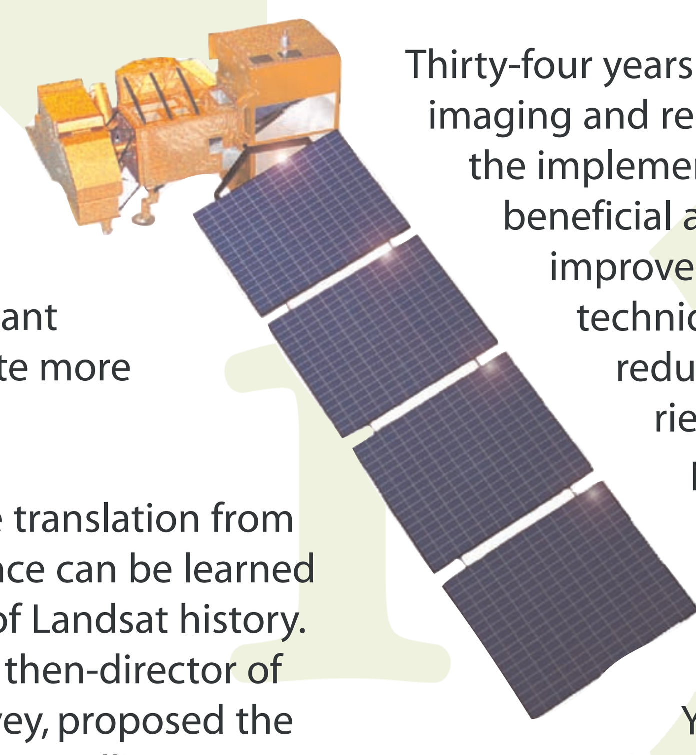
Introduction

"The continuous, consistent archive that has been generated throughout the life of the Landsat project provides the unique capability to assess changes in the landscape of our planet"

–Shaida Johnston,
former Landsat-7 senior systems engineer and space policy expert

Science has long served humankind. Breakthroughs in medicine have increased longevity while advances in technology have made modern-day conveniences possible. The social benefits that arise from the environmental sciences, while equally important, are often less obvious. To benefit today's rapidly growing world, the divide between environmental research and the implementation and appreciation of applied environmental science must be bridged. Here, we look at Landsat's long history, dissect the anatomy of one of Landsat's social benefit success stories, and we draw on the advice of Landsat experts to outline some of the important steps needed to facilitate more usable Landsat science.



Many lessons about the translation from research to usable science can be learned from the four decades of Landsat history. In 1965, William Pecora, then-director of the U.S. Geological Survey, proposed the idea of a remote sensing satellite program to gather facts about the natural resources of Earth. For the next seven years, an intense campaign showing the depth and diversity of satellite imagery applications was waged. This led to the 1972 launch of the first civilian Earth-observing satellite, Landsat 1. By 1975, successful application research based on Landsat 1 imagery prompted then-NASA Administrator Dr. James Fletcher to proclaim that if one space age development would save the world, it would be Landsat and its successor satellites. Landsat gave the world the first unabridged perspective of human-induced large-scale environmental changes, from the swift expansion of desert-cities like Phoenix, Arizona and Las Vegas, Nevada to the deforestation of the Amazon rain forest and the disappearance of the Aral Sea.

Thirty-four years of continual Landsat imaging and related-research has lead to the implementation of many socially beneficial applications, such as improved water management techniques, crop insurance fraud reduction, illicit crop inventories, natural disaster relief planning, continent-scale carbon estimates, and extensive cartographic advances.

Yet the debate continues about the future of mid-resolution remote sensing in the U.S., making it clear that the benefits of Landsat applications are not readily known or appreciated outside of the remote sensing community. The social benefits of Landsat often seem to get lost in translation between the publish-heavy research realm and the self-contained applications world.

Bridging the Divide:

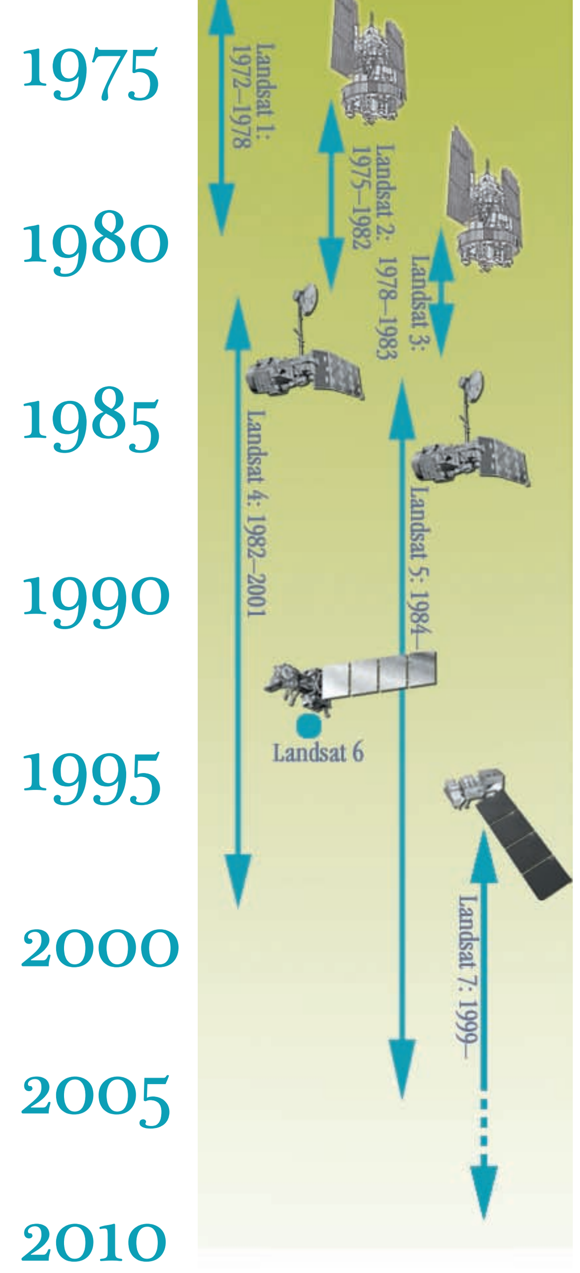
Translating Landsat Research Into Usable Science

L. Rocchio and A. Davis, presented at the AGU Fall 2006 Meeting
contact: Laura.E.Rocchio.1@gsfc.nasa.gov

History

"For the generations that follow us, and decision makers who must consider issues of population, food supply, fresh water and the overall condition of Earth's environment, finding an effective means to continue the Landsat observatory as a means to monitor our home planet is vital"

–Goward and Masek (2001)



Since the early 1970s, the Landsat series of satellites has collected information about Earth from space in the form of specialized digital photographs of the planet's continents and surrounding coastal regions. These images have enabled scientists to study the Earth's land surface and to evaluate dynamic changes caused by both natural processes and human practices.

The idea that remote sensing could benefit society largely fueled the conception of the Landsat program. Orbital photography of Earth taken during the early manned-space missions convinced land management agencies that planetary natural resources could be better monitored from the vantage point of space. Plus, the image of our home planet floating in the vast blackness of space helped the nation realize human dependence and impact on Earth's life-sustaining ecosystem.

Today, we look to Earth to provide food, water and shelter for over six billion people. Preserving the human species means ensuring the sustainability of natural resources and protecting people from natural and man-made disasters. Both require accurate geospatial information.

Landsat-1, -2, and –3 were launched by NASA in the 1970s

Landsat-1 was launched in 1972, heralding a new age of remote sensing of land from space. Landsat-1, -2 and -3, were considered experimental projects and were overseen by NASA. After being declared operational in 1979, responsibility shifted to the National Oceanic and Atmospheric Administration (NOAA), the agency operating the weather satellites.

Landsat-4 and -5 were launched by NASA in the 1980s

While NOAA was charged with Landsat satellite operations, NASA was charged with the building and launching of Landsat-4 and -5. Both carried an improved sensor that could see a wider (and more scientifically tailored) portion of the electromagnetic spectrum and see the ground in greater detail.

The era of commercialization

Based on Landsat's early success, Congress decided land satellites could be commercialized. But, the 1984 law gave the operating company, EOSAT, limited commercial freedom. Given these constraints, EOSAT raised image prices from $650 to $4400 and restricted redistribution, this practice priced out many data users. (As a result, many data users migrated to the free low-resolution land data being captured by meteorological satellites.) During the EOSAT commercialization era, Landsat standards languished. Many observations from 1984 to 1999 were missed because there was no immediate buyer. Eight years later, the Bush I Administration facilitated the Land Remote Sensing Policy Act of 1992, which recognized that the commercialization of Landsat had not worked and instructed Landsat Program Management to build a government-owned Landsat-7.

Landsat-6 fails at launch

In 1993, EOSAT's Landsat-6 failed at launch after not reaching the velocity necessary to obtain orbit. So, with Landsat-4 and -5 both beyond their design lives, the loss of Landsat-6, and a nascent Landsat-7 program, it seemed that a data gap was imminent. Somehow, Landsat-5 continued to operate (and operates to this day). "The fact that we haven't had a [Landsat data] gap so far is more a function of the incredible engineering of Landsat-5 and good luck, than the result of good planning and stewardship," the L7 project scientist says.

Landsat-7 launched in 1999; a shining success until 2003 anomaly

Landsat-7 launched in 1999 despite juggling of program management. Landsat-7's consistent global archiving scheme and reduced pricing led to a large increase of Landsat data users. The Landsat-7 mission went flawlessly until May 2003 when a hardware component failure left wedge-shaped spaces of missing data on either side of Landsat-7's images. Today, with Landsat-7 limping along past its design life and Landsat-5 well beyond its design life, a Landsat data gap again seems imminent.

Data Users

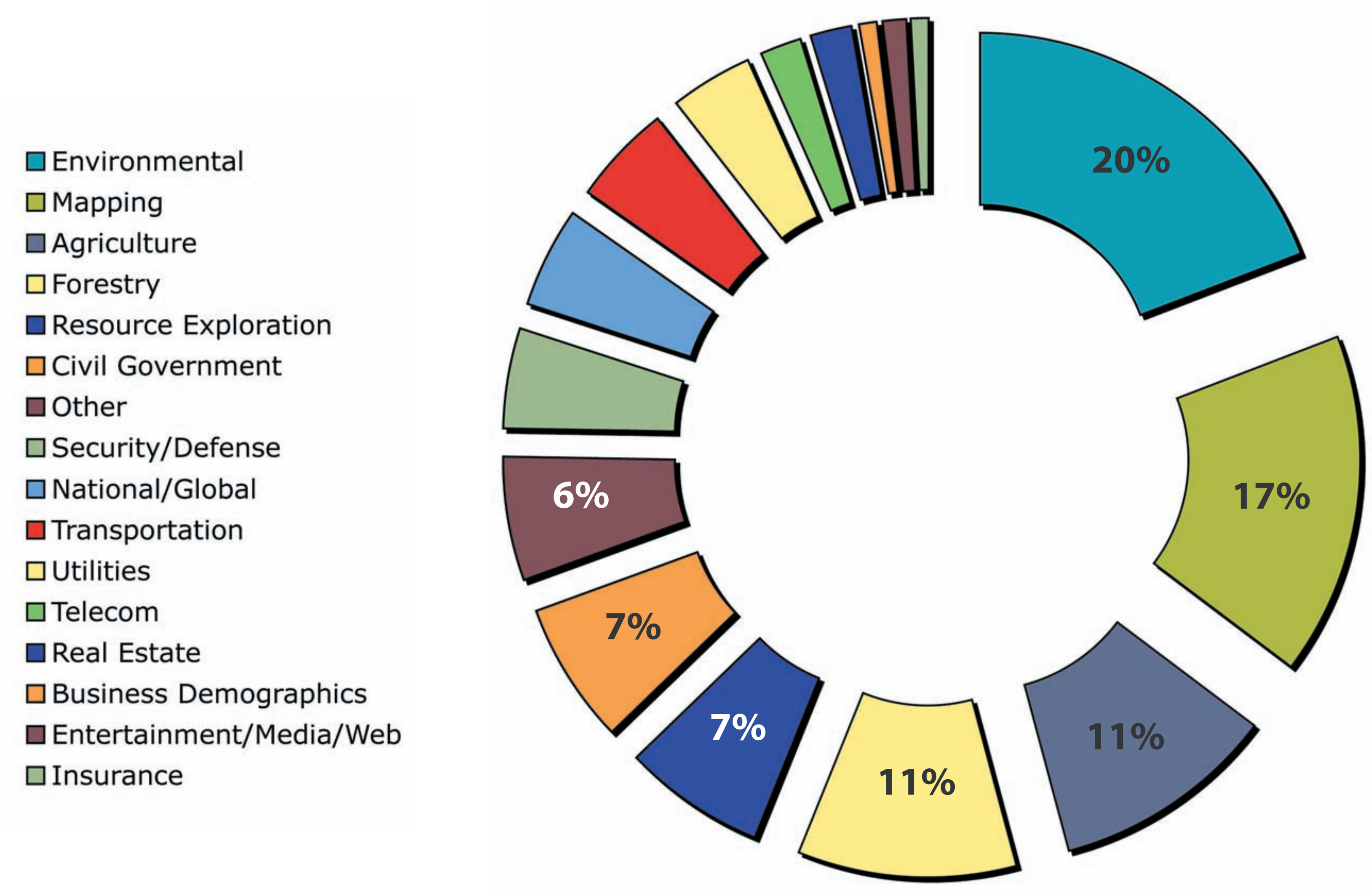
"The societal applications this program generated are so compelling that international systems have proliferated to carry on the tasks initiated with Landsat data."
–Lauer et al. (1997)

Analysis of Landsat users by application can give us some insight into understanding how Landsat data is applied to real world problems. Here we look at two such analyses.

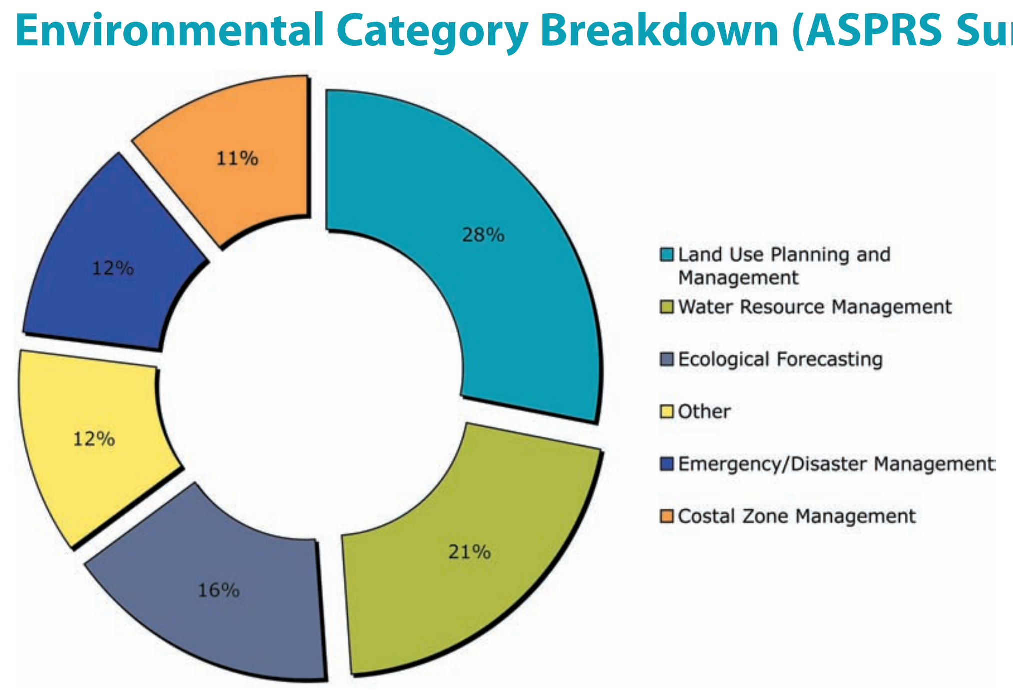
Landsat data are distributed by the USGS Earth Resources and Observation Science (EROS) center in Sioux Falls, SD. Results from a recent USGS Landsat data user characterization (by units purchased) of 193 unique customers are presented here (Krause, 2006). Defense/Security, Agriculture, and Environmental applications dominate.

This summer the American Society for Photogrammetric Engineering and Remote Sensing conducted a Landsat user survey for the Office of Science and Technology Policy (OSTP) Future of Land Imaging working group. Nearly 1300 data users responded. Environmental, mapping, agriculture, and forestry applications dominated.

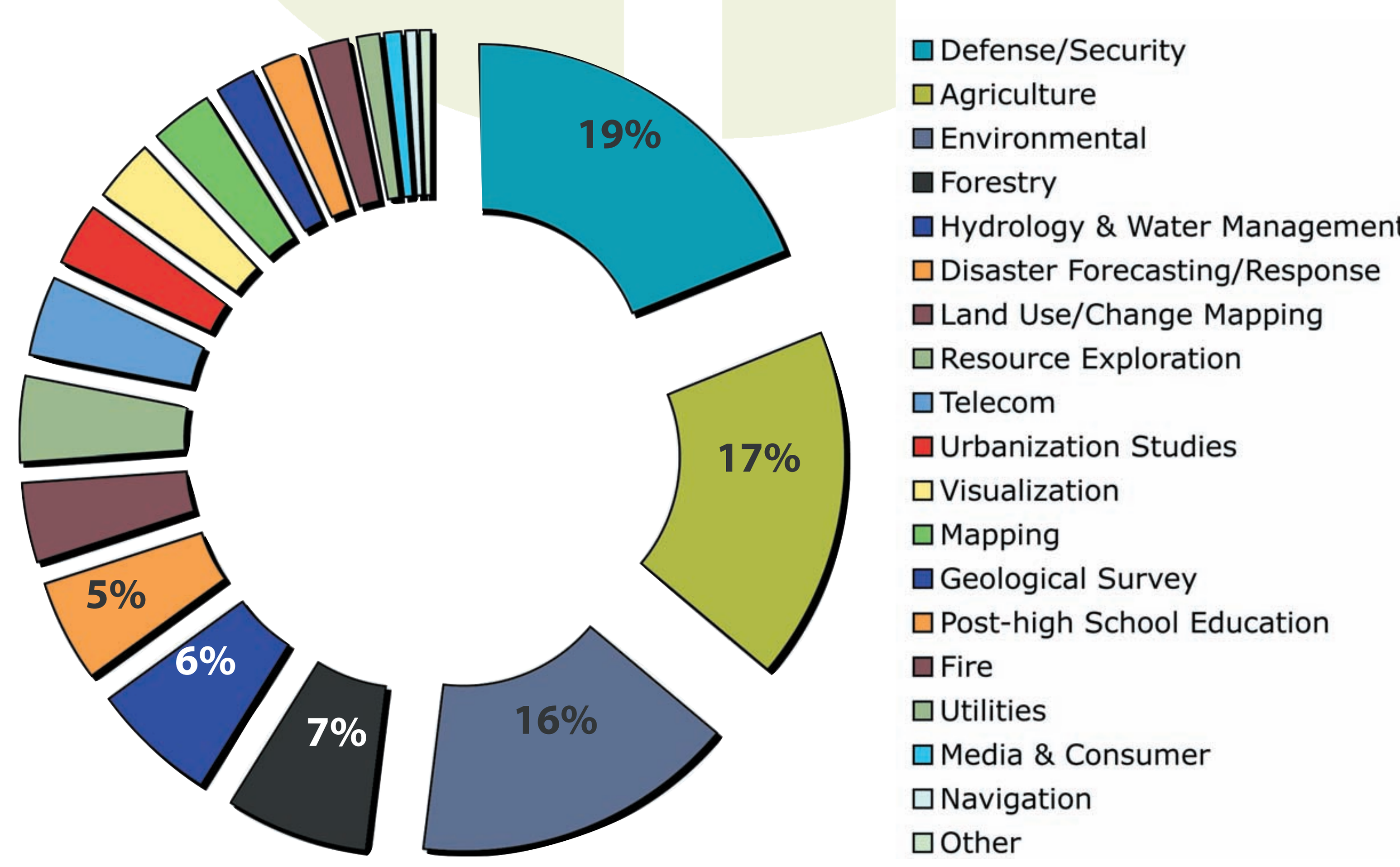
Landsat Data Usage by Application (ASPRS Survey)



Environmental Category Breakdown (ASPRS Survey)



Landsat Data Usage by Application (USGS FY99–FY05)



Anatomy of a Success Story

"No other data set allows us to assess the human condition so effectively,"
–Kass Green (2006)

As shown in both the USGS and ASPRS user studies, agriculture is one of the major Landsat applications. Here we dissect one of Landsat's applied science success stories to learn why.

The Foreign Agricultural Service (FAS) of the U.S. Department of Agriculture (USDA) has the responsibility of providing market intelligence in the form of timely, objective, unclassified, global crop condition and production estimates, for all major commodities, for all foreign countries. To accomplish this Herculean task, FAS synthesizes information from its global network of marketing experts, agricultural economists, meteorologists and remote sensing scientists.

While FAS attachés collect crop production information from foreign government reports and fields visits, it is the comprehensive view afforded by space-based Earth-observing satellites, such as Landsat, that provide the unbiased, global, farm-level observations necessary to objectively verify these reports. Unbiased report verification means food supply estimates can be used with confidence.

"Less confidence in the food supply translates into more volatile markets where food shortages and over-stocks are more likely to occur," says Brad Doorn, a Technical Remote Sensing Coordinator with FAS.

After three decades of dedicated Landsat data analysis, FAS has been forced to now use data from international satellites to fill the gap left by the crippled Landsat-7 satellite.

A look at Landsat history gives us some clues as to why Landsat was able to become such an integral part of the FAS workflow.

An interdisciplinary approach

In 1965, Prof. Ralph Shay, the Head of Purdue's School of Electrical Engineering school told young electrical engineers that by collaborating with agriculturalists they could create better agriculture management information with remotely sensed data and create knowledge necessary to solve a societal problem (Landgrebe, 2005).

Embracing change

Shortly thereafter at Purdue University, interdisciplinary research into the monitoring of crops began. In late 1970, a deadly corn blight, known as Southern Corn Leaf Blight, was discovered that threatened U.S. corn crops nationwide. Airborne spectral sensors from Purdue were used to monitor and track the spread of the blight over the 1971 growing season. Because the data could discriminate between several degrees of blight infestation before visible signs presented, skeptical USDA officials deemed the experiment a success (Landgrebe, 2005).

Large-scale application-focused experiments

A series of large-scale experiments took place during the 1970s and 1980s. Among these were the Large Area Crop Inventory Experiment (LACIE) and the Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS). LACIE (begun in 1974) tested and demonstrated a real-time capability for inventorying crop production. AgRISTARS (begun in 1980) extended crop commodity forecasting abilities.

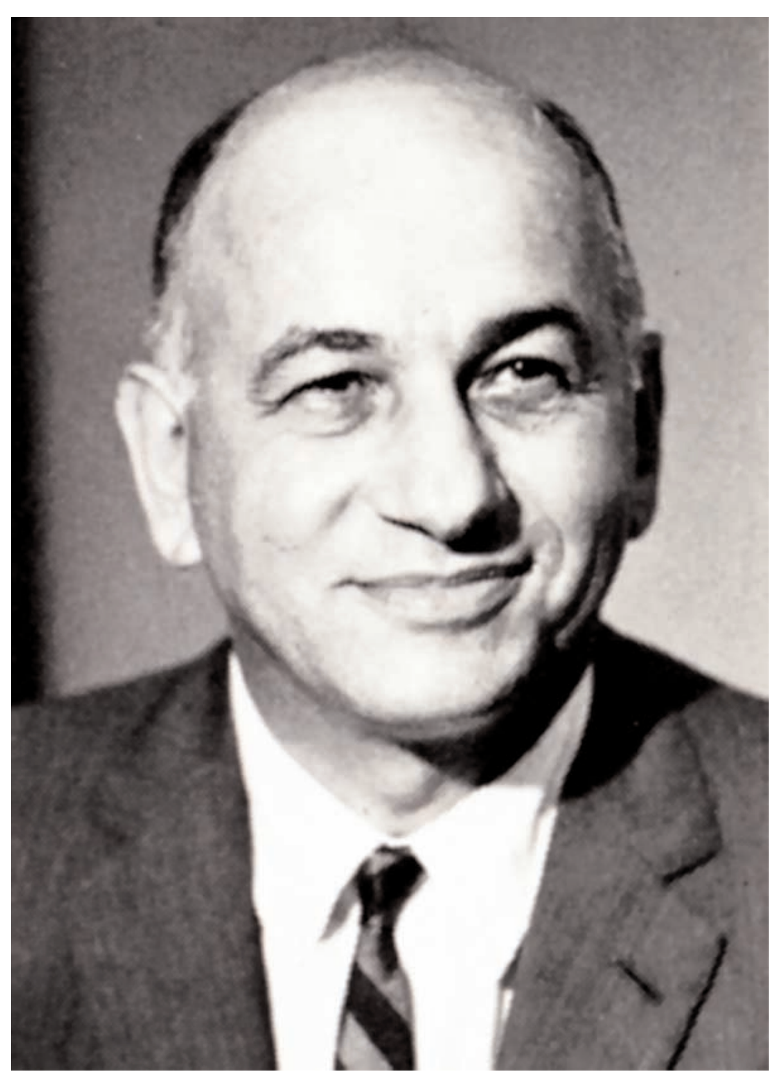
Data fusion

No sensor is an island. FAS synthesizes information from its global network of marketing experts, agricultural economists, meteorologist and remote sensing scientists. This is key; Landsat data should be considered an important data set within a suite of discipline-specific ancillary data (demographics, property boundaries, weather conditions, etc.)

Published Commentary

"One of the most challenging problems for the future in supplying remote sensing data to the user is the need to keep the material simple, to deliver it in an uncomplicated form, then make it easy to use… a real need exists for new and more timely sources of environmental and resource information."

–William T. Pecora (1972)



William T. Pecora

Here we look at published advice on increasing the applied use of Landsat data. These articles were all published in peer-reviewed literature over the past decade. The nature of the problem and the proposed solutions are outlined below.

from: Multispectral Land Sensing: Where From, Where to?
David Landgrebe, 2005

PROBLEMS

- Delays in getting data to user
- Expensive data
- Limited data coverage

"Indeed it would not seem prudent for any agency to establish the infrastructure to rely on Landsat or any other such single satellite to meet a continuing need for information since any one satellite can fail at any time, and historically, there has been a very long delay in the replacing a failed one."

SOLUTIONS

- More satellites (20!)
- More spectral bands
- Minimal data cost
- Better data analysis algorithms

Required: "an analysis procedure that any of a large and diverse user community with only layman signal processing skills could use effectively. The analogy I have used with my students is that one should not have to understand the theory of internal combustion engines to drive a car."

from: The Availability of Landsat Data: Past, Present, and Future
Draeger et al., 1997

PROBLEM and SOLUTION

- Data distribution

"It has long been recognized that the success of the Landsat program would depend on an effective distribution of its data to a wide variety of users, worldwide in a timely manner."

from: Landsat in Context: The Land Remote Sensing Business Model
Kass Green, 2006

PROBLEMS

- Data too coarse
- Early technology adoption barriers: computing power
- No institutional support
- Shallow, narrow and fragmented base of users
- Data too expensive
- Data policy too restrictive

"Landsat's base of support has been shallow, narrow, and fragmented. The user base was initially made up of scientist and the difficulty of working with the data slowed its adoption for many years. Then, seven years of ill-conceived "commercialization" resulted in Landsat prices and licensing terms which stagnated the adoption of the imagery. Without a strong user base, the institutional framework supporting Landsat has been weak from the beginning."

WHAT HAS HELPED?

- Higher resolution data
- Incorporation of geographic information systems (GIS) into image classification allowing for the integration of context and location
- Development of exponentially faster computers with larger hard drives and more memory
- Computer algorithms that increased the accuracy of terrain correction and imagery registration
- Development of more robust image classification software

"Be it food security, disaster preparedness, urban planning, endangered species protection, water quality, or battle field situational analysis, the users of Landsat data, and particularly Landsat in combination with high resolution data, have exploded and the user base is becoming politically motivated."

Expert Survey

"I believe that we are just coming into the era whereby we are making effective use of Landsat data for operational mapping and monitoring. It has certainly taken a long time to get to this point, but it is important to recognize that there have been substantial hurdles to using Landsat data for operational land cover work during much of the thirty-four years of continual Landsat imaging."

–James Vogelmann

The assertion

Despite thirty-four years of continual Landsat imaging, Landsat related-research, and the implementation of many socially beneficial Landsat applications (such as improved water management techniques, foreign crop inventories, natural disaster relief planning, continent-scale carbon estimates, extensive cartographic advances, etc.), the use of Landsat data has remained largely in the research realm and, even in this geospatially-savvy era, the utility of Landsat largely escapes policy makers.

The survey questions

Do you agree with the assertion?

If you agree:

(1) Why do you believe this is the case?

(2) What steps do you feel could be taken to facilitate more application-based uses of Landsat data?

(3) What steps do you feel could be taken to facilitate the use of Landsat in real-world problem solving?

If you disagree, can you explain the reasons you feel the above statement is incorrect?

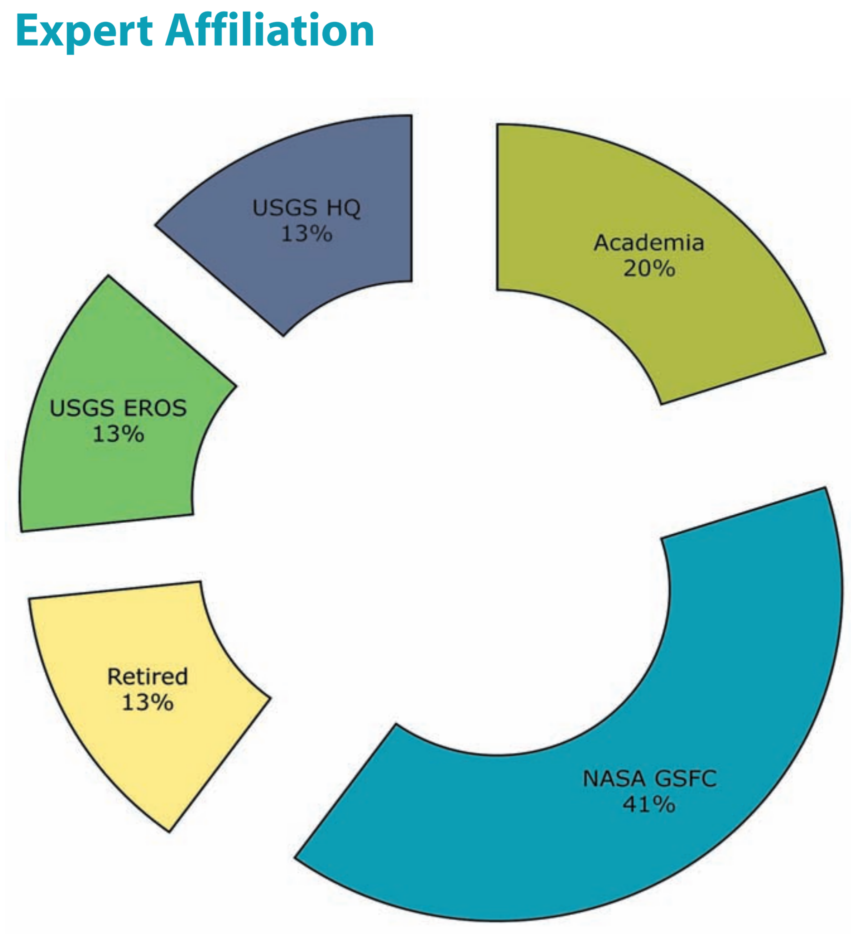
The "problem"

The use of Landsat data has remained largely in the research realm and, even in this geospatially-savvy era, the utility of Landsat largely escapes policy makers.

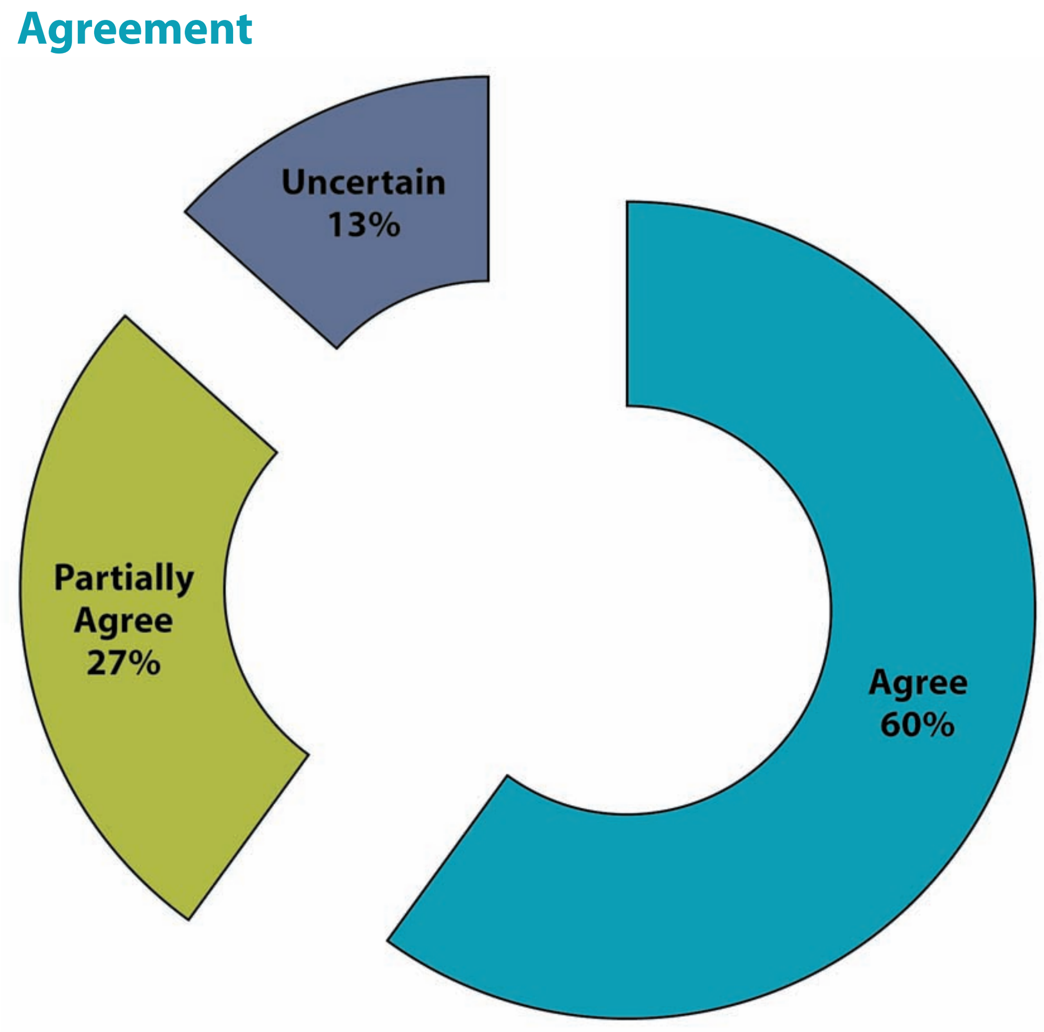
The answers

These survey questions were sent out to 36 Landsat scientists and managers, of those, 15 experts responded. None of the responders disagreed with the assertion, however, a few people agreed only partially and a couple others were uncertain. Responders attributed the problem to eight major causes (89% of responses). Among these categories, prohibitive data cost, data use difficulty, and Landsat's non-operational status accounted for over half of the responses. While the specifics of the responder suggestions for more problem-solving and application-based uses of Landsat varied significantly, all of their advice fell neatly into six major categories.

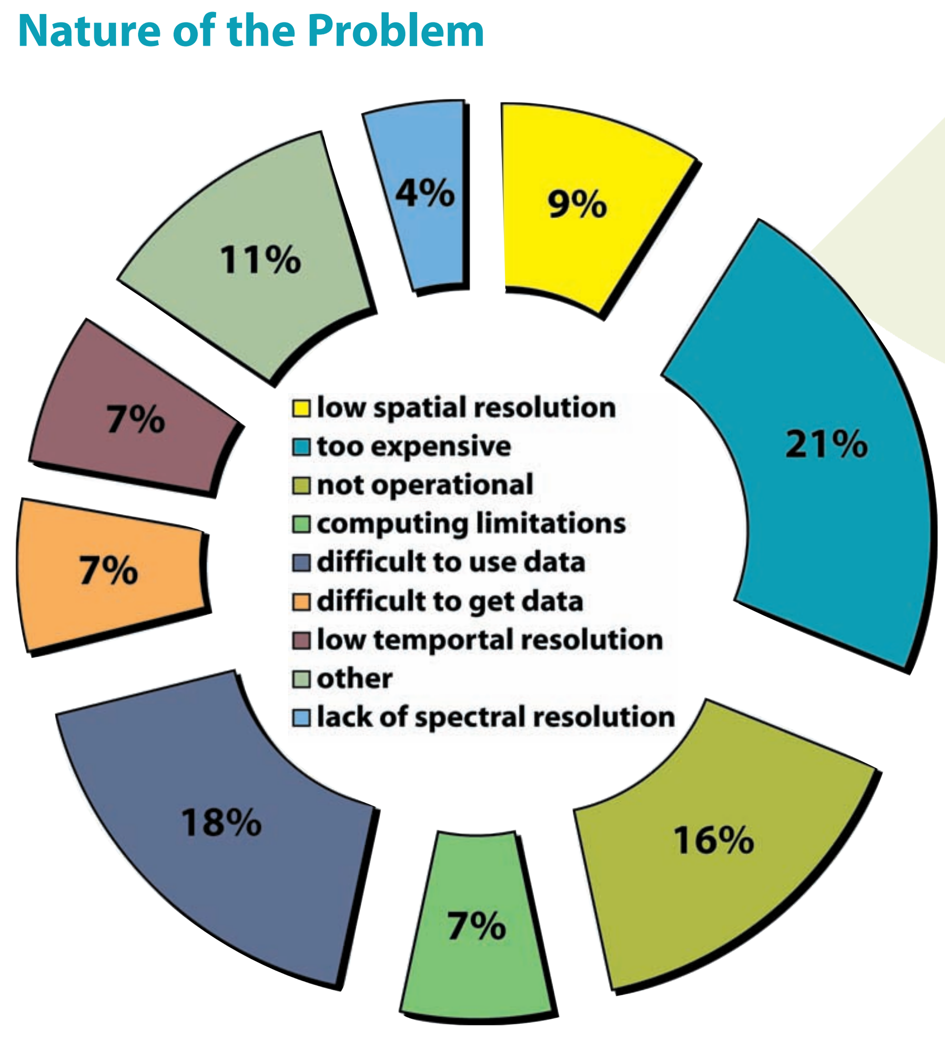
Expert Affiliation



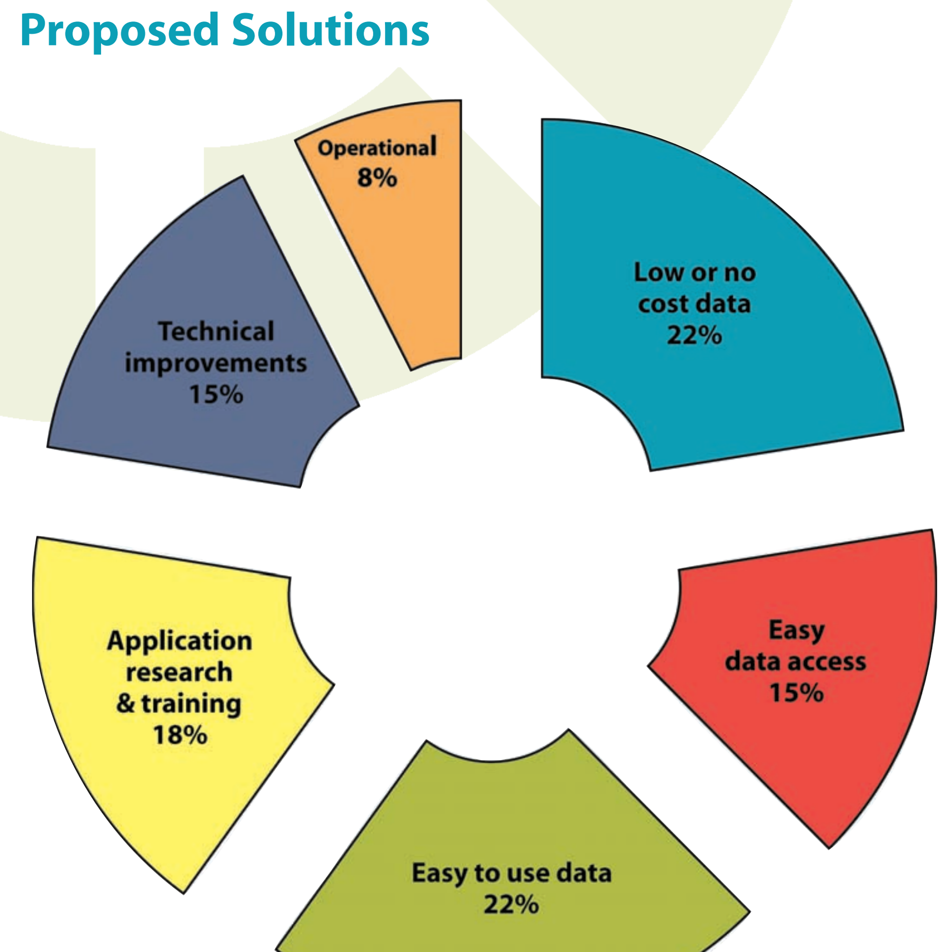
Agreement



Nature of the Problem

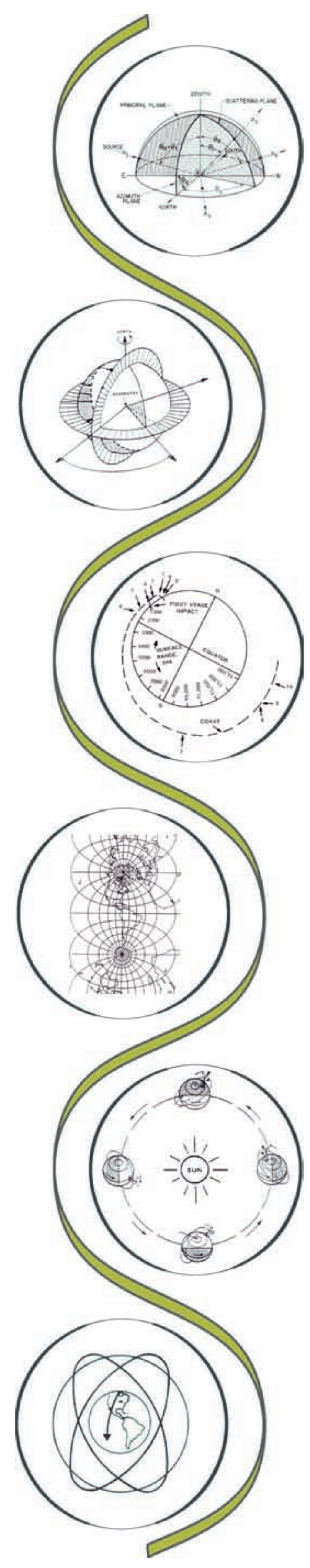


Proposed Solutions



Conclusions

"Advances in computers and software coupled with the price reductions and the elimination of licensing restrictions following the launch of Landsat-7 have allowed organizations to incorporate Landsat data into their day-to-day operations."
–Kass Green (2006)



From the moment of conception on, the desire for socially beneficial information has been ingrained in the Landsat program concept. Unfortunately, 34 years after the launch of Landsat 1, the use of Landsat data has remained largely in the research realm and, even in this geospatially-savvy era, the utility of Landsat largely escapes policy makers. Based on analysis of Landsat's long history, published commentary, and this expert survey, we can draw the following conclusions:

1

Get data into the hands of users

The applied use of Landsat data hinges on the ability of people who work in diverse fields to access and use the data. Minimal data cost, easy data access, and user-friendly tools are important ingredients. Additionally, data must be offered in an easy to use format. Ideally, the data should be terrain corrected and already converted into a product such as reflectance, vegetation index values, or land cover classifications: give the user the information they want, not digital numbers that must be processed to be understood. And, data should be offered in a digital format, such as GeoTIFF, that is easily parsed by many common software packages.

2

Operational assurances

Assurance of an operational mid-resolution sensor will enable many groups to incorporate Landsat-like data into their everyday operations without fear that they are becoming reliant on a finite resource. A 2005 Office of Science and Technology Policy memorandum stated: "it remains the goal of the U.S. Government to transition the Landsat program from a series of independently planned missions to a sustained operational program funded and managed by a U.S. Government operational agency or agencies, international consortium, and/or commercial partnership." An interagency Future of Land Imaging (FLI) working group has been assembled to discuss the feasibility of an operational land imaging program.

3

Technical improvements

The upcoming Landsat Data Continuity Mission (LDCM) will include two new spectral bands. Technical improvements beyond LDCM will be discussed by the FLI working group.

4

Data fusion & interdisciplinary approach

Landsat satellite information is best used in synthesis with other associated geospatial data. With increasingly available and accessible geographic information systems (GIS)—like Google Earth—the ability to bring together geospatial data from many sources is growing.

5

Research & outreach focused on applied data use

The role of application-aimed research cannot be understated. Just as the LACIE research lead to the Landsat success story featured in this poster, more research geared towards producing Landsat applications is needed. This may take changing the way the Landsat science teams are selected and it may mean that the criteria for Landsat-related research grants need to be adjusted. As said by one of the survey responders, "Part of the issue lies in the research done by faculty at universities and by staff at government agencies and corporations. That research is always pushing the edges, using new systems, trying new approaches to improve on past work. Unfortunately, there is not a lot of *crossing t's and dotting i's* that is needed to create an application." –Kurt Thome

"There needs to be a continued effort to educate the general public as well as students in the role of Landsat in solving problems that impact them directly."
–Eric Brown de Colstoun

References

Acknowledgments

Many thanks to Ron Beck, Robert Bindschadler, Ray Byrnes, Robert Cahalan, Jon Christopherson, Eric Brown de Colstoun, John Faundeen, Stan Freden, Brij Gambhir, James Irons, Shaida Johnston, David Landgrebe, Locke Stuart, Kurtis Thome, Jim Tucker, James Vogelmann.

ASPRS, *Report to the Future Land Imaging Working Group on The American Society for Photogrammetry and Remote Sensing Survey on the Future of Land Imaging.* Nov. 6, 2006.

Draeger, W., T. Holm, D. Lauer, R. J. Thompson, "The Availability of Landsat Data: Past, Present, and Future." *Photogrammetric Engineering & Remote Sensing*, vol. 63, no. 7, pp. 869-875, July 1997.

Goward, S and J. Masek, "Landsat––30 years and counting." *Remote Sensing of Environment,* vol. 78, no. 1-2, pp. 1-2, Oct. 2001.

Green, K., "Landsat in Context: The Land Remote Sensing Business Model." *Photogrammetric Engineering & Remote Sensing*, vol. 72, no. 10, pp. 1147-1153, October 2006.

Krause, A., "Landsat Data Characterization by Application." USGS EROS Internal Publication, 2006.

Landgrebe, D., "Multispectral Land Sensing: Where From, Where to?" *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 43, No. 3, March 2005.

Landgrebe, D., "The Evolution of Landsat Data Analysis." *Photogrammetric Engineering & Remote Sensing*, vol. 63, no. 7, pp. 859-867, July 1997.

Marburger, J., *Landsat Data Continuity Policy*, Executive Office of the President, Office of Science and Technology Policy, 13 August 2004.

Pecora, W., *Remote Sensing of Earth Resources: Users, Prospects and Plans, NASA's Long-Range Earth Resources Survey Program*, Thirteenth Meeting, Panel on Science and Technology Committee on Science and Astronautics, U.S. House of Representatives, 25 January. U.S. Government Printing Office, Washington, D.C., 8p., 1972.

Williams, D. and S. Goward, "Landsat: Yesterday, Today, and Tomorrow." *Photogrammetric Engineering & Remote Sensing*, vol. 72, no. 10, pp. 1171-1178, October 2006.