Imaging NOTES

Blueline Publishing LLC
P.O. Box 11569
Denver, Colo. 80211
USA

Imaging NOTES

Summer 2005
Vol. 20 >> No. 2

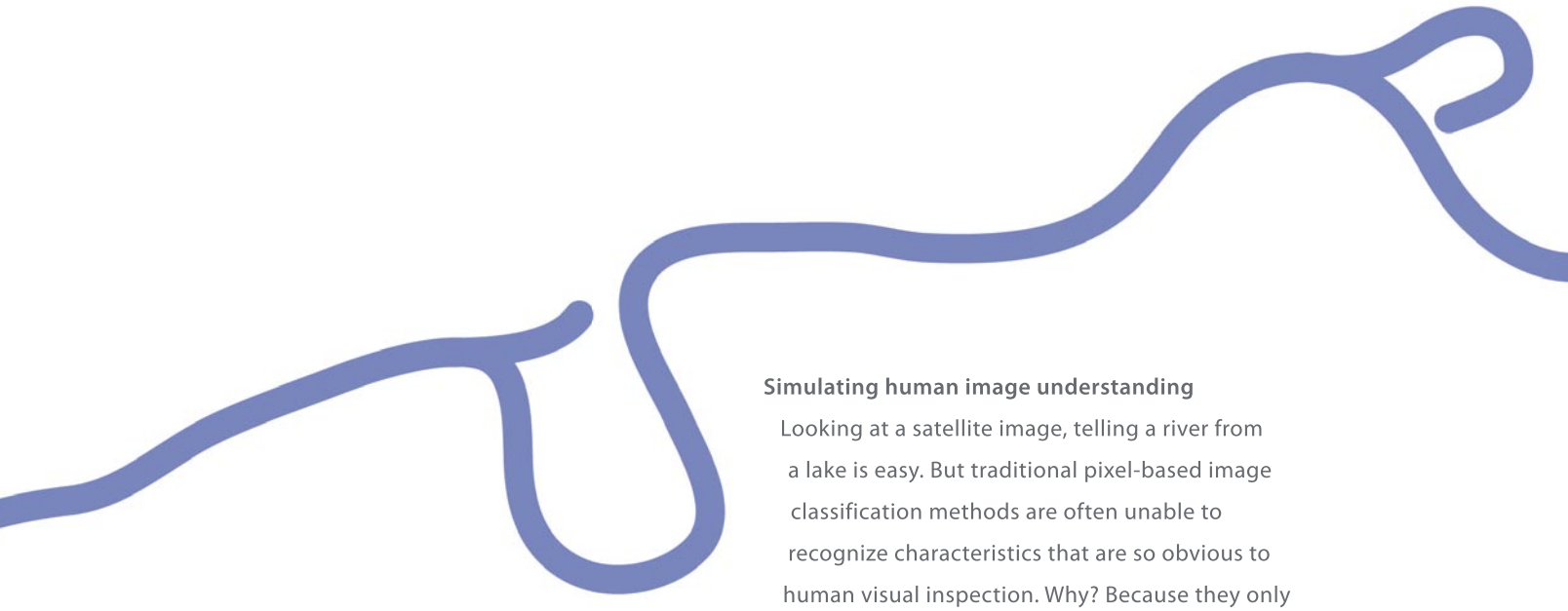
Windows into North Korea

Subsidence in Arizona

Solar Power Potential

Fire Mitigation Solutions

Can you ecognize it?



Simulating human image understanding

Looking at a satellite image, telling a river from a lake is easy. But traditional pixel-based image classification methods are often unable to recognize characteristics that are so obvious to human visual inspection. Why? Because they only use the spectral information of the pixels without looking at the big picture. But from an image analyst's perspective there is so much more to a satellite image than just digital numbers or colour. Think of shape, texture, area, scale and context, all attributes humans instantly use to understand the content of an image. It needs eCognition's unique capabilities for image segmentation and object classification to utilize all these attributes for digital image classification.

At last with eCognition you can expand your image classification beyond pixels. Isn't it time you learn more about it? Download a free trial version at **www.definiens-imaging.com**

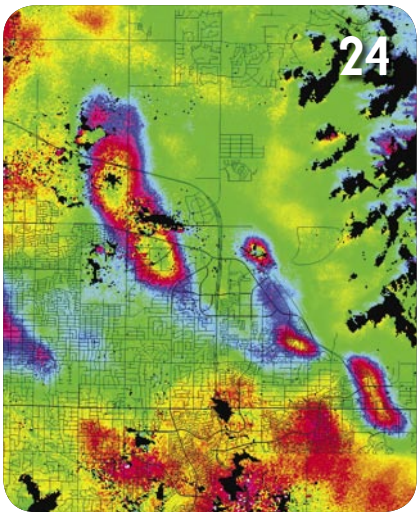
eCognition
OBJECT ORIENTED IMAGE ANALYSIS

DEFINIENS IMAGING

Definiens Imaging • Trappentreustrasse 1 • 80339 München • Germany • Phone +49 89 2311800 • Fax +49 89 23118080 • eCognition@definiens-imaging.com

Imaging NOTES

summer 2005



departments

features

The cover story of this issue is about North Korea's nuclear program, military capabilities and political prisons. The Natural Resources Defense Council explores what remote sensing can teach us on pages 16-21.

A small, central area of the capital city of North Korea, P'yongyang, is featured as the cover image. (A larger portion of the city is visible on page 16 within the article.) P'yongyang is located in western North Korea—only 150 km (93 miles) from the South Korean border and the DMZ. Geographic coordinates for the city are 39 degrees, 1 minute North and 125 degrees, 45 minutes East.

Yanggak-do island in the center of P'yongyang is shown in the cover photo. Features on the island include (from south going north): the P'yongyang Football Stadium, the International Cinema Hall, a golf course (a rarity in North Korea), and—on the northern tip of the island—Yanggak-do Hotel. This hotel features a casino, hostess bar, dance club and sauna—luxuries accessible only to the elite and to foreign visitors; locals are not allowed. This area exists in stark contrast to the famine and suffering endured by many North Koreans.

To the east of Yanggak-do island (appearing to the right of the island in groups of parallel lines) are 'spinning thermal power plants,' electric plants built in a textile factory to supply power. The bridge going across the island is Yanggak Highway Bridge, which leads northwest (left and up in the image) to the P'yongyang Rail Station and main rail marshalling yards. The section of town northeast of the rail station along the river includes several important government buildings, including the Ministry of Railroads, Ministry of Transportation and the P'yongyang City Police Department. Further northeast along the river is the P'yongyang Grand Theater.

In other parts of North Korea, nuclear sites, air fields, navy bases, and political penal labor colonies can be studied using commercial satellite imagery—practically the only way to get a glimpse into this secretive country. The cover story provides imagery and analysis first presented by the authors in a press briefing in January 2005 at the Carnegie Endowment for International Peace in Washington, D.C.

The image is a 1-m color IKONOS image, taken on April 17, 2001, courtesy of WIA (Space Imaging Asia).

Imaging NOTES

Summer 2005 / Vol. 20 / No. 2

PUBLISHER
Myrna James Yoo
Blueline Publishing LLC
myrna@bluelinepub.com

COPY EDITOR
Bette Milleson

ART DIRECTOR
Jürgen Mantzke
Enfineitz LLC
jurgen@enfineitz.com
www.enfineitz.com

EDITORIAL CONTRIBUTIONS
Imaging Notes welcomes contributions for feature articles. We publish articles on the remote Earth imaging industry, including applications, technology, and business. Please see Contributor's Guidelines on www.imagingnotes.com, and email proposals to editor@bluelinepub.com.

SUBSCRIPTIONS
To subscribe, please go to www.imagingnotes.com, and click on 'subscribe.' Subscriptions are free for those who qualify. For changes, please submit changes with old and new information to subscriptions@bluelinepub.com.

Imaging Notes is published quarterly by
Blueline Publishing LLC
Denver, Colo.

Imaging Notes (ISSN 0896-7091)

P.O. Box 11569
Denver, Colo. 80211

Imaging Notes is printed on 20% recycled (10% post-consumer waste) paper. All inks used contain a percentage of soy base. Our printer meets or exceeds all federal Resource Conservation Recovery Act (RCRA) Standards.

We've got the world covered.

RESOURCESAT-1 56-Meter
Cape Town, South Africa

RESOURCESAT-1 imagery and access exclusively available from Space Imaging.

With a combination of three sensors providing high spatial, spectral, and radiometric resolution, RESOURCESAT-1 imagery offers comprehensive global imagery ideal for agricultural, mapping, and land/resource management applications.

- 5-, 23-, and 56-meter spatial resolution
- Multispectral (R, G, NIR, SWIR) or black and white
- Frequent revisit capability—5 days w/ 5-meter
- On-board memory

1.800.232.9037 +1.301.552.0537 www.spaceimaging.com/products/irs

SPACE IMAGING®
Visual Information. Visible Results.

Welcome to the *inaugural issue of* Imaging Notes *under new independent ownership.*

EOSAT Notes became *Imaging Notes* in 1998 and has been owned and underwritten by Space Imaging LLC. Blueline Publishing (formerly Publishing Partnerships) has been publishing *Imaging Notes* for Space Imaging since the Winter 2003-2004 issue. Thank you to everyone at Space Imaging and elsewhere who has worked so hard on *Imaging Notes* magazine over the years.

A very special thank you also goes to our advertisers — past, current and future. We cannot provide this venue for sharing important industry information without you. We take great pride in delivering your message directly to those who work in this exciting, vital field of commercial remote sensing.

To the readers, whose very livelihood depends upon obtaining accurate, relevant information: *Imaging Notes* is written for you. We will strive to print what you most need to know, providing objective editorial reporting and offering a strong, relevant voice for the industry.

Ray A. Williamson will be bringing his expertise to the Editorial Advisory Board. He is Research Professor of Space Policy and International Affairs in the Space Policy Institute of The George Washington University, and a faculty member of the International Space University, Strasbourg, France. He writes extensively on space technologies and policies, has written or edited nine books, and holds a PhD in astronomy and physics.

Williamson will continue to share insights in his column, 'Policy Watch,' and is enthusiastic about the future of *Imaging Notes*. We would like to thank him sincerely for his contributions to the professional focus of the magazine.

In this issue, beginning on page 16, we provide a rare, important look into North Korea, one of the most volatile and feared nations in the world today because of its nuclear weapons buildup and threats. The cover story, prepared by experts at the Natural Resources Defense Council, shows political prisons, nuclear facilities and air bases. The imagery has been presented in a press briefing at the Carnegie Endowment for International Peace and was featured on CNN; this story has not been previously published.

Our goal is to deliver in-depth analysis of significant remote sensing projects around the globe. We strive to take readers beyond the day-to-day headlines of selected news in each issue. The Gaza Strip story in the Fall 2004 issue showing destruction of homes was featured here several months before the final report was issued by Human Rights Watch. Our recent Winter issue offered the only publication of the test results for the ARIES emergency response system spearheaded by EarthData in 'Making Rapid Response a Reality.'

Also in this issue, you'll find on page 8 a new department, 'Enjoy the View,' which provides readers with a venue to appreciate the sheer beauty of the Earth from all kinds of remote sensors.

We encourage submissions of your letters, suggestions and articles. We are most interested in hearing your feedback, and in hearing about innovative applications of Earth imaging technologies that have not yet been published, or that have a new angle.

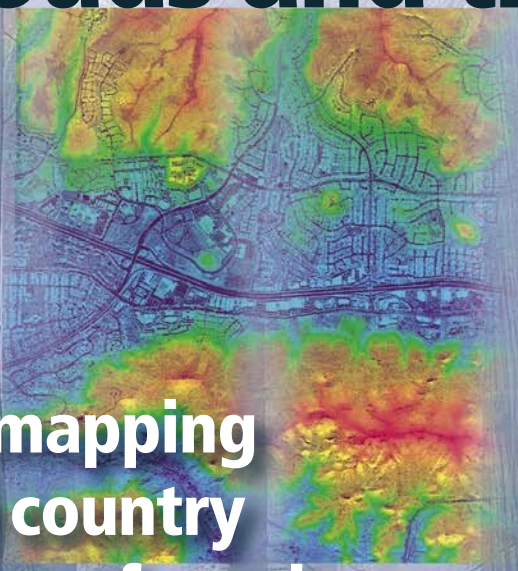
Imaging Notes will be re-launching soon. Watch for a new name and a sharper focus. Our goal is to become one of the most vital publications in the field of remote sensing.

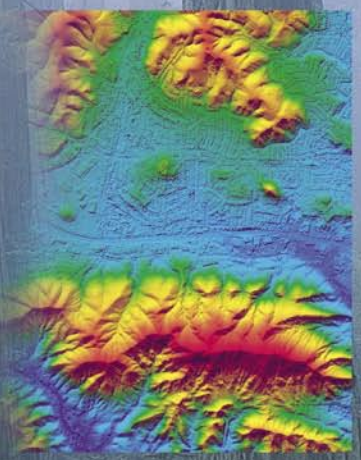
In order to continue receiving *Imaging Notes* free of charge, please fill out the enclosed card and return it with your signature. This is important as we apply for circulation audits; your subscription may expire otherwise. Thank you for reading and responding.

With much respect,

Myrna James Yoo
Publisher

Imagine
seeing through the clouds and the trees





Imagine mapping an entire country in a matter of weeks

Imagine owning your data

GeoSAR
Turning imagination into reality

GeoSAR's combined X- and P-band capability penetrates clouds and foliage to deliver an elevation model accurate to 1-2 meters. Standard GeoSAR deliverables include up to eight unrestricted-use products, including the X- and P-band DEMs, X- and P-band orthorectified radar intensity images, and X- and P-band high-resolution slant plane images, plus the multi-return lidar profiles and ground control.

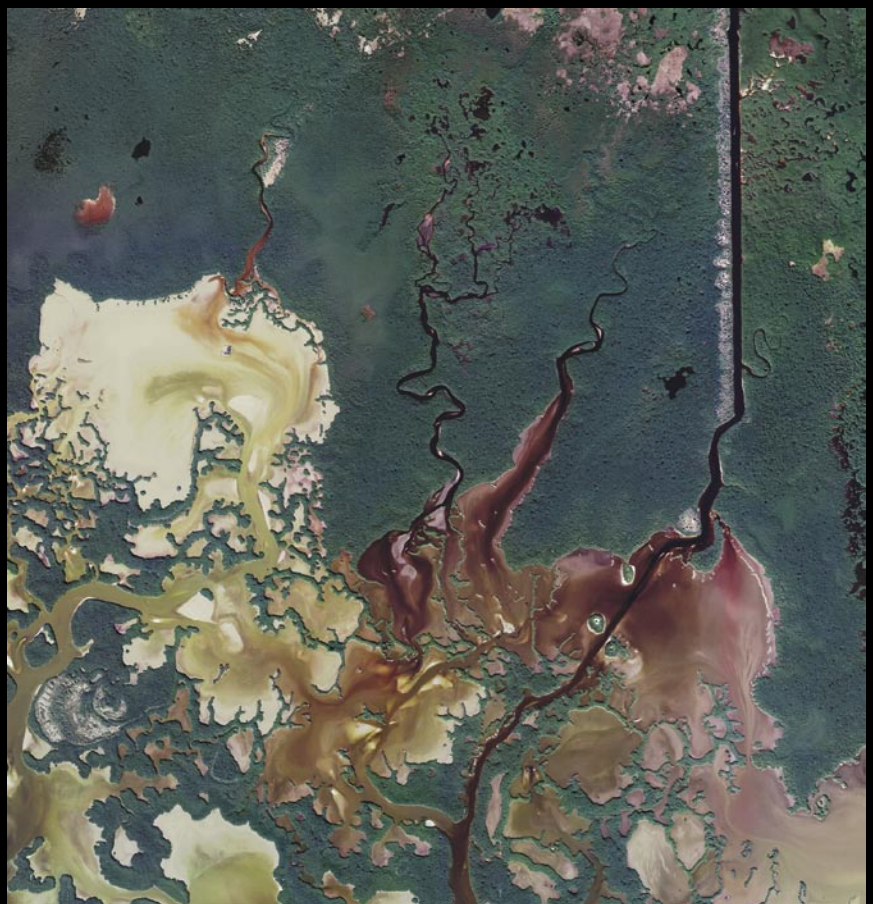
www.earthdata.com

7320 Executive Way, Frederick, MD 21704

EARTHDATA®

Upheaval Dome in Utah

This satellite image is a natural color, 2.4-m high-resolution QuickBird satellite image featuring the 5-km diameter crater referred to as Upheaval Dome in the Canyonlands National Park, Utah. Image is courtesy of DigitalGlobe.



Florida Everglades

This natural color orthoimage of the Royal Palm Hammock (SE) quarter quadrangle is located a few miles west of the Everglades National Park, in Collier County on the Gulf Coast of Florida. The image was collected at a 1-m pixel resolution on December 3, 2004, using a Leica ADS40 airborne digital imaging sensor, as part of the statewide mapping program for Florida covering approximately 54,000 square miles.

This program was sponsored by an alliance of the state's water management districts and the USGS. It is the first large-scale acquisition effort that takes advantage of the ADS40 sensor's ability to generate both natural color and false color renditions simultaneously. To accommodate the full range of data products requested, a total of 16,800 individual map tiles were produced. A total of more than 3 terabytes of image data were delivered.

This image is provided courtesy of the South Florida Water Management District and the USGS. It was acquired and processed by EarthData International.

Niagara Falls

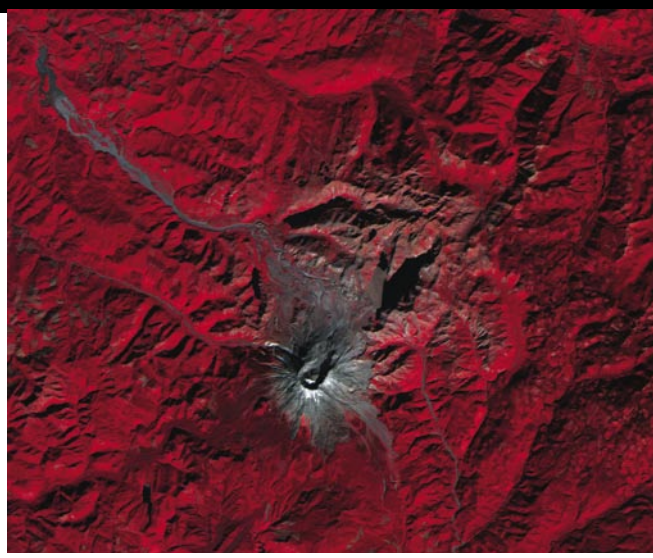
Clouds of mist rise from the bottom of Horseshoe Falls, on the Canadian/United States border, in this 1-m image collected by Space Imaging's IKONOS satellite. Every second, more than two million liters of water plunge over the Horseshoe Falls segment of Niagara Falls creating one of the world's largest waterfalls, as well as eating away as much as two meters of rock per year.

The image shows the Niagara River, which connects Lake Erie to Lake Ontario, snaking around Goat Island, in the lower left of the full image. Most of the river's water plummets over Horseshoe Falls, but some diverted water spills over American Falls and Bridal Veil Falls downstream. The image, courtesy of Space Imaging, was acquired August 2, 2004.

France's Millau Bridge

This 1-m panchromatic image of the Millau Viaduct Bridge in Millau, France, was collected by ORBIMAGE's OrbView-3.

The bridge is the world's tallest suspension bridge. Located in southern France, it connects the motorway from Paris to Barcelona at the point where it is interrupted by the River Tarn, which runs through a wide gorge between two plateaus. The bridge was opened to traffic on December 16, 2004. This project has the highest bridge piers in the world with an overall height of 336.4 meters. The bridge is located at 44.05N / 2.01E. Image is courtesy of OrbImage. «



Smallsat Remote Sensing

A New Driver in Space Development

After several years of unrealized promise, false starts and uncertainties, microsats and smallsats centered on remote sensing applications have become the focus of developing countries' aspirations to enter the league of space-capable countries.

While the large space companies in the United States and Europe seem able to offer only large, expensive, though highly sophisticated remote sensing satellites, much smaller startups in the United Kingdom and now South Africa have taken the lead in providing end-to-end, innovative solutions for countries with limited economies.

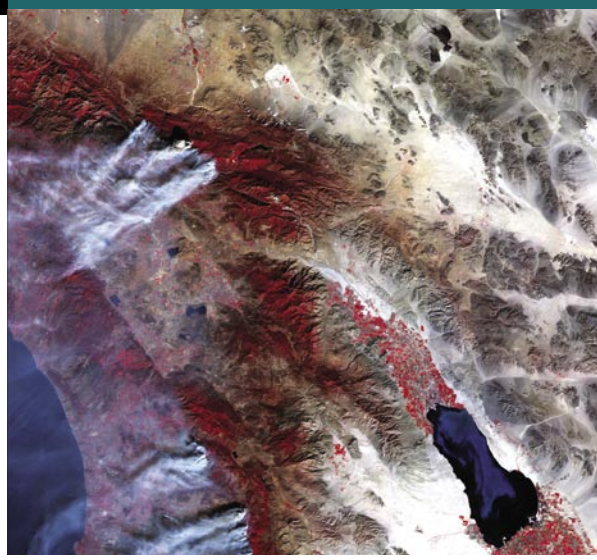
Surrey Space Technologies, Limited (SSTL) in the United Kingdom was the first to provide satellites for this growing market. Developing from a university program at University of Surrey in Guildford, England in the 1980s, SSTL has now provided small satellites to several countries at a fraction of the cost of those provided by the world's large companies.

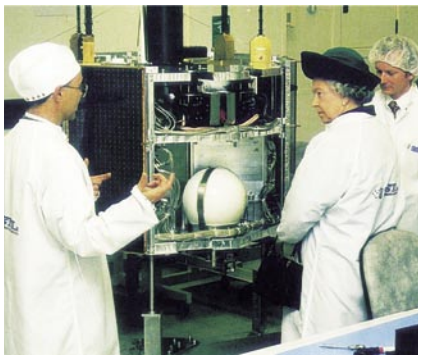
From the beginning, SSTL has struck out on a very different course from those companies, successfully marketing its concept of an inexpensive Disaster Monitoring Constellation (DMC) to Algeria, Nigeria, and Turkey. Together with the U.K.-owned Topsat smallsat, these four satellites can image the entire world every day in three spectral bands at 32-m resolution. China will join the DMC later this year, with a smallsat that includes a 4-m panchromatic camera as well as the moderate-resolution multispectral camera used by the other satellites.

Part of SSTL's success is its provision of considerable technological know-how to these countries. Technicians from the customer countries work alongside SSTL engineers, learning how to build and operate smallsats, to operate the control software and systems and to use the data for applications in their countries.

Although these satellites currently offer lower resolution and fewer multispectral channels than the more familiar government or commercial ones, these smallsats have the marked advantage of bringing to these countries capabilities they could not have dreamed of obtaining elsewhere in the marketplace. At the same time these countries are developing the capacity to put such imagery to use for a variety of purposes other than monitoring natural disasters, such as agriculture, water resources management, and resource conservation. Interestingly, improved in-country capacity to apply the data to their needs will also help create a wider market for higher-resolution data from the commercial satellites as these countries improve their technical capacities.

Recently the South African company SunSpace has emerged to provide a bit of competition with SSTL. I visited SunSpace at their headquarters in Stellenbosch, near Cape Town, and was impressed with their capabilities and their resolve to become a world-class competitor to SSTL and other firms.





« *Left: DMC image of Mount St. Helen's in Washington State, courtesy SSTL/DMCii*

» *Right: Her Majesty The Queen of England inspects UO-12 imaging satellite at SSTL/DMCii*

» *Far Right: Image taken by DMC to aid fire fighters in California, U.S.A., courtesy SSTL/DMCii*

Like SSTL, SunSpace evolved in part from a university program, this one centered in Stellenbosch University. The success of that program in building and operating the Sunsat moderate resolution satellite led directly to SunSpace. With Sunsat and subsequent subsystems that SunSpace has built for external customers, the firm has demonstrated its technical and managerial capabilities. The company now offers satellites, subsystems and services for sale. It also offers the chance for countries to advance their expertise in satellite construction by working with Sunspace to create their own microsats.

In the future, Sunspace also plans to offer small communications satellites operating in geostationary orbit. Although the capacity of such systems would be necessarily smaller than the larger ones now in commercial use, they are likely to be entirely sufficient for smaller countries' needs.

South Africa has recently been struggling with defining its approach to space technology. Though the country has several small high-technology companies like SunSpace that are highly capable, and though it makes extensive use of remotely sensed data from the world's major systems for government and private applications, it has not encouraged development of its fledgling space sector.

In 1993, South Africa was even one of the first countries outside of the United States to create its own space law. However, after the old Apartheid regime came to an end in the early 1990s and the new democracy took hold, the old space program, previously organized and run by the military, was shut down. There were, after all, many other economic and social needs to address after years of divisive and oppressive Apartheid policies.

South Africa has solid intellectual capital and a cadre of well-qualified scientists and engineers. It also has a well-trained workforce and a government focused on improving the educational level of the entire future workforce. With all of these resources, the intellectual energies of the entire population can be tapped to foster a truly dynamic space program.

To ensure that it grows and contributes broadly to South Africa's technological development, proponents of developing a focused policy approach to South African space projects will need the firm support of government officials. A well-constructed policy that recognizes the promise that space technology can hold for the future of South Africa can provide the necessary foundation for the success of SunSpace and other South African space ventures.

Several government departments are well acquainted with the application of remote sensing and other technologies to Earth-bound needs. There is also a strong will among many mid-level career people in the government to construct a coherent space policy and perhaps even form a space office or agency to encourage South Africa's space technology efforts. Yet, in part because of the connection of earlier space efforts with the previous government, the current government has been slow to grasp space technology's promise and to lead development of South African high technology efforts.

These understandable sensitivities need to be overcome before the country will succeed in bringing its capabilities to bear on the development of South Africa's space industry. If it does, South Africa could truly be the continent's space technology leader, guiding other African countries in their efforts. «

Ray A. Williamson is research professor of space policy and international affairs in the Space Policy Institute of The George Washington University, Washington, D.C.

Mining for Solar Resources

U.S. Southwest Provides Vast Potential

MARK MEHOS
Program Manager
Concentrating Solar Power
National Renewable Energy Laboratory
Golden, Colo.
www.nrel.gov/csp

RICHARD PEREZ
Research Professor
State University of New York
Albany, N.Y.
www.asrc.cestm.albany.edu

THE BAD NEWS IN ELECTRICAL ENERGY production is that prices of conventional energy sources such as natural gas and coal continue to increase. The good news, however, is that these escalating prices are spurring a renewed interest in the large-scale generation of electricity from renewable resources.

One of the primary renewable energy resources is solar energy, which is a vast, largely untapped resource, especially in the U.S. Southwest — a region deemed by some as the "Saudi Arabia of solar energy potential." Because of this potential, Congress requested the U.S. Department of Energy to research and develop an initiative to fulfill a preliminary goal of establishing 1,000 megawatts of concentrating solar power (CSP) to supply electricity to the southwestern United States. Subsequently, the Western Governors' Association (WGA) formally adopted a resolution that called for 30,000 megawatts of clean, diversified energy, including solar energy, for the western United States by 2015.

CSP technologies concentrate sunlight to provide heat to conventional power cycles such as steam-Rankine turbines, which are typical of coal-fired power plants and are most economical for large-scale installations of hundreds of megawatts. CSP is unlike other solar technologies that are based on flat-surface collectors, such as rooftop solar-electric systems and solar water heaters. In contrast, CSP requires "direct-normal" solar radiation — the component of sunlight that emanates directly from the solar disk — and excludes diffuse, or "blue-sky" radiation.

Direct-normal solar radiation values can be derived from satellite data. An analysis of these data, combined with geographical information system (GIS) data, has quantified the solar resource potential for large-scale power generation using CSP technologies. Specifically, the National Renewable Energy Laboratory (NREL), collaborating with the State University of New York (SUNY) in Albany, used this combination as an efficient, effective means for quantifying and communicating the vast solar resource potential in the U.S. Southwest. Prime locations for future solar power plants can also be identified by factoring in information on constraints on electricity transmission and access to load centers, which are the regions where electricity is consumed.

SATELLITE-DERIVED SOLAR RESOURCE DATA

Geostationary weather satellites, such as GOES (Geostationary Operations Environmental Satellite), continuously monitor the Earth's cloud cover on a time and location basis. The ground resolution approaches one kilometer for the satellite's visible-radiation sensors. This information can be used to generate solar irradiance data that are time and site specific, leading to the generation of high-resolution maps of solar radiation. Scientists have concluded that beyond 25 kilometers of ground stations, satellite-derived hourly irradiances are the most accurate data.

Researchers from the University at Albany, New York, and the University of Geneva, Switzerland, have developed a new semi-empirical model for deriving global (i.e., direct-normal + diffuse) and direct-normal solar irradiances from the visible-radiation channel of geostationary weather satellites (Perez et. al. 2002, 2003). This model evolved from the European Heliosat-1 methodology (Cano et. al. 2003), which postulates that the Earth's radiance, as seen from space, is proportional to cloud transmissivity, and hence, to the amount of solar radiation reaching the ground.

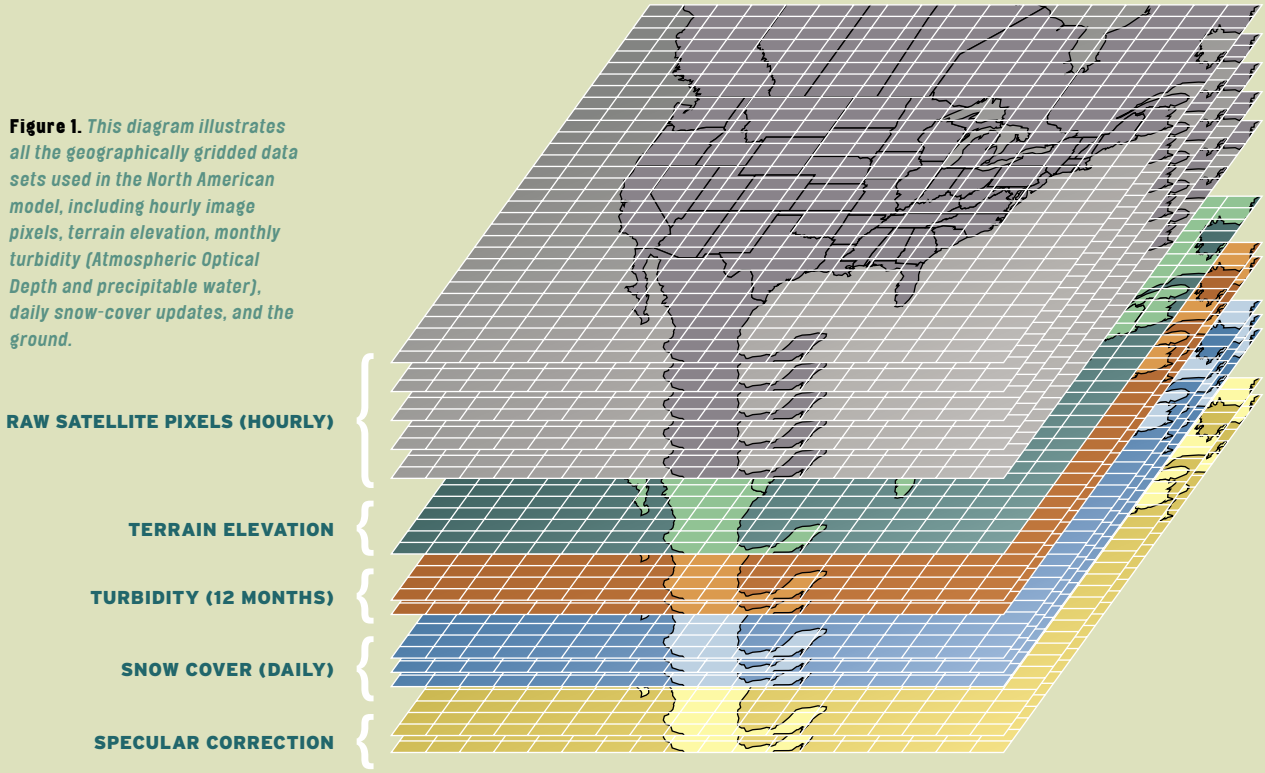


Figure 1. *This diagram illustrates all the geographically gridded data sets used in the North American model, including hourly image pixels, terrain elevation, monthly turbidity (Atmospheric Optical Depth and precipitable water), daily snow-cover updates, and the ground.*

The model consists of two main parts: (1) determining a cloud index from the satellite image, and (2) using this factor to modulate global and direct-normal clear-sky radiation envelopes. The cloud index is determined for each individualized ground location (or image pixel) being calculated from the "relative normalized pixel brightness" for a specific location. This brightness factor is the brightness of a pixel in relation to its possible maximum and minimum values at that location, where the maximum value represents cloudy conditions (or the brightness of thick cloud tops) and the minimum value represents clear conditions (or the brightness of the ground).

Because this process is individualized for each pixel, it accounts for differences in ground reflectivity over space and time and does not require an absolute knowledge of the calibration of satellite sensors. The model also accounts for site-specific characteristics for ground bi-directional (or specular) reflectance and for snow cover when present. The clear-sky radiation envelopes, which represent the upper limit of modeled irradiances, are a function of ground elevation and atmospheric transmissivity as quantified by precipitable water, ozone, and atmospheric optical depth (AOD).

The operation of the model on a geographic scale, either for preparing maps or site/time-specific time series, requires some degree of logistics and information processing. ***Figure 1*** summarizes this logistical approach and includes several layers of gridded information. The grid size of our current archive is 0.1 degree latitude-longitude, but the ultimate achievable resolution of a visible-channel GOES image can approach 0.01 degree. The gridded information layers include the following:

a. Raw satellite pixels (visible channel) — obtained via direct processing of primary GOES-EAST and GOES-WEST satellite images. Gridded raw pixel frames are archived on an hourly basis.

b. Terrain elevation.

c. Climatological AOD and water — 12 monthly layers — derived from previously gridded atmospheric optical depth data.

d. Snow cover — daily gridded frames from the National Operational Hydrologic Remote Sensing Center.

e. Specular correction factor — 216 layers (12 months by 18 hours) derived from the hourly processing of five years' worth of raw pixel data.

Table 1. *Results of satellite/GIS analysis showing area of land and associated power capacity for seven states in U.S. Southwest.*

STATE	AVAILABLE AREA (MI²)	CAPACITY (MW)*
Arizona	*19,300*	*2,467,700*
California	*6,900*	*877,200*
Colorado	*2,100*	*271,900*
Nevada	*5,600*	*715,400*
New Mexico	*15,200*	*1,940,000*
Texas	*1,200*	*148,700*
Utah	*3,600*	*456,100*
Total	**53,900**	**6,877,000**

**CSP power plants require about 5 acres of land area per megawatt of installed capacity. Solar generation can be estimated by assuming an average annual solar capacity factor of 25%-50%, depending on the degree of thermal storage used for a plant.*

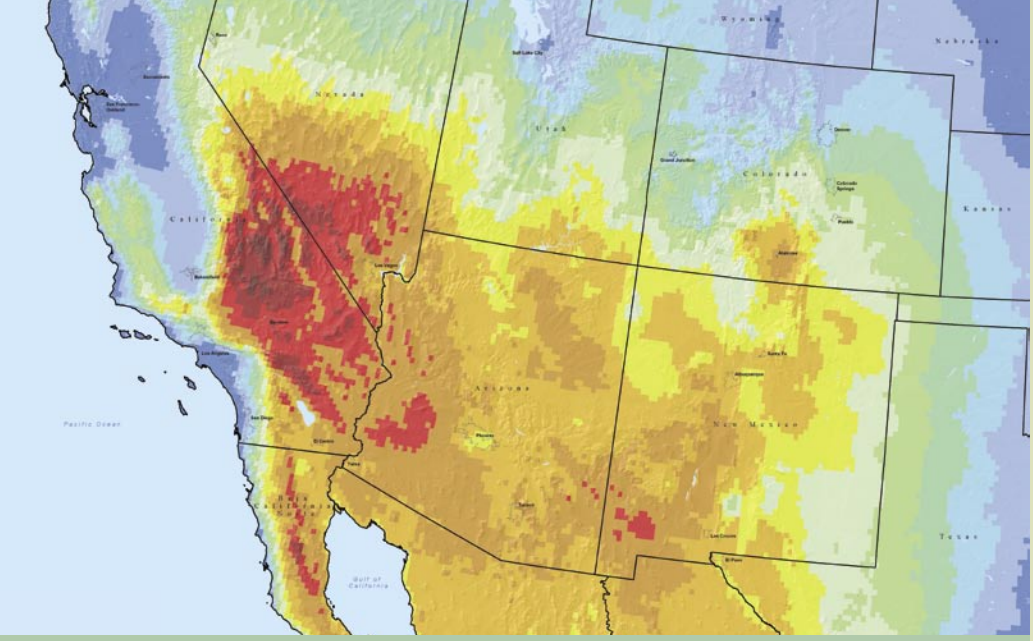


Figure 2. *Direct-normal solar radiation map is derived from 10-km resolution satellite data source. The solar resource in the southwestern United States is vast and largely untapped. Model estimates monthly average daily total radiation, averaged from hourly estimates of direct-normal irradiance over 5 years (1998-2002).*

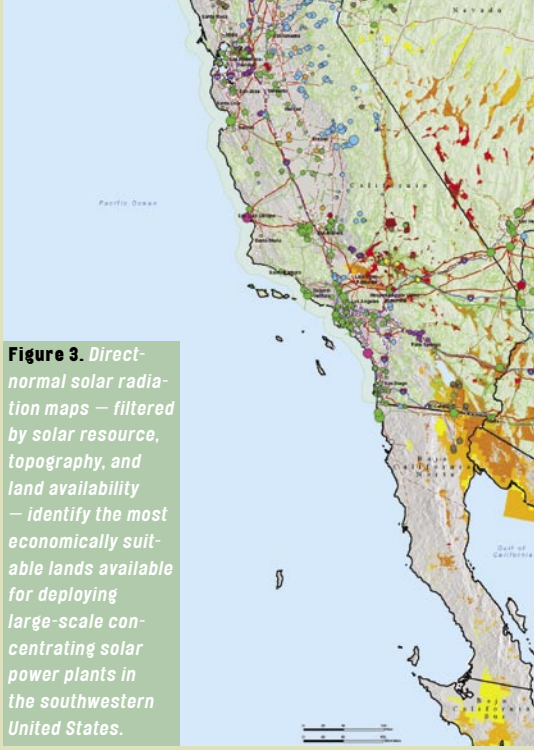


Figure 3. *Direct-normal solar radiation maps — filtered by solar resource, topography, and land availability — identify the most economically suitable lands available for deploying large-scale concentrating solar power plants in the southwestern United States.*

GIS ANALYSIS OF CSP GENERATING POTENTIAL

The direct-normal resource map shown in ***Figure 2*** was developed using the above methodology for deriving high-resolution solar resource data. However, not all the land area shown in ***Figure 2*** is suitable for large-scale CSP plants because such plants require relatively large tracts of nearly level open land with economically attractive solar resources.

To address some of the siting issues related to power plants, GIS data were applied to land type (e.g., urban, agricultural), ownership (e.g., private, state, federal), and topography. The terrain available for CSP development was conservatively estimated with a progression of filters as follows:

a. Lands with less than 6.75 kWh/m²/day of average daily direct-normal resource were eliminated to identify only those areas with the highest economic potential.

b. Lands with land types and ownership incompatible with commercial development were eliminated. These areas include national parks, national preserves, wilderness areas, wildlife refuges, water, and urban areas.

c. Lands with slope greater than 1% and with contiguous areas smaller than 10 km² were eliminated to identify lands with the greatest potential for low-cost development.

Even if we consider only the high-value resources, nearly 7 million megawatts of solar generation capacity exist in the U.S. southwest.

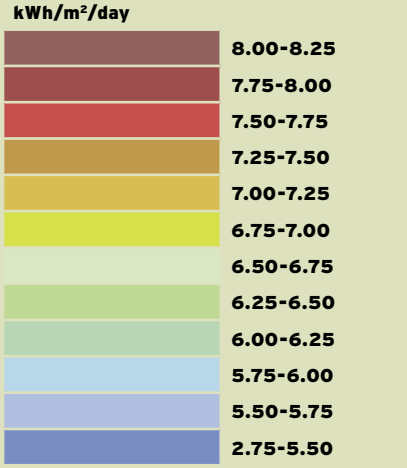
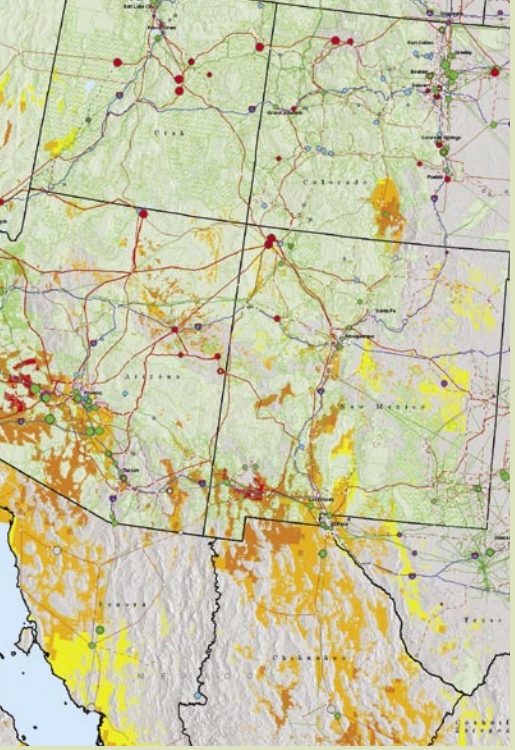


Figure 3 shows the resulting land area when all of these filters are applied, and ***Table 1*** (on page 13) provides the resulting land area and associated CSP generation capacity. This table shows that, even if we consider only the high-value resources, nearly 7 million megawatts of solar generation capacity exist in the U.S. Southwest. According to the Energy Information Agency, in 2003 about 1 million megawatts of generation capacity existed in the entire United States. Each state in the table has sufficient land illuminated by the highest levels of solar radiation such that tapping only a small portion could generate enough electricity to meet its current needs.

CONSIDERING TRANSMISSION CONSTRAINTS AND POPULATION CENTERS

The United States is divided into a number of electricity transmission control regions. The largest region, the Western Electricity Coordinating Council (WECC), covers the western third of the United States and is essentially isolated from the rest of the nation's grid. Apart from Texas, most of which lies within the Electric Reliability Council of Texas (ERCOT) control region, the states in our assessment are part of the WECC control system and have high-voltage transmission lines that interconnect the states to move power from regions with conventional and renewable resources to population centers.



A new solar power plant must fit into the transmission system. NREL, working with Platts Research and Consulting, has conducted a preliminary assessment that takes into account these additional transmission constraints. Ideal locations have been identified for many of the states described in ***Table 1*** (Mehos and Owens, 2004) and several potential sites were identified for each of the states of California, Arizona, New Mexico and Nevada. Future analysis will likely identify promising sites in Colorado, Texas and Utah.

To fully identify favorable opportunities for siting solar power plants, additional factors — land ownership, road access, and local transmission infrastructure capabilities and loadings — must be examined in greater detail and discussed with local experts and utility specialists. Preliminary discussions with these stakeholders and visits to potential sites have demonstrated the effectiveness of this methodology in identifying and communicating prospective locations for large-scale concentrating solar power plants.

Satellite imaging, combined with screening through GIS analysis, has proven to be a very cost-effective approach for quantifying the solar resource potential and identifying potential CSP generation sites in the U.S. Southwest. Analytical results indicate that the solar resource is enormous and largely untapped.

The authors would like to acknowledge the NREL resource assessment and GIS teams for their extensive analysis in support of this work.

REFERENCES

Perez R., P. Ineichen, K. Moore, M. Kmiecik, C. Chain, R. George and F. Vignola (2002). A New Operational Satellite-to-Irradiance Model. ***Solar Energy, 73 (5), pp. 307-317.***

Perez R., P. Ineichen, M. Kmiecik, K. Moore, R. George and D. Renné (2004). Producing Satellite-Derived Irradiances in Complex Arid Terrain. ***Solar Energy, 77 (4), pp. 357-373.***

Cano, D., J.M. Monget, M. Aubuisson, H. Guillard, N. Regas and L. Wald (1986). A Method for the Determination of Global Solar Radiation from Meteorological Satellite Data. ***Solar Energy, 37, pp. 31-39.***

Mehos, M. and B. Owens (2004). An Analysis of Siting Opportunities for Concentrating Solar Power Plants in the Southwestern United States, ***World Renewable Energy Conference VIII, Denver, Colo., August 29-September 4, 2004.***

FIGURE 1 *Image of P'yongyang from NaturalVue 2000, a simulated natural color, global, mosaiced image dataset derived from LandSat7 photographs acquired between 1998 and 2002 (© Earth Satellite Corporation). The cover image of this issue shows a closer view of P'yongyang. See page 4 for details.*

Satellite Views of the Hermit Kingdom

Windows into North Korea

THOMAS B. COCHRAN, PH.D.
Director of The Nuclear Program

MATTHEW G. MCKINZIE, PH.D.
Consultant

Natural Resources Defense Council
Washington, D.C.
www.nrdc.org

THE OPENING EVENT OF Condoleezza Rice's first trip to South Korea as U.S. Secretary of State this March was a speech to soldiers at the U.S. military's underground command bunker south of Seoul rather than a diplomatic ceremony — signaling that the security problems posed by the Democratic People's Republic of Korea (DPRK or North Korea) are a central focus for U.S. foreign policy in the region.[1] In February of 2005, this secretive militaristic society claimed to possess nuclear weapons and is now believed to be slowly augmenting its small arsenal.

In provocative moves this May, North Korea fired a short-range missile into the Sea of Japan and claimed that fissile material for nuclear weapons had been harvested from a reactor in Yongbyon. On May 15th, the United States warned the DPRK not to test a nuclear weapon, citing (albeit controversial) evidence from classified satellite imagery.

The United States currently seeks to bring the DPRK back to the "six-party talks" on nuclear disarmament,[2] but the road ahead appears difficult and may lead to a United Nations resolution this summer involving economic sanctions, further international isolation of the regime, or more drastic actions. Inter-Korean talks ended in late May without agreement on resumption of negotiations over North Korea's nuclear program.

Meanwhile the exodus of refugees continues as North Koreans flee famine, economic hardship and political repression. Commercial remote sensing data are among the few available research tools permitting Non-Governmental Organizations (NGOs) to understand better both the security and the human rights situations in the DPRK.

Today even basic geographic information related to North Korea's society and military is considered sensitive, much as the geography of the Soviet Union was viewed during the Cold War. In order to shed light on the North Korean military capabilities and potential targets should there be a future conflict, the Natural Resources Defense Council (NRDC), an environmental group based in Washington, D.C., undertook a project to create a geospatial database of North Korea.

The effort initially drew on information from U.S. and South Korean military maps and features visible in 10-meter resolution SPOT and 15-meter resolution LandSat imagery covering the entire Korean peninsula.

FIGURE 2 *QuickBird photograph of Pakch'on Uranium Concentration Plant, acquired December 13, 2003.*

Using this data as a guide, NRDC then systematically obtained remotely sensed data imaged by the IKONOS and QuickBird satellites for discrete areas of interest, including cities, industrial facilities, airfields, navy bases, nuclear sites, a missile test site and the demilitarized zone (DMZ). Currently the NRDC database contains over 3,500 records. As an application of this project, NRDC worked in collaboration with the U.S. Committee on Human Rights in North Korea, a Washington D.C.-based NGO, to interview DPRK defectors using high-resolution satellite imagery to identify and map out North Korea's extensive political prison camp system and to delineate the structures of specific prisons.

NORTH KOREA'S NUCLEAR INFRASTRUCTURE

For almost half a century, the DPRK has pursued a nuclear weapons capability at great cost to its society and economy. NRDC has obtained high-resolution satellite images of half a dozen key nuclear sites. The full extent of the DPRK's nuclear program is not known to NRDC, or for that matter even to the U.S. intelligence community.

IKONOS and QuickBird satellite images of the extensive Yongbyon nuclear complex have often been featured on television and in the print media, yet less has been revealed about North Korea's uranium mining, milling and enrichment programs — key uncertainties in estimating how rapidly additional nuclear weapons could be constructed. In October of 2002 North Korea claimed to have a uranium enrichment program in addition to its known plutonium path to the bomb. More recently it has been revealed that the DPRK sold uranium hexafluoride gas to Pakistan, which in turn sold it to Libya.[3]

North Korea's first uranium mill was set up at a site near Pakch'on, 80 kilometers north of the capitol city, P'yongyang ***(see Figure 1)***. This industrial facility initially processed graphite, phosphate and other substances, but in 1982 it was modified to produce uranium concentrate from the uranium ore extracted out of several DPRK mines.[4] A second uranium production plant was established in the early 1990s at P'yongsan, 170 kilometers southeast of Pakch'on. ***Figure 2*** displays a QuickBird image of the one hundred thousand square-meter uranium concentrate facility at Pakch'on, situated along the west bank of the Taeryong River. Pakch'on is also rumored to be the location of additional underground facilities associated with North Korea's nuclear program.

FIGURE 3 *IKONOS image of Koksan Airbase, acquired October 15, 2000.*

FIGURE 4 *QuickBird image of An-2 (Colt/Y-5) Biplanes at T'aech'on Airfield, photographed December 8, 2003.*

> "The pairing of commercial high-resolution satellite imagery with the testimony of North Korean defectors who were exposed to the Gulag creates a revealing window into this closed society."

At a concentrate plant, uranium is extracted from ore, purified and concentrated in the form of yellowcake, which is a yellow-colored salt. The yellowcake produced at both Pakch'on and P'yongsan is shipped to the nearby Yongbyon nuclear complex for reactor fuel fabrication. The location where North Korea produces uranium hexafluoride from yellowcake is not known.

AN UNDERGROUND AIR FORCE

The missions of the Korean People's Air Force (KPAF) are to guard North Korea during peacetime and to perform limited offensive operations in the event of war. Perhaps overshadowing these roles for the KPAF in the eyes of South Korean and U.S. military planners is the possibility that a North Korean aircraft could be used to deliver nuclear weapons against Seoul or other targets.

NRDC analyzed high-resolution commercial satellite imagery of 21 North Korean air bases to extract data on the numbers of military aircraft of different types, on base activity, and on airfield infrastructure, including underground facilities. These photographs were acquired by QuickBird and IKONOS between October 2000 and May 2004. It is known that the KPAF conducts an annual winter training exercise from November through April, and about half of the satellite images were photographed during those months.

Using these remotely sensed data, about 40 percent of all DPRK airfields and 80 percent of DPRK airfields with hard surface runways were surveyed. The QuickBird and IKONOS sensors permitted differentiation of DPRK aircraft by type, and — assuming the same aircraft were not photographed at different air bases at different times — this limited set of images captured approximately two-thirds of the estimated numbers of North Korea's fixed-wing military aircraft. NRDC found that most of the aircraft appear to be deployed north of P'yongyang, greater than 100 kilometers from the DMZ.

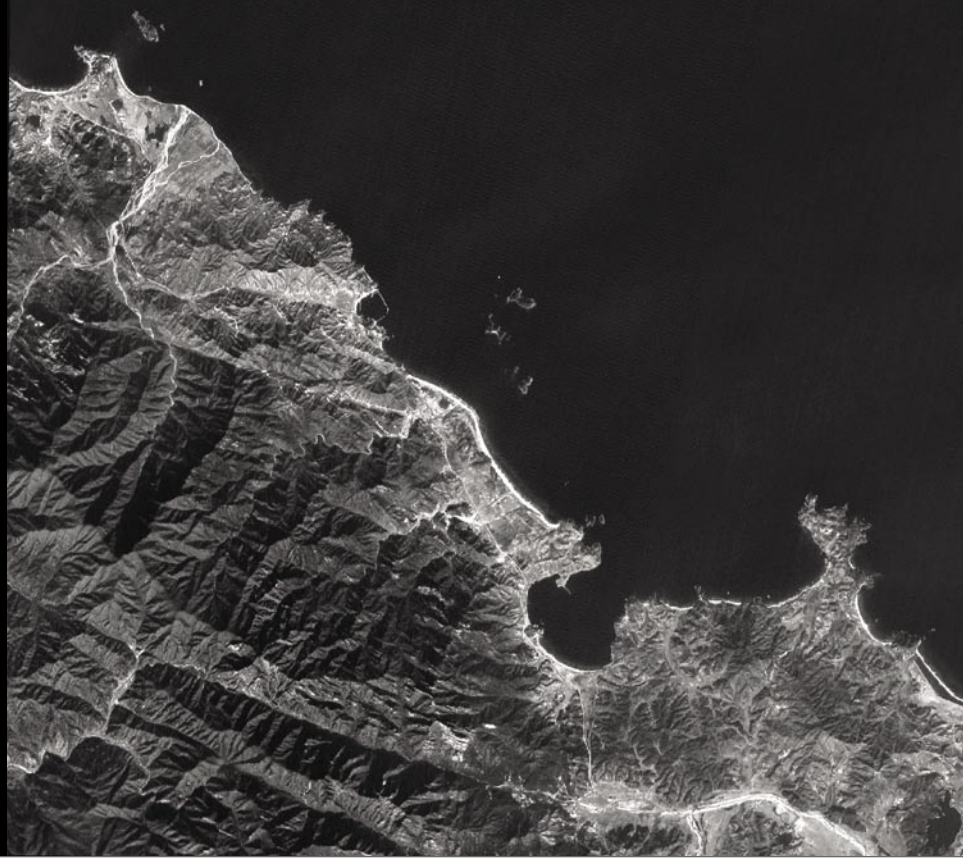


FIGURE 5 *CNES/SPOT image of North Korean Navy Bases on the east coast: Namae-ri and Kosong, acquired January 24, 1995 (© CNES/SPOT Image 1992-1994).*

NRDC determined that 20 North Korean airbases contained underground facilities accessible to aircraft. Tunnel entrances can be seen in satellite images in the sides of hills typically about one hundred meters in height and several hundred meters from the main runway. Most of these underground facilities were observed to have two to four entrances.

Figure 3 shows an IKONOS image of Koksan airbase which is located in south-central DPRK, approximately 85 km from P'yongyang and 130 km from Seoul. Koksan is a primary operating airfield for North Korea's 3rd Air Division, the combat air division with responsibility for defense of the southern section of the country (along the DMZ).[5] A total of 50 MiG-19 and MiG-21 fighters (vintage 1950s Soviet-designed aircraft) are seen parked at the southwest end of the runway near several earthen-covered hangars. Just south of the 2.5-km main runway is a hill in which entrances to underground facilities can be seen in the satellite photo connected to the main runway by a taxiway. On the south side of the hill is a second underground entrance and an auxillary runway. The two underground entrances on opposite sides of the hill are separated by 650 meters.

Of special concern would be the use of such a facility to shelter strike aircraft loaded with nuclear weapons. Seoul is no more than ten to twenty minutes in flight time from key DPRK air bases that have such underground shelters.

Significantly, most North Korean military aircraft are older models, technologically inferior to U.S. and South Korean planes. Almost 90 percent of KPAF aircraft were developed half a century ago or more. For example, a large number of North Korea's transport aircraft are biplanes. ***Figure 4*** shows An-2 (Colt/Y-5) biplanes parked in or near revetments at T'aech'on airfield, located about 100 km north of P'yongyang. The Colt biplane, which is commonly used for crop dusting elsewhere in the world, holds patriotic symbolism for North Koreans, as these aircraft were used for bombing runs in the Korean War (which is known in the DPRK as the "Fatherland Liberation War"). Despite the limitations of the biplanes, the U.S. military has expressed concern about the possibility that these transport aircraft could insert DPRK special operations forces into South Korea to attack airfields or other targets.

SUBMARINE CAVES AND HOVERCRAFT

The Korean People's Navy (KPN) is primarily a coastal defense force, with a limited ability even to guard the DPRK's territorial waters. Geographically North Korea's Navy is divided into separate West Sea and East Sea fleets with about 400-500 vessels in each fleet. The combat ships of North Korea are a mixture of former Soviet, Chinese and indigenous construction. A significant number of the vessels are more than 20 years in age and most are smaller than 100 tons.

NRDC systematically scanned the DPRK coastline along the Korea Bay, Yellow Sea (western coastline) and the Sea of Japan (eastern coastline) using SPOT and LandSat imagery to pinpoint ports and potential KPN bases. ***Figure 5*** shows CNES/SPOT imagery, which was purchased by NRDC from the U.S. government in the form of a data package called "10 Meter Resolution Digital Orthorectified Imagery" (DOI-10M), produced by the National Geospatial-Intelligence Agency (NGA).

FIGURE 6 *QuickBird image of Submarine Cave at Ch'aho-nodongjagu Navy Base, acquired on June 29, 2002.*

FIGURE 7 *IKONOS image of Hovercraft at a North Korean Navy Base at P'ungmu-ri, photographed April 24, 2000.*

IKONOS and QuickBird imagery were then obtained for these areas of interest. Nearly all of the limited number of larger KPN vessels were identified, including diesel-powered submarines, 74-meter and 102-meter length frigates, 62-meter long T-class patrol craft and 42-meter long Soju-class missile ships. NRDC located a total of 48 North Korean submarines using QuickBird images at three KPN bases.

Like the KPAF bases, many of North Korea's Navy bases have underground structures. Ten entrances to such underground sites at six Navy bases are visible in the high-resolution satellite imagery. One example is the Ch'aho-nodongjagu Navy Base, located mid-way on the DPRK's eastern coast. ***Figure 6*** shows three Romeo-class diesel-powered submarines — two berthed along a concrete pier and one berthed near the entrance to the protective cave. A partially-open double door is visible at the cave entrance.

Hovercraft is another interesting class of KPN vessel that NRDC located in the high-resolution satellite imagery. In the 1980s the DPRK began constructing "Kongbang" class hovercraft, which measure about 20 meters in length. Their military role is to insert troops or special operations forces into South Korea in time of war, particularly via navigation of the tidal flats and mud pools along the western shoreline of the Korean peninsula. ***Figure 7*** shows 16 hovercraft located at a North Korean Navy Base at P'ungmu-ri on the eastern coast. Each hovercraft reportedly can carry 40-50 troops and travel up to 50 miles per hour.

NORTH KOREA'S GULAG AND HUMAN RIGHTS ISSUES

Beginning in the mid-1990s, several thousand North Koreans have made the difficult journey to South Korea to escape famine and political repression. A small fraction of these refugees has had experience with the extensive political prison camp system in the DPRK. In collaboration with the NRDC, the U.S. Committee for Human Rights in North Korea published an unprecedented systemic study of the North Korean political prison camp system, supplementing defector interviews with satellite imagery.[6]

Because objects such as buildings, forests, orchards, fields, fences, rivers, railways, trails, and roads are easily recognizable in IKONOS and QuickBird images, satellite photographs were shown to former North Koreans once imprisoned at these places who were then able to identify specific features in the photographs and describe their purposes. Interviews with former prisoners were conducted in Seoul, Washington, D.C., and Los Angeles.

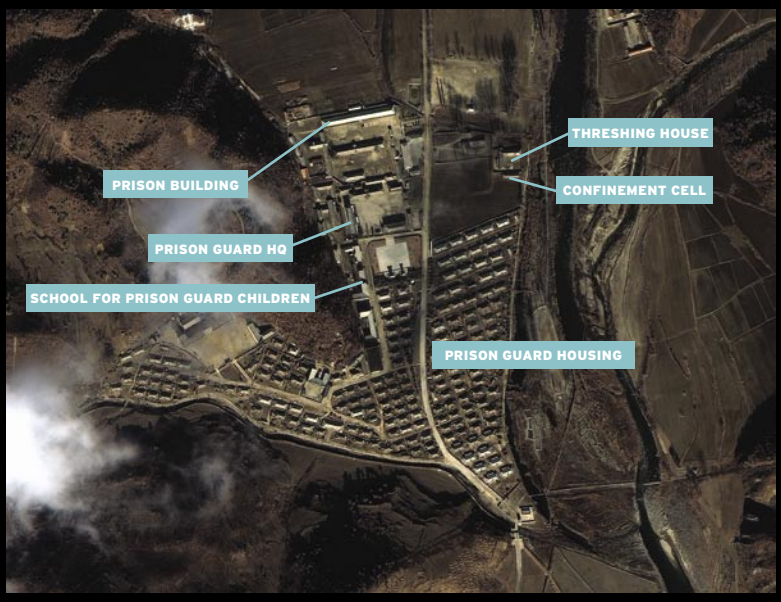


FIGURE 8 *IKONOS image of a section of Yodok Political Prison Camp, photographed on November 25, 2001.*

The pairing of commercial high-resolution satellite imagery with the testimony of North Korean defectors who were exposed to the Gulag creates a revealing window into this closed society. Annotated satellite images of five sites in the North Korean Gulag offer a glimpse into the different sorts of work that prisoners are forced to perform: food production and mining camps, for example, at very large sites consisting of several villages spread over more than a hundred square kilometers. Smaller prison sites have factories or workshops where prison laborers are forced to produce bricks, clothing, shoes, or other goods.

An IKONOS image of a small section of the Yodok political penal-labor colony is shown in ***Figure 8*** (Yodok is a very large site — approximately 80 square km in size). Yodok is one of the most thoroughly described prison camps (documented from 1977 through 1999) because a small number of prisoners held there were released back into North Korean society. Yodok's capacity is reportedly 40,000 to 50,000 prisoners, most detained for their lifetimes. Forced labor activities at Yodok include mining and agriculture. It is notable that officials at P'yongyang have declared North Korea's Yodok district off limits to the United Nation's World Food Program.[7]

High-resolution satellite imagery has proven to be a highly effective tool to understand better the North Korean military and to verify and refine public estimates of DPRK air force and navy weapons systems. Unusual features of the North Korean military were captured in the photographs — entrances to submarine caves and underground runways — which have significance for the nuclear situation on the Korean peninsula. Furthermore, satellite imagery provides added documentation and the only photographic component to an understanding of the North Korean Gulag. NRDC's efforts have revealed remarkable and unique features of the "Hermit Kingdom."

This report has not been previously published. It was presented in January 2005 to the Carnegie Endowment for International Peace in Washington, D.C., and was thereafter featured on CNN.

FOOTNOTES

1. Joel Binkley, "Visiting Korea Base, Rice Sends Forceful Reminder to the North," New York Times, March 20, 2005.

2. The "six-party talks" involve the United States, China, Russia, Japan and South Korea in diplomatic negotiations with North Korea concerning its nuclear program. Three rounds of six-party talks have taken place in Beijing, in August of 2003, in February and in June of 2004.

3. Dafna Linzer, "U.S. Misled Allies About Nuclear Export; North Korea Sent Material To Pakistan, Not to Libya," Washington Post, March 20, 2005.

4. See the Nuclear Threat Initiative's North Korea country profile at www.nti.org.

5. Joseph S. Bermudez, Jr., The Armed Forces of North Korea, *I.B. Tauris: London, 2001, pp. 128-130.*

6. David Hawk, The Hidden Gulag: Exposing North Korea's Prison Camps; Prisoners' Testimonies and Satellite Photographs *(2003), available at www.hrnk.org/hiddengulag-press.pdf.*

7. As of October 30, 2003, the World Food Program had access to 163 of DPRK's 203 counties/districts; see www.reliefweb.int.

TerraFly

A TOOL FOR VISUALIZING AND DISPENSING GEOSPATIAL DATA

NAPHTALI RISHE
Director
HPDRC and NASA Regional Applications Center

MARTHA GUTIERREZ
Manager
NASA Regional Applications Center

ANDRIY SELIVONENKO
TerraFly Project Technical Manager
HPDRC

SCOTT GRAHAM
Assistant Director
HPDRC and NASA Regional Applications Center

High Performance Database Research Center (HPDRC)
Florida International University
Miami, Fla.
www.terrafly.com

TerraFly is a geospatial database research project at Florida International University, with applications to industries ranging from real estate and urban planning to emergency preparedness and disaster mitigation. An interactive software tool for visualization of remotely sensed and spatial data, TerraFly allows users to experience virtual "flight" over imagery or maps by streaming incremental imagery tiles to a Java applet.

Presently, TerraFly delivers high-resolution imagery of the entire United States and selected cities and regions elsewhere on the globe, with increased international coverage coming soon. It manages its content via database and file system technologies developed by the High Performance Database Research Center and the NASA Regional Applications Center at Florida International University in Miami, Fla.

Virtual flight can be performed at various speeds, in all compass directions, and at various altitudes (spatial resolutions). Non-obstructing overlays are supported over the imagery including NAVTEQ NAVSTREETS Street data, property parcels, zip code contours, Geographic Names Information System (GNIS) objects, hotels, real estate listings, fire instances, and other data that have associated geographic coordinates. TerraFly's data-mining tools deliver an extensive amount of data related to user-specified geographical locations.

All the data services are provided via an Internet-based Java applet, giving TerraFly a much broader user base than conventional geographic information systems. The above-mentioned functionality suits the information needs of public users related to local geography, demography, quality of life, economics, and the environment.

However, TerraFly can also be customized for specific applications. Professionals, researchers and educators are among the groups that use customized TerraFly for their work. Among typical customization requests are:

- *support for a relatively small geographic area with recently acquired high-resolution proprietary imagery (for example, to assist water management in the area);*
- *temporal imagery support: the same geographic area over a period of time (urban construction and infrastructure development);*
- *non-obstructing custom data overlays (real estate, environmental studies, education);*
- *extra security and restricted access to sensitive imagery and datasets (homeland security, disaster management and mitigation).*

The cornerstones of the software are its portability, its fly-over technology, and its ability to integrate multiple sets of data into customizable, multi-layered products.

Fast and convenient access to a map or a remotely sensed image is achieved by the dispenser subsystem, providing an easy and intuitive way for users to choose, mark and dispense satellite images or aerial photos of any size. TerraFly's dispenser can also provide the user with textual geo-referenced data associated with a dispensed image. When combined with the requested imagery, this data gives the user a unique information package associated with the geographical area of interest. See ***Figure 1.*** This is important in many applications, including emergency preparedness and response.

TERRAFLY'S DISPENSER:

- *searches TerraFly's imagery database for all image tiles which can be used to generate the imagery for the user-defined area;*
- *searches the Space Imaging Carterra Archive for availability of IKONOS imagery over the selected area;*
- *searches TerraFly's information databases for all the possible data reports related to the area of choice;*
- *generates the web page to present users with all the unique product options available for the dispensed area.*

Among the TerraFly products and services are: aerial photography and satellite imagery (prints and digital files), posters, TerraAtlases, demographic reports, and autopilot flights.

TerraAtlas presents digital satellite imagery and aerial photos in a brochure format optimized for printing on standard letter-size paper or other user-defined paper formats. It can be downloaded by the user in a PDF format. As an option, street names and other data can be overlaid on the imagery. When additional data overlays are requested, an index is produced. The resulting TerraAtlas looks like a typical map-based street-finder atlas consisting of a background of imagery and a customized index. See ***Figure 2***.

Preparing for emergencies, and planning and documenting evacuation routes are valuable applications of TerraAltas, as is teaching the public about these routes, facilities and emergency services. The printed document

helps emergency response teams in the field, where a wireless connection to data servers is unavailable or where a shortage of electric power does not allow using computers.

TerraFly's autopilot technology supports the automation of features otherwise run by a user in manual mode. These features can be scripted to show automatically a pre-defined flight sequence that allows the user to experience TerraFly's multimedia capabilities without direct interaction. The applications for autopilot are numerous in the field of e-education, including environmental education, training for emergency preparedness in urban areas, and the study of crops in rural areas via the Internet.

Several user-specific applications have been created with TerraFly. One of these allows the software to be used as a flight planning service. Pilots can prepare future flight plans from any computer that has Internet access. TerraFly also has a set of unique features that will enrich the functionality and visualization capabilities of the flight planning process and computer training for future pilots.

Another application of this tool benefits realtors. Our application automatically downloads real estate listings from a Multiple Listing Service and places overlays onto the TerraFly imagery depicting such variables as property types, prices and square footage. Users can click on properties to get additional information via TerraFly's data mining tools. This application allows realtors to take their clients on virtual tours of neighborhoods.

TerraFly attempts to meet the challenge of making geospatial imagery and information available to consumers in an intuitive and useful manner by utilizing the latest Web and database technologies. It has received notice from the journals ***Science*** and ***Nature***, and accolades from a variety of sources, including the Yahoo! Top Pick of the Week and ***USA Today*** newspaper's Weekly Tech Pick.

As databases of Earth information continue to grow, TerraFly will demonstrate the crucial role that research advances in database technologies can play in bringing high-quality, remotely sensed data directly to end users around the globe.

This research was supported in part by NSF grants EIA-0320956, EIA-0220562, and HRD-0317692.

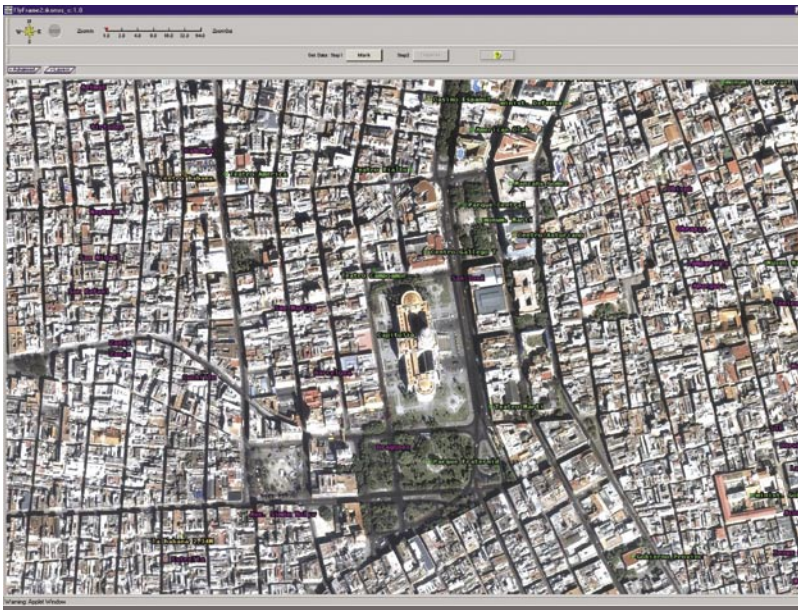


FIGURE 1: *TerraFly shows IKONOS imagery over Havana, Cuba with place and street name overlays.*

FIGURE 2: *TerraAtlas page shows USGS Urban Areas Aerial Photography over Atlanta with street names and U.S. Census city block population layers.*

A SINKING FEELING IN ARIZONA

Subsidence is Significant

JERRY SKAW
Marketing Communications Manager

Vexcel Corporation
Boulder, Colo.
www.vexcel.com

There's a sinking feeling about land levels in the Phoenix valley of Arizona.

Ground subsidence — the sinking of land surface — has been documented over several decades throughout the Phoenix valley, with measurements as large as five meters reported in the vicinity of Luke Air Force Base, west of the city of Phoenix. Even at a more moderate level of five centimeters or less per year, the hazards posed to infrastructure are very real. Ground motion compromises building foundations, canals, and sewer systems, while ground fissures (a byproduct of subsidence) have resulted in damage to dams, roads, and buried pipelines ***(see Figures 1 and 2)***. The problem is a costly one: in excess of $125 million per year, according to the National Research Council.

The root of the problem can be traced back to the early 1900s when agriculture expanded quickly across much of the western and southwestern United States. Large stretches of available land were ideal for growing the produce necessary to support the rapidly growing U.S. population. In Arizona, the agricultural industry has been a critical element of the economy with key exports that include cotton, vegetables, fruit and meat.

However, the annual precipitation of this arid region cannot support a thriving agricultural industry, and additional water sources for irrigation had to be identified. In the Phoenix valley, where the average annual precipitation is around three inches, technology has been leveraged since the early twentieth century to extract water naturally deposited in aquifers — underground geological stores. The fine-grained sediments that constitute the alluvial basins of south-central Arizona are ideal natural storage structures for vast quantities of fresh water. These geological structures are essentially composed of familiar materials like sand, clay and gravel. Water naturally deposited in these structures occupies the spaces between particles and is available for removal via pumping. This historically rich natural resource has been the impetus for much of the growth in the Phoenix and Tucson areas.

The enthusiastic extraction of water for irrigation during the early to mid-1900s, coupled with the rapidly growing population in these areas has led to a significant decline of water levels within the aquifer system. As fluid is withdrawn from the aquifer structure and the water level decreases, the hydrostatic pressure supplied by the fluid to the granular structure is also reduced. If enough ground water is withdrawn, the aquifer begins to collapse slowly under its own weight. Excessive pumping of groundwater has resulted in compaction of the aquifers, and this subsurface compaction is resulting in surface elevation change, or subsidence.

To address this growing hazard, the Phoenix valley is again turning to technology — the Arizona Department of Water Resources (ADWR), under a NASA grant, has subcontracted Vexcel Corporation (Boulder, Colo.) to apply its satellite radar remote sensing technologies to monitor the extent and rate of the subsidence problem. Using interferometric synthetic aperture radar (InSAR), Vexcel is providing measurements that are highly accurate, spatially dense, and yet significantly less expensive than traditional surveying techniques such as GPS, extensometers, and leveling surveys.

InSAR WE TRUST

The foundation of InSAR is synthetic aperture radar (SAR), a mature technology first demonstrated during the 1960s. Functionally, the approach consists of a radar system aboard a moving platform — in this case, a spaceborne satellite — emitting radar pulses and listening for the returned echoes as they are reflected from the ground. Through signal processing, the received pulses are combined to produce a high-resolution image.

The InSAR technique takes advantage of the coherent nature of SAR to extract very accurate measurements of changes on the Earth's surface. In the InSAR implementation, the satellite collects data over the region of interest at different times. The phases of the resulting data sets may be compared at each sample area on the ground to detect changes. Surface displacement measurements of less than a centimeter over an area of several square kilometers have been routinely demonstrated in subsidence applications similar to the one in Phoenix using InSAR techniques. Through more advanced applications of the same technology, displacement rates on the order of a few millimeters per year have been demonstrated.

In addition to the accuracy and wide-area continuous coverage made possible by InSAR, the technology has offered better cost efficiency than traditional surveying techniques. A standard InSAR frame covers an area of approximately 10,000 km^2 at a pixel resolution of about 50 meters — or 4,000,000 discrete point measurements within the 100 km by 100 km frame. The cost to perform static GPS survey with this same vertical precision but at 1/1000th the resolution would cost conservatively $500,000 for the two surveys required to measure change. The cost per point measurement to produce an InSAR change map using currently available satellite data is less by many orders of magnitude than with conventional technologies.

FIGURE 1
Fissures are the primary surface expression of subsidence and threaten infrastructure such as roads, dams, canals and pipelines.

FIGURE 2
This photo demonstrates 5.5 meter elevation change observed near Luke Air Force Base over 34 years. Courtesy of Herb Schumann.

PRAISING ARIZONA

An important goal in the Phoenix project is to provide time-dependent measurements to the water resource community. To meet this challenge, an entire archive of satellite imagery captured over the Phoenix valley from 1992 to 2000 was acquired. This wealth of data — roughly 80 frames of a 3600 square mile area — allows Vexcel to track the evolution of the subsidence occurring during this particular period of time for which satellite imagery exists. Applying their SAR processing technologies to this data, Vexcel is producing a time series of subsidence maps that accentuate significant ground deformation in Phoenix

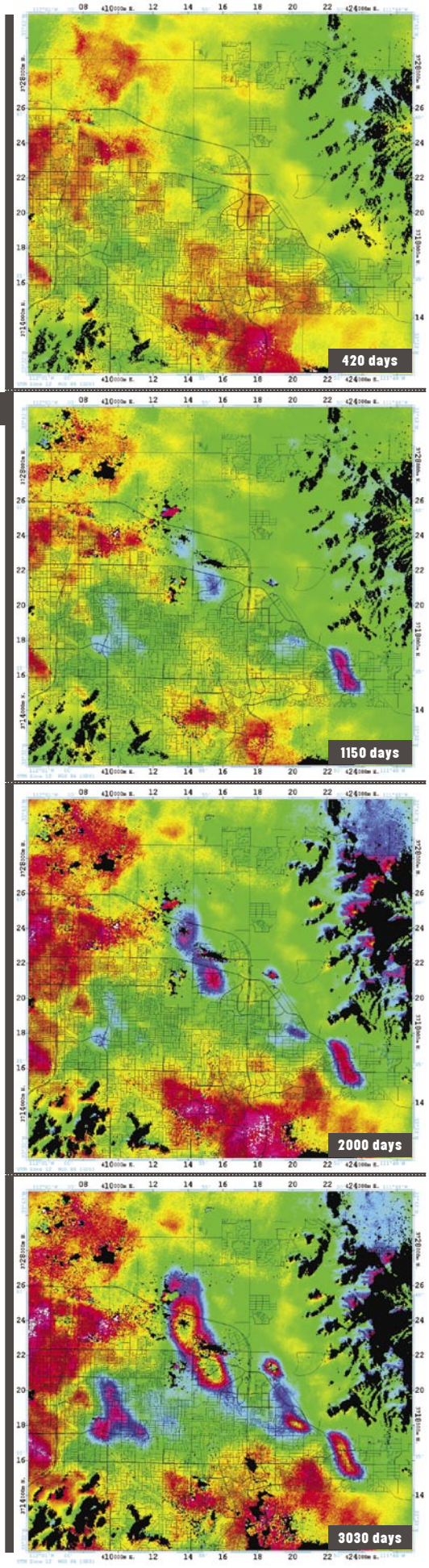


Figure 3

FIGURE 3 *Time sequence of ground deformation in Scottsdale, Ariz. area derived interferometrically from ERS 1/2 SAR data. Each cycle of color corresponds to 9 cm of ground motion.*

and the surrounding area over an eight-year period. A subset of these maps is shown in ***Figure 3***.

The ADWR and local water resource community can now compare these data to aquifer pumping, water table levels, weather patterns, urban development and other activities that occurred within this same time frame to understand better what factors are contributing to this subsidence. From this information, water management policies and city planning decisions are being developed to address the problem.

The subsidence measurements are assisting the ADWR in its efforts to educate the public and local government agencies on the reality and severity of the land subsidence hazard. For example:

a. *The visual impact of the maps is believed to have influenced residents of the city of Peoria who recently voted for an increase in water rates allowing the city to move away from reliance on groundwater pumping and toward reliance on renewable water supplies. Additionally, the city is now in the planning phase of building a $25 million wastewater treatment facility. Initial plans called for a gravity drain line to run through an area that has been identified to be subsiding. This information allows the city either to account for the deformation in their engineering design or possibly to re-route the line and avoid the impacted area.*

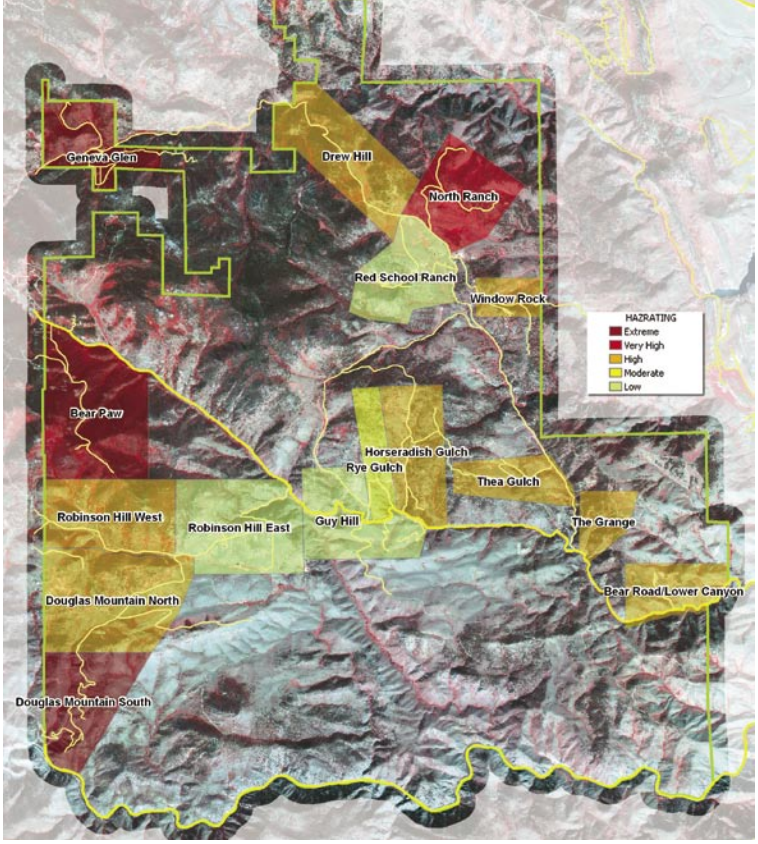
b. *The Central Arizona Water Conservation District (CAWCD) is using a number of maps to define the extent of a small subsidence feature that impacted a 2.5 km segment of the canal that runs through Scottsdale, Arizona. The center of the feature had subsided approximately 0.5 meters with respect to its edges and was restricting the maximum volume of water movement through the system. A more critical issue arose when a local geologist, using a geo-referenced subsidence map, identified a previously undiscovered earth fissure at the northwestern edge of this same subsidence feature. From the map and geophysical models, he was able to determine where earth fissures were likely to occur and found one within steps of the predicted location. Had the fissure gone unnoticed, approximately 75% of canal deliveries would have been interrupted.*

c. *The Flood Control District of Maricopa County is using the subsidence maps to define dam areas with high risk for failure due to fissure formation. The enhanced capability, through InSAR, to estimate potential areas of earth fissuring is resulting in improved dam safety and increased public safety by reducing the risk that an earth fissure will go undetected.*

The integration of InSAR displacement maps into the decision support process for a variety of users in Arizona commercial and government organizations demonstrates the value of these tools for hazard mitigation and characterization.

Ground deformation measurements using satellite remote sensing technology are being used in several locations across the U.S. and around the world. The results are providing geotechnical specialists and water resource managers with critical measurements of changes in land surface elevation due especially to depletion of aquifers.

While relatively mature, the InSAR technology continues to evolve to provide increased sensitivity and broad applicability. New radar satellites and burgeoning data processing techniques assure that this technology will continue to lead the way in monitoring changes that indicate more serious water resource issues posing threats to infrastructure.



Burning Solutions

Solving America's Worsening Wildfire Dilemma

DAVID BUCKLEY
Manager, Business Solutions Division
The Sanborn Map Company
Colorado Springs, Colo.
www.sanbornmap.com

RODRIGO MORAGA
Managing Partner
Anchor Point Group LLC
Boulder, Colo.
www.anchorpointgroup.com

FIGURE 1 *Several communities in the Golden Gate FPD with the false color IKONOS imagery and the hazard ratings derived from the assessment*

Colorado was burning. On June 11, 2002, no fewer than 12 major wildfires were ripping across the state, sending the stench and haze of smoke across the West and into cities as far away as Chicago. The biggest blaze, the 138,000-acre Hayman Fire, would grow so large so quickly that it would demand the oversight of not one, but two of the nation's 12 Incident Management Teams. In a single afternoon, the Hayman's flames would make a stunning 60,000 acre run, a stark reminder that America had a profoundly serious wildfire problem.

Others around the country had already had similar wake-up calls: Two years earlier, it was the folks in Los Alamos, New Mexico, who had seen more than 400 of their homes burn. The next year, residents of San Diego experienced a firestorm that wiped out nearly 2,000 homes and killed more than 20 people.

Still, if there is a silver lining in this dry cloud, it's the fact that in recent years, government land managers and politicians are in agreement: A century of forest mismanagement and over-zealous suppression policies, which removed healthy fire cycles from the ecosystems, have made America's forests into tinder boxes.

The sheer magnitude of the problem is the most immediate obstacle to its solution. The 'wildland-urban interface' comprises more than 100 million acres of overgrown land filled with millions of homes and many new communities. Just as daunting is the fact that all forests are not alike — a grass fire burns quite differently than a thick ponderosa pine forest. So assessing accurate wildfire hazards and risks on a large scale has been generally a complex, man-power-intensive, inconsistent, time-consuming and costly exercise.

THE NEW PRIORITY FOR GOVERNMENT

Fighting wildfires has become an expensive fiscal responsibility. In five of the past six years, suppression costs at the federal level alone have surpassed $1 billion annually, an unprecedented and problematic fact. With combined state and local costs believed to be more than double that amount, the bottom line of fighting fire is an enormous figure.

Some of the worst fire seasons on record have occurred in the past five years alone and in highly populated communities. For the first time, reliable studies are demonstrating the long-term fiscal impact of wildfires. A September 2004 study of the Hayman Fire found that, more than a year after the fire, Hayman-impacted counties like Jefferson and Douglas, as well as agencies like the Colorado Department of Transportation, were still paying hundreds of thousands of dollars for a variety of persistent costs, from mud slides to road repair to watershed contamination.

The fiscal realities have led to a deep rethinking about prevention and preparedness planning, best exemplified by Washington's 2001 $1.8 billion National Fire Plan and the 2003 Healthy Forests Restoration Act (HFRA). Both directives carry accompanying funding for prevention programs.

The HFRA includes a congressional directive whereby the 23,000 communities at risk of a wildfire event must develop a comprehensive Community Wildfire Protection Plan (CWPP). Additional money was provided through FEMA firefighter programs to assist those communities with their CWPPs, and in less than two years, the CWPP has evolved into a nationally-recognized process to save America's threatened communities from devastating wildfires.

While the CWPP is an earnest and solid start to solving the wildfire problem, it has its own dilemmas. The methodology of the CWPP requires the convening of key community decision-makers for the

FIGURE 2 « *IKONOS false color imagery with the image segmentation results that identify homogeneous fuels on the landscape (yellow)*

Table 1 Fuels Classification Scheme

Fuel Model (FM)	Typical Fuel Complex
	Grass dominated
1	SHORT GRASS (1 FT)
2	TIMBER (GRASS UNDERSTORY)
3	TALL GRASS (2.5 FT)
	Chaparral and shrub fields
4	CHAPARRAL (6 FT)
5	BRUSH (2 FT)
6	DOMINANT BRUSH, HARDWOOD SLASH
7	SOUTHERN ROUGH
	Timber litter
8	TIMBER LITTER WITH NORMAL DEAD
9	HARDWOOD LITTER/OPEN PINE WITH GRASS
10	TIMBER LITTER WITH HEAVY DEAD
	Slash
11	LIGHT LOGGING SLASH
12	MEDIUM LOGGING SLASH
13	HEAVY LOGGING SLASH

establishment of community hazard reduction priorities and recommendations. Also in the CWPP directive is the development of community risk assessments based on such key information as accurate fuel models and the likelihood of a wildfire event.

In 2003, two Colorado companies teamed up to develop an effective, scientifically sound and financially reasonable answer for governments, landowners, and corporations — The Sanborn Map Company Inc. (Colorado Springs, Colo.) and Anchor Point Group LLC (Boulder, Colo.). They approached this problem with a logical premise: Complement sound geospatial technologies with robust fire science and operational fuels and fire planning knowledge, and provide a solid basis for mitigating risk and preparing communities for fire incidents. In the fall of 2004, that unprecedented effort was finally accomplished.

DRILLING DOWN TO THE LOCAL LEVEL

GIS and remote sensing, especially for fuels mapping, have been applied successfully at the regional level and strategic scale for several years. In 2002, just as the new 'prevention' thinking was getting a foothold in federal and state governments, the State of Florida Division of Forestry successfully completed a statewide fuels mapping and wildland fire risk assessment project that quantified the fire situation across the state. The results provided a sound data platform for Florida fire professionals to plan their long-term strategies for reducing hazardous fuels and risk in fire-prone areas.

> *"With approximately 600 CWPPs completed to date (about two percent of the total needed), quality and consistency are already becoming issues."*

The Florida project raised the bar of fire prevention to an unprecedented level of accuracy and consistency by leveraging geospatial technologies, along with fire-science and operational expertise for fire planning. In the end, Florida became the first state to satisfy the requirements of the implementation plan for the federal government's 10-Year Comprehensive Strategy (Task E, Goal 4), a state and federal multi-agency effort laid out in May 2002 for wildland fire prevention planning across the nation.

Still, while GIS and remote sensing play a critical role in providing detailed data for fuels, structures and physical features, the critical ingredients to providing real wildfire solutions are on-the-ground, wildland-urban, interface-based risk assessment and fire planning. Executives at Anchor Point Group and Sanborn Map Company saw the extraordinary opportunity to blend their technological and subject-matter expertise to provide an unparalleled level of quality fire-risk assessment and planning solutions.

The partnership couldn't have come at a better time. Government agencies at all levels are struggling to define the science and methodology behind the CWPP. While several organizations such as National Association of Counties, National Association of State Foresters, and International Association of Fire Chiefs, among others, have attempted to set guidelines for CWPP development, to date there are still no hard-science standards coupled with real fire solutions. As a result, with approximately 600 CWPPs completed nationwide to date (about two percent of the total needed), quality and consistency are already becoming issues.

In an effort to bring continuity and consistency to the CWPP, the Anchor Point/Sanborn team turned to local Colorado agencies to demonstrate its revolutionary methodology. With funding from the Colorado State Forest Service and Jefferson County, the Anchor Point/Sanborn team executed a pilot project for a small community outside Denver and in the fall of 2004, completed an unprecedented CWPP.

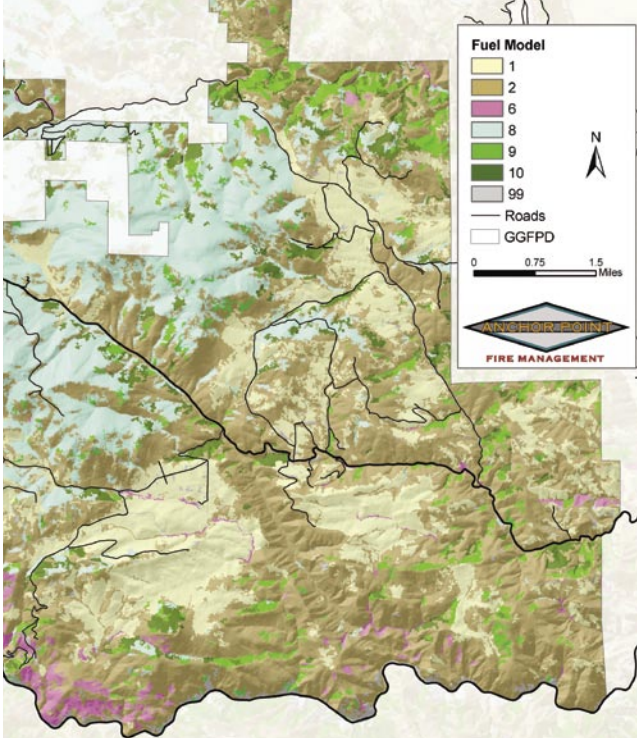


FIGURE 3 *The final fuels map developed for Golden Gate FPD*

THE GOLDEN, COLORADO PROJECT

The Golden Gate Fire Protection District (FPD) is in the heart of fire country in Colorado, located at the doorstep of the Rocky Mountains just west of Golden, 15 miles from downtown Denver. The area studied by Anchor Point/Sanborn encompasses Golden Gate Canyon State Park and the Golden Gate FPD, a total of 49 square miles with about 300 homes located in the center of the wildland-urban interface.

The project utilized high-resolution imagery combined with field surveys to derive a highly accurate fuels map for the area of interest. The fuels map is the cornerstone of the fire-risk assessment. IKONOS 4-meter resolution multi-spectral imagery was used, collected on August 13, 2004, covering the 360-square kilometer area. This imagery is orthorectified to a precision level product (4m CE90, 1:4,800 NMAS) and contains both1-m panchromatic and 4-m 4-band (R, G, B, NIR) multi-spectral information, creating a spectrally balanced and seamless mosaic.

High-resolution imagery supports accurate integration with other GIS data sets, facilitating use for the fuels mapping to be conducted in this project and for future assessment and fire planning efforts. Golden Gate FPD comprises several communities shown in ***Figure 1*** (page 27), with the false color IKONOS imagery for the area and the hazard ratings derived from the assessment.

As part of the imagery classification process, in collaboration with Sanborn, Anchor Point was sent to the study area to calibrate what appeared in the imagery with the actual vegetation types on the ground. While at the study area, the Anchor Point team identified and classified training sites that were put into the automated classification process.

The fuels map was then generated by applying image classification techniques. The initial output was a general vegetation map, which was then combined with Canopy Closure to generate the draft surface fuels model. Surface fuels models are traditionally mapped to 13 Northern Forest Fire Laboratory (NFFL) fuel models described originally by Albini and further described by Anderson (Anderson 1982). A total of 13 fuel models fall within four basic groups. See ***Table 1.***

While doing the ground-truthing and field-accuracy assessment, Anchor Point fuels specialists conducted a manual fuels assessment. Survey points were captured utilizing a standard, digital methodology to facilitate data transfer. The manual fuels data were used to refine the classification and to independently support the accuracy assessment.

This project allowed the Anchor Point/Sanborn team to test new methods for determining surface fuels with the benefits of finer spatial resolution and feature delineation. Sanborn leveraged techniques it has pioneered for land-cover and impervious mapping using high-resolution imagery, but prior to this project, they had never been applied to fuels mapping.

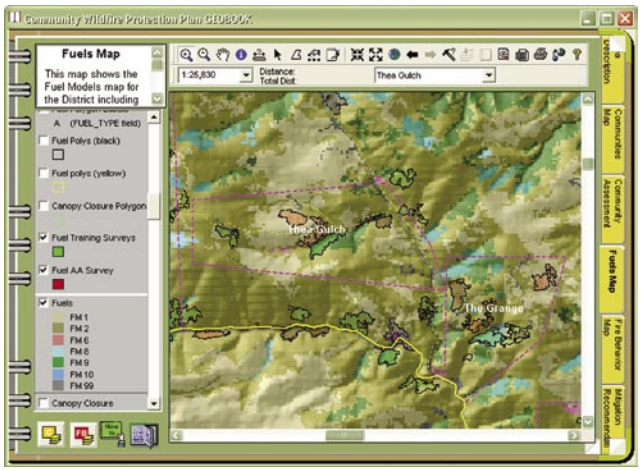
A NEW LOOK AT FUELS

The study area was mapped to the 13 Albini/Anderson NFFL fuel models.

Due to the diversity of ground cover within fuel-model polygons, the classification was performed on polygons derived from image segmentation, rather than from a per-pixel classification.

A benefit of the polygon classification is the utilization of derivative bands that characterize the general area. Use of texture, slope and aspect on a polygon level is more beneficial than on a per-pixel classification, but a polygon classification lacks the spectral diversity of the vegetation within a polygon. A general per-pixel classification was performed to minimize the loss. ***Figure 2*** shows the IKONOS false color imagery along with the image segmentation results that identify homogeneous fuels on the landscape (yellow).

FIGURE 4 *The Fuels Interactive Map page of the Golden Gate CWPP GEOBOOK*



The fuels mapping deliverables consisted of two ArcView shape files representing Canopy Closure and Fuel Models. The final edited fuels map polygons were dissolved based on the fuel model, and a one-acre minimum mapping unit was applied. The final map consisted of 5,318 polygons averaging about 15 acres in size. ***Figure 3*** shows the final fuels map that was developed for Golden Gate.

The second deliverable was a percent canopy closure map which was calculated from the pixel classification. The percent canopy was calculated for each polygon and grouped into four classes: 1-20 percent, 21-40 percent, 41-60 percent, and > 60 percent.

A fuels accuracy assessment was also undertaken through methods that were originally developed in support of land cover mapping methods for USGS and have become the standard approach for conducting accuracy assessments in the mapping industry. Quantitative accuracy assessment of maps produced from remotely sensed data involves the comparison of a map with reference information. In the end, Anchor Point and Sanborn achieved an overall accuracy of 83.2% for the Golden Gate map.

REAL COMMUNITY SOLUTIONS

Using the highly accurate fuels data, a hazard and risk assessment was undertaken at the community scale by Anchor Point fire planners to develop the CWPP and mitigation recommendations, which were then used in community meetings and public outreach providing Pre-Attack Plans for first responders, and Annual Work Plans for long-term ecosystem management programs.

To aid in delivery and distribution of the CWPP to interested parties, the results were encapsulated in Sanborn's GEOBOOK map book product. The GEOBOOK is an intuitive GIS application that is provided in an easy-to-use digital book format with no software royalty fees.

The real power of the GEOBOOK lies in the Interactive Map pages where real time GIS querying and mapping are available. Operating much like ESRI's ArcView GIS, the Interactive Map page provides the reader real-time access to the CWPP GIS data. The GEOBOOK provides a comfortable and intuitive mechanism for non-GIS audiences like local fire fighters to access the power of GIS data within the context of a sound, scientific fire plan. It can be customized to support content such as key photographs, individual home assessments, local fire policies and contacts, Pre-Attack Plans, general methodology information, FireWise guidelines, and more.

The Fuels Interactive Map page of the Golden Gate CWPP GEOBOOK provides a range of GIS tools to browse and query the fuels data in concert with other datasets, such as community infrastructures, fire behavior analysis results, and proposed mitigation recommendations. Book readers can quickly zoom to a community area using pull-down menus, or query the map for areas of interest. See ***Figure 4***.

THE NEXT FIRE SEASON

Prolonged drought and dismal snow pack in the Pacific Northwest have led most fire analysts to agree that fires in this area will be the big stories of 2005. As fire-prone communities all across the West head into the 2005 season, many of them are earnestly looking to the future, knowing that the time may come when they must prove their preparedness. The Sanborn and Anchor Point teams' efforts have left little doubt that geospatial technologies in fire management and planning are the keys to the development of effective, scientifically based CWPPs.

REFERENCES

Anderson, Hal E. 1982. Aid to Determining Fuel Models for Estimating Fire Behavior. *USDA Forest Service Gen. Tech. Report INT-122, p. 20.*

Story and R. Congalton. 1986. Accuracy Assessment: A User's Perspective. *Photogrammetric Engineering & Remote Sensing, 52(3): pp. 397-399.*

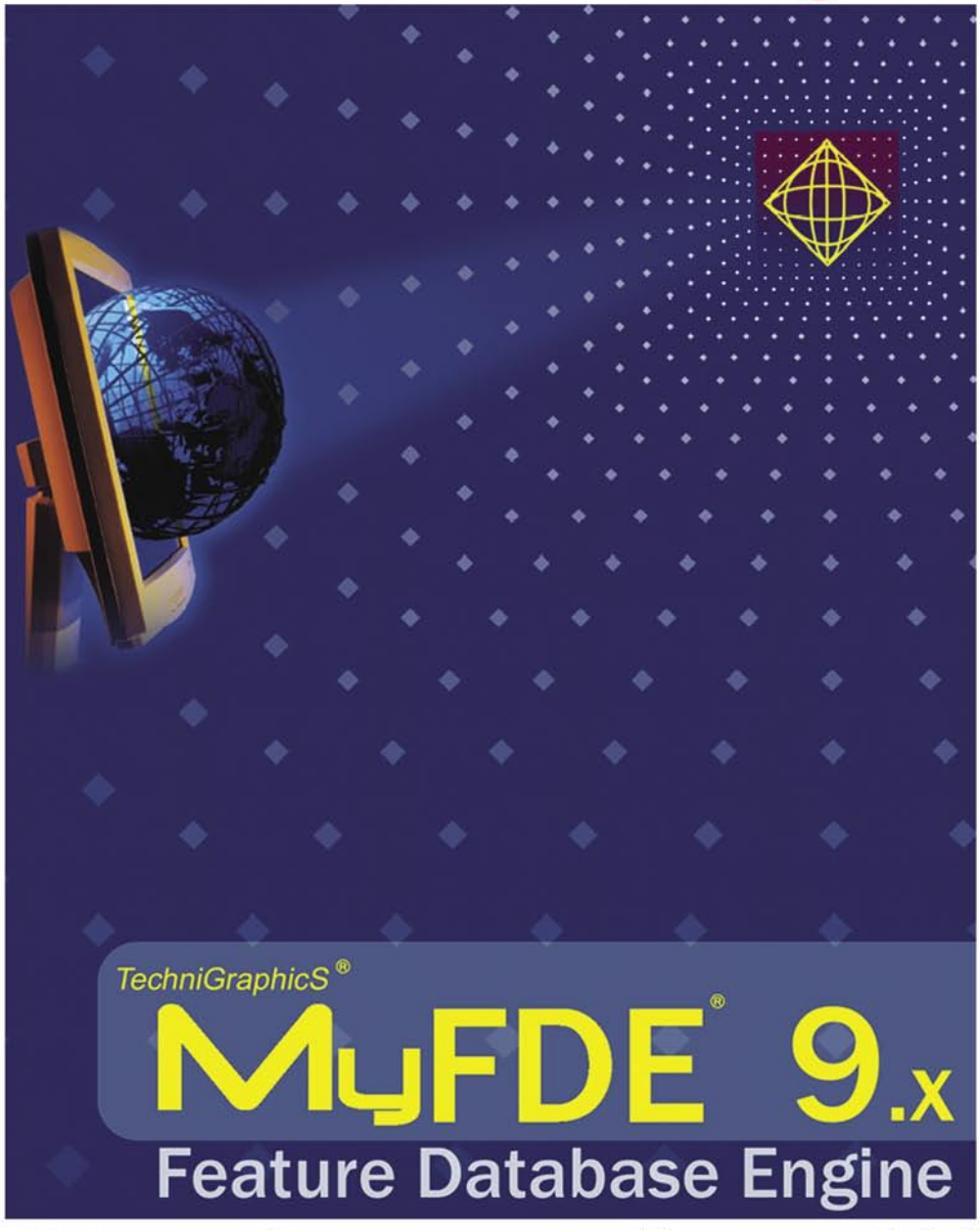
Congalton, R. 1991. A Review of Assessing the Accuracy of Classifications of Remotely Sensed Data. *Remote Sensing of Environment, 37: pp. 35-46.*

Lynch, Dennis 2004. What Do Forest Fires Really Cost? *Journal of Forestry, September 102(6): pp. 42- 49.*

New!! MyFDE®

Server Software for

Concurrent editing via ArcView®



Helps small groups work with geospatial data more efficiently!

ESRI® User Conference Special

Tel: 330-263-6222

Only $999