

# THE American Surveyor

A FOOT IN THE PAST... AN EYE TO THE FUTURE

Winter 2009

## SEE THE WORLD

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Tennessee-Kentucky border

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10 things I've learned



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An aerial photograph of a high-altitude landscape. On the left, a large glacier flows down a slope. In the center, a vibrant turquoise lake is filled with numerous icebergs of various sizes. The surrounding terrain is rugged and brownish, with patches of snow on the mountain peaks. The sky in the top right corner is a clear, deep blue with a few stars visible.

# EYEIN





# THE SKY

## A Visit to GeoEye

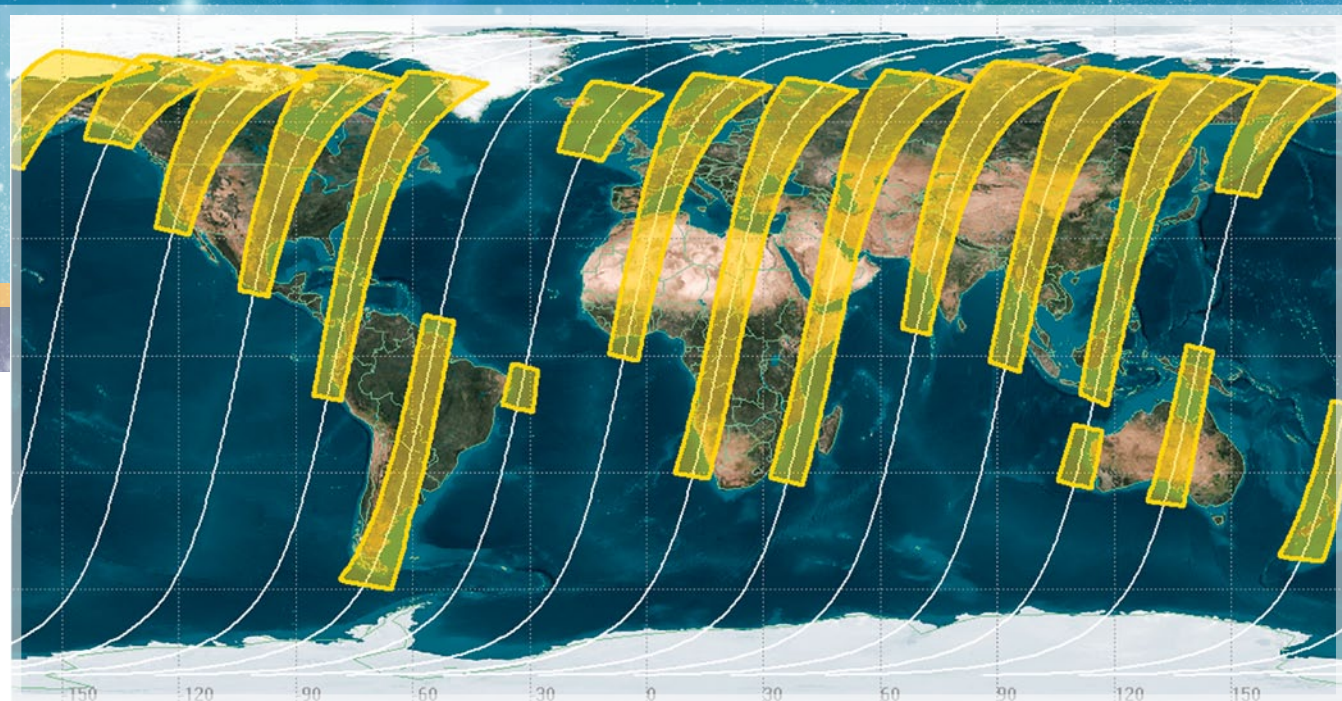


This IKONOS image shows Bear Glacier, Kenai Fjords National Park, Alaska, USA. Bear Glacier is one of 40 glaciers that flows off the vast Harding Icefield in Kenai Fjords National Park, located 130 miles south of Anchorage. The icefield is the largest in North America, and remains a 300-square-mile vestige of the last Ice Age.

**F**rom August 1960, when a capsule containing exposed film from the first classified military reconnaissance satellite was parachuted back to Earth, to present day 2009, when better than half-meter satellite imagery is available to the public, we have witnessed quantum leaps in space-borne imagery. One company that has been at the forefront of the modern era of this revolution is GeoEye, a company created when Orbimage acquired Colorado-based Space Imaging in January 2006. Growth continued as GeoEye acquired M. J. Harden, a traditional photogrammetry company, in March 2007. GeoEye has grown from the smallest U.S. commercial imagery satellite operator to one of the largest in the world in five years. Today it gathers imagery from GeoEye-1, IKONOS, OrbView-2 and traditional aerial photogrammetry. Both GeoEye-1 and IKONOS are high-resolution electro-optical satellites. As of October 2009, GeoEye had collected a combined 340 million square kilometers of imagery.

>> By Marc Cheves, LS





Depicted above are the projected flight paths for GeoEye's constellation of satellites. Fifteen synchronous orbits make up a typical GeoEye daily imaging plan. Each orbit is approximately 90 minutes and the corresponding ground tracks follow the sun around the earth. In the panchromatic mode, the high-resolution IKONOS and GeoEye-1 satellites are capable of collecting a total of almost one million square kilometers every day.

While GeoEye's primary customers are the defense and intelligence communities within the U.S. government, plans are underway to expand into markets that will serve surveyors and engineers. We recently met with Mark Brender, GeoEye's vice president of Communications to learn more about its offerings to the land development community. Earlier this year, GeoEye announced its partnership with Google, Inc. to supply imagery for Google Earth and Google Maps. Users of popular online mapping programs can already see the impact of high-resolution imagery that

has replaced previous low-resolution and outdated imagery.

GeoEye-1, the company's premier satellite, was launched in September 2008 and incorporates two technologies that dramatically increase its accuracy. First is an onboard  $\pm 1\text{m}$  military-grade GPS receiver and second are super-accurate star trackers (see sidebar). The presence of the high-accuracy GPS receiver is evidence of the cooperation between GeoEye and the U.S. government, with commercialization of earth imagery going all the way back to the Reagan administration. With

numerous countries around the world launching earth imaging satellites, government cooperation and funding is necessary for the U.S. to maintain its technological edge. In the case of GeoEye-1, 50 percent of the funding came from GeoEye and 50 percent from the Department of Defense.

Headquartered in Dulles, Virginia, GeoEye has 534 employees (as of September 30, 2009) and is dedicated to developing best-in-class geospatial, communications and information products, systems, and services. GeoEye's CONUS Terminal (pictured right) is one of four worldwide terminals used to contact GeoEye-1 several times per pass.





GeoEye's biggest customer is the National Geospatial-Intelligence Agency (NGA). Fifty-five percent of GeoEye's forecasted \$270-280 million annual revenue this year will be from the NGA, with 30 percent coming from foreign governments.

Also for competitive reasons, Brender said that GeoEye is working to have the half-meter resolution limit removed. GeoEye-1 is capable of .41-meter resolution but the government currently requires GeoEye to restrict the publicly-available imagery by down-sampling it to .5 meters. True or not, we've heard for years that the spy satellites can read a license plate from space. What we do know, though, is that GeoEye-1 can "see" an object the size of home plate on a baseball diamond from 423 miles in space. But Brender said the



This half-meter resolution image of the airport at Palma, Majorca was captured by the GeoEye-1 satellite on April 6, 2009. Palma is the major port on the island of Majorca, and it is the capital city of the autonomous community of the Balearic Islands in Spain. Circle inset shows high resolution.

## THE FIRST U.S. RECONNAISSANCE SATELLITE

In early 1958, a few months after the Soviets launched the first Sputnik, President Eisenhower authorized a top-priority reconnaissance satellite project jointly managed by the CIA and the U.S. Air Force. It was to launch into orbit a camera-carrying spacecraft that would take photographs of the Soviet Union and return the film to Earth. Code-named Project Corona, more than 100 Corona missions took more than 800,000 photographs from 1960 to 1972. As cameras and imaging techniques improved, Corona and other high-resolution reconnaissance satellites provided increasingly detailed information to U.S. intelligence analysts.

The Corona camera used a stereo-vision technique that helped CIA photographic analysts better estimate the dimensions of missiles and other objects. Two cameras were mounted side by side, one pointing slightly ahead in the satellite's direction of motion, the other slightly behind. Both took pictures of the same territory, but from different angles and with a slight delay.

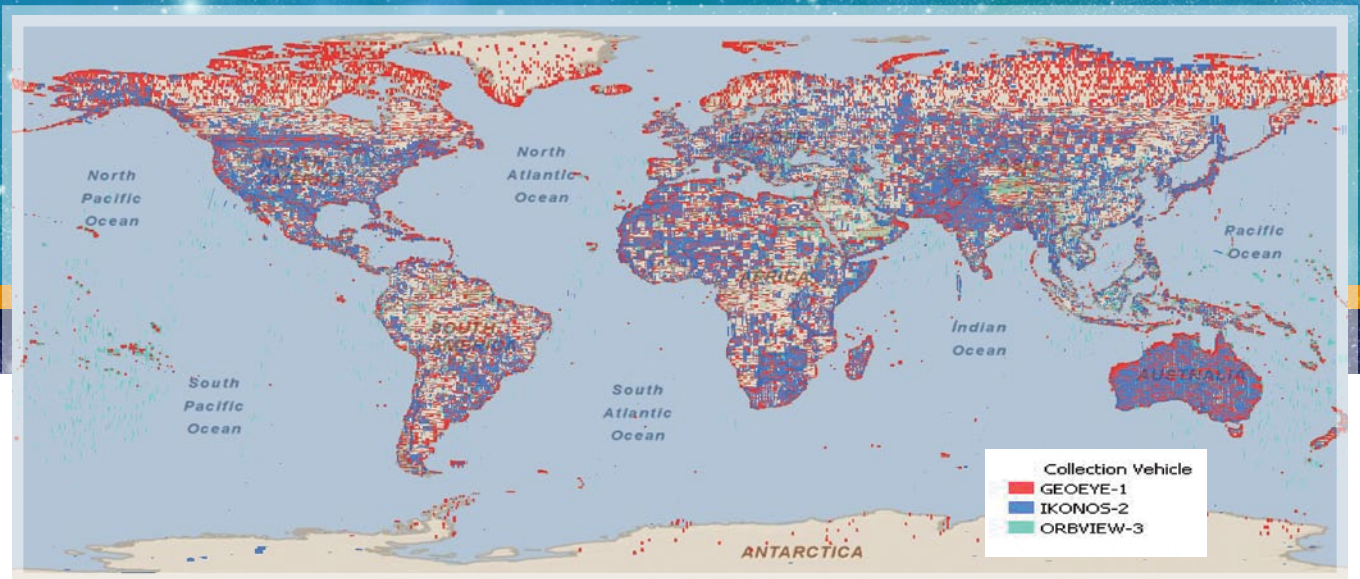
When all the exposed film had been wound onto the reel, the nose cone return capsule was ejected at a pre-

determined time and location. As the capsule descended to Earth, a heat shield protected it and a radio beacon indicated its position. A special Air Force unit based in Hawaii retrieved the Corona capsules. The squadron flew modified C-119 and C-130 aircraft, trailing a "trapeze" bar with hooks to snag the capsule's parachute.

Starting in the early 1970s, both nations began to rely on satellites to monitor compliance with arms control treaties. In 1995 President Clinton de-classified Corona. Details of reconnaissance satellites more recent than Corona remain officially secret, but some features are known. Today's reconnaissance satellites are larger, school bus-sized like the Hubble Space Telescope. They no longer return hardcopy film from space. Instead, visual images are converted to digital data and transmitted to Earth. Corona photo-analysts usually had to wait a week or more for photographs. Today images from reconnaissance satellites can be received in a matter of minutes, permitting almost instant analysis of a developing threat.

Source: *Smithsonian Air & Space Museum* <http://www.nasm.si.edu/exhibitions/gal114/SpaceRace/sec400/sec430.htm>





This world coverage thematic map shows vast amounts of archived, high-resolution satellite imagery collected daily by GeoEye’s imagery sources. The imagery is processed and used in a multitude of applications such as mapping, disaster response, infrastructure management, and environmental monitoring.

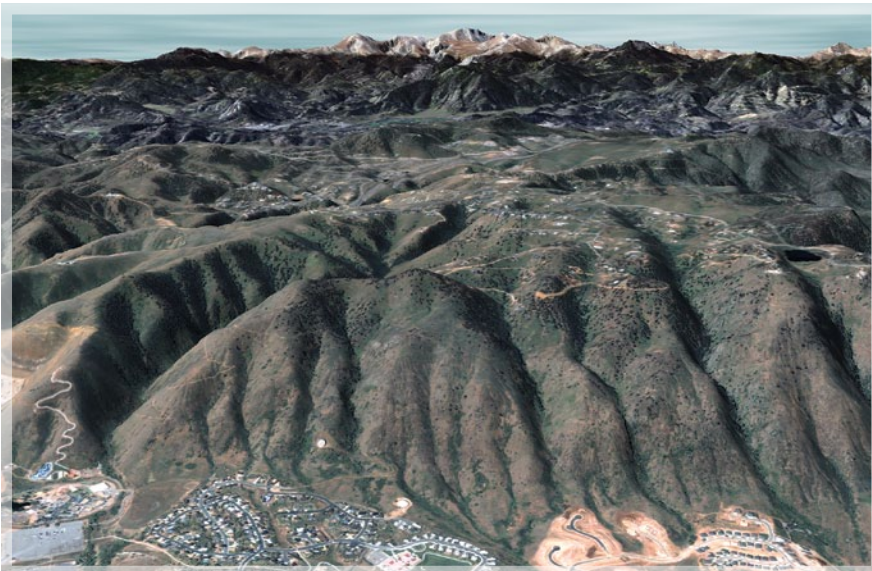
next-generation GeoEye-2 satellite will be capable of .25 meters. With that capability we’ll be able to identify objects less than one foot in size!

When I inquired about GeoEye’s decision to acquire M.J. Harden, Brender acknowledged the competition from foreign imaging satellites and said, “Only so much money can be made from selling pixels. As pixels become commoditized, value-added services for our customers will be critical.”

I also met with Michael Madden, the Director of Systems Engineering, to learn more about the GeoEye-1 technical details. He emphasized that the onboard military-grade GPS and star tracker set the GeoEye-1 satellite apart from other imaging satellites. GeoEye-1 is the first commercial satellite with military-grade GPS. Unprocessed imagery can be geo-located anywhere to  $\pm 5m$ , but when captured as a stereo view—stereo views can be taken by looking forward

and backward and left and right as the satellite passes overhead—the accuracy increases to  $\pm 3m$  (both with a circular error (CEP) of 90 percent). In an experimental project in Australia, it was demonstrated that, with only a single ground control point, one sigma planimetric accuracies of 0.1m and vertical accuracies of 0.25m can be achieved.

In terms of orbit, GeoEye-1 revisits the same place on the globe every three days, but from a slightly different angle. Because



GeoEye’s IKONOS satellite collected two images of Jefferson County along the Front Range of Colorado which gives the company the ability to generate a 3D image from stereo data collected during a single orbital pass. When combined with digital elevation models (DEMs), the result is a 3D map-accurate image that can be quickly and cost effectively acquired.

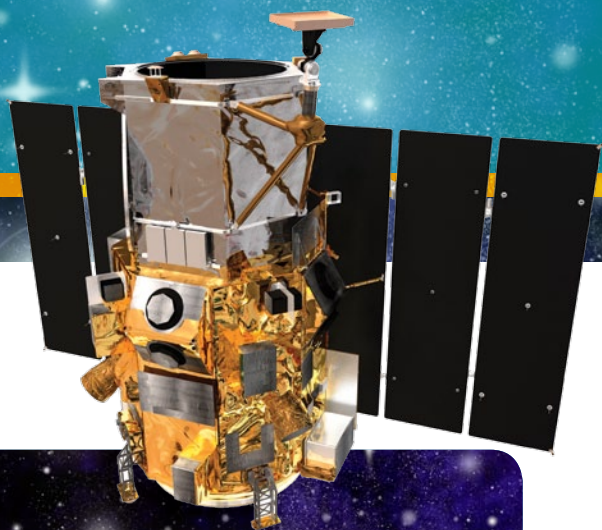


This photo of GeoEye-1 was taken from General Dynamic’s facility in Gilbert, AZ in May 2008. The photo shows test engineers in the clean room after successful completion of all environmental testing on GeoEye-1, which is an important step prior to being shipped to the launch pad.





A GeoEye employee provides an overview of the image processing system to Editor Marc Cheves and Mark Brender.



it is sun-synchronous, the revisits take place at approximately 10:30 A.M., the time the satellite crosses the equator. This time was chosen because there are usually less clouds in the morning and shadowing is minimized near noon. But because GeoEye continues to operate IKONOS, which follows the same orbit but 180° out of phase, the revisit time over any point on the earth is actually every 1.5 days.

Will space imaging ultimately supplant traditional aerial photogrammetry? Madden says no, and for several reasons: planes can be more rapidly mobilized than satellites, they can fly below/around cloud cover, and they are much more flexible in terms of the amount of side view. For example, a satellite might only occasionally see the north side of a building, but a plane can gather whatever views are needed. Even so, the stereo capability of the satellite brings to the table the possibility of an enormous amount of value-added products. Through the use of gyroscopic reaction wheels, the satellite is capable of angling its view up to 60°. The sensors are fixed on the platform, so the reaction wheels—driven by electricity from the solar panels—physically rotate the satellite. This allows the satellite to easily image east to west even while moving north to south. Furthermore, the sensors can narrow their view down to a block-sized area or a mile-wide patch.

I inquired about how GeoEye determines the satellite orbits. GPS provides precise information about where the satellite is, but not its attitude determination. For that, the star trackers are used. With this information, GeoEye can predict exactly when the satellites

## TECHNICAL DETAILS

**T**he IKONOS satellite was launched in September 1999. Capable of 0.82-meter panchromatic (black and white) and 3.2 meter multispectral imagery, the name IKONOS comes from the Greek word for “image.” Two satellites were originally planned, but the launch of IKONOS-1 in April 1999 failed when the payload fairing of the Athena rocket failed to separate, preventing the satellite from reaching orbit. IKONOS-2 was planned for launch in 2000, but was renamed IKONOS and was launched on September 24, 1999 from Vandenberg Air Force Base in California.

IKONOS has a polar, sun-synchronous, 681-km, 17,000 mph, low-earth orbit, and both sensors have a swath width of 11 km. Its weight is 1,600 pounds. The more than 300 million square kilometers of imagery that IKONOS has collected over every continent is being used for national security, military mapping, air and marine transportation, environmental monitoring, oil and gas industry and by regional and local governments. IKONOS uses a Kodak camera. Kodak’s camera division has since been acquired by ITT, which made the camera for GeoEye-1.

GeoEye-1 imagery is .41m with a swath of 15.2 km. Through the use of folded optics, the focal length of the GeoEye-1 camera is 13.3 meters—in a space 2 meters long—as opposed to the 10 meter focal length of IKONOS. At 4,310 pounds, GeoEye-1 is more than twice as heavy as IKONOS and nearly twice as long. GeoEye-1’s primary mirror is 1.1 meters in diameter, which is 50% larger than that of the mirror on IKONOS.

The satellite uses pushbroom scanner technology, and individual pixels in the panchromatic sensor are 8 microns, while the red, green, blue and near infrared pixels are 32 microns in size. The multispectral pixels are larger because they contain four times the amount of information, and because, due to the four filters (Red, Green, Blue and near infrared), less light reaches the sensor.

The sensor scans the ground at 20,000 lines per second and creates a 90 billion-pixel image every minute. The data is compressed and stored on the 1Tb solid-state recorder for downlink to the ground. In addition to the normal downlinks using company-owned worldwide terminals, for military and commercial users, GeoEye-1 also provides real-time image and downlink, as well as uplink for commercial affiliates.



# STARTRACKER



**A**s an artillery surveyor in the late 60s, we used the M2 Aiming Circle to orient artillery batteries. It had three points etched into its objective lens. By aligning these three points with a star pattern (one of which was the North Star), the instrument would be roughly aligned with North. Years later I had the opportunity to interview Capt. Jim Lovell when he was on Ashtech's board of directors. He discussed the star pattern etched into one of the windows of the Apollo 13 spacecraft. By aligning this pattern, the astronauts could determine their heading. Unfortunately, the *en route* explosion caused thousands of tiny pieces of Mylar to surround the capsule, and sunlight reflecting off the Mylar made it impossible to use the star pattern, thereby adding to the navigational difficulties of the crew.

GeoEye-1's star tracker—two are used—is all digital, capable of 0.04 arc-second accuracy, and is tied directly into the spacecraft's flight computer. Manufactured by Ball Aerospace, the tracker uses CCDs and a 6,000-star catalog to enable the satellite to determine and maintain its orientation, or attitude. More than 30 of these trackers are in use on such spacecraft as the Shuttle and the Chandra X-ray Observatory.

will show up over a particular area. Furthermore, because this is known, it's easier to not only plan the missions, but it's less costly to gather the imagery than it is with traditional photogrammetry.

"Our main business is pushing pixels," said Madden, "but value-add is where the true utility of the imagery lies." He added, "With 16-inch ground sample distance imagery, large scale topographic mapping is possible, at scales of 1:5,000 or maybe even larger." (Ground Sample Distance, or GSD, refers to the size

of the pixels in a digital orthophoto, expressed in ground units. For example, if an orthophoto has a .41m GSD, each pixel represents a ground area measuring .41m x .41m.) This is the promise for land development uses, and already the imagery is being used for large-scale planning and GIS. Once the pixels are archived, they can be used over and over for all the various value-added products.

Value-added products fall in three categories and include Geo™ map-oriented imagery, GeoProfessional™ terrain-

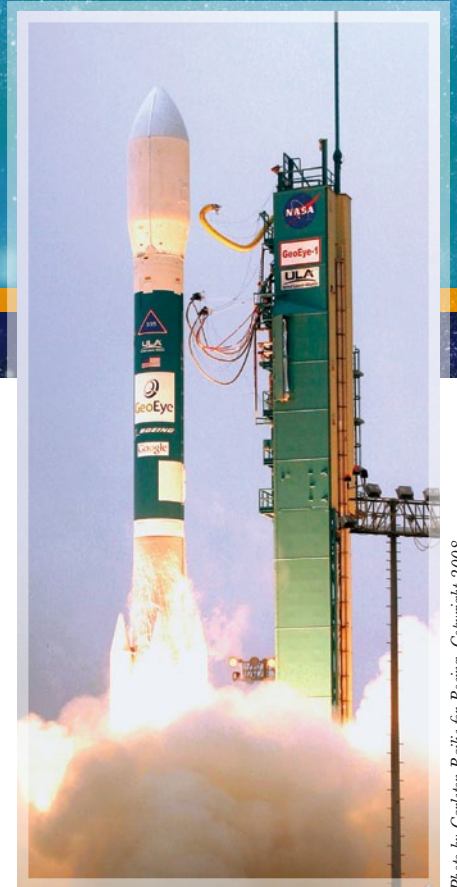


Photo by Carleton Bailie for Boeing, Copyright 2008.

This photo shows the successful liftoff of the GeoEye-1 satellite at 11:50:57 a.m. PDT on September 6, 2008 from Space Launch Complex 2 West at Vandenberg Air Force Base. The satellite was launched aboard United Launch Alliance's Delta II, 7420-10 rocket, on behalf of Boeing Launch Services.

corrected imagery and GeoStereo™ 3D imagery. Additionally, the latter two are available in a Precision flavor.

- The Geo imagery can be used for environmental monitoring, image interpretation, large-scale photogrammetry and disaster response. Users of Geo can apply their own DEM information to create terrain-corrected products.
- GeoProfessional imagery is automatically orthorectified and can be used for base mapping, change detection, planning, infrastructure management, location services, visualization and simulation and online mapping.
- The GeoStereo imagery can be used for 3D feature extraction and DEM extraction. The 3D products have been used for more than 1,200 airport obstruction projects worldwide.

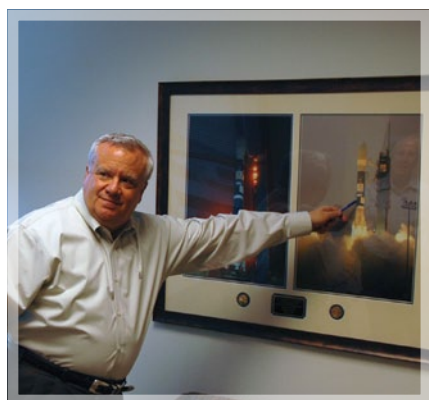




This photo captures a typical day from GeoEye's Dulles Satellite Operations Center, which is staffed 24/7 by GeoEye employees. The centralized command and control facility is the primary ground station for the GeoEye-1 satellite, which sends tasking and operating commands to the satellite and receives data downlinks from it.



Editor Marc Cheves and Mark Brender examine a half-meter resolution image of Washington DC's National Mall that was collected by the GeoEye-1 satellite on Jan. 20, 2009 to commemorate the Inauguration of President Barack Obama. The image, taken through high, wispy white clouds, shows portions of the monuments along the National Mall and the masses of people between the Capitol and the Washington Monument.



Mark Brender, Vice President of Communications, shows off photos commemorating the successful GeoEye-1 satellite. The photo on the left captured the Mobile Service Tower Rollback, Sept. 6, 2008, approximately 3 a.m. PDT; while the GeoEye-1 satellite awaited launch. The photo on the right shows successful liftoff of the GeoEye-1 satellite.

GeoEye's DEM products within the U.S. are based on the 30-meter spacing USGS DEM. Outside the U.S., they are based on the 90-meter spacing Space Shuttle SRTM DEM. GeoProfessional meets National Map Accuracy Standards (NMAS) of 1:12,000 (Precision meets NMAS of 1:5,000), and GeoStereo meets NMAS of 1:5,000 (Precision meets NMAS 1:2,500). All of these products are available online through GeoFuse, GeoEye's image catalog search and retrieval system.

At 750,000 square kilometers per day, GeoEye-1 gathers the area equivalent in size to the state of Texas every day. That's in the panchromatic imaging mode. Pan-sharpened and multispectral imagery equivalent to the size of the state of New Mexico can be processed and quickly made available. In addition to its download links in Dulles, Va., and Barrow, Alaska, the 534-employee company also has download stations in Norway and Antarctica. The spacing of these links allows the satellite to empty its memory at least once per orbit so the imagery can be quickly sent to Dulles and elsewhere for processing. Additionally, the company has image processing facilities in St. Louis, Mo.; Norman, Okla.; Mission, Kan.; and Thornton, Colo.

Rightfully proud of its public-private partnership, Brender commented that GeoEye-1 was built within four years of contract award, a little under budget, and without a single change order. He continued, "Space-borne imagery aggregates interests and fears, for example borders, natural resources, areas of conflict and areas of bounty." He said the United States loses four acres of open space per minute, and imagery can be used, for instance, for change detection along coastlines. Another common illustration is fire maps. Insurance companies will now be able to examine the amount of brush and combustible material around

a house and urge the owner to clear the fire fuel or risk an increase in premiums.

Brender showed me a cool GeoEye image of the Capitol Mall during President Obama's Jan. 20 inauguration, made even more interesting by the fact that the orbit of GeoEye-1 was 198 miles west of the District of Columbia, over West Virginia, when the image was taken.

The company's public service initiatives include the GeoEye Foundation, which awards scholarships and imagery grants from the GeoEye archive to university students and researchers. GeoEye imagery is even being used in the gaming and movie industries: Tom Clancy's H.A.W.X flying game incorporates GeoEye imagery, as did the movies "Transformers" and "The Bourne Ultimatum."

GeoEye-2 is scheduled to launch in the 2012 timeframe. Just as the Internet has transformed our access to information, the commercializing of earth imagery—formerly only available to U.S. and some allied governments—has broadened our scope as well. Many governments, most notably China, severely restrict their citizens' access to aerial imagery, but publicly-available high-rez satellite imagery represents an unstoppable sea change. As Brender put it, "Commercialized space imagery will do for our country what the interstate highway system did; only now it's pixels and not pavement." *AS*

Marc Cheves is Editor of the magazine