 3.1 billion years old. Other fossil remains also support the conclusion that there have been living forms on the earth for billions of years.

Life is very persistent. The horseshoe crab of today bears a remarkable resemblance to the trilobites of half a billion years ago. Some bacterial forms of today appear to have survived through aeons. Some forms thrive in what we would regard as extremely hostile environments, such as an atmosphere of ammonia. The tardigrade (a small invertebrate organism) can be completely desiccated to look like a little flaky crystal, and upon being resupplied with water revives and resumes its normal life cycle.

The chemistry of life is remarkably uniform. The nucleic acids and proteins are invariably basic constituents of living matter. The very complicated DNA molecule furnishes the means by which genetic information is stored in the cells of living organisms, and by which growth and specialized development of the cells are controlled. Many organic molecules have right-handed and left-handed forms, evidenced by producing right- or left-handed rotation of the electric vector of polarized light as it passes through a solution of the substance. It is an interesting fact that biological processes never use both right- and left-handed forms of a specific chemical indiscriminately. For example, all living species use left-handed amino acids.

In sum, the chemistry of life on Earth is such as to suggest that, given the right environmental conditions and adequate time, life will inevitably result. Futhermore, it appears likely that the basic chemistry of life will be the same wherever it is found.

This is the framework in which we are investigating the behavior of terrestrial life under space conditions. By sending various forms of life aloft in satellites and space probes, we can search into the relative roles of chemistry and of Earth conditions, such as gravitation and the day-night cycle, in the evolution of life and life processes as we now know them.

This is also the framework of interest in the possibility that there may be some forms of life on Mars or Venus. Environmental conditions on Mars may well have been adequate for the formation of life, although the apparent lack of water raises serious doubts in the minds of some scientists. The apparently high surface temperature of Venus, above the melting point of lead, is too hot for life. But some investigators suggest that improved temperature measurements may show that the surface is considerably cooler than most scientists now believe. Others suggest that mountains or perhaps the poles on Venus may provide a temperate environment. In either case, Venus might be capable of supporting the development and preservation of life. Were life to be found on another planet, our experience on Earth suggests that it would be basically similar to terrestrial life in its chemistry. Having been formed under different conditions from those on Earth, however, extraterrestrial life may show some significant large-scale differences. The comparison of this similar, yet somewhat different, life with that on Earth, which could be the source of sweeping new generalizations concerning biology, should prove most illuminating to terrestrial biology and its applications in medicine and agriculture. Moreover, there may be much to learn of the chemical steps toward life on a planet unmodified by the activity of living organisms. Hence, even if life is not found on Mars or Venus, the investigation of the state of evolution of the planet's chemistry will still be important biologically.

Because of the important challenges of space science, over 200 colleges and universities have become involved in space research. The major fraction of our space science research is carried out in these institutions. At present, approximately 1500 faculty members and over 2000 graduate students are actively engaged in space science and technology. In addition, under NASA's sponsorship there are about 3600 students now studying for doctoral degrees by working on space-related problems in some 30 academic disciplines. The effect is to enrich graduate education in science and engineering and to strengthen the national base of scientific and technical competence on which we may draw to cope with the severe technical problems that beset mankind.

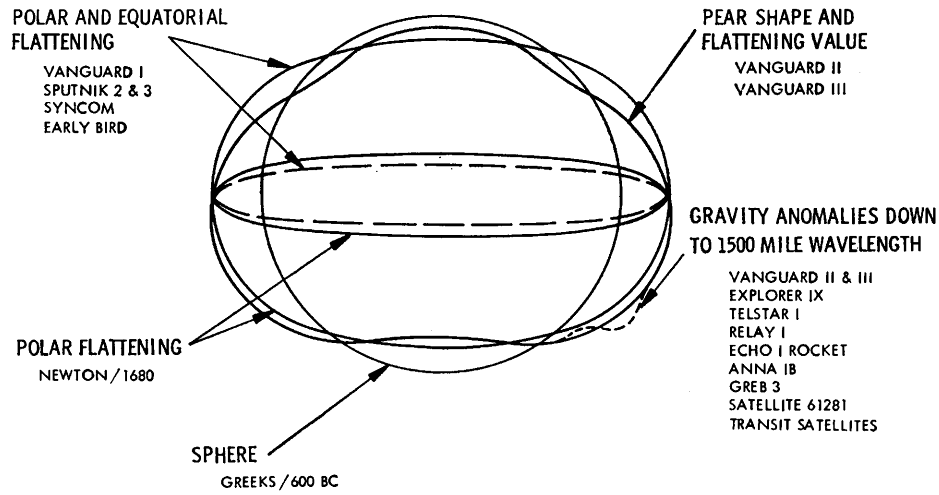

Fig. 6. Size, shape, and gravity field of the earth (through satellite geodesy).

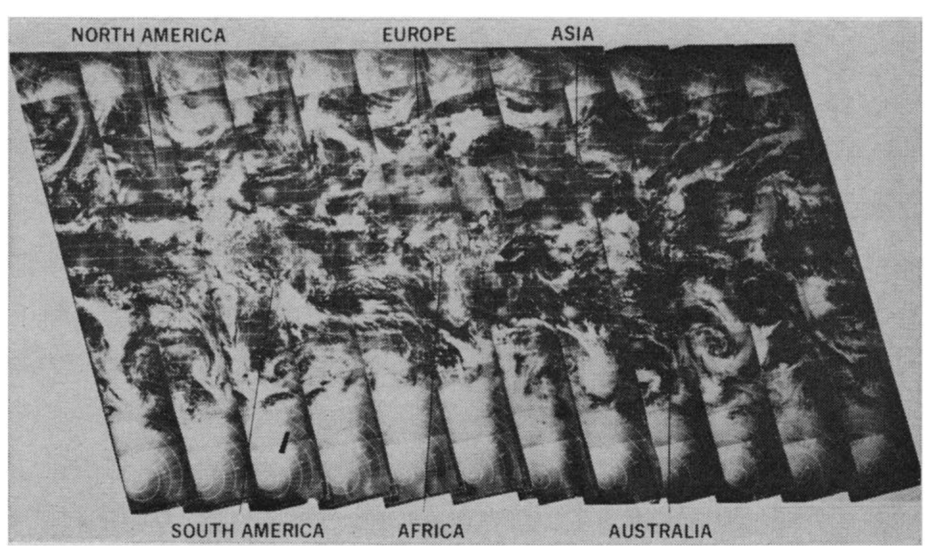

Fig. 7. ESSA-3 24-hour world cloud cover, 31 October 1966.

Space Applications

Let us paraphrase Socrates, speaking about 400 B.C.: "We who inhabit the Earth dwell like frogs at the bottom of a pool. Only if man could rise above the summit of the air could he behold the true Earth, the world in which we live" (*1*). Socrates could hardly have understood how prophetic his statement of 2400 years ago was, for it has only been in the last few years that we have been able to rise above our atmosphere and fully appreciate the power of observing our own Earth from that vantage point.

Most of us have become familiar with some of the uses of satellites in the fields of communications and meteorology, but we are just beginning to appreciate the real potential in those fields as well as the possibilities in many others, such as geodesy, geology, hydrology, cartography, navigation, air traffic control, oceanography, and even geography.

Next we discuss some of the more apparent potential uses of space, in the areas of geodesy, communications and navigation, meteorology, and earth resources survey. The review is by no means complete, for space is still in its infancy, and we have yet to visualize many of its uses.

Geodesy. Until 1958, progress in defining the shape of the earth was slow (Fig. 6). The Greeks postulated a spherical Earth about 600 B.C., and estimated the circumference with remarkable accuracy. In the 17th century Sir Isaac Newton recognized the flattening of the earth at the poles. But the next real advance had to wait for the space era.

The use of satellites for geodesy serves two purposes: (i) to establish a common world geodetic reference system and (ii) to define the gravity field of the earth accurately.

A common geodetic reference system is related directly to our ability to map the surface of the earth. Cartographers have long been plagued by the fact that in place of a single reference system today we have about 80 more or less independently derived reference systems or datums. Satellites are now being used to tie these independently derived datums together with the required accuracy. The satellites Echo I, Echo II, Pageos, and GEOS-I have already permitted us to establish the relative positions of 12 of the 75 control points required to establish a single reference system for the earth.

Of equal and perhaps greater importance to the determination of the size and shape of the earth is a precise definition of its gravity field. Not only will this permit great improvement in our ability to predict and control satellite orbits, but it will also provide us with basic scientific information on the composition and structure of the earth, for the earth is not uniformly dense, and the anomalies in the shape of the earth, including the equatorial flattening and pear shape, must be related in some way to varying composition and structural strength.

Communications and navigation. We have already established the technology for the use of satellites for large-volume point-to-point or intercontinental communications as represented by the current commercial satellite systems. These systems are bringing about healthy competition with the older conventional systems, such as undersea cables, as evidenced by recently reduced transatlantic telephone rates.

However, the potential uses of satellites in the broad areas of communications are many. The ultimate and complete potential is probably beyond our ability to predict. Today, economic use of satellites is restricted to large-volume traffic through a rather small number of very large ground terminals which cost millions of dollars. We can, however, foresee the extension of the advantages of satellites for communication between smaller and smaller ground terminals in larger and larger numbers. Achievement of large-scale multiple access to relatively small and inexpensive earth terminals could ultimately make it economical for many more areas and nations to have their own earth terminals. This direct access to a global satellite system would eliminate the need to cross political boundaries and territories for such access.

If we carry this communication capability for small stations one step further and combine it with a position determination capability with that same satellite system, we can foresee the development of an air and sea navigation and traffic-control satellite system. Such a capability is already needed on the North Atlantic air routes to permit a closer and safer spacing of aircraft within the optimum air lanes and to provide up-to-date weather and sea-state information to pilots and ship captains to improve the economy, comfort, and, above all, safety of their journey.

Nine commercial airlines, both foreign and domestic, as well as the Federal Aviation Agency and the Department of Defense, are now participating in the current Applications Technology Satellite program to develop aircraft equipment and techniques for working with satellites in this area.

As we go to more sophisticated spacecraft in our program for lunar, interplanetary, and galactic exploration, it is also quite probable that we shall need the help of data-relay satellites to provide for the high capacities of communications required. A data-relay satellite system around the earth could minimize the requirements for continuing expensive major additions to

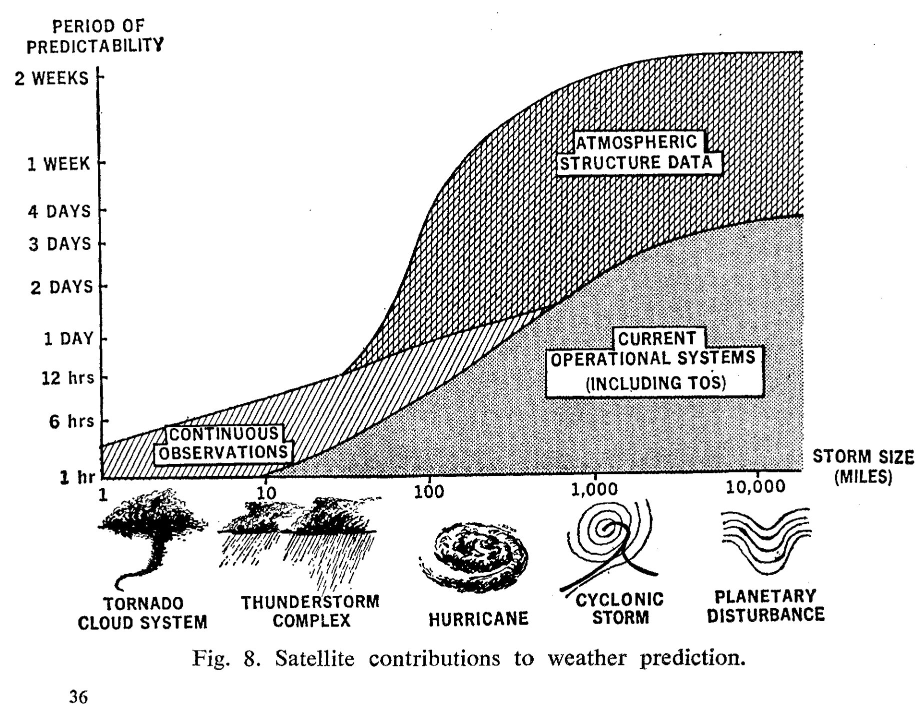

Fig. 8. Satellite contributions to weather prediction.

the global network of tracking, command, and data-acquisition stations.

Data-relay satellites orbiting the moon and planets could provide for continuous communications with orbiters and landing craft when they are obscured from the earth, and could minimize power required on board the research spacecraft or landing craft for communications over the interplanetary distances back to Earth.

In the broadcast area, as our ability to fly larger spacecraft and carry more power into space progresses, it will be possible to provide for television transmission, for community services, to specially designed receivers with costs that might be practical for use by schools or for viewing by groups of people, perhaps in villages where such services are urgently needed. As we progress further, direct broadcasting (from a satellite) of voice or eventually even of television to conventional radio or television sets in the home is possible. Due to the size and power requirements of a satellite for the latter capability, a television broadcast system cannot be made available until near the end of the next decade.

In addition to the potential economic benefit to the United States and other advanced nations of the world, exploitation of this application of space could result in important political and social benefits to developing nations. A voice or TV-broadcast capability could bring the advantages of modern mass communications to regions lacking adequate broadcasting networks for educational and informational programs. This could bring modern teaching techniques to these areas, provide education in elementary health and hygiene, and encourage regional cohesion, especially the use of a common language in areas where there are now many languages or dialects. The development of such a capability by the United States would demonstrate to the world the vigor of our space research and development effort and our willingness to use our strengths on behalf of those developing nations which are currently unable to participate in space activity.

We should work toward conserving one of the nation's and the world's most valuable resources—the Radio Frequency Spectrum. Space offers the possibility of effective use of areas of the spectrum which cannot be used with earth-based systems.

Meteorology. Meteorology is the second major space application that has already resulted in an operational space system; this system provides daily observation of the global cloud cover (Fig. 7), which is the most visible and dramatic indication of the dynamic state of the earth's atmosphere. In addition to a determination of large-scale atmospheric circulations, delineation of jet streams, mountain lee waves, and wind shears, such presentations reveal large-scale storms and permit monitoring of their progress, thus providing a sound basis for issuing warnings. This is one of the most striking benefits accruing from our current satellite view from above.

The operational satellite system for the Environmental Science Services Administration (ESSA), based on satellites and instruments developed in the TIROS and Nimbus research programs, was established in 1966. The role played by the operational system in weather forecasting is given schematically on the chart of Fig. 8, which

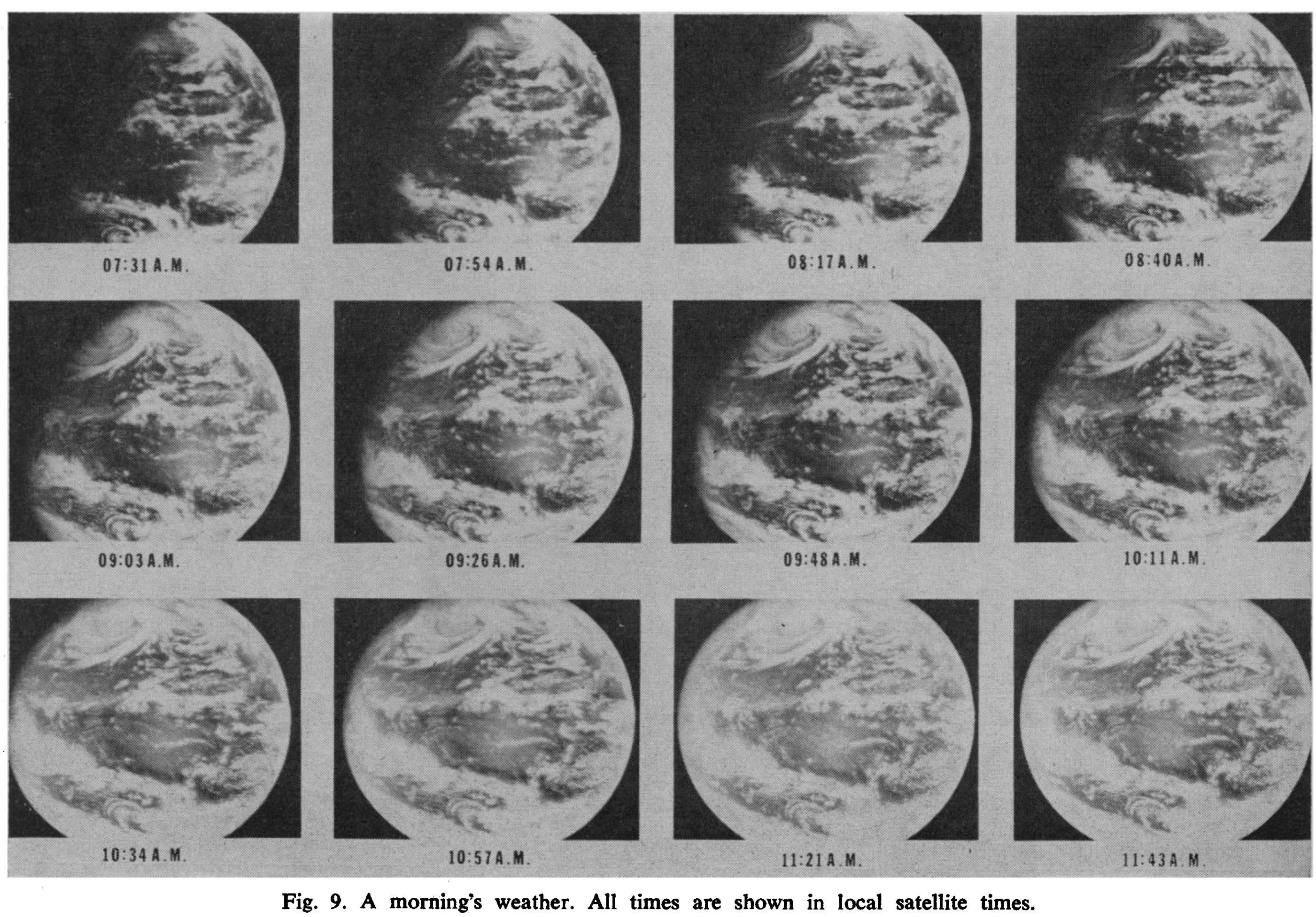

Fig. 9. A morning's weather. All times are shown in local satellite times.

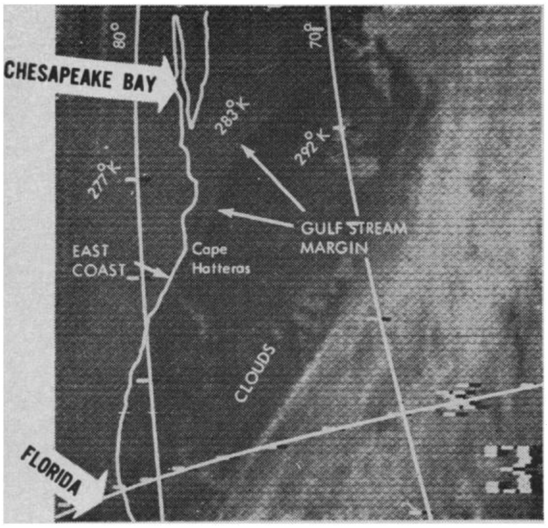

Fig. 10. Sample of useful data on earth resources, obtained by Nimbus II. The high-resolution infrared imagery clearly depicts the Gulf Stream. Temperature values were determined by microdensitometer. The imagery can be very useful in determining the location, distribution, and movement of the major ocean-water masses. Studies of this nature will be of great value to oceanographers, meteorologists, and the world's fishing and shipping industries.

shows the relationship between storm size and the period over which its behavior can be predicted, and indicates the capabilities of our current operational systems including the TIROS Operational Satellites (TOS) or ESSA satellites (in the stippled area of Fig. 8). Current systems permit forecasts of the behavior of larger-scale weather phenomena, including storms of the scale of hurricanes and cyclones over a period of 1 or 2 days. The quality of the predictions (within this stippled area) will be greatly improved when nighttime observations of cloud cover become available. Such a capability of observing cloud cover at night was developed in the Nimbus program and is being incorporated in the next generation of operational meteorological satellites.

However, many of the most violent but small-scale storms, such as tornadoes and thunderstorms, have durations of only a few hours and can develop, wreak havoc, and dissipate without being observed by these satellites. To provide adequate warning of these storms, there must be a capability for continuous observation of these very local phenomena. A satellite in synchronous orbit offers the potentiality for the required continuous observations and permits short-term forecasting of these events (as shown in the barred area of Fig. 8). Dramatic progress toward developing this capability is curently being made with the Applications Technology Satellite, ATS-I. A sequence of pictures taken 23 minutes apart on 24 January 1967 in the Pacific is shown in Fig. 9. A detailed examination of these pictures is necessary to observe the changes that are taking place over such a short period.

While short-range predictions of the weather are important to our daily activities and to the saving of lives and property, the value of weather forecasts would increase manyfold if such predictions could be extended over a longer period, perhaps as much as 2 weeks or more. The National Academy of Sciences–National Research Council in a 1965 report estimated that the potential savings as a result of such long-range forecasting could approach $2½ billion annually for the United States alone (*2*).

The ingredients needed to permit such forecasts are an adequate model of the atmosphere, sufficiently large computers, and quantitative measurements of the total atmospheric structure, including such parameters as pressure, temperature, moisture content, and wind velocity at various altitudes on regular periodic schedules over the entire earth. Atmospheric models and adequate computer technology already exist. Techniques for the acquisition of atmospheric-structure data need to be developed to further improve our models and to make possible the 1- to 2-week forecasts of larger-scale weather shown in Fig. 8. Recognizing this, the World Meteorological Organization established the World Weather Watch Program which will lean heavily on data to be gathered by the advanced sensors and techniques being developed in the Nimbus program to probe the atmosphere both directly and remotely.

Earth resources survey. Our need to develop, protect, replenish, and use our natural resources wisely becomes more apparent and more urgent as the world's population continues to grow. The air and atmsophere, the oceans, fresh water, glaciers, forests, minerals, and tillable land are among the resources of the earth. Efficient utilization of these resources includes not only their discovery and management, but also detection and control of pollution which is becoming an extremely important factor. In many areas this need is reaching crisic proportions. Fortunately, with the advent of the space age, new techniques are being discovered and developed to assist us in meeting this crisis. For nearly 2 years, we have been exploring the use of both manned and automated spacecraft to develop the potential of surveying earth resources from space. Much of our work to date has been done with data acquired from aircraft and with data which we have been able to extract from existing satellites such as TIROS, Nimbus, ATS, and, of course, with the valuable photographs taken by the astronauts of the Mercury and Gemini programs.

Space photography can reduce greatly the number of photographs required and thus decrease the cost incurred in mapping the earth. The number of accurately surveyed control points on the ground required to convert space photography to topographic base maps is over 300 times less than the number of references required to use photographs taken from aircraft. The Department of the Interior estimates that the value of up-to-date topographic maps is worth nearly $700 million annually to our national economy alone.

Photography from space sometimes provides us with a clearer picture of many large geographic features than it is possible to obtain with a mosaic of photographs taken from aircraft. Recognition of large-scale features, particularly large fractures or faults in the earth's crust in remote areas, offers great promise in identifying new major ore bodies which are frequently related to such fractures.

In agriculture, there is good promise for the detection and identification of soil types from space. Infrared photographs can show the onset of disease in our forests, due to the fact that diseased trees exhibit a change in temperature which is registered on infrared film. We believe that operational surveys of food and forest areas can ultimately be made from space and that the data can be handled automatically by computers to map the conditions of the various types of crops and soils.

We can do a great deal toward surveying our freshwater situation from space. Lake colors can be correlated with their biology, chemistry, sediment, and pollutant content. Infrared imagery can be utilized to locate fresh water which is escaping along our coast lines. It has been estimated that such water losses may amount to one-sixth of the total fresh water available to our ever-increasing population. With infrared techniques, we have also been able to locate areas of water trapped by faults in the earth's crust. Glaciers are an important source of fresh water, and their growth and decline which can be monitored from space are very sensitive indicators of the total available supply.

Satellites such as Nimbus have demonstrated their ability to monitor the thermal characteristics of the oceans. Figure 10 shows that we are able to map the Gulf Stream by satellite. There is a close correlation between the location of fish and the temperature patterns of the oceans. Even today, this country must purchase from foreign fishing fleets over half of the fish products consumed in the United States annually. The prospects of transforming fish into a high-protein general-purpose food—a potential partial solution to the world food-shortage problem—requires a more efficient fishing industry throughout the world.

The mapping of navigation routes in coastal and shoal-water areas to help control and counteract silting in our major harbors and navigable rivers, as suggested by the Gemini picture of Fig. 11, and, ultimately, the observation of the sea-state and wave heights of our oceans will also be of major interest to our use of the earth's waterways.

A number of agencies have been exploring the potential of these techniques. The Departments of Agriculture, Commerce, and Interior, NASA, and many universities and other research organizations are undertaking a broad assessment of this area. Specifically designed space experiments can aid in the assessment and at the same time lay the groundwork for actual applications that may evolve.

Fig. 11. View of the mouth of the Colorado River, taken from Gemini 4 in June 1965, at an altitude of 200 to 220 kilometers. The Sonora Desert of Mexico appears at the lower right.

Conclusion

Science and technology are themselves a part of our modern culture. They contribute to the arts, furnish new media for human expression, provide better and new musical instruments and improved acoustics for enriched enjoyment of them, and give the artist new materials and techniques for his work. They enrich the humanities in furnishing man with a broader basis for understanding himself, his potentialities, and his place in nature. The historian has a better approach to his subject because of scientific methodology. The archeologist has a surer grasp on temporal relationships because of the tools that physics and chemistry give him for dating materials and identifying their sources. Slowly, an entire world absorbs the increased understanding of man and nature that science generates, and reflects that understanding in its literature, its social, political, and economic institutions, and its application to human daily living. Today, much of the world's population is aware of the world as a body of a solar system in a galaxy among millions of other galaxies. These people can conceive of man in a historical and cosmological perspective that did not exist in centuries past. As this understanding and these concepts spread to more and more of the world's people, it may be hoped that this common bond of understanding will not only give increased motivation to solve peaceably the problems that beset the world, but will also provide increased means for doing so.

The two cultures of C. P. Snow do not live in isolation from each other. The forces generated by living together, writing together, working together, debating political and social issues together, struggling for survival together, battling human problems, playing together, traveling together, viewing television together, and reading newspapers together irresistibly impel an interaction between the cultures that generates more commonalities than differences. By spreading this sort of interaction to more and more of the world's people, science and technology can be used to strengthen the common bond of humanity. To use properly and effectively these powerful tools of our times is an inescapable challenge to men and governments the world over.

References and Notes

1. Plato, *Phaedo* (Dutton, New York, new ed., 1955).
2. "Economic Benefits from Oceanographic Research," *Nat. Acad. Sci.–Nat. Res. Council Pub. 1228* (1965).

3. All figures in this article were prepared by NASA, except for Fig. 7 which was prepared by the Environmental Science Services Administration.