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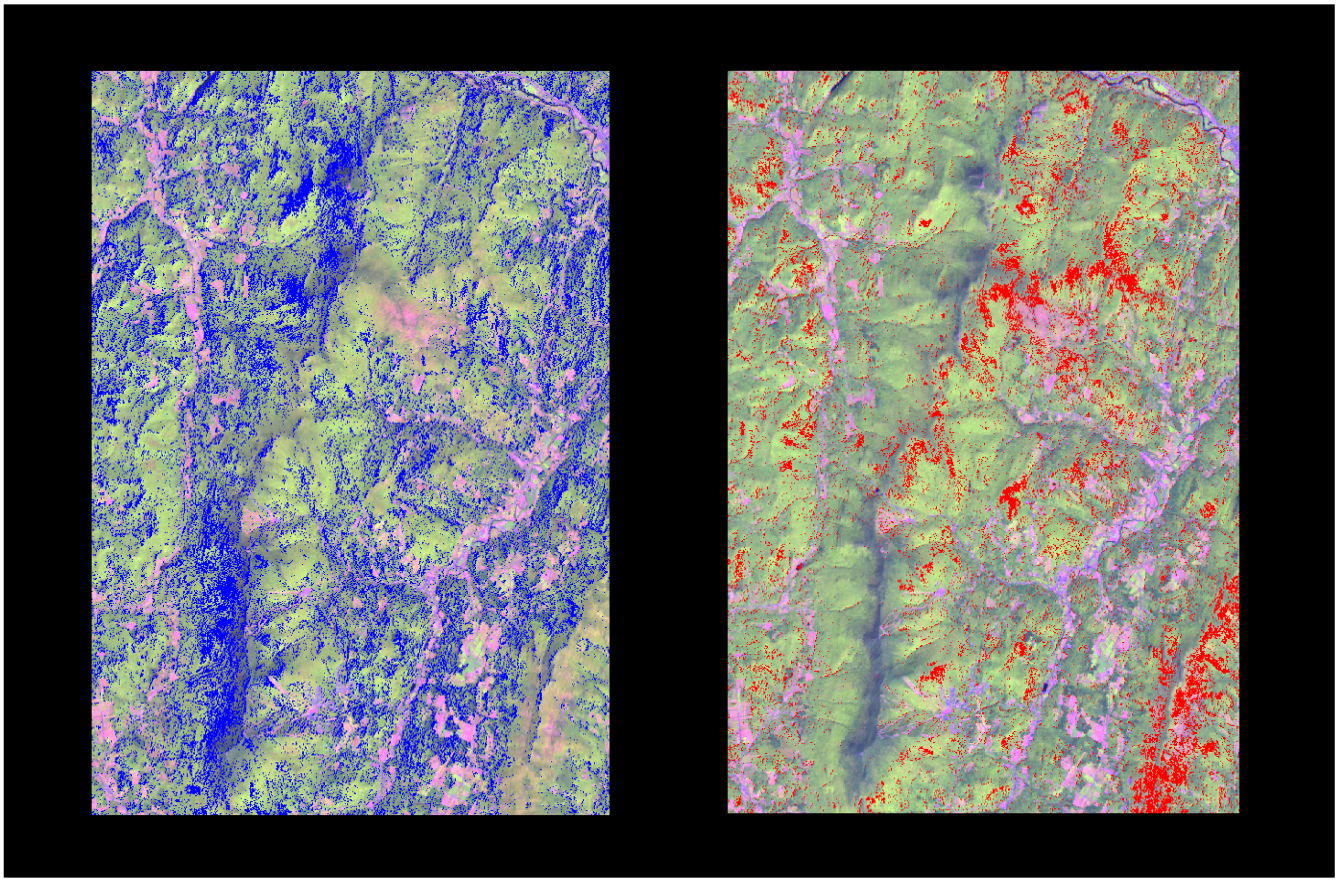
NASA

LANDSAT PROGRAM REPORT
2002



U.S. Department of the Interior
U.S. Geological Survey

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INTRODUCTION

In early 2001, the U.S. Geological Survey (USGS) published a report on the initial progress of the Landsat 7 program. The report covered the first 18 months of Landsat 7 mission operations and provided an outline of sensor and data characteristics, as well as the mission goals of the program. Since that time, the Landsat Program has successfully completed the second 18 months of Landsat 7 mission operations.

This second report provides the latest information on the Landsat 7 mission and statistics covering the first three years of mission operation. In addition, in July of 2001, Landsat 4 and Landsat 5 operations were returned to the government by the commercial operator, thereby expanding the scope of the Landsat 7 program. This report details the de-commissioning of the Landsat 4 satellite and the transition and continued operation of the Landsat 5 mission. The Landsat 5 satellite continues to operate and provide data for the U.S. and global archives; the mission has operated continuously for an astonishing 18 years.

The over-arching purpose of the program is to provide remote sensing data for use in applications developed by a global community of academic, commercial, and government users. To highlight the importance of these activities, and to spotlight the robust variety of uses for the data we collect, a substantial portion of this report is devoted to detailing some of the on-going research conducted with Landsat data.

The second 18 months of operation of the Landsat 7 mission have continued to provide the highest quality data ever available from a Landsat mission using a very successful cloud avoidance strategy for global acquisitions. The mission is creating an invaluable global data resource for current and future generations and is continuing the unbroken history of Landsat earth observation covering the last 30 years.

Tracy L. Zeiler
Landsat Program Manager
U.S. Geological Survey

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LANDSAT PROGRAM REPORT 2002

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Cover illustration

Landsat 5 data, acquired in 1991, were compared to Landsat 7 data acquired in 1999, to evaluate changes within forests in the Green Mountains of Vermont. The two cover images illustrate the change in infrared reflectance from 1991 to 1999. The blue-gray tone in the left image represents near infrared increases in reflectance within the forest areas; the red tone in the right image represents decreases in near infrared reflectance within the forest. The changes imply that the forests changed over the time period, but the meaning of these changes is speculative without additional and more in-depth analyses. The reflectance changes may be related to different weather patterns affecting vegetative growth changes in health of the trees or changes in forest community composition.

For information regarding this report, please contact Tracy L. Zeiler, U.S. Geological Survey, EROS Data Center, Mundt Federal Building, Sioux Falls, SD 57198

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INTERESTING FACTS ABOUT THE LANDSAT 7 MISSION

The Landsat 7 Program grew out of the Land Remote Sensing Policy Act of 1992 (Public Law 102-555). Nearly seven years later, on April 15, 1999, the Landsat 7 mission began with the launch of the 2,105 kg (4,631 pound) spacecraft into orbit 705 km (423 miles) above the earth. After a three-month commissioning period, Landsat 7 was declared operational for data acquisition and down link on June 29, 1999.

Since launch it has been the goal of the satellite operator, the U.S. Geological Survey (USGS), and its civil agency partner, the National Aeronautics and Space Administration (NASA), to build a record of the Earth's landmass that is unequalled from all previous land remote sensing missions. The archive that has been created is unprecedented in its combination of geographic extent, spatial resolution, temporal depth, and scientific value. The spacecraft and its payload, the Enhanced Thematic Mapper Plus (ETM+), have operated nearly flawlessly while capturing and transmitting the imagery to the ground.

Consider the following facts regarding Landsat 7 during its operational life through March 1, 2002:

Distances Traveled:

- The satellite has been in operations for 976 days.
- It travels around the world at a speed of 7.5 km/sec. at an average altitude of 705 km.
- Since its launch, Landsat 7 has traveled 15,296 times around the Earth. With the distance of one orbit being 44,528 km, Landsat 7 has traveled over 680,655,905 km. That's equivalent to flying to the Sun and back 2.27 times.
- By the end of the Landsat 7 mission, the spacecraft will have flown a distance equivalent to a trip to Saturn.

ETM+ Operation

- Since going operational the ETM+ has been turned on and off 31,043 times. This is an average of 31.8 times per day.
- The ETM+ has been operated for over 11,861,045 seconds. That's equivalent to 197,684 minutes, or 3,295 hours or 137.3 days.
- When operating, the ETM+ collects nearly 150,000,000 bits of data every second.
- The ETM+ mirror strikes a bumper as it reaches the end of its east and west travel. As of March 1, 2002, it had struck a bumper over 83 million times.

Imagery Collection

- Through March 1, 2002, the ETM+ had collected over 250,000 images for the U.S. archive – over 175,000 images covering areas outside the U.S.
- During that same time, over 240,000 additional scenes have been down linked to the 11 International Cooperators.
- The scenes collected represent an archive requiring over 187 TB of storage space – that's over 187,000,000,000,000 bytes of data. If the average home computer has 20 GB of data storage, it would require 9,364 just to hold the raw data.
- A single ETM+ scene covers 31,110 sq/km. The total worldwide archive now holds 9,333,000,000 sq/km of image data. Looking at the celestial bodies in our solar system, the Landsat 7 archives would cover:

Mercury 126.7 times	Mars 47 times	Uranus 1.3 times
Venus 19.5 times	15% of Jupiter	Neptune 1.6 times
Earth 18.3 times	22% of Saturn	Pluto 90 times

If this sounds like a lot, consider that the complete world archive of Landsat 7 data would cover only .15 percent of the surface of the Sun.

A BRIEF HISTORY OF THE LANDSAT PROGRAM

In the mid-1960's, stimulated by success in planetary exploration using unmanned remote sensing satellites, NASA, in partnership with the Department of the Interior (DOI), the Department of Agriculture and others, embarked on an ambitious program initiative to develop and launch the first Earth-monitoring satellite to meet the needs of resource managers and earth scientists. The DOI USGS assumed responsibility for archiving the data acquired by the new program and for distributing the anticipated data products.

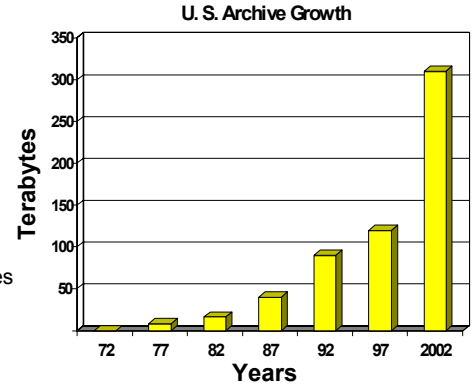
On July 23, 1972, NASA launched the first in a series of satellites designed to provide repetitive global coverage of the Earth's landmasses. The Landsat series, originally dubbed 'ERTS', for Earth Resources Technology Satellite, has continued to provide quality, moderate resolution data of the land and coastal regions of the planet. As a result of subsequent satellites launched in the Landsat series, there is a continuous set of Landsat data from mid-1972 until the present.

Artist's Rendition of Landsat 7

NASA was responsible for operating the program through the early 1980's, with the USGS having responsibility for archiving the data and producing the resulting image products. In January 1983, a plan was initiated to transfer operation of the Landsat Program to the private sector. The first step of this plan required transfer of the Landsat system operation to the Landsat Commercialization Division of the National Oceanic and Atmospheric Administration (NOAA). In October 1985, the Earth Observation Satellite Company (EOSAT), now Space Imaging, assumed responsibility for Landsats 4 and 5 under contract to NOAA.

Landsat U. S. Archive Growth

- **30 years of Landsats 1-5**
  - MSS
    - 1972-92; 631,000 images
  - TM
    - 1982- present; 471,000 images
  - 130 terabytes
- **3 years of Landsat 7**
  - ETM+
    - 1999 – present; > 200,000 images
  - 187 terabytes



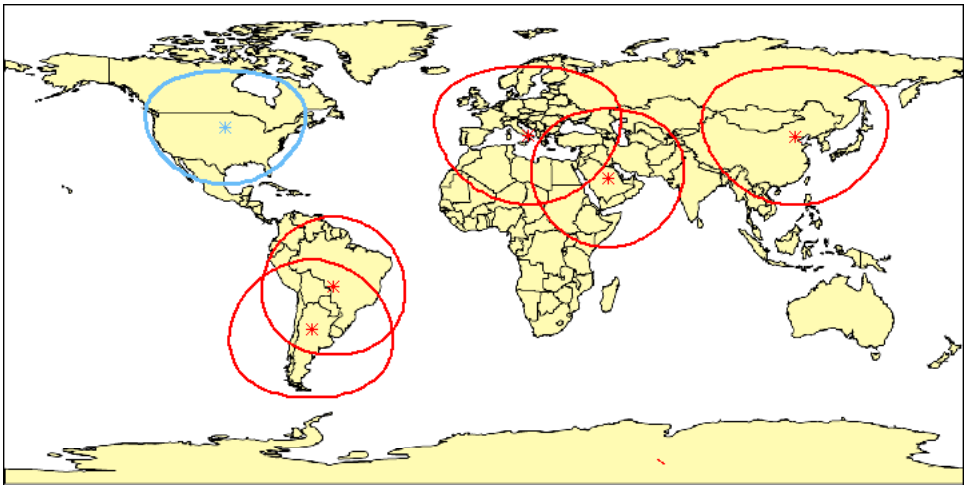
This contract was transferred to the USGS in 1998, but Space Imaging continued to operate Landsats 4 and 5 until mid-2001, when the commercial operator returned responsibility for Landsats 4 and 5 to the U.S. Government. Throughout these changes, the USGS retained primary responsibility for long-term preservation as the Government archive of Landsat data. The Landsat Program underwent additional management changes with the passage of the Land Remote Sensing Policy Act of 1992. This act returned the Landsat Program management to the Government under joint management of the Department of Defense (specifically, the U.S. Air Force (USAF), and NASA, and created the legislative mandate for the National Satellite Land Remote Sensing Data Archive and assigned responsibility to the Department of the Interior.

The Landsat management structure changed repeatedly from NASA/USAF/USGS to NASA/NOAA/USGS to NASA/USGS from1992 through 1998. The USGS assumed operational responsibility for the Landsat Program in 1999; NASA continued flight operations for Landsat 7 until 2000, when the USGS implemented a new flight operations contract. In mid-2001, the USGS assumed responsibility for Landsat 5 flight operations.

CURRENT OPERATIONS

Launched July 1982, Landsat 4 provided the science community with important ground observation during its lifetime, flying in an imaging attitude controlled mode for nearly 20 years and over 100,000 orbits.
With help from NASA, USGS decommissioned Landsat 4 in June of 2001. On June 15, the last of the deorbiting maneuvers was completed and the spacecraft was placed in a power starvation configuration.

The transition of responsibility for Landsat 5 to the USGS has gone well. The USGS ground station in Sioux Falls, South Dakota, is the only U.S. Landsat 5 ground station with five international ground stations continuing to acquire Landsat 5 data.



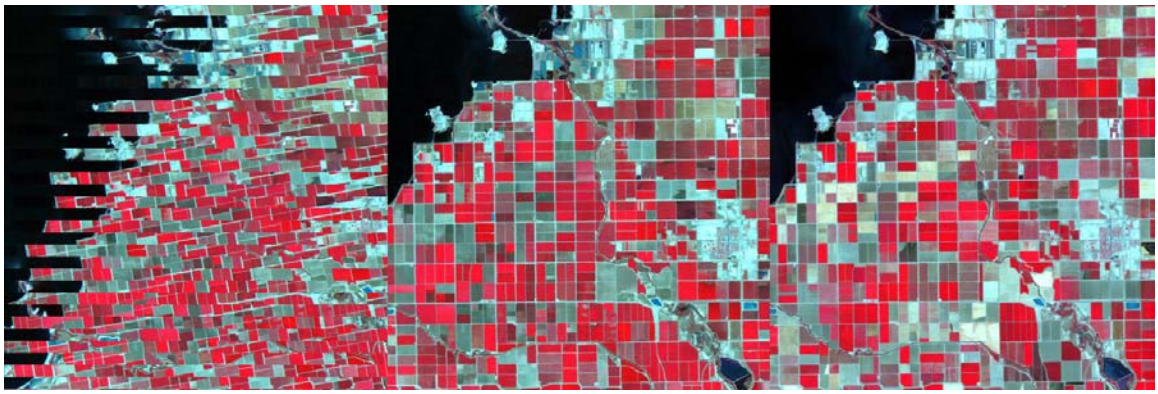
Landsat 5 Receiving Stations

Landsat 5 continues to function. It is in synchronous orbit cycle with Landsat 7, offering potential coverage every eight days; however, for the past year the mission has been experiencing problems with its operational payload, the Thematic Mapper (TM). Testing was conducted to determine if the primary Scan Angle Monitor (SAM) imaging mode for the TM instrument was still operational. On Monday, April 15, 2002, the USGS Landsat Program determined, after extensive testing and evaluation by flight operations and hardware specialists, that the Landsat 5 Thematic Mapper instrument is no longer capable of collecting artifact-free data in the SAM imaging mode. Wear of the scan mirror's bumper material has now increased to the point where synchronization between the movement of the mirror and calibration shutter cannot be achieved. The resulting incursions of the calibration shutter into the active scan field of view, partially obscuring the Earth,

cannot be prevented through modified operational procedures or manipulation of the instrument's thermal properties.

While it represents a significant loss of capability, the inability of the TM to operate in SAM mode does not necessarily result in the end of the instrument's useful life. An alternate imaging mode, bumper mode, is currently being evaluated. Bumper mode uses a different method for controlling the scan mirror's movement that doesn't inhibit synchronization with the calibration shutter. In SAM mode the TM reports three times (active scan start time, scan start to mid-scan time, and mid-scan to scan stop time) as the scan mirror passes through three precisely located points (scan angles). Feedback mechanisms adjust the speed of the mirror to keep the active scan times within specification. The wear of the scan mirror bumpers over time has increased the time between forward and backward active scans (the mirror turnaround time) so much that the calibration shutter can no longer synchronize with the scan mirror and stay out of the image.

There are technical challenges associated with the use of imagery collected in bumper mode. The change in the scan mirror control that allows it to again synchronize with the calibration shutter also changes the approach needed to geometrically align the successive scan lines to each other and to the Earth.



Path 39 Row 37: Uncorrected bumper mode data acquired on March 30, 2002, the same data after corrections are applied, and comparison scene acquired by Landsat 7 on June 4, 2000.

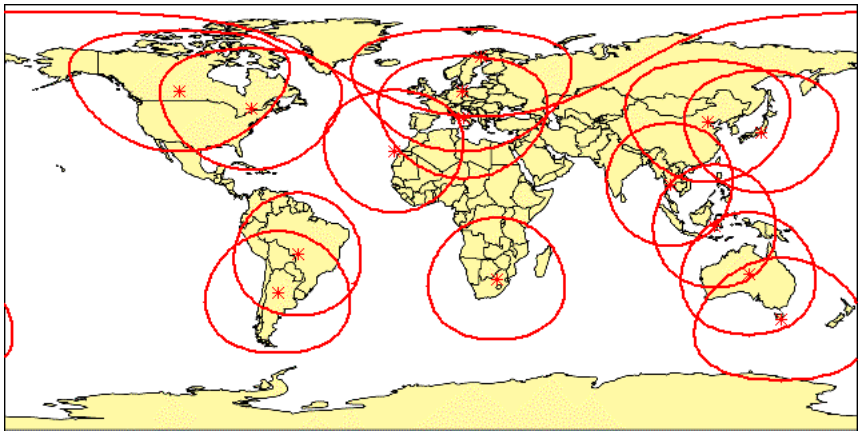
Test images have been collected in bumper mode and algorithm development has begun. The early results are very encouraging and suggest that a systematic process can be developed which will correct the imagery to a geometric fidelity equaling that required by the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) instrument. If operations in this mode prove feasible, the TM instrument would have a new lease on life, allowing the mission to continue for the next 2½ years until it is scheduled to end due to on-board fuel depletion.

Landsat 7 continues to function well. All spacecraft elements are operating nominally, with the exception of two of 24 Solid State Recorder memory boards which, to date, have not affected mission capability. On occasion power surge protection guards have tripped and prevented any damage to the spacecraft or sensor. The three U.S. managed ground stations are receiving data with a 99% success rate. In the first 2½ years of the mission, over 250,000 images were added to the U. S. archive. In that same period, over 240,000 images were down linked to the network of international ground stations.

The Landsat ground station at the USGS EROS Data Center (EDC) is the primary U.S. receiving station for Landsat 7 and the only North American ground station for Landsat 5 data. Typically, 75 Landsat 5 scenes and 140 Landsat 7 scenes are received daily through the ground station's 10-meter dish. Another 110 scenes from the U.S. managed stations in Alaska and Norway are received by tape and archived each day. The output product production systems are capable of producing 72 Landsat 5 Level1G products, 220 Landsat 7 Level OR products, and 290 Landsat 7 Level 1G products per day.

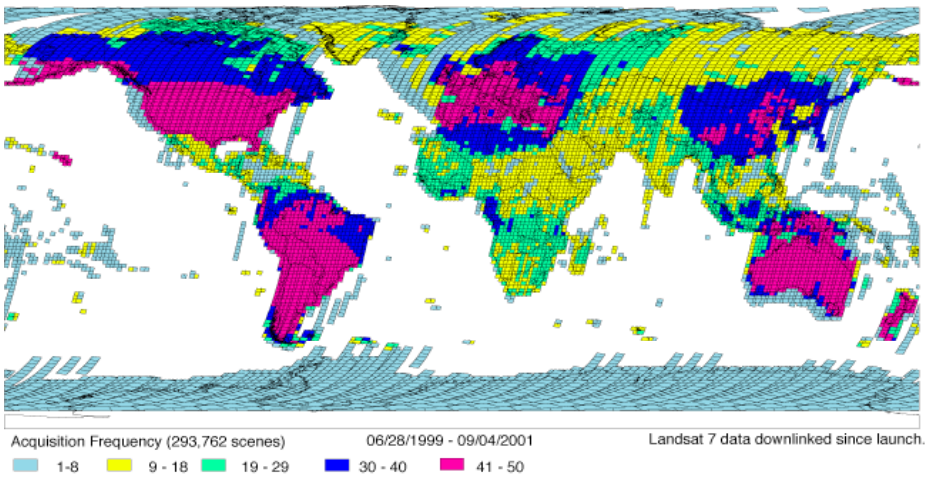
The international ground station network for Landsats 5 and 7 are coordinated by the USGS EDC. For Landsat 7 acquisitions, the USGS has negotiated agreements that require the International Cooperator to pay annual cost sharing fees. The Landsat 7 satellite downlinks imagery within the direct reception area of an international ground station. The U.S. Government retains ownership of all raw Landsat 7 data; however, the International Cooperator may set prices and redistribution policies on the data they collect. International Cooperators have the same flexibility for pricing and distribution of Landsat 5 data they acquire.

Landsat 7 International Ground Stations



Argentina **Australia (2)** **Brazil** **Canada (2)**
China **ESA (4)** **Indonesia** **Japan (3)***
Thailand **South Africa** *limited to one downlink

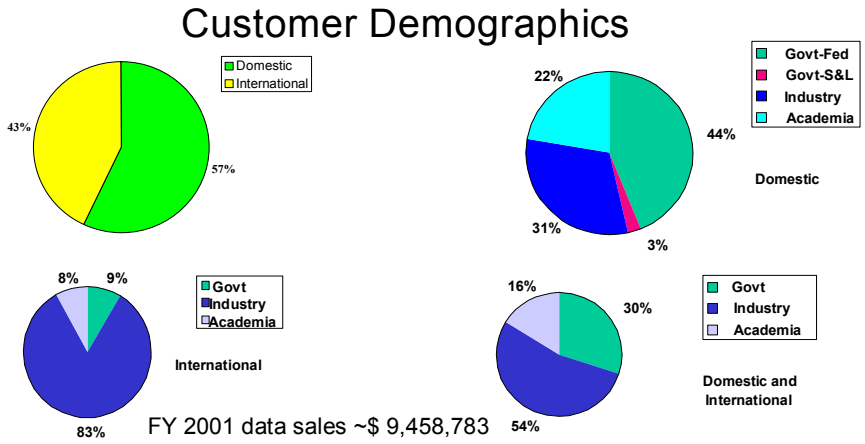
Landsat 7 Worldwide Acquisition Density



In 2001, the USGS assumed flight operations responsibility for Landsat 7. Mission management is performed at EDC, while USGS staff at the NASA Goddard Space Flight Center in Maryland manage flight operations. Flight operations responsibilities encompass tasking the spacecraft, providing data quality and reception reliability, anticipating responses to degrading or changing systems, and 24 X 7 operations. The flight operations team participates in investigations of spacecraft sensor anomalies and, generally, maintains the 'health' of the system. A similar team, under contract to the USGS, performs flight operations for Landsat 5. Based in Lanham, Maryland, the Landsat 5 flight operations team monitors the satellite operations and has command and control of the spacecraft.

DATA ACCESS AND SALES

On July 1, 2001, the USGS began to receive Landsat 5 direct down link. Additionally, the private operator transferred the Landsat 5 archive to the USGS. The Landsat 5 archive consists of 457,500 scenes from the historic archive; 10,900 scenes acquired in the transition period before July 1, 2001, and over 5,400 scenes acquired after July 1, 2001.



In FY 2001 (October 1, 2000 to September 30, 2001), 19,304 Landsat 7 scenes were sold totaling $9,458,783 in revenue. Customer demographics show a mix of government and industry customers.

In the last three years, since the USGS Business Partner program was expanded to include the product lines held at the EDC, more than 150 private companies have become re-sellers of these products. The partners are more or less equally divided among dealers of aerial photographic products, satellite remotely sensed data, and digital data derived from USGS maps.

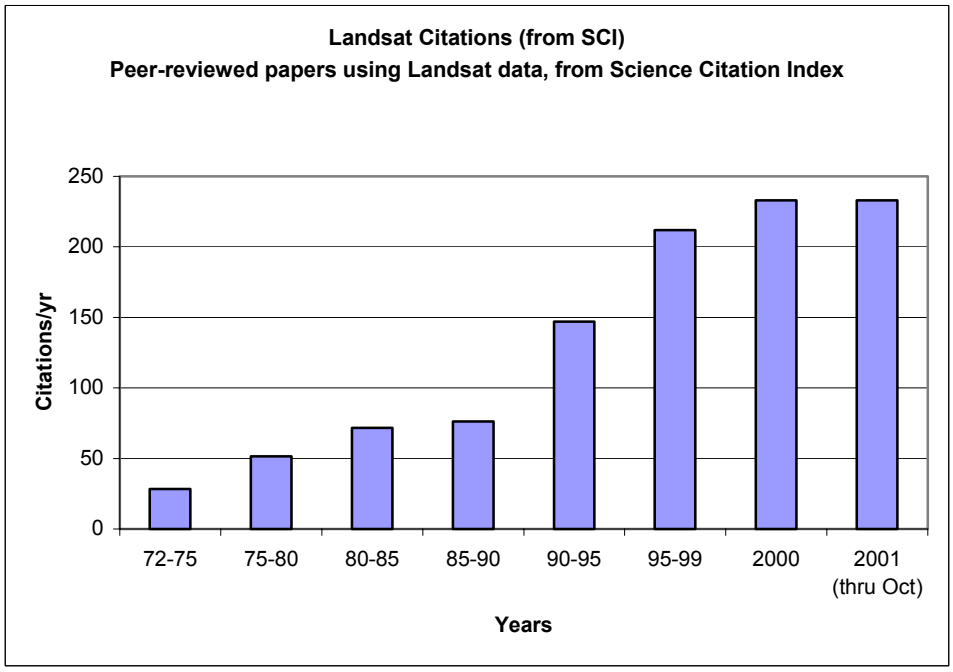
Annual sales to Business Partners from EDC amount to over $4 million, the bulk of it in Landsat 7 products. The partners help the USGS realize its goal of increasing distribution of its products to end-users. Frequently, Business Partners add value to these products and re-sell them as parts of larger product suites for a growing variety of scientific, engineering, and land-use planning applications.

Business Partners receive the same price reductions on most of their purchases as those available to the general public. They also benefit from a staff of User Services personnel dedicated to serving their needs. Often the USGS staff introduces partners to each other when working together might be mutually beneficial for the partners.

Recruitment of Business Partners continues, but growth in the number of Business Partners is not a specific goal of the program. Increasing product distribution and decreasing the Customer Services workload at the EDC are direct benefits of the Business Partners program.
A list of the Satellite Business Partners is found in *Appendix A.*

Landsat data have also become vital to the commercial and applications communities because of advances in scientific understanding of these observations. Value-added resellers (VARs) produce a variety of products for agencies such as the Department of Agriculture (USDA), Census Bureau, Department of State, Department of Defense, State and local governments, resource telecommunications and extraction companies, and agribusiness. Overseas, the International Cooperators supply foreign VARs with products as well. At the Landsat Data Continuity Mission (LDCM) conference held in January 2001 in Reston, Virginia, the consensus among both science and industry was that Landsat data served as a “gateway” data product, introducing consumers to remote sensing at relatively low-cost, and paving the way for use of high spatial resolution commercial sources.

SCIENCE SUPPORT



Landsat observations, acquired over a nearly thirty-year period, have found increasingly wide acceptance within the science and applications communities. As one measure, the Science Citation Index records some 3,200 peer-reviewed articles making use of Landsat data since 1972, with significant increases in these citations over time. These studies cover topics as diverse as land cover change, urban growth, agricultural production, grasslands productivity, forest state and biodiversity, water quality, archeology and anthropology, the geographic distribution of malaria, and volcanology. In fact, the use of Landsat data within the science community has spread through time. Early papers were largely confined to the remote sensing science community and often reported on promising, if hypothetical, uses of remote sensing. Today Landsat has evolved to become an important data source for addressing basic questions in the earth sciences.

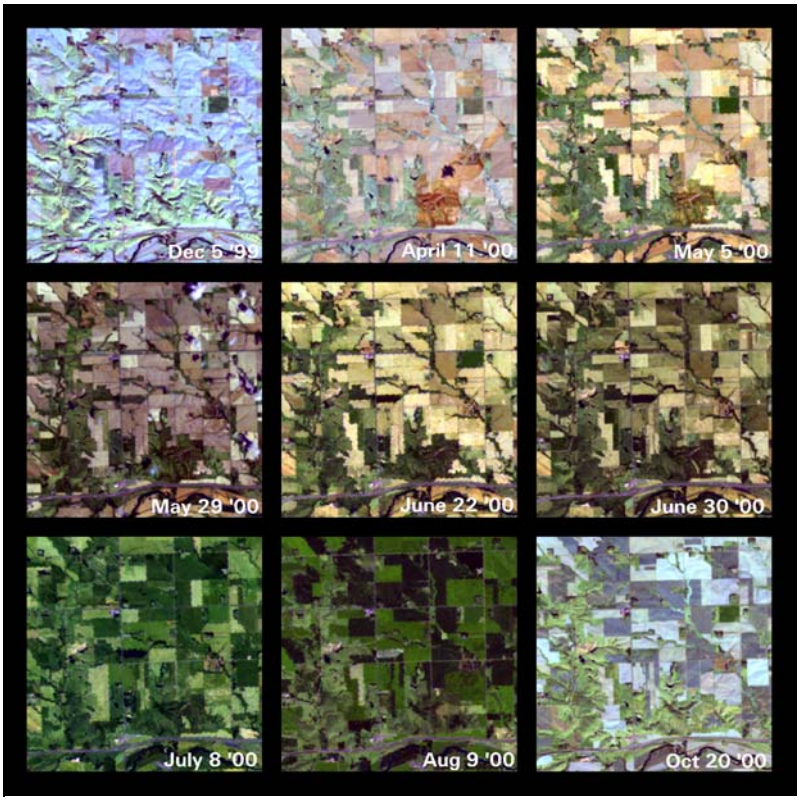
For science applications, Landsat observations fill an important niche between the highly-repetitive but coarse spatial resolution observations from the NOAA AVHRR, NASA EOS MODIS, and French VEGETATION instruments and the high spatial resolution, local observatories such as the Space Imaging Corporation IKONOS instrument and the Digital Globe QuickBird instrument. Landsat provides systematic global coverage at a frequency sufficient to capture seasonal variations and at a spatial resolution where land cover dynamics, under the influence of natural processes and human activities, is clearly evident.

Landsat 7 has built upon the historic strengths of the Landsat Program. The low cost of Landsat 7 data, as well as the elimination of copyright, have fostered an environment in which users are free to experiment with novel applications and use large quantities of data for existing applications. Technically, the improvements in Landsat 7 have proven a boon to researchers. As described by Dr. Samuel Goward, Landsat 7 Science Team leader:

> "Analyses and evaluations indicate that the data quality is outstanding, particularly with respect to radiometry, image geometry and geographic registration, and repetitive coverage of the global continental and coastal regions. …The Landsat 7 mission achieves both the promise conceived by early visionaries who designed this Earth land observatory as well as the experience and wisdom of scientists and engineers who have spent the better part of 30 years exploring its potential. ”

Landsat 5 and Landsat 7 data were acquired over Southeastern South Dakota and the spectral pattern changes over common areas were examined. The two satellites offered an opportunity to collect more seasonal data for the intra-annual reflectance comparisons. The comparisons allowed a more clear discrimination of vegetation.

In 2001 Landsat 7 data proved useful for analyzing the effects of two major disasters. In June 2001, a tornado swept through Siren, Wisconsin, causing significant human and material damage. Landsat 7 data, acquired the morning after the tornado went through the region, recorded the track of the storm. Comparing that image with one acquired a month before the storm Wisconsin disaster agencies could accurately measure the direction and extent of the devastation.



Spectral change patterns in southeastern South Dakota

Pre- and post tornado images of Siren, Wisconsin

Landsat 7 data were acquired over New York City the morning of September 12, 2001. Disaster agencies used the data to outline the direction and extent of the smoke and debris flow from the collapse of the World Trade Center buildings. Studying the direction of the smoke was important, as there were concerns about harmful particles drifting over major population areas.

LANDSAT 7 SCIENCE TEAM:

The NASA Landsat Science Team, selected in 1996, provided science guidance to the Landsat 7 Project Science Office at NASA Goddard Space Flight Center (GSFC) concerning development and deployment of the mission as well as pursuing advances in the use of Landsat 7 data for global change research. The Landsat 7 Science Team activities ended in June 2001. Much of the Landsat Science Team research has been summarized in the October 2001 Landsat 7 special issue of Remote Sensing of the Environment (Vol. 78, Issues 1-2). Some highlights of this special issue include:

Landsat 7 Long-Term Acquisition Plan: Terry Arvidson, John Gasch, and Sam Goward report on the development and use of the innovative Landsat 7 Long-Term Acquisition Plan (LTAP). This is a new concept in the history of the Landsat mission in which an automated process, based on historical land cover information and cloud cover statistics, combined with current cloud cover forecasts, provides a systematic process to acquire comprehensive global observations from Landsat as cloud-free as possible. The results to date have been exceptional, with better than 90 percent of all the Earth's land areas viewed with less than 10% cloud cover in less than one year.

Landsat 7 Characterization: Several papers in this special issue cover the radiometric (Thome, Teillet, Vogelmann, Hu, Schott, Masek) and geometric (Vogelman, Masek) characteristics of the Landsat 7 observing system. In all cases the Landsat 7 data are both better than equivalent data from Landsat 5 and, in many cases, better than the specifications laid down for the system during design and construction. For example, the radiometric performance exceeds pre-flight specifications by up to a factor of two and geographical positional accuracy is up to five times better than specified, after the USGS applies post-orbital pass information on satellite positioning. These results demonstrate the value of the attention that the Landsat 7 Science Team and the NASA/USGS Project Science Office paid to development of the Landsat 7 mission.

Atmospheric Corrections: Studies by Susan Moran (USDA, Tucson, AZ), et al, Robert Cahalan, et al, and Chuanmin Hu, et al, demonstrate that because of the high quality radiometry in Landsat 7 observations, it is now easier to relate these satellite measurements directly to ground conditions (surface reflectance and surface-leaving radiance), effectively reducing the impact of variable atmospheric conditions. These studies hold the promise that in future missions these unwanted variations in satellite remote sensing measurements may be substantially removed.

Mid-latitude Forest Cover Change: Building upon the Tropical Deforestation research carried out in 1980, Curtis Woodcock with his team at Boston University in conjunction with Warren Cohen (Oregon State University) have developed multi-scene analysis procedures that permit continental to global-scale analyses of mid-latitude deforestation rates. These rates for some locations may be higher than in the tropics. On the other hand recent studies of the Earth's carbon budget suggest that the northern hemisphere forests may currently be serving as at least a short-term sink for atmospheric carbon (placed there primarily by fossil fuels consumption). The methods demonstrated by. Woodcock and his team provided the knowledge and tools needed to address these uncertainties about mid-latitude forest dynamics.

Agricultural and Grasslands Productivity in Semi-arid Environments: Susan Moran and her research team have combined Landsat observations with other remotely sensed measurements and models of plant growth to track the seasonal evolution and annual productivity of irrigated agricultural fields and rain-fed grasslands in southern Arizona. They show that the Landsat observations provide critical information on the state and dynamics of vegetation canopies in these systems permitting accurate assessment of plant growth in these water-limited environments.

Coral Reef Monitoring: Coral reefs are called the "rainforests" of the ocean, in that they host tremendous concentrations of marine biodiversity. Serge Andrefouet and Frank Muller-Karger (U. South Florida) have been monitoring the Carysfort Reef in Florida, the largest reef in the Florida Keys. Their findings indicate that only 5 percent of the coral in the Carysfort Reef is left alive, a decrease from more than 50 percent in 1975. Landsat 7 data are allowing the structure and extent of coral reefs to be monitored globally for the first time, and more than 5,000 coral reef images have been acquired worldwide since launch.

Antarctic Icebergs: Dr. Robert Bindschadler (NASA GSFC) has been using Landsat 7 imagery to map the velocity field of ice streams in Antarctica. On January 16, 2001, during his daily review of new Landsat 7 images of Antarctica, he noticed a striking feature on the Pine Island Glacier, a thin crack more than 25 kilometers (15 miles) long, stretching more than two-thirds of the way across the glacier. This new feature, not present on earlier imagery, provided warning before a new "super iceberg" calved from Antarctica in early 2002. These large icebergs can present a hazard for shipping in the southern oceans, and reveal important information on the environmental conditions on the ice cap.

High-Plains Sand Dune Reactivation: Dr. Alexander Goetz (U. Colorado) has been focusing on the potential reactivation of Holocene sand dunes in the Western High Plains. During periods of drought (such as the 1930's Dust Bowl) these dunes can be stripped of their plant cover and rapidly erode, harming the agricultural productivity of the region. Goetz has assembled a GIS-based model, using land-cover data derived from Landsat 7 imagery, and measured precipitation and wind fields to create maps showing the locations where sand dunes may be reactivated by drought.

NASA LAND-COVER LAND-USE CHANGE (LCLUC) PROGRAM

The LCLUC program funds research on global land-cover change, including studies on the socio-economic and climate drivers for change. Associated studies have also concentrated on developing methods for analyzing remotely sensed data and initiating pilot programs for the Global Observations of Forest Cover (GOFC) project, which is attempting to map the world's forests. Landsat data are widely used by LCLUC investigators, at a variety of scales. While some investigators are looking in detail at changes occurring in a local region, an increasing number are expanding their studies to encompass entire countries and regions. Recent applications of Landsat include:

Carbon Fluxes in the Miombo Woodlands: Dr. Paul Desanker (U. Virginia) is using Landat 5 and Landsat 7 data in order to create regional estimates of carbon pools and carbon fluxes for the Miombo Woodlands of Southern Africa. This dry, tropical region is subject to both natural disturbance (fire cycles) as well as forest clearing by humans. By combining multi-temporal Landsat data (detailing land-cover changes) with carbon accounting models, Dr. Desanker is producing the first regional assessment of carbon balance for the region.

Rates of Land-Cover Change in the U.S.: Dr. Tom Loveland (USGS) is studying the spatial and temporal dimensions of contemporary U.S. land use change by sampling 84 U.S. ecoregions with 20x20km blocks of multitemporal Landsat data (1973-2000). Initial results indicate that while the driving forces for land-cover change vary from place to place, similar drivers may have different consequences in different regions. Over the last 30 years, Loveland has found areas of land-cover conversion varying between 13 percent for the southeastern plains to just 3 percent for the Northern Piedmont.

Amazonian Forest Degradation Mapping: Much of the biomass removal from the Amazon rain forest may occur as "canopy degradation", that is the removal of individual trees through species-specific logging rather than as clear-cutting. Dr. David Skole (Michigan State University) has developed spectral unmixing techniques to quantify canopy degradation using Landsat data and has applied these methods to a time series of Landsat 5 and Landsat 7 data from the 1980's and 1990's. Dr. Skole finds considerably less area of degraded canopy than previously estimated by limited ground sampling.

SOLID EARTH/NATURAL HAZARDS

The NASA Solid Earth/Natural Hazards program funds basic investigations into solid earth geodynamics, geology, and geomorphology, as well as applied work on predicting and mitigating natural hazards. Landsat data are commonly used by this research community, often in combination with other data sources such as GPS, interferometer radar, and seismologic data.

Bhuj Earthquake: On January 26, 2001, a magnitude 7.6 earthquake struck the Indian province of Gujarat, killing nearly 20,000 people and injuring over 160,000. A neotectonics team from Columbia University, San Diego State University, and University of Nevada-Reno was quickly dispatched to the epicenter to map surface ruptures and measure fault displacements. The team relied on merged Shuttle Radar Topography Mission (SRTM) digital topography and Landsat 7 ETM+ data supplied by Robert Crippen (JPL) in order to

locate the fault trace and put the local geology into context. The team mapped numerous liquefaction and local slumps, although there was little surface evidence of fault rupture.

Mt. Etna Eruption: During July and August 2001, Mt. Etna (Sicily) experienced its most sustained eruption in a decade. A variety of satellite sensors, including Landsat 7's ETM+, captured the daily and weekly evolution of the event. Using Landsat 7 data, the thermal development of lava plumes and hotspots could be tracked and measured. Using data such as these, Drs. Luke Flynn, Andrew Harris, and Rob Wright (U. Hawaii) are calculating lava effusion (volume flux) rates from Mt. Etna and other active volcanoes. Trends in these data can indicate changes in the style of magmatism or long-term changes in eruptive capacity.

NATIONAL AND INTERNATIONAL PROGRAMS

In addition to individual science investigations, projects within the U.S. and overseas have been set up to use large volumes of Landsat 7 data for specific tasks. These projects encompass processing and analysis flows larger than those that can be easily handled by individual scientists.

Year 2000 Data Buy: In order to facilitate interannual comparisons and large-area analysis of Landsat data, NASA has sponsored a series of Landsat Data Buys through the Stennis Space Center and the Earth Satellite Corporation. Three data buys were offered. 1980's MSS data were used for a mosaicking project. A global dataset of over 7,000 orthorectified Landsat 5 images centered on the year 1990 resulted in the creation of the GeoCover product, together with an RGB (red-green-blue) mosaic useful for visual interpretation and educational uses. Following the success of these projects, NASA awarded a data buy contract to the Earth Satellite Corporation to produce a Year 2000 Landsat 7 orthorectified global dataset. Planning for this product is underway now, with product delivery expected in 2002-2003.

Millennium Ecosystem Assessment: An international consortium is working to produce the first integrated assessment of the status of the world's ecosystems. The overall assessment will include component assessments undertaken at several different geographic scales, ranging from individual villages to the globe, and the process will be designed so that the findings at any given scale are informed by the assessment components undertaken at other scales. In September 2000, President Clinton stated to the United Nations Security Council that the U.S. would commit support to the Millennium Ecosystem Assessment process with data from its TERRA, SeaWifs, and Landsat satellites. (These data have been valued as an in-kind contribution of approximately $60 million.) The Year 2000 Data Buy will also help to satisfy this commitment. In October 2001, a workshop on "Remote Sensing and the Millennium Ecosystem Assessment" was held to discuss technical approaches for collecting and analyzing satellite data for this important activity.

NASA Climate Change Initiative: In order to help the Nation understand, predict, and mitigate future climate changes, President Bush has pursued an interagency Climate Change Initiative. Workshops held during CY 2001 to outline NASA's contribution focused attention on the need for repeated land-cover analysis in order to quantify land-atmosphere carbon fluxes related to land-cover conversion and natural disturbance (e.g. fire, insect damage, etc). While plans are still being formulated, there is a clear consensus among participating scientists that Landsat 7 data will form the basis for North American land-cover change assessments and carbon accounting models.

Australia National Carbon Accounting System: The Australian Greenhouse Office devised the National Carbon Accounting System (NCAS) in 1997 to provide an accounting system for sources and sinks of greenhouse gas emissions from Australia in order to meet international standards and treaties. Following serious consideration of sampling alternatives, the decision was made to base the system on a full inventory, modeling carbon at a hectare scale building on Landsat data from 1972 to 2000 in ten time slices. A continental mosaic has been constructed from ETM+ data and earlier scenes are being registered and calibrated against this. A site-specific carbon model (FullCAM) is used to estimate total land based carbon fluxes over the 28-year period for each 25-meter pixel.

LANDSAT PROGRAM NEAR-TERM PLANS

The Landsat program has always been a dynamic endeavor, and CY 2002 is no exception to that trend. During this year there are initiatives underway to add new products to the product line, embark on our first long-term archive migration, re-evaluate some of our program policies and practices, expand our cooperator network, and coordinate our activities to provide the benefit of our operations experience to the next generation of Landsat satellites.

In mid 2002 the Landsat program will add multi-scene and floating-scene products to the Landsat 7 product line. The multi-scene product will allow the user to order up to a 10-scene swath of L0Rp data or up to a 3-scene swath of L1G data. These swath products are of interest to the Landsat users engaged in regional and global studies, and to those users involved in the mosaicking of Landsat data. The floating-scene product will allow for L0Rp or L1G data selections that start or end on non-row boundaries within a path. These products aid researchers whose area of interest fall on or across a normal scene boundary, and also allow the user to better match an order to their specific geographic area of interest.

After three years of operation, the Landsat 7 mission will embark on its first long-term archive migration in the fall of 2002. The dynamic nature of technology development in both the hardware and software industries dictates that operational missions must constantly re-evaluate their architectures and migrate to new technologies to avoid obsolescence. The Landsat program will be migrating the long-term archive of Landsat 7 data from existing StorageTek D3 tape technology to new StorageTek 9940B tape technology. The migration will take several months to complete. Once the migration is complete, the storage capacity of the system will quadruple and will hold up to six mission-years of Landsat 7 data.

Since the return of Landsat 5 to the Government, the USGS has been working to establish an International Cooperator (IC) network worldwide for reception of Landsat 5 data. Initial participants include Argentina, Brazil, China, and Saudi Arabia. The Landsat Program continues to receive inquiries from potential new cooperators for both Landsat 5 and Landsat 7 data. We work with all interested parties to assess their requirements and evaluate alternatives for providing the service they seek while minimizing the impact on the existing network of cooperators.

In 2002 the Land Remote Sensing Program at USGS Headquarters will review the Landsat data policy. This review has been initiated, in part, because of the return of Landsat 5 and its operation to the Government from the private sector in mid-2001. It is now possible to develop a combined Landsat data policy that encompasses both Landsat 5 and Landsat 7 data products. This review will include an assessment of the success of the Landsat 7 data policy since launch and will consider the composition of the NASA/USGS Landsat Data Continuity Mission (LDCM) data policy.

In 2002, the formulation phase of the LDCM will be executed. During this first phase of the contracting process NASA and the USGS will be evaluating the approaches of the potential LDCM contractors to implementing the LDCM mission. The USGS has participated in NASA's selection of the formulation phase contractors, and in the subsequent evaluation of each contractor's approach to the LDCM implementation. The USGS Landsat Program will coordinate the activities of the International Cooperator Network to facilitate interaction between the LDCM formulation phase contractors and the IC technical and management representatives. The IC interaction with the LDCM formulation phase contractors is critical to ensuring proper definition and execution of the International Cooperators partnerships in the LDCM system design and operations concept development.

2002 promises to be an exciting and challenging time for the Landsat program. Those of us involved in the program will continue to provide the exceptional quality products and service that have characterized the program to date, while continually striving to better serve our user community, and improve our program through efficiency and innovation.

APPENDIX A:

SATELLITE BUSINESS PARTNERS

Applied Analysis Inc., Billerica, Massachusetts
Bio Geo Recon Sonora, California
Certeza Surveying & Aerophoto Systems Inc., Quezon City, Metro Manila, Philippines
Computamaps, Constantia 7848, South Africa
Cooper Aerial Surveys Co., Phoenix, Arizona
CSIR/Satellite Applications Centre, Pretoria, Gauteng, South Africa
Earth Imaging Center, Stennis Space Center, Mississippi
Earth Satellite Corporation, Rockville, Maryland
Earth Watch Inc., Longmont, Colorado
East View Cartographic Inc., Plymouth, Minnesota
EGS Technologies Corp., Bloomingdale, Illinois
Engesat Imagens De Satellites, Curitiba, Brazil
Eurimage S.P.A., Rome 00155, Italy
Forest One Inc., Evanston, Illinois
Geo Spectrum Ltd, Moscow 119048, Russia
Geocarto International Centre, Hong Kong, Peoples Republic of China
Geoid Inc., Trois Rivieres, Alberta, Canada
Geoimage, Taringa, Australia
Geosys, Inc., Plymouth, Minnesota
GTT Net Corp., Tampa, Florida
Hadjimitsis Consultants, Paphos, Cyprus
I-Cubed, Fort Collins, Colorado
Imagelinks, Inc., Melbourne, Florida
Infoterra Ltd., Farnborough, Hampshire, United Kingdom
INGR Philippines Corporation, Makati City, Philippines
International Remote Imagery, Sioux Falls, South Dakota
Intersat Imagens De Satelite, Sao Jose Dos Campos, Sao Paulo, Brazil
Istar, Sophia Antipolis, France
Le Groupe Systeme Foret Inc., Quebec City, Quebec, Canada
Madecor Group, Los Banos, Philippines
Mapmart, Englewood, Colorado
Natural Systems Analyst, Inc., Winter Park, Florida
Nigel Press Associates Limited, Edenbridge, Kent, United Kingdom
Orbis GIS, Inc., Charlotte, North Carolina
Pacific Geomatics Ltd., Surrey, British Columbia, Canada
Perry Remote Sensing Llc, Englewood, Colorado
Prosis S.A., Bogota, Columbia
Pt Blom Nusantara, Jakarta 12710, Indonesia
Pt Earthline, Jakarta 12310, Indonesia
Pt. Adinugraha Satelindo, Jakarta 10270, Indonesia
Radarsat International Inc., Richmond, British Columbia, Canada
Remote Sensing Instruments, Hyderabad - 500 013, India
Resource21, Denver, Colorado
RGI Resource GIS & Imaging Ltd, Vancouver, Alabama
Servicios Sigis, Caracas, 1071, Venezuela
Silvana Import Trading Inc., Montreal, Quebec, Canada
SPOT Image Corporation, Reston, Virginia
Telemorphic Inc., Berkeley, California
Terra Space C.A.G. , Moscow 117342, Russia
Test Ext Org For USGS Use, Denver, Colorado
TMS Communications Ltd., Kobe, Japan
Tobin International Ltd., San Antonio, Texas
TTI Production, Nimes, France
Victor Torres, Washington, District of Columbia
World Satellite Images, South Skyvue Court, New York

Images, Figures, and Tables