PEER-REVIEWED ARTICLE

Commercial Remote Sensing Program

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Abstract

The mission of the Commercial Remote Sensing Program (CRSP) Office at NASA's John C. Stennis Space Center is to maximize U.S. industry's exploitation of remote sensing and related space-based technologies and to develop advanced technical responses to spatial information requirements. *This mission is accomplished through NASA partnerships with companies to develop remote sensing technology applications in response to market-driven spatial information demands. The program builds private-sector capability to supply economically viable remote sensing solutions. The CRSP conducts market research to identify technology limitations that ultimately drive NASA research and development initiatives. Through its commercial partnerships, the program hopes that market demand and advanced technology solutions will increase the use and reduce the cost of spatial data. This paper describes the CRSP's method of addressing both the demand for spatial information and its specific responses to promote an economically viable U.S. industry.*

Introduction

In response to NASA's mandates for maximizing the commercial use of space-based remote sensing and related technologies, the Commercial Remote Sensing Program (CRSP) Office at NASA's Stennis Space Center has created several remote sensing partnership programs. The CRSP works with companies in both the supply sectors and demand segments to achieve systems and technology integration. The CRSP promotes a robust spatial information industry based on remotely sensed data. A model of interrelationships among the components of a spatial information industry has been developed by the CRSP. This model will be described in the **Challenges** section.

The first part of this paper describes the challenges identified by NASA's CRSP in building a spatial information industry. The second part of the paper presents the programs and infrastructure developed in response to those challenges and highlights several partnership projects. The paper concludes with a summary of benefits realized by the commercial sector and by NASA.

Challenges

The mission of the Commercial Remote Sensing Program Office at NASA's John C. Stennis Space Center is *to maximize U.S. industry's exploitation of remote sensing and related space-based technologies and to develop advanced technical responses to spatial information requirements.*

Fulfilling NASA's desire to seek and encourage commercial use of space includes development of space-based remote sensing markets. Current markets for remote sensing and related technologies will expand in response to the increasing demand for spatial information. Experience with NASA programs indicates a growing demand for higher spatial resolutions of 1 to 5 metres and pixel-level geolocation accuracies. Demand indicators include increased use of site-level Geographic Information System (GIS) monitoring for management and operations. For example, the current demand for GIS data includes municipal, utility, and construction applications. Site-level applications in these market segments will benefit from planimetric data in the 1- to 5-metre range. In order to serve many municipal tax and cadastral-level applications, data requirements will push the sub-metre level of spatial resolution and seek elevation accuracies of less than 2 metres (T. Alexander, personal communication, 1993).

The GIS data and services market is expected to expand from $2B in 1992 to $4B in 1996. These figures represent a twofold expansion over four years and a 19 percent compounded annual growth rate (Antenucci, 1993). The total value of the remote sensing market during 1992, including data acquisition, hardware/software, and other components, is estimated at $850M (Table 1). Because the value of remotely sensed data and its related products and services is tied to the GIS market, a comparable increase in the remote sensing market is inferred from these figures.

Operational commercial satellite systems through 1992 have provided spatial resolutions of 80, 30, and 10 metres. Foreign governments and U.S. firms have announced plans to launch remote sensing systems prior to the year 2000 that will provide 1- to 5-metre spatial resolution with location knowledge that approaches pixel resolution. This geolocation knowledge is based on information derived from the Global Positioning System (GPS) and a High Accuracy Reference Network (HARN) for ground control.

NASA's challenge is to assist U.S. firms in developing state-of-the-practice technologies that cost-effectively support this market. High resolution data are currently unavailable to value-added companies exploring the benefits of using remote sensing to derive information required by their customers. The lack of raw data for product development is limiting the ability to serve new markets or expand existing markets. The CRSP responds by coordinating market-driven requirements to define a technology demonstration. NASA provides opportunities to perform advanced satellite system technology demonstrations by airborne simulation of satellite instrumentation. By providing U.S. businesses with the tools

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TABLE 1. 1992 REMOTE SENSING MARKET SUPPLY AND DEMAND

Supply Sectors	1992 U.S. Revenue ($M)	Demand Segments	Market (%)
Data Acquisition • Satellite • Aircraft	150	Infrastructure Management	30–35
		Resource Management	35–40
Data Distribution/ Conversion • Standard Data Products • GIS Databases	100	Environmental	20–25
		Public Information Services	5–10
Information Products/ Services	300		
Hardware/Software	300		
Total:	850	Total:	100

Sources: EOSAT, "Services Survey" (1990); Matra, "Market Distribution by Application" (1990); NASA, "VIP/EOCAP Project Profile" (1992); Peat-Marwick, SRSC MapSat Study (1991); Scope and Profile Estimated by SDS, Inc. (1992).

for new product development, NASA can facilitate development and growth of a dominant U.S. high-resolution spatial information industry.

In addition to higher spatial resolution, emerging markets for remotely sensed data also demand more timely data availability, better quality assurance, and reliable data standards. Integration of technologies, including communications, small satellite systems, global positioning, and digital data storage, is required to establish economically viable solutions to these demands. The CRSP works with companies to facilitate the successful introduction of advanced market products, processes, and services and provides simulated data sets for performing demonstrations.

As remote sensing technologies become more accessible, a strong potential for growth and expansion exists in four major markets (Table 1). **Resource Management** represents a well-established remote sensing product market. Applications include management of agriculture, wetlands, forestry, fisheries, petroleum, and mineral resources. Availability of low-cost, high-performance computer systems has enabled companies within this market to capitalize on information derived from aerial photography, satellite imagery, and meteorological data. In response to the growing need for resource management information, demand for site-scale monitoring is increasing in contrast to the regional-scale activities of the past. **Environmental** and **Infrastructure Management** also show an increasing demand for a lower cost, more timely high-resolution monitoring capability. These markets require the ability to monitor facilities and sites that cover less than 30 kilometres and features of 1 to 5 metres in size. Finally, new applications of remotely sensed data are being investigated for meeting the Earth observation needs of **Public Information Services**. Applications include education, public safety, media, and entertainment.

Many organizations that may benefit from remote sensing technology lack an understanding of its capabilities. NASA offers opportunities for matching user demands for spatial information with advanced technologies developed within NASA, other government laboratories, and the private sector.

NASA's responsibility to provide assistance in building a remote sensing industry is founded in enabling legislation and policy; excerpts from pertinent legislation are shown in Figure 1.

Responses to Challenges

The CRSP enables the use of remote sensing in business operations by providing the following incentives:

- Access to government facilities and programs that support business/marketing development and technical innovation;
- Opportunities for cost reduction by examining potential markets through viability demonstrations;
- Access to public service applications as emerging markets for U.S. companies; and
- Access to cost-effective, dedicated data acquisition sources of earth observation information.

In order to address the various aspects of the supply and demand process, a model of the remote sensing data flow between organizations contributing to spatial information product development has been constructed to show the process' working relationships. Figure 2 illustrates the various technology elements of this model. The arrow in the center of the diagram shows the data process flow from infrastructure through sensors, data transfer/handling, data processing/archiving, analysis, and application to end-user information. Above the arrow are major types of companies that contribute both supply and demand within the process. Below the arrow are the supporting infrastructure and NASA Commercial Remote Sensing Programs that work with individual companies to enable capabilities for different elements in the process.

The aerospace, tool maker, and value-added companies listed at the top of the model are providing spatial data and information in response to market demand from emerging markets in both the public and commercial sectors. Aerospace companies that have traditionally provided space systems and related infrastructure for defense applications and scientific research are increasing their response to commercial needs. The tool-maker companies that build computers, software, and GPS systems offer space-based products in easily usable, increasingly affordable packages. Value-added companies transform data from the airborne and spaceborne systems developed by the aerospace community by using instrumentation and software from the tool makers. These companies produce the information products to meet the demands of end-users in the existing and emerging markets.

The NASA CRSP portfolio of programs shown below the arrow on the model is tailored to work with the different elements of the data flow process. This portfolio includes the Technology/Market Program (TMP), Earth Observations Commercial Applications Program (EOCAP), and Visiting Investigator Program (VIP), which provide opportunities for developing applications. These programs are described in the **Partnership Agreements** section. Data acquisition is supported by the Airborne Instrument Test System (AITS), Airborne Terrestrial Applications Sensor (ATLAS), HARN, and Commercial Remote Sensing Technology Initiative (CRSTI). These elements are described further in the **Data Acquisition Infrastructure** section. Co-investment in remote sensing innovation is encouraged by matching corporate dollars with NASA facilities and technical expertise. The partnership projects are intended to demonstrate market acceptance of new remote sensing/GIS products. The stimulated markets assist in establishing incentives for corporate investment in airborne

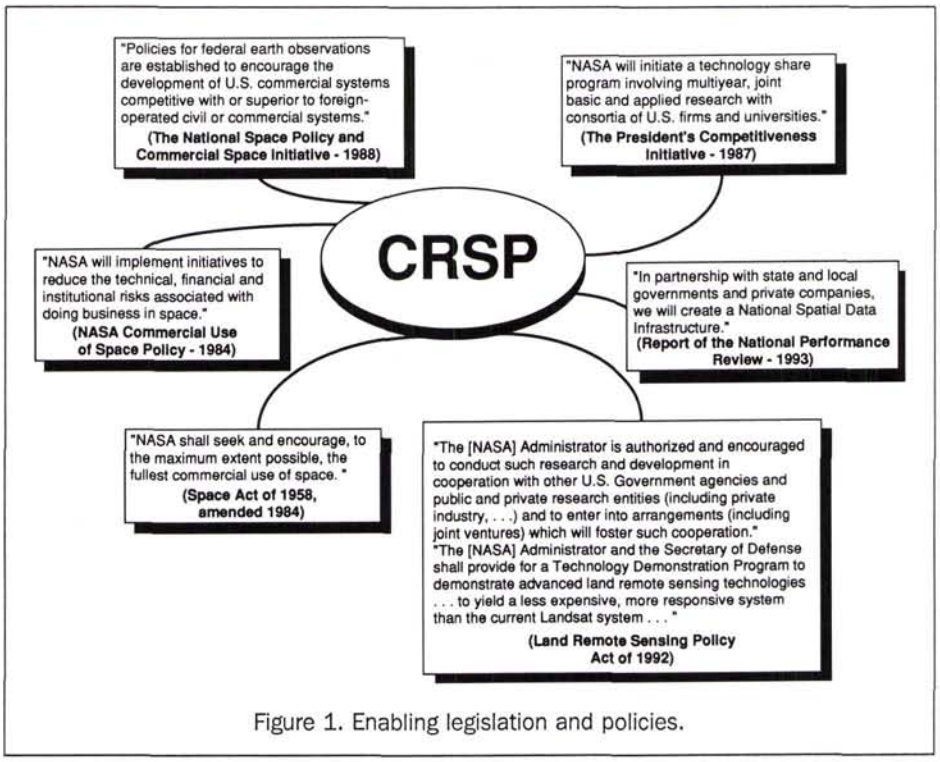

Figure 1. Enabling legislation and policies.

and satellite remote sensing systems and in defining areas for NASA technology development programs.

The CRSP plans a combination of terrestrial, airborne, and spacecraft initiatives involving data acquisition, product innovation, and software applications to expand the demand and capabilities in the field of remote sensing.

Partnership Agreements

The CRSP has developed the programs shown in Figure 2 in response to the challenge of enabling a spatial information industry based on remotely sensed data while protecting companies' proprietary interests. The VIP offers partnership opportunities for end-user companies to explore the utility of the technologies to meet specific demands. The EOCAP helps tool-maker and value-added companies further develop and integrate available technologies and overcome market, cost, distribution, and demonstration hurdles. The TMP encourages aerospace and tool-maker companies to use their capabilities and NASA's technology, facilities, and expertise to integrate sensor, data handling, and archiving technologies to create marketable products, processes, and services. The following sections describe each of these programs and present brief case studies.[1]

Visiting Investigator Program

Implemented in 1988, the Visiting Investigator Program provides businesses in emerging markets with low-risk opportunities to assess the commercial applications of remote sensing and GIS technologies. Program partners develop prototype applications and perform market acceptance tests. This process results in new commercial product lines that benefit the company, the public, and NASA (Davis *et al.*, 1993).

These three- to six-month projects allow partner companies to investigate remote sensing solutions to their spatial information needs. Costs to the partner are limited to company personnel's salary, travel, and living expenses while working with the CRSP at NASA's Stennis Space Center. VIP projects are solicited through an open invitation.

The CRSP provides access to facilities and technology experts encompassing a full range of remote sensing and image processing capabilities. The facilities allow partners to conduct viability demonstrations and create marketing products.

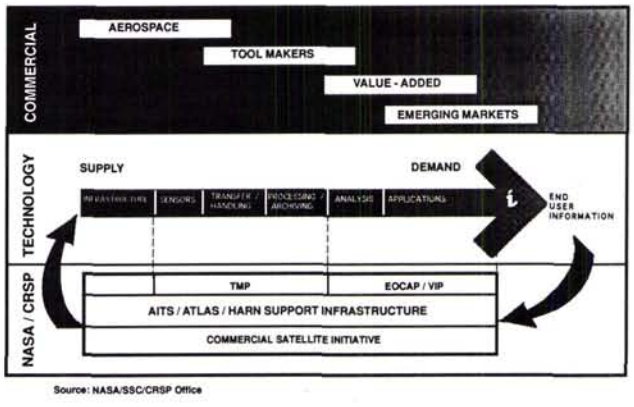

Figure 2. Remote sensing data flow.

[1] Specific projects are described with the consent of the companies involved.

TABLE 2. VIP CORPORATE PARTNERS

VISITING INVESTIGATOR PROGRAM PARTICIPANTS		
Company	Market/Technology	Topic
BellSouth Telecommunications Birmingham, AL	Infrastructure Management	Digital Mapping/GIS Development
Community Coffee Port Allen, LA	Resource Management	Coffee Crop Forecasting
DataStar, Inc. Picayune, MS	Resource Management	Lower Pearl River Valley Hydrology
Earth Search Sciences McCall, ID	Resource Management	Mineral Exploration
Environmental Enterprises USA Slidell, LA	Resource Management	Change Detection and Wetland Monitoring
Fraiser Group, Inc. Nacogdoches, TX	Resource Management	Environmental Consulting
GeoSpectra Corporation Ann Arbor, MI	Data Processing	Aircraft Digital Data Geometric Correction
Global Analysis, Inc. Columbia, MD	Environmental Monitoring	Landfill/Hazardous Condition Detection/Monitoring
Gulf Weather Corporation Stennis Space Center, MS	Data Processing/Analysis	Sonar Software Development
Law Environmental, Inc. Kennesaw, GA	Environmental Monitoring	Environmental Effects of Thermal Effluents
Vernon F. Meyer & Associates New Orleans, LA	Infrastructure Management	Digital Land Information Analysis
Natural Systems Analysts, Inc. Winter Park, FL	Infrastructure Management	Pristine Area Environmental Impact Analysis
Pacific Bell San Ramon, CA	Infrastructure Management	Forecasting and Network Planning
Pyron Consultants Pottstown, PA	Resource Management	Petroleum Exploration
Site Engineering Consultants, Inc. Murfreesboro, TN	Infrastructure Management	Rutherford County Comprehensive Plan
Subra Company New Iberia, LA	Environmental Monitoring	Non-Point-Source Pollution

Partner companies become familiar with the theoretical and practical bases for remote sensing, airborne/spaceborne data acquisition, related instrumentation, and data analysis techniques. Participants work with NASA personnel in all stages of the project from needs analysis through data processing to solutions/product development. As a result, remote sensing technology is integrated into corporate portfolios. The VIP has worked with 16 companies through this program, 12 of which decided to incorporate the technology into their businesses. Table 2 lists these 16 companies along with their market segments and project titles. Two recently completed VIP projects are described in detail in the following sections.

Site Engineering Consultants, Inc.

Site Engineering Consultants, Inc. (SEC, Inc.) is a consulting engineering company whose primary activities involve civil/mechanical engineering applications. Through VIP participation, SEC, Inc. developed an in-house remote sensing/GIS capability for land use planning using satellite digital data and commercially available vector data to determine the optimal location for siting a spray irrigation system for waste water (Figure 3). This application allowed SEC, Inc. personnel to develop an understanding of digital image processing techniques and GIS data manipulation. SEC, Inc.'s experience in building land-cover classification maps and conducting spatial analysis for municipal facility sites is being incorporated into the company's services.

This VIP opportunity has incorporated the use of remote sensing/GIS tools into a non-traditional user forum – a consulting civil engineering company. Secondary benefits include integrating more economical solutions directly into the working environment and thereby introducing other clients of the firm to the technology through presentations and capability demonstrations.

Law Environmental, Inc.

Law Environmental, Inc. (LAW) is an environmental engineering and earth sciences consulting firm. LAW's VIP project evaluated the use of thermal remote sensing to monitor an electric generating plant's hydrothermal discharge (Plate 1).

The Calibrated Airborne Multispectral Scanner (CAMS), mounted in Stennis Space Center's Learjet, was used to analyze characteristics of the power plant's thermal plume. LAW used remote sensing techniques to produce images indicating the thermal plume's shape, isotherms, and areal coverage and measuring the spatial distribution of surface water temperature within the plume. A LAW scientist assisted NASA personnel with thermal data analyses and photographic interpretation, including development of graphic results.

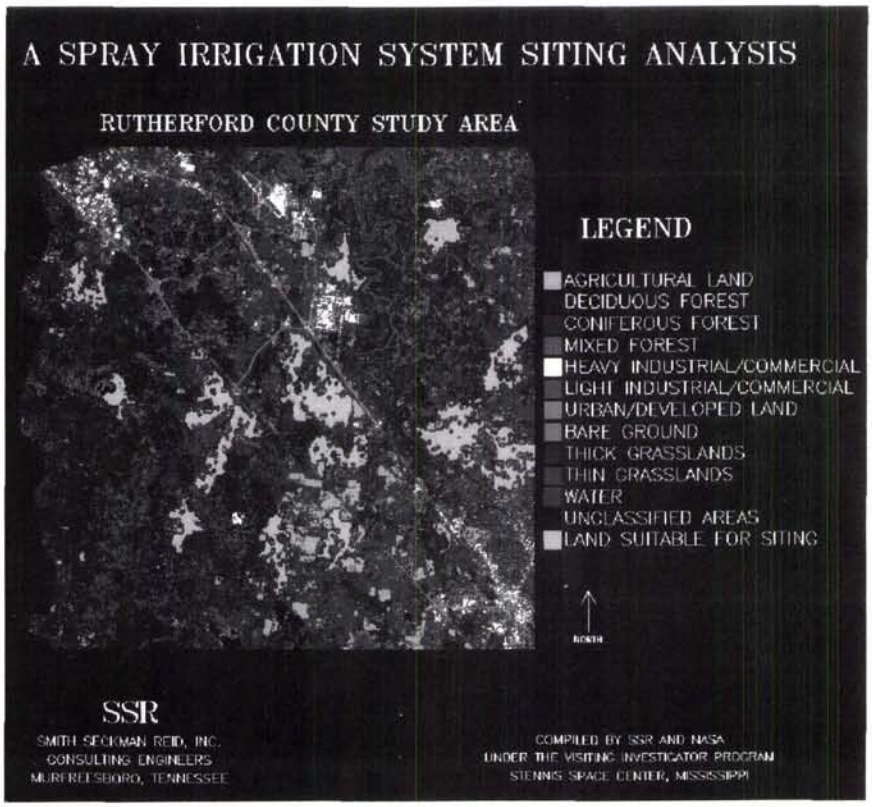

Figure 3. Spray irrigation system siting analysis.

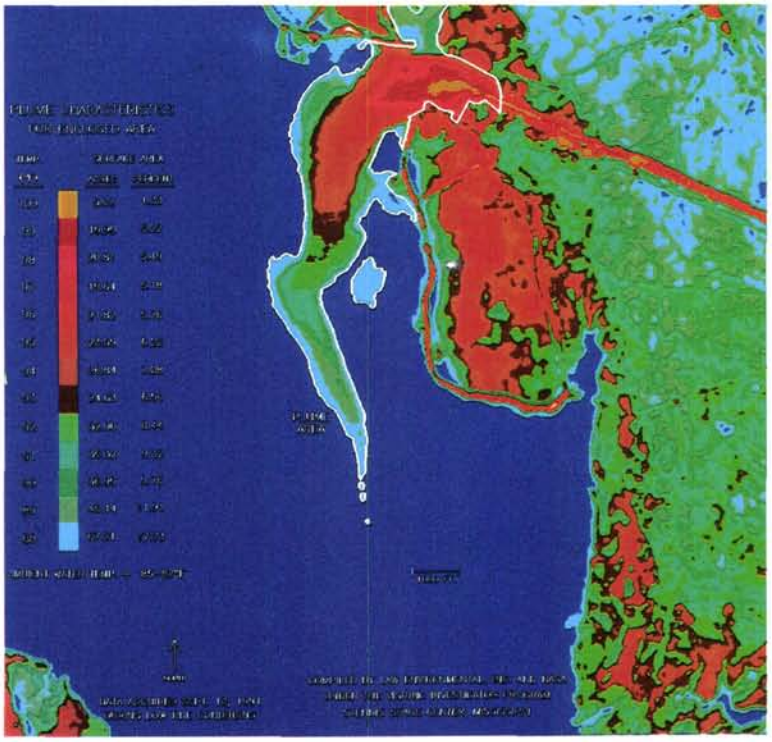

Plate 1. Plume characteristics.

The environmental community has benefitted from the introduction of a monitoring source with synoptic and temporal revisit capability. The government agency responsible for regulating the discharge area commended the effort as exemplary.

The VIP has benefitted end-user companies through short-term, low-risk investigations exploring the use of remote sensing/GIS technologies to meet their needs.

Earth Observations Commercial Applications Program

EOCAP supports technical, market, and business innovation to develop new products that serve emerging domestic and international markets. Technical innovation is augmented by improvements in product performance, establishment of standards, reduction in costs, and expansion of market size. EOCAP sponsors an annual solicitation for proposals through a NASA Research Announcement. The competitive review of the proposals is based on evaluation of business and technical criteria. Winning proposals typically exhibit the following characteristics:

- Strong business and marketing plans to introduce innovative solutions to spatial information demand through effective packaging of mature technology,
- Product Advisory Boards to guide the quality of the product to market stage, and
- Substantial financial commitment to the project by the companies.

Two solicitations, each with contracts for three-year projects, have resulted in EOCAP I (1986-90 with nine companies) and EOCAP II (1990-94 with ten companies). The results of the EOCAP I projects are highlighted in a final program report (Hill, 1992).

EOCAP is experiencing increasing demand from companies and end-users in emerging and new markets — infrastructure management, environmental monitoring, and public information services. A shift has occurred in market focus from regional-scale monitoring to site-scale monitoring in local management applications. Site-scale applications indicate a need for high spatial resolution data (< 5 metre) with increasing geolocation accuracy (< pixel size) and more frequent revisit capability (< 1 week) from data acquisition sources. A comparison of 2.5- and 10-metre data is shown in Figure 4. NASA's EOCAP provides opportunities for companies to address solutions to these developing market demands.

Corporate partners for EOCAP I and II are listed in Table 3. Selected examples of EOCAP partnerships are briefly described below. Please refer to articles published in this journal describing additional NASA EOCAP II partnerships with BellSouth Services, James W. Sewall Company, and Pacific Meridian Resources.

Applied Analysis, Inc.

Applied Analysis, Inc. is developing a new multispectral image processing software product for management of wetlands and other natural resources. The product will be marketed as a module for commercial off-the-shelf (COTS) image processing systems, such as ERDAS[2]. The Applied Analysis Spectral Analytical Process (AASAP) Module will provide a sub-pixel detection capability to enhance multispectral discrimination power significantly, provide finer spatial scale detections of surface units, and increase existing systems' mensuration accuracies. Such tools facilitate the use of remote sensing for expanding and emerging markets. An advisory panel representing a significant fraction of potential customers with resource management interests in the southeastern U.S. is closely reviewing the product and assessing its utility for wetlands delineation.

Earth Satellite Corporation

Detecting and mapping natural marine oil seeps has long been an important goal of offshore petroleum exploration. Hydrocarbon seeps provide conclusive evidence of petroleum generation and migration within a basin, guidance for further exploration, and a crude measure of ultimate basin reserves, thereby greatly reducing a company's exploration risk. Earth Satellite Corporation (EarthSat) is examining and synthesizing data from a variety of satellite-based and airborne sensors to determine which wavelengths of the electromagnetic spectrum, and which operational and planned sensors, are the most useful for detecting naturally occurring marine oil seeps. The company defined two study areas and constructed a database of known, reported, and suspected locations of natural marine oil seepage in these areas. EarthSat then acquired, processed, interpreted, and analyzed remotely sensed data in these areas. Surface sampling and examination using a deep submersible then confirmed two of the previously undocumented seeps detected. One digital Landsat Thematic Mapper scene was acquired, interactively processed to enhance the numerous oil slicks present, and printed for marketing and demonstration use. This scene generated much interest and discussion among EarthSat's industry contacts and figures prominently in their planning of future sea-truth efforts. EarthSat has initiated data-sharing agreements with several oil companies to investigate possible oil seepage and comparison of the results of their survey technique with the results of passive airborne laser fluorosensor surveys.

EOCAP Economics

NASA uses rigorous analysis methods to determine the success of EOCAP. Analysis of EOCAP I reveals positive net revenues and favorable qualitative developments. Figure 5 illustrates the actual economic return from EOCAP I with an extrapolated return to 1994 (Macauley, 1993). EOCAP I companies show gross cumulative revenues of $7.6M through FY92 and net return of just under 8 percent on the total (industry plus government) investment. These results indicate a break-even return on investment within four years. As of early 1993, EOCAP I and II commercial partners have contributed more than $13M (54 percent), which more than matches NASA's $11M (46 percent) public investment.

Technology/Market Program

NASA uses the Technology/Market Program to work with suppliers of hardware, software, or services with the potential to expand remote sensing data sources and tools to address related spatial information markets. Partnership candidates may be developers seeking a link to potential markets or seeking to move from prototype to operational status. The TMP emphasizes exploration of new markets, drawing on NASA and other federal resources to provide technology solutions.

Past TMP projects have included a GPS receiver study in conjunction with airborne data acquisition (Rockwell-Collins), the investigation of commercial applications for NASA's

[2] Mention of specific vendors and/or products is provided for the reader's benefit and does not constitute endorsement on the part of NASA or Sverdrup Technology, Inc.

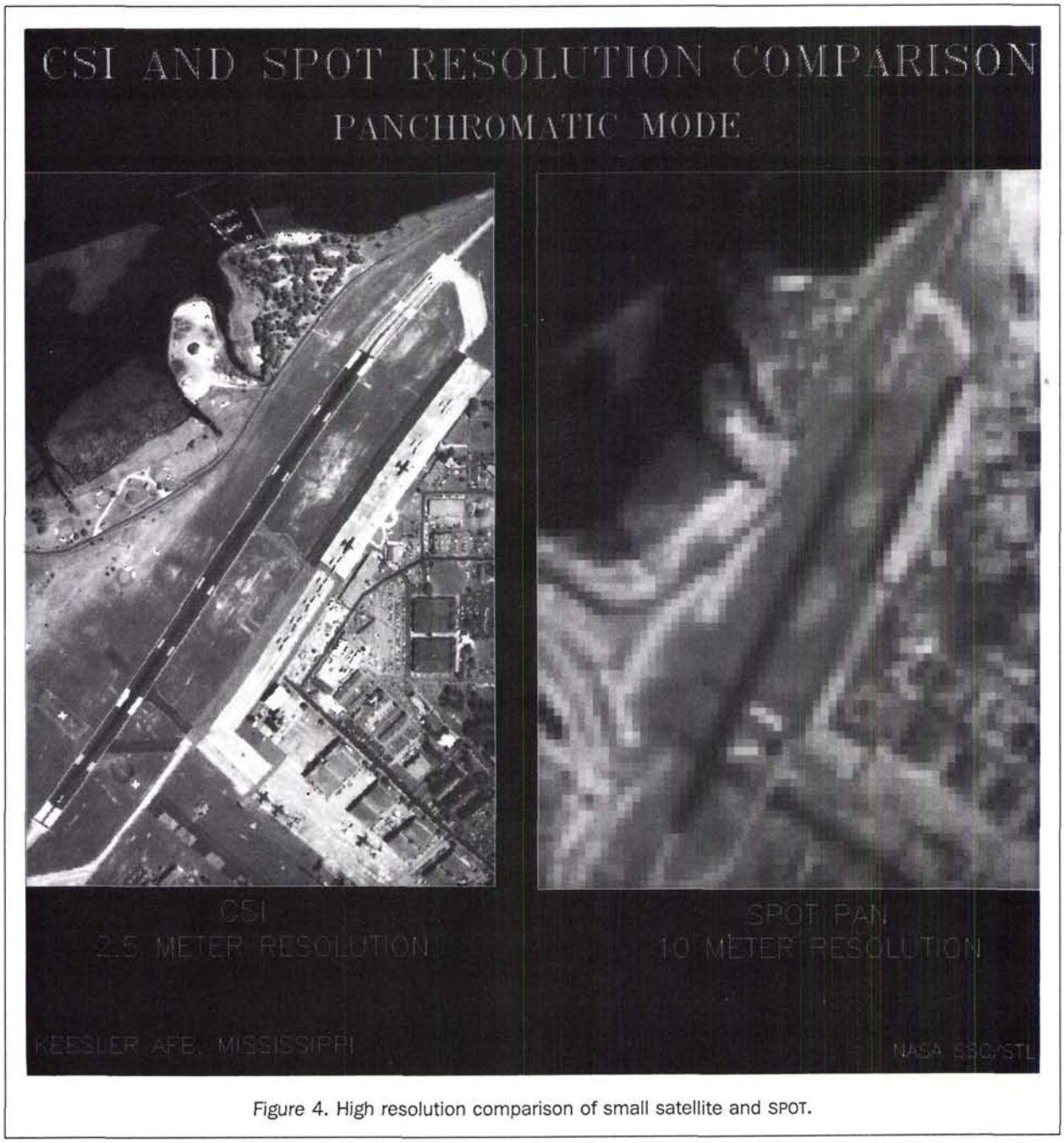

Figure 4. High resolution comparison of small satellite and SPOT.

Large Format Camera, and a study of thermal applications of the Thermal Infrared Multispectral Scanner (TIMS) sensor to geological phenomena. Current TMP projects include agreements with Lockheed Missiles and Space Company (LMSC) and the Getty Conservation Institute (GCI).

Lockheed Missiles and Space Company

LMSC is investigating commercial product development issues and applications for high spatial resolution, multispectral remotely sensed data. LMSC is examining the feasibility of improved airborne sensor systems and/or new remote sensing satellites to provide more efficient and cost-effective infrastructure mapping, environmental monitoring, and natural resource assessment.

Based on market analysis results, including presentations of prototype high spatial resolution products developed with Stennis Space Center, LMSC has filed an application with the Department of Commerce for a license to launch and operate the Commercial Remote Sensing System (CRSS) satellite.

Getty Conservation Institute

The Getty Conservation Institute (GCI) is examining the utility of remotely sensed data and related spatial information

TABLE 3. EOCAP CORPORATE PARTNERS

EOCAP I CORPORATE PARTNERS

Company	Market/Technology	Topic
Battelle Space Systems Columbus, OH	Infrastructure Management	Commercial Development of an Ice Data and Forecasting System
CROPIX Hermiston, OR	Resource Management	Using Landsat to Provide Potato Production Estimates to Columbia Basin Farmers and Processors
NASA/Ames Research Center Moffett Field, CA	Resource Management	Application of the Airborne Ocean Color Imager for Commercial Fishing
NASA/Stennis Space Center Stennis Space Center, MS	Public Information Services	An Environmental and Archeological Assessment of the Piedras Negras Region of Guatemala and Mexico
Research Planning, Inc. Columbia, SC	Environmental Monitoring	Commercial Environmental Sensitivity Index Mapping Using Remote Sensing and GIS Technology
San Diego State University San Diego, CA	Infrastructure Management	Efficient Updates of Vector-coded GISs Using Remotely Sensed Data
James W. Sewall Company Old Town, ME	Resource Management	Development of Practical, Cost Effective Methods Utilizing Satellite Data for Forest Resources Management
Systems West, Inc. Carmel, CA	Infrastructure Management	Algorithm Development for an Integrated Satellite SST and OCS *Receive/Process/Display System for Ocean-Going Vessels*
The University of California/Berkeley Berkeley, CA	Resource Management	An Evaluation of Current and Recommendations for Future Uses of Remotely Sensed Data for Commercial Forest Inventory

EOCAP II CORPORATE PARTNERS

Company	Market/Technology	Topic
Applied Analysis Inc. Billerica, MA	Resource Management	Wetlands Information Services: A Commercial Application of Remote Sensing and GIS for Economic Development Planning and Wetlands Management
BellSouth Services, Inc. Birmingham, AL	Infrastructure Management	Improved Urban Infrastructure Mapping for Market Forecasting Using Remote Sensing and GIS Technology
CROPIX Hermiston, OR	Resource Management	Satellite Remote Sensing for Agricultural Production Management
Earth Satellite Corporation Rockville, MD	Resource Management	Demonstrate and Market Oil Seep Surveys
Earthscan, Inc. Austin, TX	Environmental Monitoring	Hazardous Waste Detection: A Pilot Remote Sensing Assisted Environmental Audit
Natural Resource Consultants Seattle, WA	Resource Management	Marketing Remote Sensing Data for North Pacific Fisheries Development and Management
Pacific Meridian Resources Emeryville, CA	Analysis/Applications	Development and Marketing of Land Use and Cover Change Analysis System (LUCCAS)
James W. Sewall Company Old Town, ME	Infrastructure Management	Gas Pipeline Infrastructure and Monitoring and Management
Statistical Sciences, Inc. Seattle, WA	Data Analysis	Integrated Software System for Analyzing Remotely Sensed Data
Terra-Mar Resource Information Services Mountain View, CA	Public Information Service	Application of Remote Sensing Technology for Realtime Disaster Assessment

technologies in conservation efforts for World Heritage sites around the world. The *Convention Concerning the Protection of the World Cultural and Natural Heritage*, an international agreement dedicated to the conservation of cultural and natural resources at approximately 370 sites worldwide, was drafted by the United Nations in 1972. The GCI and the CRSP are evaluating the use of remote sensing to support site management programs for managing the protection of cultural and natural resources. The CRSP and the GCI are focusing on two World Heritage sites as prototypes. The GCI/Stennis Space Center partnership will compile and analyze cost/benefit information and will examine the economic returns of a global information, monitoring, and communications system.

Working with the GCI, NASA has the opportunity to introduce remote sensing to a major new application area, potentially opening up new markets for private-sector suppliers.

Public Service

The remote sensing capability which resides at Stennis Space Center also serves public needs for remotely sensed data in times of emergency or when commercial systems are unavailable. This need was dramatically demonstrated in 1992 by Hurricane Andrew and again by the Mississippi River flood in the summer of 1993. Stennis Space Center acquired valuable digital remote sensing data and color infrared photography for use in disaster assessment during these periods.

Using remotely sensed data, information concerning

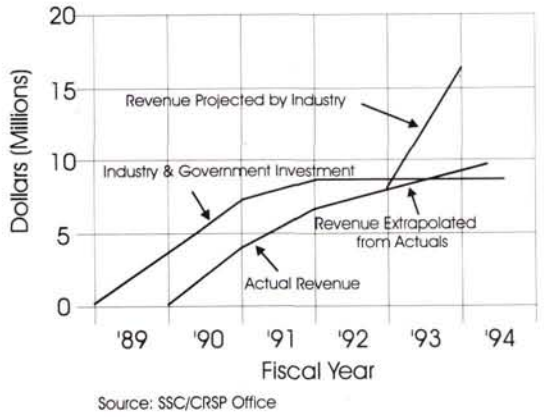

Figure 5. EOCAP I investment and revenue stream.

damage from a particular area is collected, analyzed, and compiled more quickly than with traditional cartographic and windshield survey methods. Changing conditions detected through remote sensing are integrated into the disaster response plan immediately, providing important information for disaster relief efforts.

In August 1992, personnel from Stennis Space Center flew a Learjet equipped with NASA sensors to southern Florida to acquire digital images of the areas hit hardest by Hurricane Andrew (Figure 6). Researchers used NASA's facilities and capabilities to demonstrate the viability of analyzing the urban area of south Florida. Areas of severe damage were mapped and priorities were set for the use of limited relief resources. State officials used the remotely sensed data to make an accurate assessment of economic impact and develop convincing documentation to illustrate the requirement for assistance. Land-cover maps were generated to show state officials the hurricane's impact on commercial, residential, and natural resources. This information will be used to de-

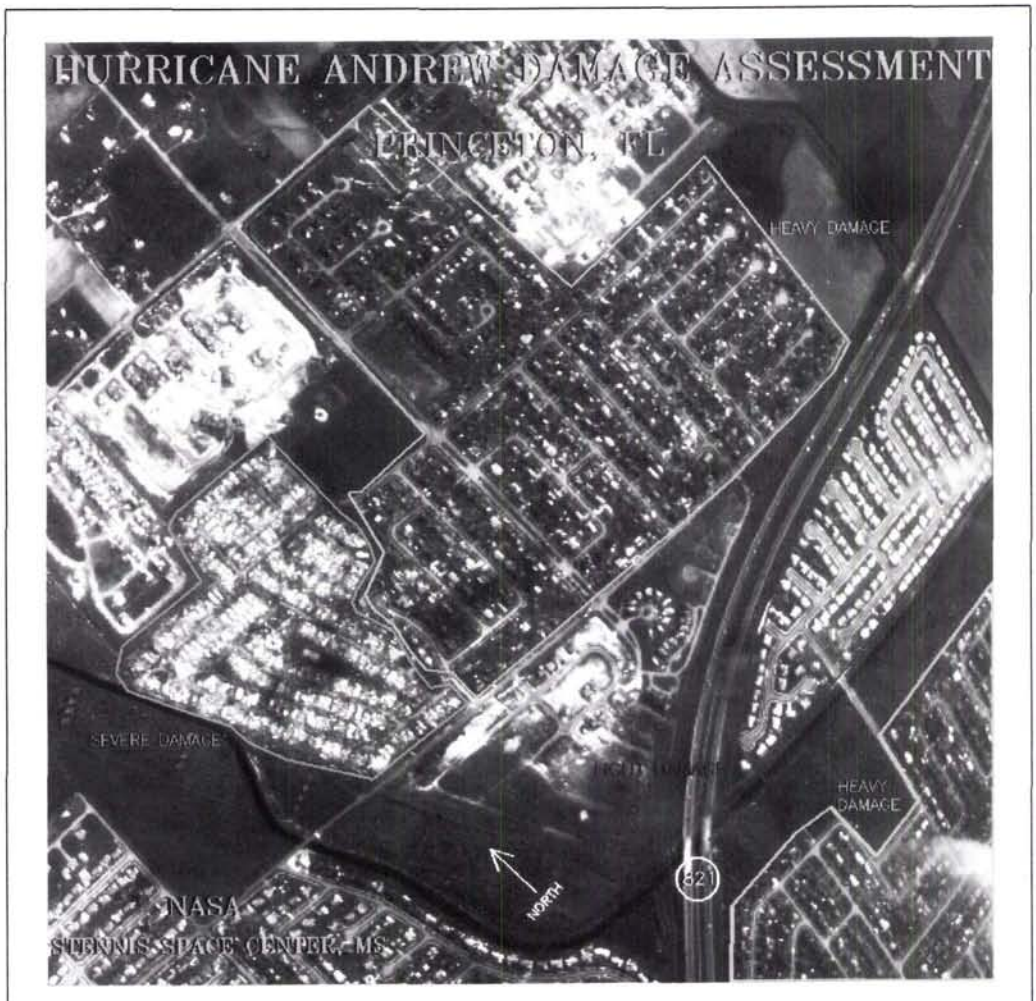

Figure 6. Hurricane Andrew damage assessment.

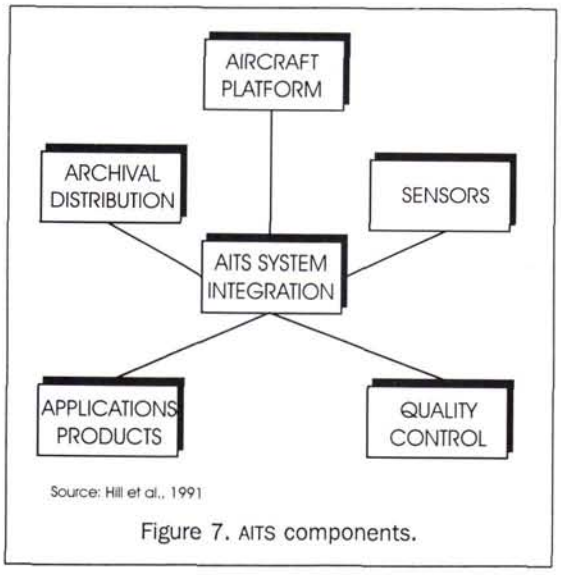

Figure 7. AITS components.

velop long-term land-use plans and more effective disaster response measures for southern Florida.

More recently, Stennis Space Center assisted the Federal Emergency Management Administration (FEMA) in the inventory of damage caused by flooding on the Mississippi and Missouri Rivers. NASA personnel collected digital multispectral data and color infrared photography to assist FEMA in mapping the extent of flooding and assessing damage.

The acquisition of remotely sensed data to support Federal relief efforts served a dual purpose. First, and most important, was the support to relief efforts in the many cities for which data were acquired. The second was verification and understanding of the market for data that could be used in future disasters to develop data bases and assess damage. Furthermore, use of this damage assessment method by Federal agencies may stimulate greater demand for remote sensing services provided by U.S. industry.

Data Acquisition Infrastructure

NASA supports the spatial information industry through a data acquisition and processing infrastructure. Stennis Space Center has developed an airborne testbed for validating new sensor systems and acquiring prototype data sets that can simulate future satellite products. Location accuracy requirements are met by infrastructure based on the GPS, which provides a universal reference for co-registering GIS data. Stennis Space Center has developed and is testing the use of the HARN for precisely geolocating GIS base-map data layers. In response to the aerospace industry's interest in developing remote sensing systems, Stennis Space Center has conducted feasibility studies for a remote sensing small satellite system (Birk *et al.*, 1991). These NASA activities are described in the following sections.

TABLE 4. ATLAS PERFORMANCE

ATLAS SPECTRAL, RADIOMETRIC, AND SPATIAL SPECIFICATIONS								
Channel #	1	2	3	4	5	6	7	8
Band Limits, μm	0.45 – 0.52	0.52 – 0.60	0.60 – 0.63	0.63 – 0.69	0.69 – 0.76	0.76 – 0.90	1.55 – 1.75	2.08 – 2.35
Channel #	9	10	11	12	13	14	15	
Band Limits, μm	3.35 – 4.20	8.20 – 8.60	8.60 – 9.00	9.00 – 9.40	9.60 – 10.2	10.2 – 11.2	11.2 – 12.2	

Source: DaMommio and Kuo, in publication

Airborne Instrument Test System

The AITS is an end-to-end data acquisition and processing facility. AITS optimizes the data acquisition process by providing a digital data handling environment from application to delivery. Quality control, sensor reliability, documentation, and ease of operation are prime performance objectives. System implementation entails the integration and enhancement of five elements (Figure 7): aircraft, sensor systems, data conversion, analysis and applications, and archival distribution (Hill *et al.*, 1991).

The primary objective in using the AITS is to develop new products and markets for remote sensing data. The system provides all the engineering and computational support required for scientific and commercial remote sensing market development. Specialized sensor system requirements can be determined for meeting niche markets. Niche-specific systems may allow less expensive fabrication, operation, and data processing costs.

The AITS supports the VIP, EOCAP, and TMP projects through access to a dedicated data acquisition and processing system.

Airborne Terrestrial Applications Sensor

ATLAS is designed specifically to support NASA's industry partners in commercial applications. ATLAS provides versatility in acquiring high- and mid-resolution spectral and spatial information as shown in Table 4 (DaMommio and Kuo, in publication).

The system consists of an operator console rack and a scan head designed to mount in the equipment bay of a Learjet 23 aircraft. ATLAS is available to the CRSP's partners for investigating potential remote sensing applications. Optimal spatial and spectral specifications for individual applications can be determined through acquisition of coincident spectral coverage over a range of spatial resolutions. These data specifications can then either be obtained from an existing commercial data acquisition service or be provided to commercial sensor manufacturers for production. ATLAS is designed to simulate the high resolution satellite data systems of the future (Birk and Spiering, 1992).

The sensor system provides quality imagery, high geometric fidelity, and the ability to record digital data on an 8-mm media Exabyte tape recorder, enabling a direct sensor-to-computer interface. An example of ATLAS data is shown in Figure 8.

High Accuracy Reference Network

The HARN, established using GPS technology, is a set of statewide networks of precisely determined benchmarks referenced to the North American Datum 1983 geoid. The Mississippi HARN network serves both general and special requirements at regional, state, area-wide, and local scales (Figure 9).

An A-order station, enabling GPS measurement accuracies to within a millimetre, has been installed at Stennis Space Center along with regional network leveling (i.e., elevation). HARN benefits for commercial and public users include the following:

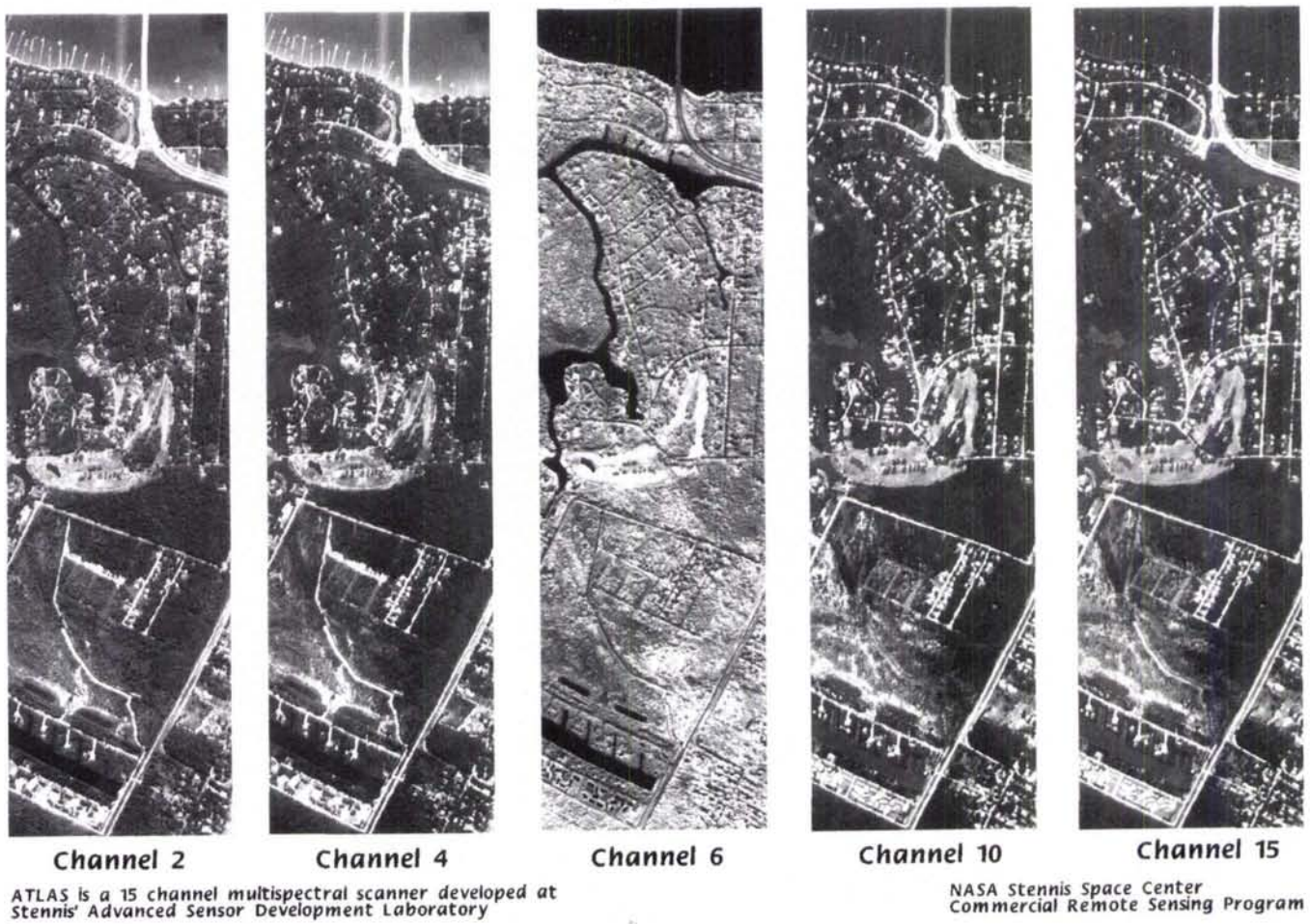

Figure 8. ATLAS multispectral data.

- An efficient network of reference stations in Mississippi and its adjacent states supporting GPS-based data collection and positioning accuracies at the centimetre level,
- A physical and communications infrastructure facilitating application of GPS technology to GIS development within the region,
- A common reference system that facilitates sharing of spatial data between regional organizations, and
- A universal grid for tying together GIS data.

HARN is used by the CRSP to demonstrate the viability of a highly accurate georeferencing system for GIS base maps. GIS data layers can be registered with high accuracy in a single reference system, allowing adjacent areas to form a seamless mosaic and avoiding controversy over discrepancies in boundaries and site perimeters (Mick *et al.*, 1993).

Commercial Remote Sensing Technology Initiative

The prime objective of the CRSTI is to facilitate successful space-based remote sensing ventures in the Earth observation and aerospace industry. The CRSTI is dedicated to enabling market viability tests and demonstrations to prove the efficiency of small satellite systems.

Through evaluation of performance parameters derived while working with VIP and EOCAP partners, the CRSP has developed an envelope of system performance specifications for Visible/Near Infrared (VNIR), Short Wave Infrared (SWIR), and Long Wave Infrared (LWIR) small satellite systems (Table 5).

World-wide demand for remotely sensed data with specifications similar to those in Table 5 has stimulated the launch of a number of satellites over the next six years. A technology challenge is presented to the U.S. in that the first satellites scheduled to be launched are from foreign competitors, giving them an early advantage. A list of the commercial satellite initiatives that have announced plans for launch prior to the year 2000 are presented in Table 6.

If the cost of placing a remote sensing satellite in orbit could be significantly reduced, the industry would have a higher incentive for U.S. corporate investment. For example, using the AITS to simulate data and to validate markets and relative parameter specifications before sending up a satellite could help prove the feasibility of the satellite before funding is committed, reducing the investment risk. Two key meth-

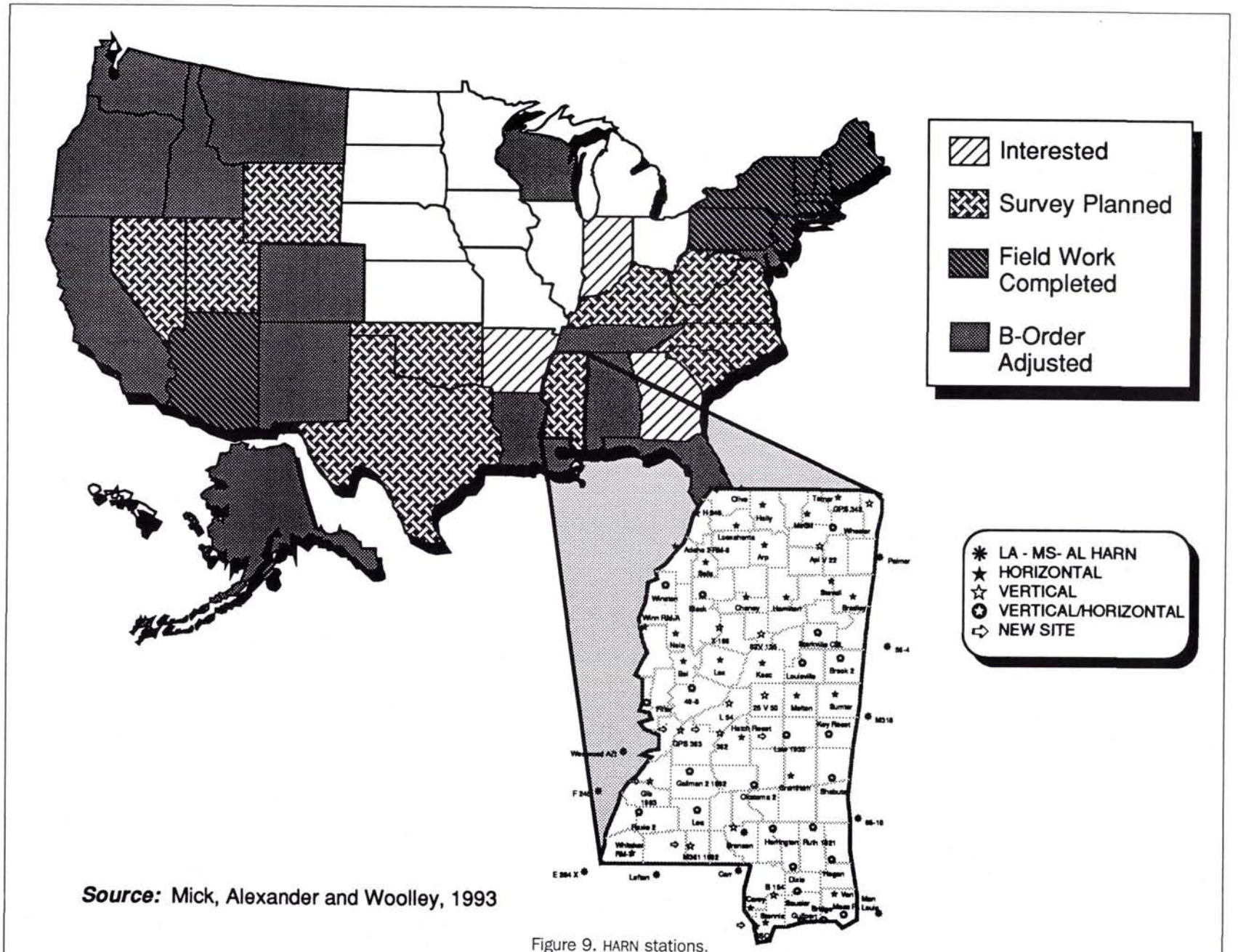

Figure 9. HARN stations.

TABLE 5. SMALL SATELLITE PERFORMANCE PARAMETERS

PARAMETERS	VNIR	SWIR	LWIR
Spectral Range (μm)	0.4–1.0	1.5–2.5	8–12
• Resolution	10–15 nm	50–100 nm	500-1000 nm
• Number of bands	10–30	2–5	1–10
Spatial Resolution	≤ 5 m	≤ 10 m	≤ 20 m
• Zoom	1–2.5 m		
• Swath	10–50 km		
• Stereo	Yes		
Revisit Frequency	≤ Daily	≤ Weekly	≤ Weekly
Radiometric Resolution	0.5% (NER)	0.5% (NER)	0.1°C (NEΔT)

Source: SSC, CAMEO/ARPA (Advanced Systems Technology Office)

ods are available for decreasing development and implementation costs associated with a remote sensing system:

- Implementation within the framework of a small satellite configuration, and
- Utilization of subsystems derived from proven off-the-shelf technology.

For a privately funded remote sensing satellite to be commercially profitable, the development and implementation budget must promise a reasonable opportunity for total cost recovery and profit. This budget implies recovery of costs during the period of satellite operations, profit from the continued sales of archived data, and development of a range of value-added services. Current remote sensing satellite systems, such as Landsat 5 and SPOT 2, have development costs in the range of $350M and $310M, respectively. Given limited system operational lifetimes of 3 to 5 years, revenues would have to exceed $60M annually just to recover these costs. In comparison, the estimated lower limit for a 5-metre panchromatic system is around $20M, including integration and ground station implementation and operational costs. Available technology in small launch vehicles and space-qualified subsystem miniaturization, with associated decreased costs, could provide a development environment capable of reducing overall costs while maintaining performance (Birk *et al.*, 1991).

Summary

The Commercial Remote Sensing Program Office at Stennis Space Center supports three programs and a technology base to assist in developing a competitive U.S. spatial information industry. The Visiting Investigator Program provides low-cost, entry-level investigation of remote sensing technology. The Earth Observations Commercial Applications Program provides larger scale, reduced-risk opportunities for companies to package innovative technologies for market. The Technology/Market Program allows companies to use NASA resources to perform end-to-end spatial information demonstrations and to develop new and emerging markets.

The Airborne Instrument Test System, including its dedicated commercial applications development multispectral sensor and high accuracy reference network, supports these partnership programs with dedicated data acquisition infrastructure. The Commercial Remote Sensing Technology Initiative encourages commercial investment in advanced remote sensing instrumentation deployment.

Through the CRSP, NASA is supporting the development of new products, processes, and services utilizing remote sensing and related spatial technologies. Only successful companies create jobs, accumulate capital for further investment, and produce economic utility to boost long-term growth potential. The working partnerships between NASA and the U.S. commercial sector described in this paper facilitate a two-way flow of ideas and innovation capabilities that makes optimum use of the government's investment in remote sensing.

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TABLE 6. SCHEDULED SATELLITE LAUNCHES

SYSTEM	SPONSOR	LAUNCH	SPECTRAL	SPATIAL (m)
MIR PRIRODA	RUSSIA	1994	VNIR, SWIR, LWIR	6-18m
RADARSAT	CANADA	1994	RADAR	15m
INDIASAT	INDIA	1995	VNIR, SWIR, LWIR	10m
GREENSAT	SOUTH AFRICA	1995	VNIR	2.5m
SPOT 4	FRANCE	1996	VNIR	5m
SPOT 5	FRANCE	2000	VNIR	5m
WORLDVIEW	USA/WorldView Imaging Corp./CTA Inc.	1996	VNIR	3-15m
CRSS	USA/Lockheed Missiles and Space Company	1997	VNIR	1-4m
LANDSAT 7	USA/Defense Landsat Program Office	1998	VNIR, SWIR, LWIR	5-60m
EDOS	USA/JAPAN	TBD	VNIR	15m
CAMEO	USA/Advanced Research Projects Agency	TBD	VNIR, SWIR, LWIR	2.5m

Source: Space News, Aviation Week & Space Technology