

# **ADVANCES IN DESERT AND ARID LAND TECHNOLOGY AND DEVELOPMENT VOLUME 1**

Papers presented at the International Conference on the Applications of Science and Technology for Desert Development. The American University in Cairo, Egypt, September 9-15, 1978.

Editors:

ADLI BISHAY  
The American University in Cairo

WILLIAM G. McGINNIES  
The University of Arizona

**1979**



**harwood academic publishers**  
chur • london • new york

## MONITORING THE DESERT ENVIRONMENT FROM SPACE

FAROUK EL-BAZ

Research Director, Center for Earth and Planetary  
Studies, Smithsonian Institution, Washington, D.C.,  
U.S.A.

### ABSTRACT

*The immensity, remoteness and inaccessibility of deserts make difficult their detailed study by conventional means. Space platforms provide a unique opportunity to study and monitor the desert environment, especially because deserts must be studied on a regional basis and because climatic conditions favor their observation and photography from Earth orbit. The Space Shuttle program will allow the acquisition of mapping quality photographs of world deserts in the early 1980's. This will be done using the Large Format Camera, which will obtain color, stereo and high resolution photographs.*

*In addition, space age technology can remedy the scarcity of meteorological data on the desert environment. Automated stations can be placed in remote areas to collect the necessary data and beam them to orbiting satellites. The latter can in turn re-transmit the data from orbit to receiving stations on the ground for analysis and synthesis. Monitoring the deserts from space in this way will help us better understand and utilize more of the land area of the Earth for the benefit of mankind.*

### INTRODUCTION

The term desert comes from the Latin verb *desero*, to abandon, thus *desertum* and *desertus* meaning abandoned, relinquished or forsaken. It is an exceedingly descriptive term since most desert regions once hosted greater numbers and varieties of flora and fauna than they do today. When their weather conditions changed, these tracts were forsaken by the biota for other regions where life-sustaining water was more plentiful.

A desert is commonly defined as a land area that receives less than 25 cm of precipitation per year. It cannot, therefore, hold much vegetation and remains dry most of the time. This definition includes the polar ice of the frozen tundra, which is characterized by perpetual snow cover and intense cold. Regions of "cold deserts" include one-sixth of the landmass of the Earth, or over 23,000,000 km<sup>2</sup> (Figure 1).

However, the term desert is here applied to hot and dry regions of the Earth which are concentrated between 10 and 40 degrees north latitude and 20 and 30 degrees south latitude. These are belts of land fairly close to the Tropic of Cancer and the Tropic of Capricorn, where rainfall is scarce and where the wind is very dry. The "hot deserts" constitute over one-fifth of the landmass of the Earth, or nearly 31,000,000 km<sup>2</sup> (Figure 1).

In general, hot deserts are formed in areas where subtropical high pressure atmospheric belts prevail. These belts produce cold dry winds in the winter, and hot dry winds in the summer. The aridity of these regions varies depending on the type of winds and the topographic characteristics of the terrain.

The sizes of individual deserts are staggering. For example, the North American Desert is approximately 1,300,000 km<sup>2</sup>; the Arabian Desert is 2,600,000 km<sup>2</sup>; the Great Australian Desert is nearly 3,800,000 km<sup>2</sup>; and the Great Sahara Desert is over 9,000,000 km<sup>2</sup>. The immense size of these deserts has precluded their detailed study by conventional means, particularly in view of the many difficulties encountered in desert travel. Consequently, deserts remain as the least understood of all the landforms of the Earth.

Two additional factors have limited geological knowledge of deserts. First, the Earth sciences had their origins in Europe, which is the only continent without a desert. Therefore, unlike mountain ranges, river basins, and even glaciers, deserts and arid lands received no attention in the classical literature. Second, by the nature of their training, geologists looked for solid rock layers to decipher the history of the Earth. Flat desert terrain that is covered by sand and soil attracted only a handful of investigators.

In 1965, when astronauts first observed and photographed the Earth from orbit, they did not fully realize the enormous usefulness of this new vantage point. Visual observations from orbital altitudes were made of the Earth and the Moon. Given the extensive dynamic range of the human eye, astronauts

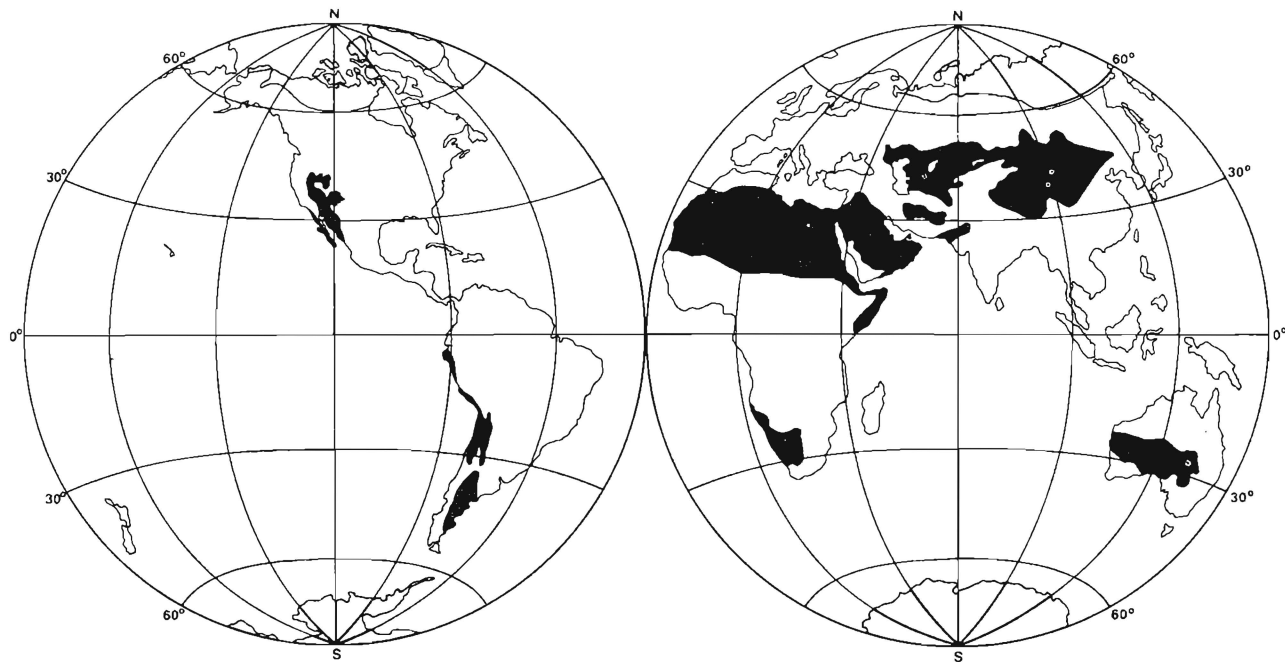


Figure 1: World map on an equal area projection showing the distribution of "cold deserts," north and south of  $60^{\circ}$  latitude and "hot deserts," particularly near  $30^{\circ}$  north and south. The largest expanse of desert is that occupied by the geographic region of the Arab World in North Africa and the Arabian Peninsula.



could see more color and textural variations than could be recorded on the most sensitive instrument or film. The astronauts were also able to document their observations by photographs and to test instruments for later use by manned and/or unmanned spacecraft.

During the Apollo lunar program the utility of orbital photographs in making accurate topographic maps was also established. On Apollo lunar missions 15, 16 and 17 two camera systems were used to photograph the Moon's surface from 100 km altitude. These systems included a 76 mm metric camera and a 609 mm panoramic camera. From these systems orthophotomaps of approximately 15% of the lunar surface have been made at 1:250,000, 1:50,000 and 1:10,000 scales (Masurky *et al.*).<sup>1</sup> These maps of the Moon are better than those available for many areas of the Earth.

New techniques were also learned in photographing the planet Mars by Mariner and Viking spacecraft. Concerning the exploration of Mars, Gilbert Grosvenor wrote: "To look upon this rust-red alien world with clear eyes of modern space techniques is an experience that ancient mythology reserved only for gods. Then, to probe and assess the Martian soil for signs of life, as far away as 235 million miles, so enlarges human capabilities that we must wonder why we cannot apply some of that power to problems that plague so many earthly cultures."<sup>2</sup>

The truth of the matter is that we can apply much of the power of space technology to solving certain earthly problems. This paper deals with two such applications to the study of world deserts and their environment via orbital observations and meteorological monitoring.

#### ORBITAL OBSERVATIONS

Photographs of the Earth, used chiefly for land surveys and geological mapping, are usually obtained from airplanes. However, during the past decade, Earth scientists have recognized the value of observations from space. For the purpose of photographing the Earth, orbiting spacecraft have three advantages over airplanes: 1) a spacecraft travels at higher altitudes (several hundred kilometers) and can, therefore, view a larger area and depict broader features; 2) since spacecraft travel above the atmosphere, they avoid gusts of wind and air pockets that make aircraft relatively unsteady; and 3) a spacecraft follows an orbit around the Earth with a

precision that increases the cartographic value of the photographs.

The Gemini, Apollo, Skylab, and Apollo-Soyuz missions established the utility of color film in studying the Earth (El-Baz).<sup>3</sup> Color photographs from these missions have been used to map major fault systems and subsidiary fractures (Figure 2), to classify soil types in desert regions, and to determine sediment patterns at the mouths of major rivers. However, the stereo-coverage and the resolution of these photographs are below what is required for detailed study and mapping. These drawbacks are also applicable to Landsat data, which provide very limited stereo-coverage and an effective ground resolution of approximately 200 m.

Knowledge gained from previous space missions will help us to better photograph the Earth from orbit during the Space Shuttle program. The Space Shuttle is the major new program of the National Aeronautics and Space Administration (NASA). It is scheduled to start Operational Flight Test (OFT) missions in mid 1979. Following the OFT program, the Space Shuttle will be considered operational and will be termed the Space Transportation System (STS). It is anticipated that eventually there will be a total of four Shuttle vehicles with 30 to 50 missions flown each year.

Launching of the Shuttle will initially take place from the Kennedy Space Center. Range safety conditions there restrict the maximum orbital inclination to 57°, which will permit the Orbiter vehicle to cover a large part of the land-masses of the Earth, especially the desert belts. By 1983, launch operations may be available at the Vandenberg Air Force Base, California. From that locality polar orbits can be attained. Circular orbits from 200 to 1,200 km high can be achieved depending upon payload weight and orbit inclination. Mission duration will be from three to thirty days (Doyle).<sup>4</sup>

It is planned to operate the Shuttle in two different modes. In the sortie mode, experiments will be mounted in the Orbiter cargo bay, operated for the mission duration, and then returned to Earth. The cargo bay is 18.3 m long and 4.6 m in diameter and can carry a maximum of 30,000 kg payload (Doyle).<sup>4</sup> The payload will consist of a combination of pressurized modules in which crew members can work in a shirt-sleeve atmosphere and a number of external pallet modules on which experiments can be mounted.

In the second mode of operation the Shuttle will be employed to carry individual spacecraft into space, to place



Fig. 2: South-looking, Apollo-Soyuz photograph of the eastern Mediterranean region showing the fractures of the Levantine Rift zone.

them in appropriate orbit, and to service them on demand. A Remote Manipulator System (RMS) will extract the payload from the cargo bay and release it into its own orbit. Subsequently, the Shuttle Orbiter can rendezvous with the free-flying satellite, the RMS can retrieve it to be serviced in the cargo bay, or else returned to Earth for major refurbishment (Doyle).<sup>4</sup>

In addition to astronaut observations, the main tool that will be utilized in obtaining photographs of the Earth in the Shuttle era is the "Large Format Camera" or LFC (Figure 3, top). This camera will allow the acquisition of mapping quality, stereo, color, and high-resolution photographs from Earth orbital altitudes. Photographs from this camera can be used for mapping using conventional techniques and instruments without costly electronic and digital enhancement or image correction, which are necessary when dealing with Landsat data.

This new camera is designed to satisfy the operational requirements of cartographers, geologists, land-use planners, agricultural experts, environmentalists, and other Earth scientists. It features high photographic resolution on a choice of black-and-white or color film. It also features stereoscopic observation, orthographic (vertical) perspective, metric fidelity, and large areal coverage of each frame. Geometric/topographic maps may be made from its orbital photographs at scales of 1:100,000 and 1:50,000. These maps can be used for photogeologic interpretations and the compilation of data acquired by other means.

The Large Format Camera derives its name from the size of its individual frames, which are 45.7 cm in length and 22.9 cm in width, with a post-mission calibrated format option of 22.9 x 22.9 cm. It has a 305 mm, f/6 lens with a 40° x 74° field-of-view. Both the rotary shutter and camera controls are derivatives of the Skylab S-109A camera. The camera back includes supply and take-up spools with a 1200 m film capacity. The film will be driven by a forward motion compensation unit as it is exposed on a vacuum platen, which will keep the film perfectly flat. Moving rollers will insure the synchronization of film advance into the vacuum platen and in and out of the take-up and supply spools (El-Baz and Ondrejka).<sup>5</sup>

The film calibration reference will be provided by 12 edge fiducial marks and 45 reseau marks. The radial distortion across each frame will be  $\pm 10$  micrometers. The operating frame rate will be 80% (Figure 3, bottom), which provides the required base/height ratio for topographic mapping 20 m contours. The framing rate will vary from 5 to 45 seconds to

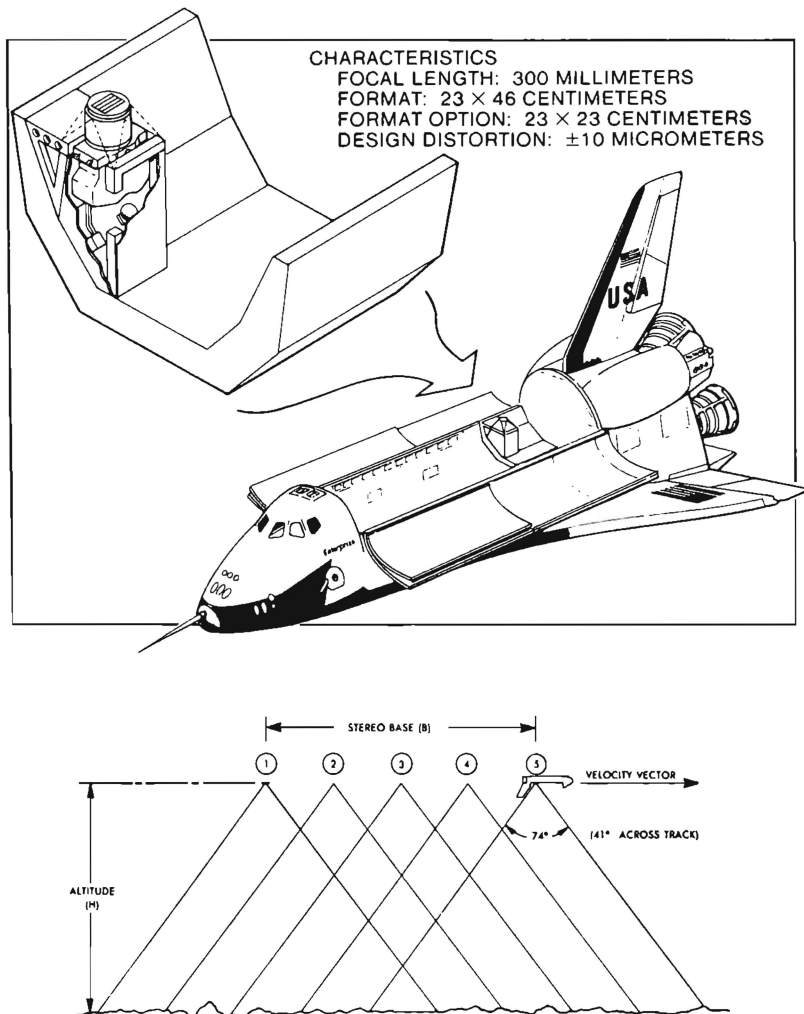


Fig. 3: Drawings showing the utilization of the large Format Camera on the Space Shuttle (top) and the mode of its stereo overlap photography (bottom).

allow the use of the camera various spacecraft altitudes. The illumination uniformity within each frame will be 10% to minimize vignetting (Doyle).<sup>6</sup>

The spectral range of the Large Format Camera will be 400 to 900 nanometers and the system resolution will be 100 lines/mm (1000:1 contrast) to 88 lines/mm (2:1 contrast). This means a photo-optical resolution of 10 to 20 m from an altitude of 260 km. The camera will have the ability to utilize a number of films, particularly Kodak high resolution black-and-white (3414), color (SO-356), and color infrared (SO-131) in magazines with a capacity of 1,200 m of film. An electronic filter changer will permit different films to be used during a single mission (El-Baz and Ondrejka).<sup>5</sup>

The orbital inclination of the first shuttle missions to carry the LFC will be relatively low (28.5°). This low orbital inclination will be suitable for coverage of the Earth's equatorial regions, and thus for study of the desert belts north of the equator.

Data from manned space missions and Landsat satellites show that the reflectance properties of desert surfaces are indicative of the composition of the exposed rock and rock rubble. Examples have been given of distinct color zones in desert photographs that correlate with the amount of sand, desert-varnished pebbles, and clay minerals in the exposed soil (El-Baz).<sup>7</sup> Similarly, it has been shown that desert sands become redder as the distance from their source increases. This is due to the fact that individual sand grains become coated with an increased amount of iron oxides with the passage of time (Norris).<sup>8</sup> Color zones in orbital photographs of these areas can be used to delineate age zones within the sand fields. This would allow better determination of areas of the world that are in danger of desertification by shifting, relatively young (light-colored) sand accumulations.

Desertification, the spread of desert-like conditions in arid and semiarid regions due to overuse of land or to climatic change (Rapp)<sup>9</sup> has led to widespread starvation and to disruptions of landuse patterns along the perimeters of many of the world's deserts. Desertification results from local changes, such as dune migration and soil denudation as a result of slash-and-burn techniques, as well as more regional changes. The Agency for International Development (AID),<sup>10</sup> estimates that over one million square kilometers and about 60 million people are affected by desertification. The United Nations estimates that 20 million square kilometers have recently reverted to desert or desert-like conditions (UNEP).<sup>11</sup>

The features associated with desertification are most easily studied from orbital images, largely because the extensive areal coverage facilitates investigations of regional patterns and of large-scale landforms. Orbital images taken in different seasons or years can be compared to determine changes in desert areas. Desertification studies have been made using orbital images and photographs by MacLeod, *et al.*<sup>12</sup> and Brera and Shahrokhi,<sup>13</sup> among others.

From the above it is clear that orbital photography is an excellent tool for the study of world deserts. High resolution photographs taken from orbit can help in classifying desert surfaces and monitoring the changes to the desert environment. Planning for the use of Large Format Camera photographs in desert study should commence on both a local and regional basis.

#### METEOROLOGICAL OBSERVATIONS

In recent years, studies of the evolution of desert landscapes have been facilitated by the interpretation of orbital images. For example, McKee and Breed<sup>14</sup> and Breed<sup>15</sup> have used Landsat imagery to formulate a classification scheme for sand seas. As stated above, because of the large regional coverage and the ability to monitor distributions that vary with time, space photographs have provided a new way of observing the desert environment. However, the results of these studies are hindered by the lack of extensive ground-truth data, including details of dune morphology, and most importantly, information on wind speed and direction.

Space age technology has provided a wide variety of sensing devices that can, for example, measure air and water quality, monitor the flow within a pipeline, or detect earthquakes. It is here proposed that the same kind of technology be applied to monitoring climatic and meteorological conditions in remote desert regions. Automated stations can obtain the measurements, average them over a period of time, and relay them to orbiting satellites. The satellites, in turn, can beam these data to Earth for analysis and synthesis.

At the present time, the U.S. Geological Survey is operating a program of remote monitoring of hydrologic data for water resources assessment (Paulson).<sup>16</sup> Preliminary results of this program indicate both the cost-effectiveness of the

method, and the advantages gained from realtime collection of the data. In at least one instance this program has resulted in a practical benefit. According to Carter and Paulson,<sup>17</sup> improved estimates of runoff were instrumental in avoiding flood damage and generating extra electrical energy during the runoff period.

There is a great number of satellites that can receive and transmit data collected on the ground. These include satellites of the Landsat type, Nimbus-F, GEOS, Tiros-N, and the communications satellites of Comsat, Intelsat, Anik, and conceivably Arabsat.

The proposed meteorological data collection scheme is a telemetry system that uses Earth orbiting satellites to relay data from a great number of stations to one or more receiving stations. There are three basic elements to such a scheme: 1) a field radio, usually called Data Collection Platform, that is connected to the sensor recorders; 2) a radio transponder with receive and transmit capability on board a satellite; and 3) a data receiving station for retrieval, processing and dissemination to investigators.

Remote meteorological stations have been developed with the capability of transmitting data to orbiting satellites. These stations consist of an aluminum free standing tripod with a mast that extends to 6.1 m for mounting the wind sensors. Swiveling tundra pads are provided with holes for securing to the ground, and one leg is adjustable for leveling. A lockable steel enclosure is provided to house the electronic equipment.

The standard complement of sensors is usually made up of seven components which measure: 1) cumulative precipitation; 2) wind speed with a time-weighted average; 3) wind direction; 4) temperature with vane aspirated radiation shield; 5) relative humidity with sky shield; 6) barometric pressure; and 7) battery power.

The only device that needs to be added to such an array of sensors for desert monitoring is a dust particle counter. This counter would help monitor dust storms which plague desert regions. Dust storm prediction and monitoring would be a useful addition because of benefits to aviation and other forms of transportation in desert regions.

Based on the above, it is recommended that testing of this method of meteorological monitoring via orbiting satellites be conducted in the Western Desert of Egypt. This desert is ideal for this type of research. In this desert



"the free interplay of sand and wind has been allowed to continue for a vast period of time, and here, if anywhere, it should be possible in the future to discover the laws of sand movement, and the growth of dunes" (Bagnold).<sup>18</sup>

Present-day meteorological stations in Egypt are concentrated in populated areas, where their locations are chosen primarily on the basis of accessibility. However, these stations are usually located in oases within depressions where local topography exerts a great influence on both wind direction and velocity. Consequently, the local environment for the proposed stations should be carefully chosen to give representative wind data for the region. Although only 8 stations are proposed at present (Figure 4), it is anticipated that no less than 20 stations would be required to provide adequate coverage for both research and practical benefits.

The proposed program for remote monitoring of near-surface (up to 3 m) meteorological information in the Western Desert will help to close the gap between orbital and Earth-based studies in four ways. These monitors will aid the study of: 1) the relationship between dune form and the mean (or effective) dune-forming wind, 2) the relationship between macro- and micro-environment and location of extensive sand accumulations, 3) both long- and short-term meteorological effects on areas prone to desertification, and 4) orbital interpretations of dune orientation with respect to local and regional wind regimes.

The major scientific objectives of the proposed research can be accomplished through measurements of the magnitude, frequency and duration of winds. By continuous monitoring of these factors and by field checks (to determine amounts of ablation and deflation, and rates of dune migration), quantitative estimates of local and regional sand budgets can be made. Near populated areas, this analysis will aid immediately in plans to stop desert growth, while in more remote regions, it will provide the ground-truth information necessary for studies of orbital images.

Although these data could be recorded *in situ* with chart recording devices, the personnel, field support and time requirements would be prohibitively expensive. In addition, there would be an extensive time lag between acquisition and use of the data. Consequently, the proposed method of monitoring coupled with satellite relay is considered the only feasible way of gathering the required data in a timely manner.



Fig. 4: Landsat image mosaic of Egypt showing the proposed minimum number of locations of meteorological satellite monitoring stations at: 1) north of Qattara; 2) west of Nile Delta; 3) south of Faiyum; 4) north of Kharga; 5) Abu Tartur plateau; 6) South New Valley; 7) Oweinat area; and 8) Great Sand Sea.

## SUMMARY

Deserts are among the least understood of Earth's features. Basic research of the world deserts has been hampered by inaccessibility, and harsh conditions. World-wide drought problems and increased desertification of semiarid lands has focused some attention on deserts, which occupy a large, unused part of the landmasses of the Earth.

This attention has been increased by the recent realization that space photographs can assist in the study of desert morphologies. The desert environment is particularly suited for orbital surveys because of the usually clear weather. Deserts also display different color tones which can be recorded on film, to aid in photointerpretation.

To satisfy the need for detailed studies of the desert environment it is necessary to obtain: 1) stereo photographs to allow photogeologic interpretations and the making of accurate topographic maps; 2) high-resolution photographs to allow the study of dune morphologies and sand movement; and 3) color photographs to depict color-tones that are indicative of the chemical makeup and relative-age of desert sands. These requirements can be met by presently planned use of the Large Format Camera on the Space Shuttle. The Shuttle provides the unique capability of carrying these cameras into Earth orbit, and returning them with the exposed film.

In addition to orbital observations and photographs of the deserts, space age technology allows the timely monitoring of their meteorological conditions. This can be accomplished by installing automated stations in remote localities to monitor the environment. These stations can monitor wind speed and direction, temperature, humidity, rainfall and barometric pressure. They also include dust particle counters to monitor dust storms and give early warnings of their development.

Data from these meteorological stations can be transmitted by radio to any number of Earth orbiting satellites with receiver capabilities. These satellites can then beam the data to Earth for analysis and dissemination. It is here proposed to test such a data collection system by installing eight automated monitoring stations in remote areas of the Western Desert of Egypt.

The space program has provided us with numerous new technologies. These are being utilized to a maximum extent in the developed countries. Utilization of such technologies in the

understanding and monitoring of the desert environment will have far reaching benefits directly or indirectly to all mankind.

## REFERENCES

1. H. Masursky, G.W. Colton, and F. El-Baz (1978) Apollo over the Moon: A view from orbit. NASA SP-362, 255 pp.
2. G.H. Grosvenor (1977) National Geographic, v. 151, n. 1, p. 1.
3. F. El-Baz (1977) Astronaut Observations from the Apollo-Soyuz mission Smithsonian Studies in Air and Space, Number 1. Smithsonian Inst. Press, Washington, D.C., 400 pp.
4. F.J. Doyle (1978a) The next decade of satellite remote sensing. Photogramm. Engin. and Remote Sens., v. 44, n. 2, p. 155-164.
5. F. El-Baz and R.J. Ondrejka (1978) Earth orbital photography by the Large Format Camera. Paper presented at the 12th Inter. Sym. on Remote Sens. of Environ., 20-26 April 1978, Manila, Philippines.
6. F.J. Doyle (1978b) A large format cartographic camera for Space Shuttle mission. Paper presented at the 44th Ann. Meet. of the Amer. Soc. Photogramm., 26 Feb. - 4 Mar., 1978, Washington, D.C.
7. F. El-Baz (1978) The meaning of desert color in Earth orbital photographs. Photogramm. Eng. and Remote Sens., v. 44, n. 1, p. 69-75.
8. R.M. Norris (1969) Dune reddening and time. Jour. Sed. Pet., v. 39, p. 7-11.
9. A. Rapp (1974) A review of desertification in Africa--with vegetation and man. Secretariat for International Ecology, Stockholm, Sweden.
10. A.I.D. (1972) Desert encroachment in arable lands: Significance, causes and control. Agency for International Development, Washington, D.C.

11. U.N.E.P. (1975) Review of the environmental situation and of activities relating to the environmental programme. Governing Council, Nairobi, 12 April - 2 May, 1975.
12. N.H. MacLeod, J.S. Schubert and P. Anaeijonu (1977) Report on the Skylab 4 AFrican drought and arid lands experiment. In: Skylab Explores the Earth. NASA SP-380, p. 263-286.
13. A. Brera, and F. Shahrokhi (1978) Application of Landsat data to monitor desert spreading in the Sahara region. In: Remote Sensing of Earth Resources; F. Shahrokhi, ed., Univ. of Tenn. Space Inst., Tullahoma, v. 3, 813 pp.
14. E.D. McKee, and C.S. Breed (1974) An investigation of major sand seas in desert areas throughout the world. Third Earth Res. Tech. Satel.-1 Symp., v. 1, Tech. Pres. Sec. A, Paper G6, p. 665-679.
15. C.S. Breed (1978) Morphology and distribution of dunes in sand seas observed by remote sensing. In: A global study of sand seas. U.S. Geol. Surv. Prof. Pap. (in press).
16. R.W. Paulson (1978) Use of Earth satellites for automation of hydrologic data collection. In: Collection, storage, retrieval, and publication of water resources data. U.S. Geol. Surv. Circ. 756, p. 8-14.
17. W.D. Carter, and R.W. Paulson (1978) Introduction to monitoring dynamic environmental phenomena of the world using satellite data collection systems. Comm. on Sp. Res. (COSPAR), Tech. Man. Ser. Man. No. 8.
18. R.A. Bagnold (1933) A further journey through the Libyan Desert. Geo. Jour., v. 82, p. 103-129.