MONITORING THE DESERT ENVIRONMENT FROM SPACE: EXAMPLES FROM THE ARAB REGION

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Summary

Photography of the Earth from space has greatly benefited ecological and environmental sciences by allowing the study and analysis of large regions. Because the same region may be imaged at different times, the space-borne data are particularly useful in monitoring environmental changes. This contribution deals with examples in arid regions with emphasis on the largest desert belt in the world, including the Great Sahara of North Africa and the Arabian Peninsula. The used examples are from the author's experience of scientific research during the past 25 years in this desert belt.

The advent of digital imaging from space allowed the use of information technology methods to extract important environmental characteristics and establish their change in space and time. Changes due to both natural causes and activities of mankind can be identified in digital images using computer hardware and software.

The American Landsat system and the French SPOT acquire repeat coverage of much of the desert landscapes with resolutions from 30 to 10 meters, respectively. Furthermore, radar waves beamed from space penetrate the thin sand cover in desert regions to reveal buried courses of ancient rivers, which were active during humid episodes in the geological past.

Discussed examples include: (1) establishing the wind pattern in the Great Sahara from the orientation of linear dunes; (2) deciphering the origin of desert sand by flowing surface water that deposited the sand in inland depressions in the Western Desert of Egypt; (3) unveiling the channels that the ancient rivers carved in the landscape of North Africa; (4) correlating these past events with the archaeological record; (5) determining the interplay between water and wind in the open desert; (6) establishing the implication of these space-borne observations to groundwater exploration; (7) deciphering a similar setting displayed by a channel of an ancient river in the northern part of the Arabian Peninsula; and (8) using satellite images to establish changes in agricultural patterns in the Nile Delta as well as disturbances to the desert surface in Kuwait due to the Gulf War.

These examples make it clear that satellite images afford a better understanding of the origin and evaluation of the desert environment. They are also ideal for monitoring the natural and man-made changes in space and time. Similar methodologies can be applied to other features of the Earth.

1. Introduction

During the past three decades, ecological sciences greatly benefited from space technology. As astronauts and cosmonauts began to train their cameras toward the Earth, the value of the unique perspective from orbit became clear. Most observers ascribe the popularity of the “environmental movement” to the first image of the Earth above the lunar horizon. That view was captured by the Apollo 8 astronauts as they circled the Moon in December 1968 and depicted an earthrise above the Moon’s surface. The life-giving uniqueness and fragile appearance of a globe without country borders entered the consciousness of people worldwide. Throughout the Apollo program, and until its end in 1972, the astronauts continued to describe and photograph the Earth in fascinating detail.

Since that time, the Earth has been the object of intensive exploration from space. It was realized that photographs from space are ideal for monitoring the changes to the environment in space and time. This became particularly obvious when images of the same region could be compared to others obtained at a later time. Views from space allowed the study of global phenomena as well as local features. They also allowed the evaluation of changes due to: (a) natural processes such as droughts, forest fires, floods, locust infestations, earthquakes, etc.; and (b) activities of mankind, such as agriculture, deforestation, land degradation due to organizing, etc.

Nowhere were these factors as important as they were to the understanding of the origin and evaluation of arid landforms of the Earth (El-Baz, 1988). The reason being that the desert remained the least known of all the features of the earth because:

- Earth sciences began in Europe, which is the only continent that does not have a desert. Therefore, the fathers of geology did not write about arid landforms and those who came after them followed suit. To this day, one can find a textbook about the Earth without a single chapter on the desert.
- The desert is vast and harsh, therefore, few researchers venture into it because of the immensity of scale and the dangers of desert travel.
- In the course of field work, geologists seek solid rock *in situ*, in place, to sample for later study. Most desert surfaces, however, are covered by transported mixtures of rock fragments, soil and sand. Therefore, there is little for the conventional geologist to do in a desert.

Space photography presented a unique tool to study the deserts and monitor their environment (El-Baz, 1988). This is particularly true for of three reasons:

- Desert regions are usually free of clouds, thus, are easy to photograph from above.
- Space photographs cover large areas and allow the recognition of regional patterns, which is important in the case of extensive deserts.
- Due to the lack or scarcity of vegetation cover, a space photograph can be considered a map of the chemical composition of the exposed rocks, soils and sands.

Based on the above, the first part of this contribution includes a description of the imaging systems whose data are most applicable to studying and monitoring the arid lands of the Earth. The second part includes examples of work by the author in utilizing satellite images in learning about the Arab region, which represents the largest desert belt in the world (Figure 1).

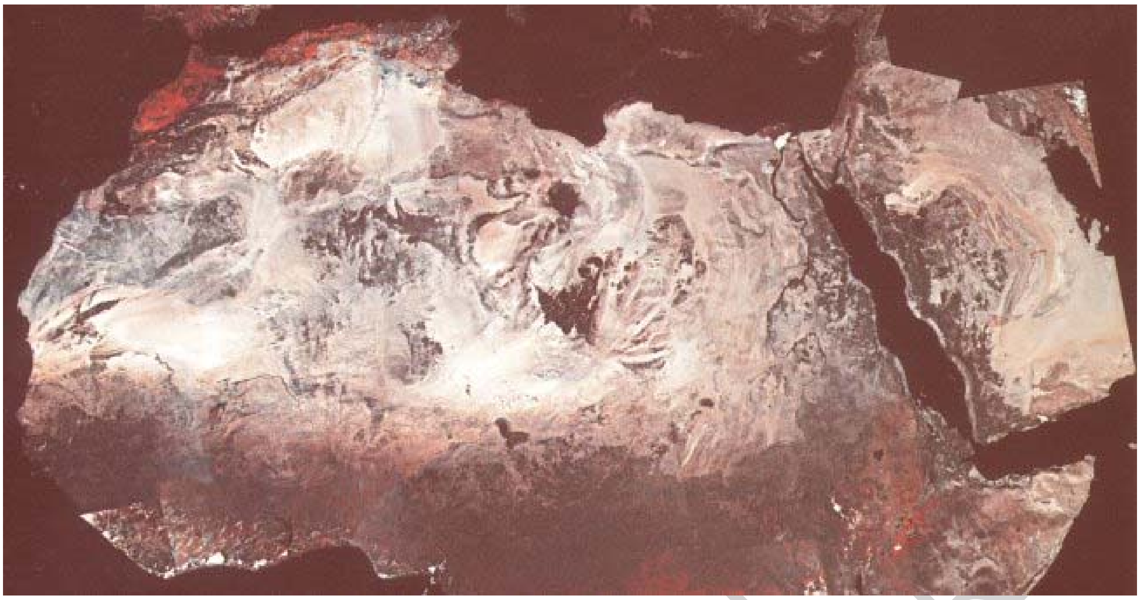

Figure 1: Mosaic of NOAA satellite images of the desert belt that includes the Arab region. The bright red color represents natural vegetation in the Atlas Mountains of Morocco. The dark band in the lower part is due to natural vegetation in sub-Saharan Africa. Note the linear patterns of dunes in both the Great Sahara and the Arabian Peninsula

2. Images from Space

Increasingly detailed photographs from space resulted from advancements in the technology of remote sensing during the past three decades. Remote sensing is simply defined as investigating an object or a phenomenon from a distance, such as by imaging the surface of the Earth from a spacecraft and probing its subsurface with radar waves.

Photographing the Earth from space began with the manned Gemini, Apollo, Skylab, Apollo-Soyuz, and Space Shuttle missions (El-Baz, 1998). Photographs on these missions were mostly obtained by cameras aimed by astronauts at important features or significant phenomena. In addition, the unmanned Landsat program introduced digital imaging from space in 1972 (Short et al., 1976). In this case, the image data are transmitted to ground receiving stations for processing and distribution to the analysts.

In the acquisition of data from Earth orbit, unmanned and manned spacecraft are planned to fly in high, medium, or low orbits. The highest orbits are left to the unmanned weather satellites, such as Meteosat of the European Space Agency (ESA). These are propelled to a height of 36 000 kilometers above the Earth. At this altitude, their motion is equivalent in speed to the rotation of the Earth about its axis. Such satellites are termed geostationary, and they remain above the same point on the Earth to acquire and transmit repetitive images as frequently as hourly.

At the low end, most manned missions are placed in orbits below 300 km, to a minimum of 150 km above the Earth. For example, the Space Shuttle’s operational altitude is about 200 km. From this altitude, images show greater detail such as those of the Large Format Camera which produced images with 10 meter resolution (El-Baz, 1998).

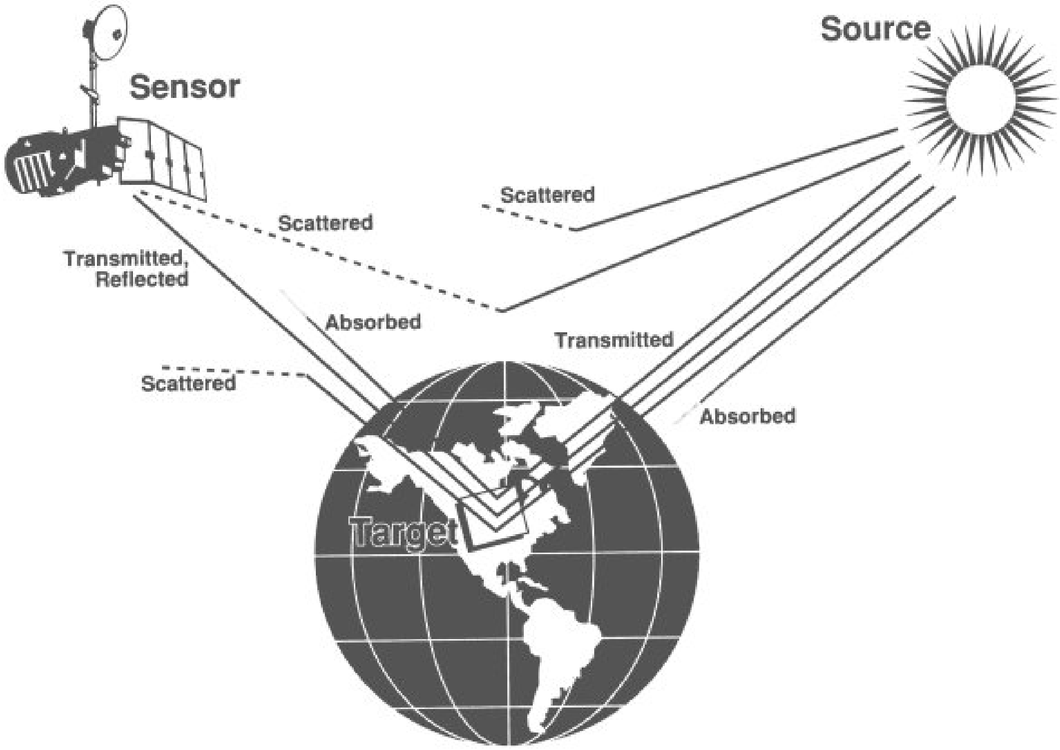

Figure 2: Illustration of the recording by the Landsat sensors of solar radiation as it is reflected by the surface or scattered by atmospheric effects. Brightness levels of the various targets on the Earth's surface are recorded by the sensors and the data are transmitted to ground receiving stations

Intermediate orbits, from 700 to 1000 km above the Earth, are left to most unmanned imaging satellites. For example, the polar-orbiting satellites of the National Oceanic and Atmospheric Administration (NOAA) fly at altitudes of 835 to 870 km; the near-polar orbits of Landsat (Figure 2) reach a maximum altitude of 920 km above the Earth; and the French digital imaging satellites, *Systeme Pour l'Observation de la Terre* (SPOT) operate from an altitude of 830 km or less. Images collected from these altitudes provide greater local detail than is possible from the high-altitude satellites (El-Baz, 1998).

The following section is a review of the systems that have acquired the most extensive and useful photographs of the Earth from space. These include digital imaging systems and radar imaging systems. At the end of the section, an example is given of the new operational systems that acquire high resolution images of the Earth from orbit.

2.1 Digital Imaging

2.1.1 Landsat

Systematic imaging of the Earth in digital form was introduced by the Earth Resources

Technology Satellite (ERTS-1) that was launched on 23 July 1972; the program was later named Landsat (Figure 2). Two other satellites from the same series were launched at intervals of a few years and carried a Multi-Spectral Scanner (MSS) and a return beam vidicon.

The Landsat MSS produced images representing four different bands of the electromagnetic spectrum (Figure 3) with a ground resolution of 80 meters. The MSS onboard Landsat 1, 2 and 3 covered a 185-km swath in four wavelength bands: green (0.5 to 0.6 μm, micron), red (0.6 to 0.7 μm), and two in the near infrared (0.7 to 0.8 μm and 0.8 to 1.1 μm). These bands were designated as bands 4, 5, 6, and 7 respectively (Lillesand and Kiefer, 1994).

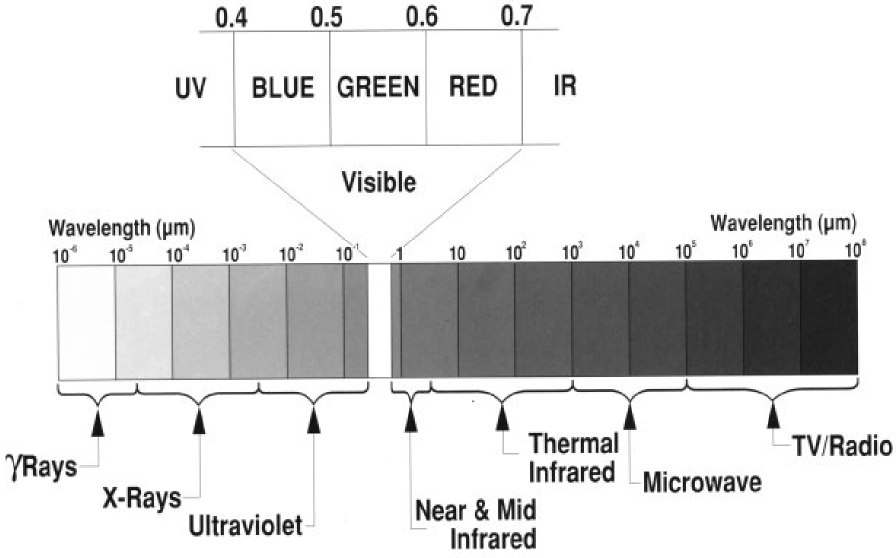

Figure 3: Illustration of the continuous sequence of energy based on wavelength or frequency, which constitutes the electromagnetic spectrum. Only the energy range labeled “visible” is detectable to the human eye. Especially designed sensors are required to detect and image wavelengths in other parts of the spectrum

Combination of bands of MSS imagery were selected for each interpretive use. Bands 4 (green) and 5 (red) were designated for detecting cultural features such as urban areas, roads, gravel pits, and quarries. In such areas, band 5 had better atmospheric penetration, providing a higher contrast image. In areas of deep, clear water, greater water penetration was achieved with band 4.

The near-infrared bands 6 and 7 clearly delineated water bodies. Since the energy of near-infrared wavelengths penetrates only a short distance into water, where it is absorbed with very little reflection, surface water features have a very dark tone in bands 6 and 7. Wetlands with standing water or wet organic soil also have a dark tone in bands 6 and 7, as do asphalt-surfaced pavements and wet bare soil areas (Lillesand and Kiefer, 1994). These two near-infrared bands measured the reflectance of the Sun’s rays outside the sensitivity of the human eye (visible range). These bands were useful in agricultural studies, because of the high reflectance of vegetative matter (El-Baz, 2000).

False-color images are produced when these four bands are combined. For example, in the most popular combination of bands 4, 5 and 7, the red color is assigned to the near-infrared band number 7 (and green and blue to bands 4 and 5 respectively). Vegetation appears red because plant tissue is one of the most highly reflective materials in the infrared portion of the spectrum, and thus, the healthier the vegetation, the darker the red on such images.

2.1.2 Thematic Mapper

The Thematic Mapper (TM) sensor was carried on Landsats 4, 5, and 6 (the latter was lost during launch) with seven spectral bands covering the visible, near infrared, and thermal infrared regions of the spectrum. It was designed to satisfy more demanding performance parameters from experience gained in the operation of the Landsat MSS. The TM picture element (pixel) size is 30 meters square as compared to 80 meters for the MSS. At this ground resolution, even small agricultural farms in the desert may be identified (e.g., Figure 4).

The seven spectral bands of the Landsat TM sensor, as summarized by Lillesand and Kiefer (1994), are as follows:

Blue (0.45-0.52µ): designed for water body penetration, making it useful for coastal water mapping. Also useful for soil/vegetation discrimination, forest type mapping, and cultural feature identification.

Green (0.52-0.60µ): designed to measure green reflectance peak of vegetation for vegetation discrimination and vigor assessment. Also useful for cultural feature identification.

Red (0.63-0.69µ): designed to sense in a chlorophyll absorption region aiding in plant species differentiation. Also useful for cultural feature identification.

Near infrared (0.76-0.90µ): useful for determining vegetation types, vigor, and biomass content, for delineating water bodies, and for soil moisture discrimination.
Mid-infrared (1.55-1.75µ): indicative of vegetation moisture content and soil moisture.

Thermal infrared (10.4-12.5µ): useful in vegetation stress analysis, soil moisture discrimination, and thermal mapping.

Mid-infrared (2.08-2.35µ): useful for discrimination of mineral and rock types. Also sensitive to vegetation moisture content (Figure 6). This last band is primarily motivated by geological applications, including the identification of rocks that are altered by percolating fluids during mineralization.

Landsat 7, which began operations in mid 2000, replicated the bands of the Thematic Mapper. In addition, it introduced a panchromatic band at 15 meter resolution. Merging this higher resolution black and white band with a color composite of the multi-spectral bands increased the utility of the mages, where greater detail was deemed useful.

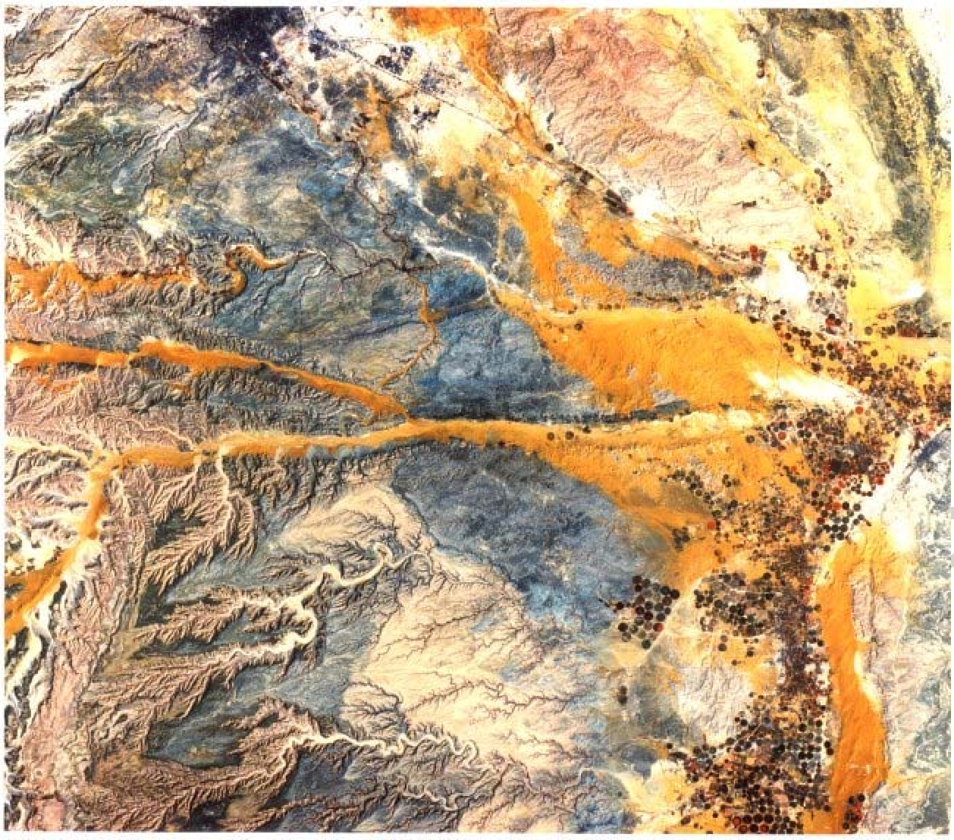

Figure 4: Landsat image obtained on 23 September 1984 of the circular irrigation farms (red and dark circles at lower right) in and near Al-Kharj area, southeast of Riyadh (dark areas at upper left edge). Width of the image is approximately 100 km

2.1.3 SPOT

In early 1978, the French government decided to undertake the development of the Systeme pour L'Observasion de la Terre (SPOT) program. Shortly thereafter, Sweden and Belgium agreed to participate in the program with the aim of launching the first of a series of earth observation satellites. From its inception, SPOT was designed as a commercially oriented program that was operational, rather than experimental like Landsat.

Conceived and designed by the French *Centre National d'Etudes Spatiales*, SPOT has developed into a large scale international program. Much like the Landsat program it had ground receiving stations and data distribution outlets in more than 30 countries. The first satellite in the program was launched from the Kourou Launch Range in French Guiana on February 21, 1986, onboard an Ariane launch vehicle. It began a new era in space remote sensing, for it was the first satellite system to include a linear array sensor and employ "pushbroom" techniques, rather than the scanning mirror of Landsat. Avoiding the motion of the scanner, allowed the high resolution of the system. It was also the first system to have mobile optics. This enabled side-to-side off-nadir viewing capabilities, and it afforded full-scene stereoscopic imaging from two different satellite tracks (Lillesand and Kiefer, 1994).

SPOT-1 was retired from service on December 31, 1990, and SPOT-2 was launched on January 21, 1990, and SPOT-3 on September 25, 1993, with identical orbits and sensor systems. SPOT-4 was launched in 1998.

The sensor payload of SPOT consisted of two identical *high resolution visible* (HRV) imaging systems and auxiliary magnetic tape recorders. Each HRV sensor was designed to operate in either of two modes of sensing: (a) a 10-m-resolution (Figure 7) panchromatic (black-and-white) mode over the range 0.51 to 0.73 µm; or (b) a 20-m-resolution multi-spectral (color infrared) mode over the ranges 0.50 to 0.59, 0.61 to 0.68, and 0.79 to 0.89 µm.

The HRV employs along-track or pushbroom sensing, which does not use a scanning mirror as do across-track systems. Rather, it utilizes a linear array of Charged Coupled Devices (CCDs) arranged side by side along a line perpendicular to the satellite's orbit track. A line of image data is obtained by sampling the response of the detectors along the array, and successive lines of coverage are obtained by repeated sampling along the array as the satellite moves over the Earth.

Each HRV contains four CCD subarrays. A 6000-element subarray is used in the panchromatic mode to record data at 10 meter resolution. Three 3000-element subarrays are employed in the multi-spectral mode at 20 meter resolution. Data are effectively encoded over a 256-digital-number range and are transmitted at a rate of 25 million bits per second. Each instrument's field of view is 4.13°, such that the ground swath of each HRV scene is 60 kilometers wide under nadir viewing conditions (Lillesand and Kiefer, 1994).

One significant aspect of all digital images is the fact that data from different systems could be merged utilizing computer registration techniques. For example, to merge a SPOT scene to the same area on a Landsat TM image, the latter would be first "resampled" at the resolution of SPOT. This results in a composite image of the high spectral resolution of the TM image and the greater spatial resolution of the SPOT image. This was done for several desert areas resulting in improvements that assisted in the data interpretation.

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Bibliography

Bagnold R. A. (1941). *The Physics of Blown Sand and Desert Dunes*, 265 pp. London: Methuen. [This is a definitive treatment of particle transport by the wind and the mathematical equations that explain this action.]

Cortright E.M. (1968). *Exploring Space with a* Camera, 503 pp. Washington, D.C.: NASA SP–168. [This is a summary of space photography at its infancy.]

Elachi D., Brown W. E., Cimino J. B., Dixon T., Evans D. L., Ford J. P., Saunders R. S., Breed C., Masursky H., McCauley J. F., Schaber G., Dellwig L., England A., MacDonald H., Martin-Kay P., and Sabins F. (1982). Shuttle imaging radar experiment. *Science* 218, 996-1003. [This paper explains the first experiment of radar imaging from space.]

El-Baz F. (1988). Origin and evolution of the desert. *Interdisciplinary Science Reviews* **13**, 331-347. [In this paper, the author corrects the misconception that the desert is man-made and shows how arid landforms originated by the lack or scarcity of rain.]

El-Baz F. (1998). *The Arab World and Space Research: Where Do We Stand?* 70 pp. Abu Dhabi, United Arab Emirates: The Emirates Center for Strategic Studies and Research. [This is a book that summarizes the methodologies of satellite imaging and describes a plan for “Desertsat,” a satellite to be dedicated to study of the desert.]

El-Baz F. (2000). Satellite observations of the interplay between wind and water processes in the Great Sahara. *Photogrammetric Engineering and Remote Sensing* **66**(6), 777-782. [This paper relates surface water processes to the deposition of sand in inland basins and its later redistribution by wind.]

El-Baz F. and Al-Sarawi M. (2000). *Atlas of the State of Kuwait from Satellite Images*, 145 pp. Kuwait: Kuwait Foundation for the Advancement of Sciences. [This is a review of environmental characteristics of the land and coastal waters of Kuwait.]

El-Baz F. and Makharita R. M. (1994). *The Gulf War and the Environment*, 206 pp. Lausanne, Switzerland: Gordon and Breach. [This is the basic scientific treatment of the effects of the Gulf War on the Environment of the eastern part of the Arabian Peninsula.]

El-Baz F. and Warner D. M., eds. (1979). *Apollo-Soyuz Test Project Summary Science Report*, Volume II: *Earth Observations and Photography*, 692 pp. Washington, DC: NASA SP-412. [This volume includes 42 chapters that detail the use of photographs obtained from orbit in the study of a variety of Earth environments from deserts to ice-covered regions.]

Lillesand T. M. and Kiefer R. W. (1994). *Remote Sensing and Image Interpretation*, 3rd edn., 750 pp. New York: John Wiley and Sons. [This is a definitive textbook on satellite imaging.]

McKee E. D., Breed C. S., and Frygerger S. G. (1977). Desert sand seas. In: *Skylab Explores the Earth*. Washington, DC: NASA SP-380. pp. 5-47. [This is a thorough treatment of the analysis of Skylab photographs of the Earth’s deserts.]

Short N., Lowman P. D., Jr., Freden S. C., and Finch W. A., Jr. (1976). *Mission to Earth: Landsat Views of the World*, 459 pp. Washington, DC: NASA SP-360. [This is a definitive analysis on the landforms of the Earth as revealed in early Landsat images.]

Biographical Sketch

Dr. Farouk El-Baz is Research Professor and Director of the Center for Remote Sensing at Boston University. He received his B.Sc. (1958) in chemistry and geology from Ain Shams University, Cairo, Egypt; his M.S. (1961) in geology from the Missouri School of Mines and Metallurgy, Rolla, Missouri; and his Ph.D. (1964) in geology from the University of Missouri, after performing research at the Massachusetts Institute of Technology, Cambridge, Massachusetts (1962–1963). He taught geology at Egypt’s Assiut University from 1958–1960, and at the University of Heidelberg in Germany between 1964–1966. In 1989, Dr. El-Baz received an honorary Doctor of Science degree from the New England College, Henniker, New Hampshire. Between 1967 and 1972, Dr. El-Baz participated in the Apollo program as Supervisor of Lunar Science Planning at Bellcomm, Inc. of Bell Telephone Laboratories in Washington, D.C. During these six years, he was Secretary of the Site Selection Committee for the Apollo lunar landings, Chairman of the Astronaut Training Group, and Principal Investigator for Visual Observations and Photography. From 1973 until 1983, he established and directed the Center for Earth and Planetary Studies at the National Air and Space Museum, Smithsonian Institution, Washington, D.C. In 1975, Dr. El-Baz was selected by NASA to be Principal Investigator for Earth Observations and

Photography on the Apollo-Soyuz Test Project. This was the first joint American-Soviet space mission. From 1982 to 1986 he was Vice President for International Development and for Science and Technology at Itek Optical Systems of Lexington, Massachusetts.

Dr. El-Baz has served on the Steering Committee of Earth Sciences of the Smithsonian Institution, the Arid and Semi-Arid Research Needs panel of the National Science Foundation, the Advisory Committee on Extraterrestrial Features of the U.S. Board of Geographic Names, and the Lunar Nomenclature Group of the International Astronomical Union. In 1979 he coordinated the first visit by US scientists to the desert regions of northwestern China. In 1985 he was elected Fellow of the Third World Academy of Sciences and represents the Academy at the Non-Governmental Organizations Unit of the Economic and Social Council of the United Nations. He also served as Science Advisor (1978-1981) to the late Anwar Sadat, President of Egypt. He is known for pioneering work in the applications of space photography to the understanding of arid terrain, particularly the location of groundwater resources. Based on the analysis of space photographs, his recommendations have resulted in the discovery of groundwater resources in the Sinai Peninsula, the Western Desert of Egypt, and in arid terrains in northern Somalia and the Red Sea Province of Eastern Sudan. Furthermore, during the past twenty years, he contributed to interdisciplinary field investigations in all major deserts of the world. At present, his research objectives include applications of remote sensing technology to the fields of archaeology, geography, and geology.

Dr. El-Baz is President of the Arab Society of Desert Research and the recipient of numerous honors and awards, including: NASA's Apollo Achievement Award, Exceptional Scientific Achievement Medal, and Special Recognition Award; the University of Missouri Alumni Achievement Award for Extraordinary Scientific Accomplishments; the Certificate of Merit of the World Aerospace Education Organization; and the Arab Republic of Egypt Order of Merit-First Class. He also received the 1989 Outstanding Achievement Award of the Egyptian American Organization, the 1991 Golden Door Award of the International Institute of Boston., and the 1992 Award for Public Understanding of Science and Technology of the American Association for the Advancement of Science. In 1995, he received the Award for Outstanding Contributions to Science and Space Technology of the American-Arab Anti-Discrimination Committee, and the Achievement Award of the Egyptian American Professional Society. He also received the 1996 Michael T. Halbouty Human Needs Award of the American Association of Petroleum Geologists. In 1999, the Geological Society of America established "The Farouk El-Baz Award for Desert Research" to annually encourage and reward arid land studies.