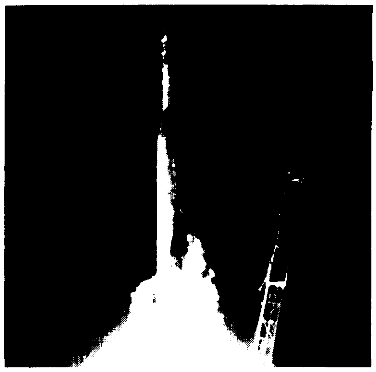
Introduction 1

Since the first civilian remote sensing satellite was launched in 1960, the United States has come increasingly to rely on space-based remote sensing to serve a wide variety of needs for data about the atmosphere, land, and oceans (table l-l). Other nations have followed the U.S. lead. The vantage point of space offers a broadscale view of Earth, with repetitive coverage unaffected by political boundaries. Recent advances in sensors, telecommunications, and computers have made possible the development and operation of advanced satellite systems (figure 1-1) that deliver vital information about our planet to Earth-bound users.

Many Federal agencies, including the Department of Defense (DoD), use remotely sensed data to carry out their legislatively mandated programs to protect and assist U.S. citizens and to reserve and manage U.S. resources. For making routine observations of weather and climate, the National Oceanic and Atmospheric Administration (NOAA) operates two environmental satellite systems. DoD also operates a system of environmental satellites.[1] The scientific satellites and instruments of the National Aeronautics and Space Administration (NASA) probe Earth's environment for scientific research. Future NASA scientific satellites will include NASA's Earth Observing System (EOS), a series of sophisticated, low-orbit satellites to gather global environmental data and assist in assessing global environmental change. DoD and NASA now jointly manage the Landsat program, which provides highly useful images of the land and coastal waters.



[1] This report is not concerned with any satellite system built exclusively for national security purposes, except for the Defense Meteorological Satellite Program. Data from DMSP are made available to civilian users through NOAA.

Table l-l--Current U.S. Civilian Satellite Remote Sensing Systems[a]

System	Operator	Mission	Status
Geostationary Operational Environmental Satellite (GOES)	NOAA	Weather monitoring, severe storm warning, and environmental data relay	1 operational; 1994 launch of GOES-1 (GOES-Next)
Polar-orbiting Operational Environmental Satellite (POES)	NOAA	Weather/climate; land, ocean observations; emergency rescue	2 partially operational; 2 fully operational; launch as needed
Defense Meteorological Satellite Program (DMSP)	DoD	Weather/climate observations	1 partially operational; 2 fully operational; launch as needed
Landsat	DoD/NASA EOSAT[b]	Mapping, charting, geodesy; global change, environmental monitoring	Landsat 4&5 operational, 1993 launch for Landsat 6
Upper Atmosphere Research Satellite (UARS)	NASA	Upper atmosphere chemistry, winds, energy inputs	In operation; launched in 1991
Laser Geodynamics Satellite (LAGEOS)	NASA/Italy	Earth's gravity field, continental drift	One in orbit; another launched in 1992
TOPEX/Poseidon	NASA/CNES (France)	Ocean topography	In operation; launched in 1992

a The United States also collects and archives Earth data from non-us. satellites.
[b]EOSAT, a private corporation, operates Landsats 4, 5, and 6. DoD and NASA will operate a future LandSat 7.

SOURCE: Office of Technology Assessment, 1993.

This report is the first major publication of an assessment of Earth observation systems requested by the House Committee on Science, Space, and Technology; the Senate Committee on Commerce, Science, and Transportation; the House and Senate Appropriations Subcommittees on Veterans Affairs, Housing and Urban Development, and Independent Agencies; and the House Permanent Select Committee on Intelligence.

This report examines the future of civilian remote sensing satellites and systems. In particular, it provides a guide to the sensors and systems operating today and those planned for the future. The report also explores issues of innovation in remote sensing technology and briefly examines the many applications of remotely sensed data. In addition, the report examines the use of civilian data for military purposes, although it does not investigate the potential civilian use of classified remotely sensed data acquired for national security purposes.[2]

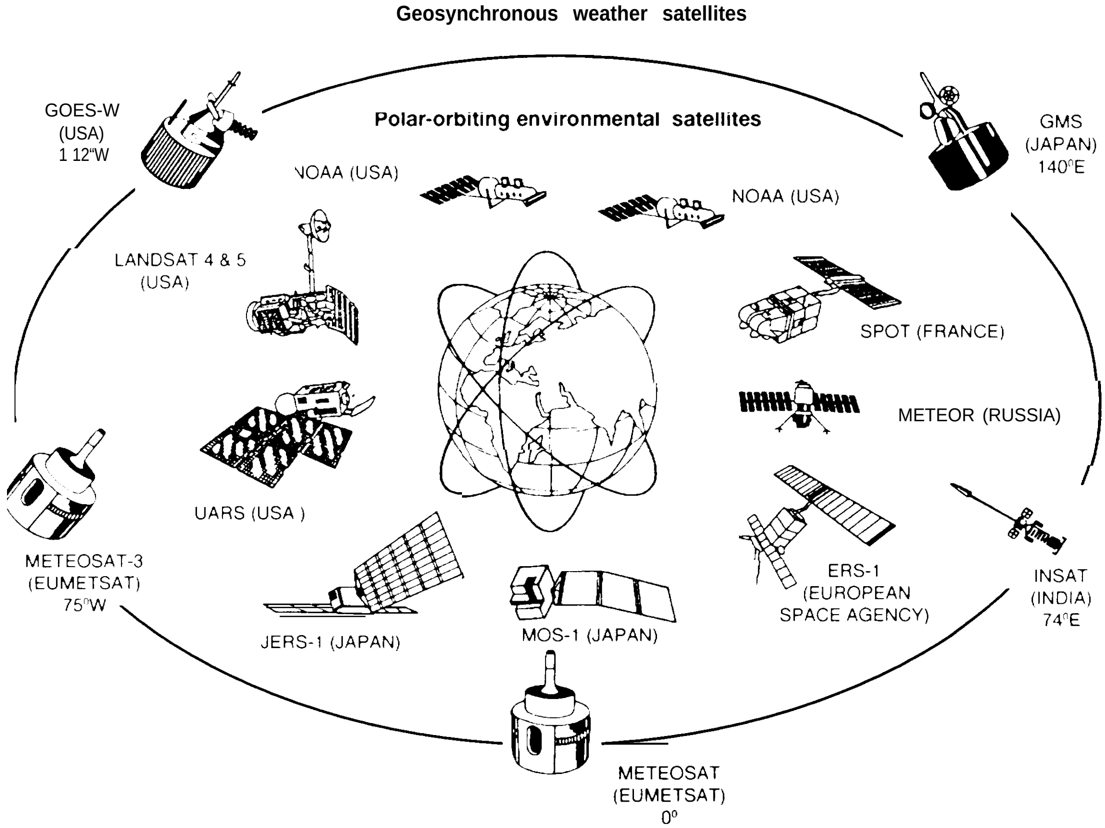
The United States is entering a new era, in which it is planning to spend an increasing proportion of its civilian space budget on the development and use of remote sensing technologies to support environmental study. Building and operating remote sensing systems for U.S. Government needs could cost more than $30 billion[3] over the next two decades. The extent of future public investment in space-based remote sensing will depend in part on how well these systems serve the public interest. Remote sensing activities already touch many aspects of our lives. The future of space-based remote sensing raises questions for Congress related to:

- U.S. commitment to global change research and monitoring, which requires long-term funding and continuity of data acquisition;

[2] A committee of scientists organized by Vice President Albert Gore in his former role as chairman of the Senate Subcommittee on Science, Technology, and Space, is examining the potential for such data to assist in global-change research.

[3] In 1992 dollars.

Figure I-I—Existing Earth Monitoring Satellites



Several countries operate satellites to monitor Earth and gather environmental data. This figure depicts most of those satellites that are in either geosynchronous or polar/near-polar orbits.

SOURCE: Office of Technology Assessment, 1993.

- the role of U.S. industry as partners in supplying sensors, satellites, ground systems, and advanced data products;
- America's competitive position in advanced technology; and
- U.S. interest in using international cooperative mechanisms to further U.S. economic, foreign policy, and scientific goals.

These items of public policy intersect with questions concerning the overall structure and focus of the U.S. space program, and the scale of public spending on space activities. Thus, Congress will have to decide:

- The total spending for space, as well as the allocations for major programs such as Earth science from space, space science, space shuttle, and the space station;
- The role of remote sensing in the space program;
- The role of satellite remote sensing in U.S. global change research; and
- Congress' role in assisting U.S. industry to maintain U.S. competitiveness in satellite remote sensing and related industries.

Existing and planned satellite systems raise issues of utility, cost effectiveness, and technology readiness. The United States pioneered the

Box l-A-Report Appendixes

Appendix A: Global Change Research From Satellites outlines the U.S. Global Change Research Program and examines the use of space-based remote sensing for assessing the long-term effects of global change. In particular, it examines the roles played by NASA's Earth Observing System, NOM's envirormental satellites, and foreign systems.

This report examines the issues raised by the development of new remote sensing technologies in Appendix B: The Future *of Remote* Sensing Technologies. In particular, the appendix summarizes the state-of-the-art in technology development and explores the issues raised by innovation in sensor and spacecraft design. it also summarizes the characteristics of planned instruments that were deferred during the 1991 and 1992 restructuring of EOS.

The Gulf War provided a clear lesson in the utility of data from civilian systems for certain military uses. More the war, no accurate, high quality maps of Kuwait and the Gulf area existed. Hence, U.S. military planners had to depend in part on maps generated from remotely sensed images acquired from Landsat and the French SPOT satellite for planning and executing allied maneuvers. Appendix C: *Military* Uses of Civilian *Sensing Satellites explores* the technical and policy issues regarding the military use of data from civilian systems.

Appendix D): Infernational Remote Sensing Efforts summarizes non-U.S. satellite systems and some of the international cooperative programs.

SOURCE: Office of Technology Assessment, 1993.

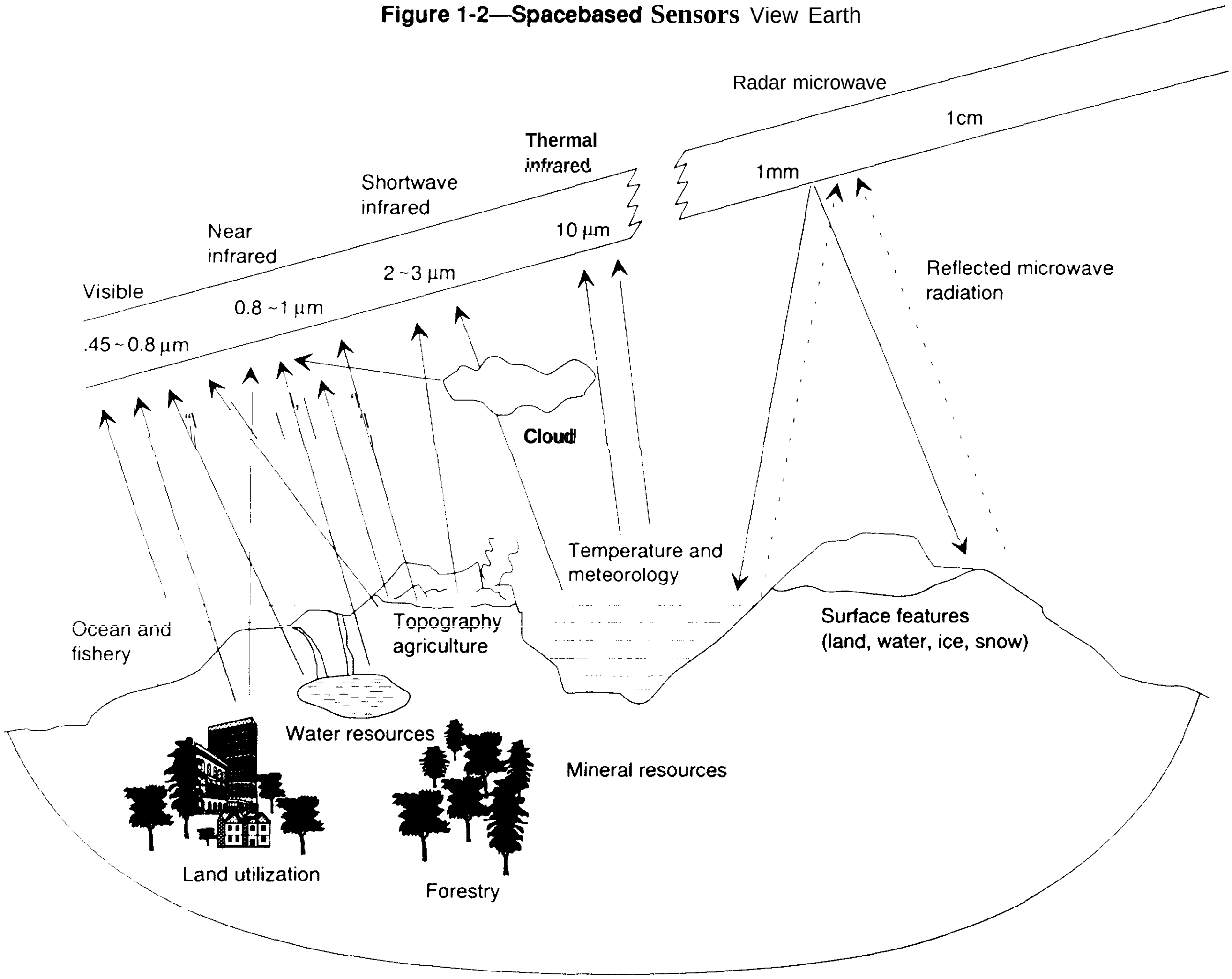
use of space-based remote sensing in the 1960s and 1970s; today the governments of several other countries and the European Space Agency (ESA) also operate highly sophisticated environmental remote sensing systems for a variety of applications (figure l-l). For the future, other nations are planning additional remote sensing satellites that will both complement, and compete with, U.S. systems. These circumstances present a formidable challenge to the United States.

Satellite remote sensing is a major source of **data** for global change research as well as weather forecasting and other applications. Data from these systems must be integrated with a wide variety of data gathered by sensors on aircraft, land, and ocean-based facilities to generate useful information. This report explores how satellite remote sensing fits in with these other systems. It also addresses U.S. policy toward the remote sensing industry. Detailed discussion of many of this report's findings may be found in the appendixes (box l-A).

By the early 21st century, U.S. and foreign remote sensing systems will generate prodigious amounts of data in a variety of formats. Using these data will require adequate storage and the ability to manage, organize, sort, distribute, and manipulate data at unprecedented speeds. NASA, NOAA, and DoD are responsible for developing and operating the data gathering systems, yet other government agencies and many private sector entities will also use the data for a variety of ongoing research and applications programs. A future report in this assessment, expected for release in late 1993, will examine issues connected with data analysis, organization, and distribution.

The distribution and sales of data form Landsat and other land remote sensing systems raise issues of public versus private goods, appropriate price of data, and relations with foreign data customers. These issues are discussed in a background paper, Remotely *Sensed Data From Space:*

Figure 1-2—Spacebased Sensors View Earth



Remote sensors detect reflected energy in the visible and infrared portions of the spectrum. The intensity and extent of this energy reveals much about Earth's surface and the lower atmosphere. Satellite- and aircraft-borne radars generate microwave radiation that is reflected by the surface. Returning microwaves (which are not affected by clouds) allow researchers to study land features and observe the extent of snow/ice cover.

SOURCE: Japan Resources Observation System Organization, JERS-I Program Description; Office of Technology Assessment, 1993.

Distribution, Pricing, and Applications, which was released by OTA in July 1992.[4]

WHAT IS REMOTE SENSING FROM SPACE?

Remote sensing is the process of observing, measuring, and recording objects or events from a distance. The term was coined in the early 1960s when data delivered by airborne sensors other than photographic cameras began to find broad application in the scientific and resource management communities. Remote sensing instruments measure electromagnetic radiation emitted or reflected by an object (figure 1-2) and either

[4]U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data from Space: Distribution, Pricing, and Applications* (Washington, DC: Office of Technology Assessment, International Security and Commerce Program July 1992).

Box 1-B–How Remote Sensors "See" Earth

Earth receives, and is heated by, energy in the form of electromagnetic radiation from the sun (figure 1-3). About 95 percent of this energy falls in wavelengths between the beginning of the x-ray region (290x 10^{9} meters) and long radio waves (about 250 meters).

Some incoming radiation is reflected by the atmosphere; most penetrates the atmosphere and is subsequently reradiated by atmospheric gas molecules, clouds, and the surface of Earth itself (including, for example, forests, mountains, oceans, ice sheets, and urbanized areas); about 70 percent of the radiation reaching Earth's surface is absorbed, warming the planet. Over the long term, Earth maintains a balance between the solar energy entering the atmosphere and energy leaving it (figure 1-4). Atmospheric winds and ocean currents redistribute the energy to produce Earth's climate.

Clouds are extremely effective unreflecting and scattering radiation, and can reduce incoming sunlight by as much as 80 to 90 percent. One of the important functions of future remote sensors will be to measure the effects of clouds on Earth's climate more precisely, particularly clouds' effects on incoming and reflected solar radiation.

Remote sensors maybe divided into passive sensorsthat observe reflected solar radiation or active sensors that provide their own illumination of the sensed object. Both types of sensors may provide images or simply collect the total amount of energy in the field of view:

Passive sensors collect reflected or emitted radiation. These include:

- an imaging ***radiometer*** that senses visible, infrared, near infrared, and ultraviolet wavelengths and generates a picture of the object;
- an atmospheric sounder that collects energy emitted by the atmosphere at infrared or microwave wavelengths. Used to measure temperatures and humidity throughout the atmosphere.

Active sensors include:

- a radar sensor that emits pulses of microwave radiation from a radar transmitter, and collects the scattered radiation to generate a picture;
- a scatterometer that emits microwave radiation and senses the amount of energy scattered back from the surface over a wide field of view. It can be used to measure surface wind speeds and direction, and determine aloud content;
- a radar altimeter that emits a narrow pulse of microwave energy toward the surface and times the return pulse reflected from the surface;
- a *lidar* altimeter that emits a narrow pulse of laser light toward the surface and times the return pulse reflected from the surface.

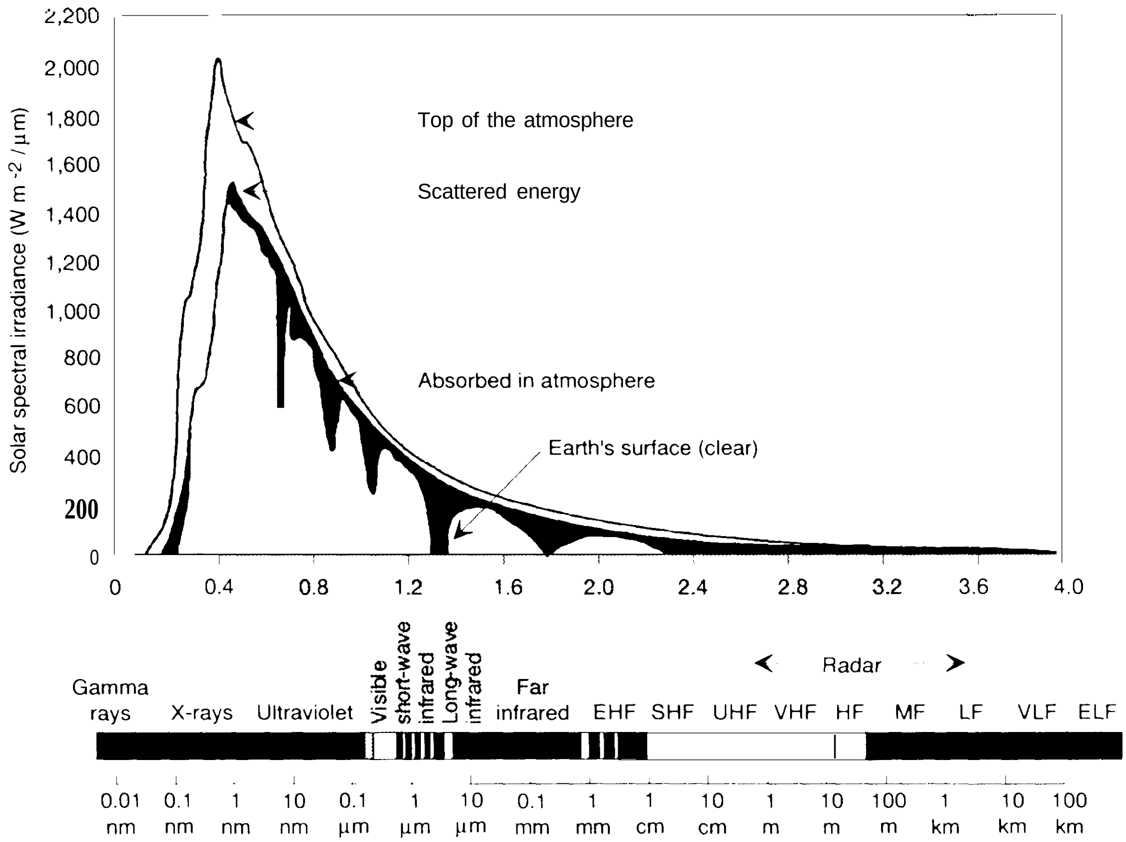
SOURCE: Office of Technology Assessment 1993.

transmit data immediately for analysis or store the data for future transmission (box l-B). Photographic cameras, video cameras, radiometers, lasers, and radars are examples of remote sensing devices. Sensors can be located on satellites, piloted aircraft, unpiloted aerospace vehicles (UAVS), or in ground stations. Thus, the data acquired by space-based remote sensing feed into a wide array of mapping and other sensing services provided by surface and airborne devices.

REMOTE SENSING APPLICATIONS

Earth orbit provides unique views of Earth and its systems. Space-based sensors gather data from Earth's atmosphere, land, and oceans that can be applied to a wide variety of Earth-bound tasks (box l-C). Probably the best known of these applications is the collection of satellite images of storms and other weather patterns that appear in the newspapers and on television weather forecasts each day. Such images, along with soundings and other data, allow forecasters to predict

Figure I-3—incoming, Reflected, and Scattered Solar Radiation



This figure shows the shortwave radiation spectrum for the top of the atmosphere, **and as depleted by passing through the atmosphere (in the absence of clouds). Most of the energy that is reflected, absorbed or scattered by the Earth's atmosphere is visible or short-wave infrared energy (from.4 micron to 4 microns). In the thermal infra-red, most attenuation is by absorption. Short wavelength radiation is reflected by clouds, water vapor, aerosols and air; scattered by air molecules smaller than radiation wavelengths; and absorbed** by ozone in shorter wavelengths (<O.3 micron), **and water vapor at** the longer visible wavelengths (>1.0 micron).

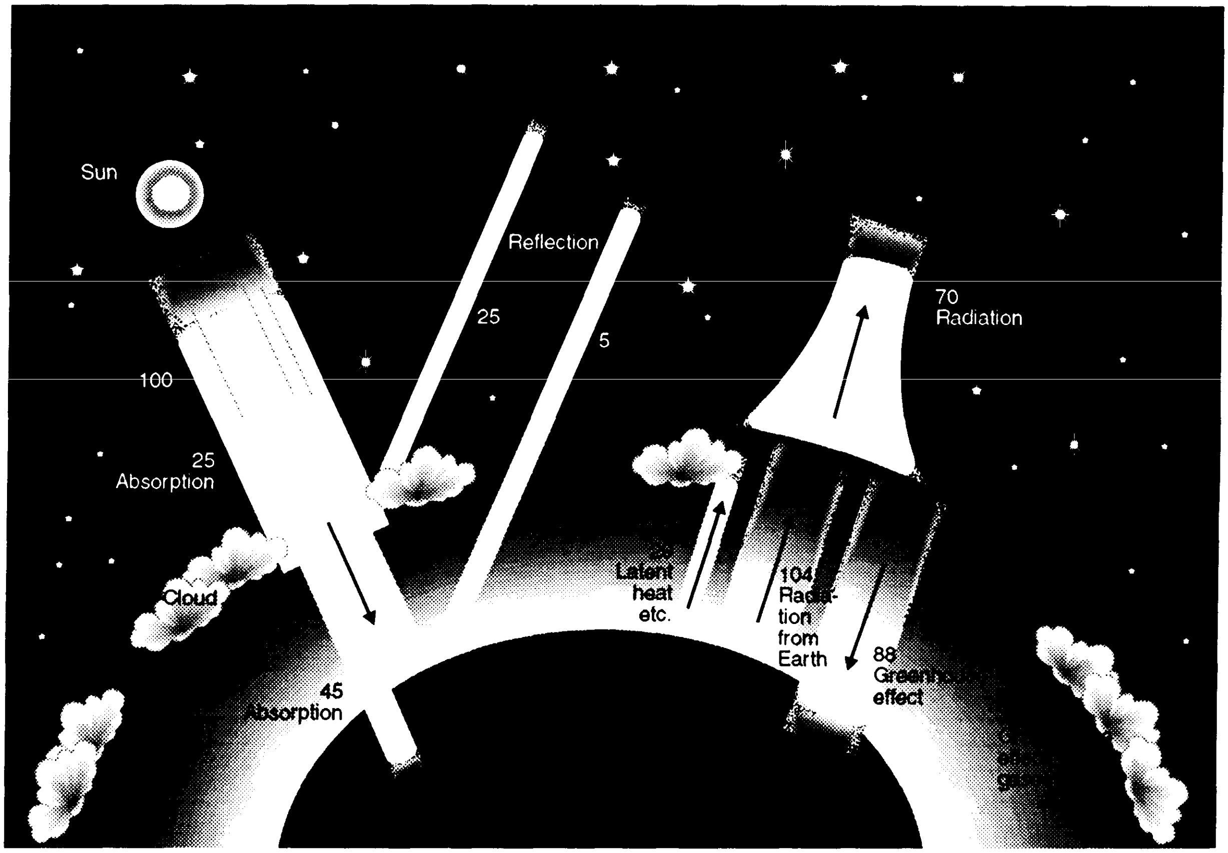
SOURCE: Andrew M. Carleton, *Satellite* **Remote Sensing in Climatology, CRC Press, 1991, pp. 44-45.**

the paths of severe storms as they develop, and to present dramatic, graphic evidence to the public. When large storms head toward populated areas, such as happened after Hurricane Andrew developed in August 1992 (plate 1), consecutive satellite images, combined with other meteorological data, coastal topography, and historical records, provide the basis on which to predict probable trajectories and to issue advance warning about areas of danger.[5] U.S. and foreign environmental satellites also provide valuable data on atmospheric temperature, humidity, and winds on a global scale.

Government agencies with the responsibility of managing large tracts of land, or of providing information regarding land conditions, make use

[5]Thousands of people evacuated south Florida and low lying areas near New Orleans before the September 1992 Hurricane Andrew struck land.

Figure 1-4-Earth's Radiation Budget



Earth's radiation budget is the balance between incoming solar radiation and outgoing radiation. Small changes in this balance could have significant ramifications for Earth's climate. Incoming solar radiation is partially reflected by the atmosphere and surface(30%). The Earth reemits absorbed energy at longer, infrared wavelengths. Some of this energy Is trapped by natural and anthropogenic atmospheric gases-the greenhouse effect.

SOURCE: Japan Resources Observation System Organization, Office **of Technology Assessment, 1993.**

of data from the Landsat or the French SPOT series of land remote sensing satellites (table 1-2). They also use data from the NOAA Advanced Very High Resolution Radiometer (AVHRR) to create vegetation maps (plate 2). Commercial data users with interests in agriculture and forestry, land use and mapping, geological mapping and exploration, and many other industrial sectors also use data acquired from the land remote sensing satellite systems.[6]

Data gathered by recently launched foreign synthetic aperture radar instruments **on European** and Japanese satellites provide information concerning ocean currents, sea state, sea ice, and ocean pollution for both governmental and commercial applications. U.S. satellites have made significant contributions to the science of radar sensing and the measurement of Earth's precise shape.[7] The U.S./French TOPEX/Poseidon satellite, launched in 1992, will provide measurements

[6] The city of Chicago also used LandSat and SPOT data in the aftermath of flooding in its underground tunnels in early 1992.

[7] I.e., Earth's geoid.

Box I-C-The Use of Satellite Remote Sensing

Remote **sensing from space provides Scientific, industrial, civil governmental, military, and individual** users **with the capacity to gather** data for a variety of useful tasks:

1. simultaneously observe key elements of vast, interactive Earth systems (e.g., clouds and ocean plant growth);
2. monitor clouds, atmospheric temperature, rainfall, wind speed, and direction;
3. monitor ocean surface temperature and ocean currents;
4. track anthropogenic and natural changes to environment and climate;
5. view remote or difficult terrain;
6. provide synoptic views of large portions of Earth's surface, unaffected by political boundaries;
7. allow repetitive coverage over comparable viewing conditions;
8. determine Earth's gravity and magnetic fields;
9. identify unique geologic features;
10. perform terrain analysis and measure moisture levels in soil and plants;
11. provide signals suitable for digital or optical storage and subsequent computer manipulation into imagery; and
12. give potential for selecting combinations of spectral bands for identifying and analyzing surface features.

In addition, data from space provide the following advantages:

1. Convenient *hsitoric record, stored on optical or magnetic media and photographs:* each data record, when properly calibrated with in situ data, establishes a baseline of critical importance in recognizing the inevitable environmental and other changes that occur.
2. Tool *for inventory* and assessment: satellite images can be used whenever a major natural or technological disaster strikes and massive breakdowns of communication, transportation, public safety, and health facilities prevent the use of normal means of inventory and assessment.
3. *Predictive* tool:property interpreted data used with models can be used to predict the onset of natural and technological disasters.
4. *P/arming and management ted:* **data** can be used for a variety of planning and management purposes.

SOURCE: Office of Technology Assessment, **1993.**

of global ocean topography and ocean circulation (plate 8).

All of the preceding satellite types also generate data vital to understanding global change. When properly archived and made available to the research community, these data can result in information useful for modeling the effects of climate and environmental change.

Table 1-2--Summary of Land Remote Sensing Applications

Agriculture	*Environmental management*
Crop inventory	Water quality assessment and planning
Irrigated crop inventory	Environmental and pollution analysis
Noxious weeds assessment	Coastal zone management
Crop yield prediction	Surface mine inventory and monitoring
Grove surveys	Wetlands mapping
Assessment of flood damage	Lake water quality
Disease/drought monitoring	Shoreline delineation
	Oil and gas lease sales
Forestry and rangeland	Resouroe inventory
Productivity assessment	Dredge and fill permits
Identification of crops, timber and range	Marsh salinization
Forest habitat assessment	
Wildlife range assessment	*Water resources*
Fire potential/damage assessment	Planning and management
	Surface water inventory
Defense	Flood control and darnage assessment
Mapping, charting, and Geodesy	Snow/ice cover monitoring
Terrain analysis	Irrigation demand estimates
Limited reconnaissance	Monitor runoff and pollution
Land cover analysis	Water circulation, turbidity, and sediment
	Lake eutrophication survey
Land resource management	Soil salinity
Land cover inventory	Ground water location
Comprehensive planning	
Corridor analysis	*Geological mapping*
Facility siting	Lineament mapping
Flood plain delineation	Mapping/identification of rock types
Lake shore management	Mineral surveys
	Siting/surveying for public/private facilities
Fish and wildlife	Radioactive waste storage
Wildlife habitat inventory	
Wetlands location, monitoring, and analysis	*Land use and planning*
Vegetation classification	Growth trends and analysis
Precipitation/snow pack monitoring	Land use planning
Salt exposure	Cartography
	Land capacity assessment
	Solid waste management

SOURCE: Office of Technology Assessment, 1993.