PHOTO: CORBIS

# ::Good Eye in the Sky::

When the USSR launched the first Sputnik, the other major powers rushed to launch military satellites. But increasingly, the data beamed back to earth by satellites is being put to more benevolent uses rather than just for warlike purposes.

*By* DANIEL WEISS

**After a quarter of a century of scouring the Burgundy** region of France for potential dig sites that would illuminate the area's rich cultural history from the Iron Age to the present, archaeologist Scott Madry was accustomed to a sluggish pace of discovery. His best available option was taking to the skies in a small plane, to reach a vantage point where faint geometric patterns became visible: straight lines, right angles and circles that bore evidence of ancient roads, walls and buildings. But such flights were expensive and only possible on the clearest of days. Even then, the plane's constant motion made it difficult to stay oriented.

This all changed in late 2005 when Madry discovered Google Earth's trove of high-resolution satellite imagery. From the comfort of his office at the University of North Carolina in the United States, he freely ranged over an area nearby the one he'd studied, as if piloting a virtual helicopter. Geometric patterns indicating the presence of ruins were everywhere.

"I saw clear evidence of Roman villas, pre-Roman Celtic farmsteads, medieval earth-walled fortified farms," Madry says. "Within a few days, I found more sites than I had found in years of doing aerial and field surveys. It just knocked my socks off."

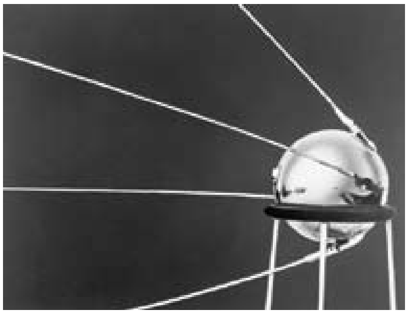
**Upside-Down :::**

To sample the power of earth-imaging satellites, anybody can simply boot up Google Earth and zoom in. Depending on the part of the globe you've chosen, the view may be close enough up to reveal individual cars and trees. The source

of many of these astounding aerial shots: satellites orbiting the earth at more than 7 kilometres per second with their high-resolution cameras trained on the ground hundreds of kilometres below. (Cameras mounted on planes also supply much of the close-up imagery on Google Earth.)

The satellite images on Google Earth are patched together from a variety of different sources. Broad landscape views are provided by satellites such as NASA's Landsat series, which produce full-colour imagery at a resolution of 30 metres, meaning that each pixel in an image represents a square on earth measuring 30 metres by 30 metres. Landsat satellites have been snapping images of earth since 1972, and Landsat 5, one of the two currently in orbit, just celebrated its 25th year of labour – not bad for a mission initially set to last only three years.

Google Earth's higher-resolution satellite imagery comes from a series



Satellite facilities have advanced since the **Soviet Union first launched Sputnik** (above) in 1957. An ALOS "Daichi" satellite is put through thermal vacuum testing at the giant **Tsukuba Space Center** (top) in Japan. The centre is key to the country's space programme, where satellites and rockets are developed and then tracked after launch.

of advanced commercial imaging satellites that have been launched in recent years. The current champion is GeoEye's GeoEye-1, launched in September 2008 with a Google decal affixed to its carrier rocket. This can produce full-colour images with a resolution of just 50 centimetres (at this resolution, it's possible to tell the difference between a car and a truck). GeoEye-1 has just begun feeding imagery to Google Earth, but DigitalGlobe's QuickBird, with a full-colour resolution of 61 centimetres, has been beaming imagery down since its launch in 2001.

**Spotted Plants :::**

While Madry uses satellite imagery to reveal what's right under his nose (and under the ground), conservation biologists are using it to locate undiscovered habitats far off the beaten path. The resource has been invaluable to the efforts of Britain's famous Royal Botanic Gardens, Kew,

PHOTOS: CORBIS; COURTESY OF JAXA

to survey and conserve mountainside forests in southeastern Africa that tend to be rich in indigenous flora and fauna but increasingly under threat by development.

In 2005, Kew Gardens scientist Julian Bayliss searched Google Earth images of southeastern Africa for large green patches in mountainous areas and spotted a promising candidate in northern Mozambique: 6,000-7,000 hectares (just smaller than the size of Hong Kong Island) of what appeared to be previously unexplored forest. After preliminary ground investigations established that there was indeed a large forest on Mozambique's Mount Mabu, previously known only to local villagers, a Kew expedition travelled there last year to conduct a survey. The medium-altitude forest yielded a bounty of wildlife, including new populations of at least five threatened species, three new species of butterfly and a new snake species.

A much broader application of satellite imaging to conservation has been undertaken by Brazil, which uses it to monitor and combat deforestation of the Amazon rainforest. Each year, the country's National Institute for Space Research (INPE) assembles at least one complete satellite image of the Amazon region (more than 5 million square kilometres) and then compares it with the previous year's images, and an accumulated deforestation map, to determine how much rainforest has been lost. This survey is based on imagery from a number of satellite sources, including Landsat and CBERS, a joint project operated by Brazil and China. The imagery includes recordings on the visible red band, in which reddish soil shows

The uses of satellite images are varied: to **commemorate the inauguration of US President Barack Obama** at National Mall, Washington, DC (top); to **show cyclone damage**, before and after, along Myanmar's Yangon River (middle); or to learn about an area's cultural history through an image of **Iron Age funeral tumuli** (bottom).

PHOTOS: GEOEYE; COURTESY OF CRISP-SINGAPORE; DIGITALGLOBE

## Brazil's rainforest monitoring programme has become a model for the rest of the world

up bright and greenish vegetation shows up dark, and recordings on the near-infrared band, in which soil appears dark and vegetation bright.

Since 2004, the institute has also used imaging from NASA's Terra satellite to catch deforestation as it happens and pass the information to the country's environmental enforcement agency IBAMA. Terra captures images with a resolution of 250 metres, which means the results are produced more quickly than higher-resolution images, but only detect incidents of deforestation larger than 25 hectares (about the size of 35 football pitches). "Considering the amount of deforestation we get, even with this level of detail we give IBAMA a lot of work to do," says Dr Dalton Valeriano, who works as coordinator of INPE's Amazon satellite-monitoring programme. "We report up to 500 incidents a month." Good for the trees; not so good for the forest-destroyers.

"In the past, we could only measure the deforestation after it happened," says Dr Humberto Mesquita Jr, head of IBAMA's remote sensing centre. "Now the satellite monitoring is helping us to interrupt the deforestation as it happens."

Brazil's rainforest monitoring programme has become a model for the rest of the world, and the country shares its expertise and resources with other tropical countries so they can institute similar programmes. However, with Amazon deforestation rates still topping 10,000 square kilometres (about half the size of Bali) per year, the country continues to work to improve its own results. The cloudiness of the Amazon region – it is a rainforest, after all – renders conventional imaging satellites blind for much of the year. Even during the dry season, from April to September, clouds often interfere. Forest cutters who want to evade the law have learned to take advantage of the enforcers' weakness. "In the old days, there was no deforestation in the rainy season because the roads are a mess and getting around is very difficult," says Mesquita. "Nowadays they do the deforestation in the rainy season and then transport the wood in the dry season."

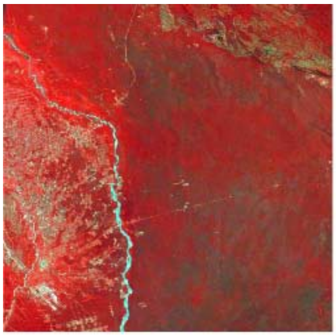
Later this year, Brazil will begin to incorporate L-band radar imaging from Japan's Advanced Land Observing Satellite (ALOS), allowing it to track deforestation and pursue those responsible for it all year round, regardless of weather. The radar images, which have a resolution of 100 metres, show a strong signal from tree trunks. Areas of recent deforestation, littered with felled trees, appear white or light grey; areas that have been completely cleared of trees are black; and intact forests are grey. "We are already testing it, and it is very, very encouraging," says Valeriano.

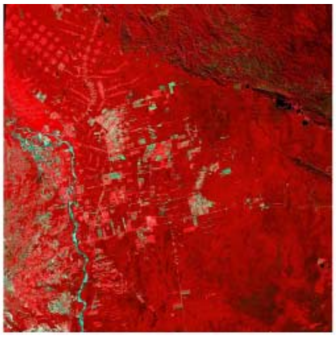


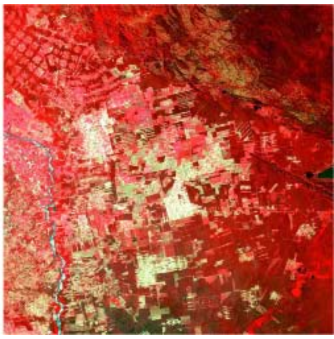
Highlighting the plight of some of the people of Myanmar, this "before" image (below, left), taken of the Papun District, shows **a settlement**. The photograph taken six years later (below, right) shows the settlement gone. The area was **reportedly attacked eight months earlier.**

PHOTOS: USGS NATIONAL CENTER AND NASA LANDSAT PROJECT

**Scores of fires** marked by red dots can be seen in this Terra satellite image (above) taken of **northern Mato Grosso**, in west central Brazil. The three time lapse images (right) show the gradual progression of deforestation from 1975 to 2000 in an area east of Santa Cruz de la Sierra, Bolivia. The **radial-patterned fields** are part of the San Javier planned resettlement scheme.







Satellites often give us images that stand alone as pieces of art, such as this **"whirlpool"** captured off the eastern coast of Greenland. It shows **a spinning formation of ice,** clouds and low-lying fog.

PHOTO: USGS NATIONAL CENTER FOR EROS AND NASA LANDSAT PROJECT SCIENCE OFFICE

Ironically, a tool that is famously used for government spying is now also being used to shine a light on government repression. Human rights activists are using satellites to verify allegations of abuse by regimes in some countries, including Zimbabwe, Sudan, Ethiopia and Myanmar. "The satellites allow us to look over wide areas that we have limited or no physical access to," says Lars Bromley, project director with the Science and Human Rights Programme at the American Association for the Advancement of Science in Washington, DC. "In a lot of these areas, outside investigators would be shot on sight, so to speak."

An example of this humanitarian capability comes from a 2007 analysis of satellite images that were taken of Myanmar. Bromley found evidence that villages in the country's Karen State and surrounding areas had been levelled. The images also showed that new settlements had been constructed near military installations, lending support to claims that people from the destroyed villages had been forcibly relocated. "We are trying to send a message to the military junta that we are watching from the sky, taking evidence of their crimes against humanity," Aung Din, policy director for the US Campaign for Burma, said at a news conference announcing the findings. "We are watching what you are doing."

The increased resolution of commercial satellite images could benefit Bromley's work. With recently launched satellites now capable of 50-centimetre resolution for non-governmental applications, he says, it has become possible to make out details like barbed wire fences in images and to distinguish between military and civilian automobiles. Though Bromley hasn't made use of this yet, would-be human rights abusers must be aware their actions are becoming more and more difficult to hide.

> "The satellites allow us to look over wide areas that we have limited or no physical access to"

Likewise, the power of satellite imaging has been harnessed to save lives by fighting the spread of epidemics. Until recently, there has been no way to predict outbreaks of Rift Valley fever, a mosquito-borne disease for which there is no human vaccine. Since outbreaks are triggered by extended, abnormally heavy rains and greening of vegetation in semi-arid areas that prompt dormant infected mosquito eggs to hatch, the traditional method of forecasting was based on seasonal weather models and monitoring of rain gauges. This method was unreliable and gave little advanced warning of outbreaks. After a massive 1997-98 outbreak of Rift Valley fever infected 90,000 people in the Horn of Africa, NASA scientists began work on a satellite-based advanced warning system.

The system predicts abnormal rains from satellite data showing sea surface warming in the Pacific equatorial and western equatorial Indian oceans, and monitors the landscape's "greenness" through the Normalised Difference Vegetation Index (NDVI). This information is used to map out areas at risk of an outbreak.

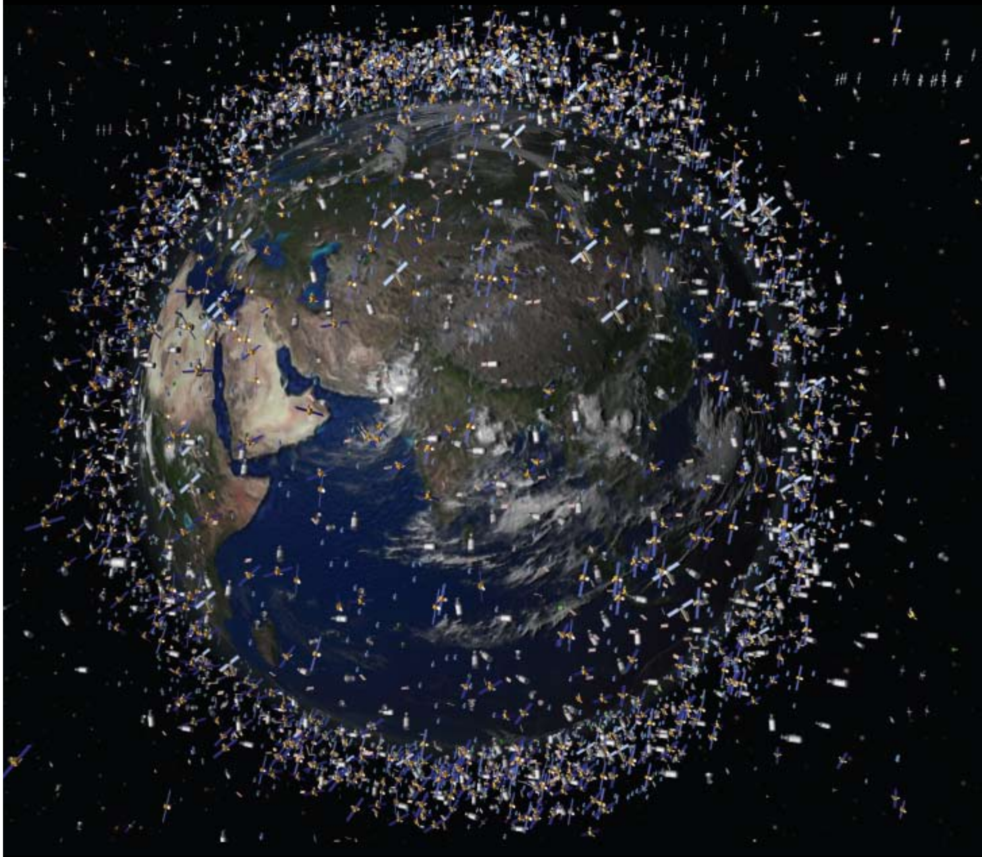
In September 2006, the system showed a heightened risk of Rift Valley fever outbreak in East Africa. By November, the governments of both Kenya and Tanzania along with partner organisations had taken a number of preventative measures, including distributing mosquito nets and banning movement of livestock from affected areas to unaffected ones. "The response to the risk of outbreak in 2006-2007 was about 2-2.5 months earlier than in 1997-1998," says Assaf Anyamba, a NASA geographer and remote sensing scientist who helped develop the early warning system.

The list of creative applications of satellite imagery goes on. A combination of the NDVI and readings on the shortwave infrared band has been used to create maps showing the extent of damage caused by mountain pine beetles to the forests of western Canada. Satellite images have been used to create precise maps of the earth's surface and the ocean floor. A Chinese satellite, Beijing-1, was even tasked with keeping track of development and pollution in the run-up to the 2008 Olympic Games in Beijing.

These applications will continue to come, especially now that so much imagery is available on the Internet. "There are hundreds of millions of people using Google Earth, and we don't even know what they're doing with it," says Michael Jones, Google's chief technology advocate and one of Google Earth's original designers. "We built a tool and then we just waited for people to do something great with it. And the greatest story is not yet written. It's the things that people are thinking up right now."

**Long Way Round**

Communications satellites orbiting more than 35,000 kilometres above the earth play a much bigger role in our lives than most people realise. When you watch television, chances are the programming has been beamed up to a satellite and then back down on its journey to your home. When you make a credit card purchase, the transaction is sent for authorisation via satellite. When you log on to the Internet in parts of the



# Orbits

## Up high in the sky – or maybe low?

**Low Earth Orbit (LEO):** 300–2,000 kilometres. LEO is home to many imaging and scientific craft, which profit from the close-up view of earth, along with some communications satellites, such as the Iridium and Globalstar fleets. While it takes more LEO satellites to provide coverage to the entire globe than it does using higher orbits, signal transmission is much more rapid here, which is an advantage for satellite phone service.

Due to the strength of the earth's gravity, LEO satellites must maintain velocities to the order of 7 to 8 kilometres per second to remain in orbit. Many LEO observation satellites fly in sun-synchronous orbits, which take them over the North and South poles and ensure that the local time is the same whenever a given satellite passes over the sunny side of earth.

**Medium Earth Orbit (MEO):** 2,000–35,786 kilometres. Due to the effects of the Van Allen radiation belts, vast stretches of MEO are inhospitable to satellites. There are some communications satellites in MEO, but navigation satellites make up the bulk of the population here. The NAVSTAR GPS fleet orbits at an altitude of 20,350 kilometres, while the Russian GLONASS navigation satellites are at 19,100 kilometres.

**Geostationary Orbit (GEO):** 35,786 kilometres. Satellites in GEO are stationed directly above the equator and complete a single orbit in 24 hours, which means that they are always above the same spot on earth. This fixed position makes them ideal weather and communications satellites. However, when used for satellite phones or Internet service, GEO satellites have a half-second delay due to the time it takes the light-speed signals to complete the 70,000-kilometre-plus round trip.

PHOTO: CORBIS

world off the fibre-optic grid, that connection has been made through a satellite.

Thanks to the Cospas-Sarsat satellite system, over **24,000 people worldwide** have been **rescued from distress situations** as of 2007 – including the survivors of this plane crash in **Brazil in 2005**.

PHOTO: 2/10 GAV – ESQUADRÃO PELICANO

High-tech entrepreneur Greg Wyler wants to use satellites to connect more of the developing world's population to the Internet. His company is called O3b Networks, short for "the other 3 billion," a reference to the estimated number of people living in areas where Internet service is unavailable or prohibitively expensive. While attempting to build a ground-based Internet infrastructure in Rwanda earlier this decade, he realised he would need to make use of a geostationary satellite (see sidebar) or fibre-optic connection, neither of which made economic sense.

Wyler's solution: launch a fleet of satellites into orbit at an altitude of only 8,000 kilometres that can give a feed to Internet service providers anywhere in the world. The lower orbit will reduce costs and significantly cut down the half-second lag time it takes for signals to travel to and from conventional communications satellites. The venture has received an initial round of funding from investors including Google, which sees O3b helping to further its goal of making information universally accessible. O3b plans to launch its first eight satellites late next year, with another eight to follow if there is sufficient demand for the service.

**Where to from Here?**

Although many people find their way around with the help of GPS satellites, another less well-known satellite system that helps locate us on the planet is even more helpful than GPS. This is the Cospas-Sarsat satellite search-and-rescue system, which consists of sensors affixed to ten satellites, five in low-earth orbit and five in geostationary orbit, which relay distress signals from radio beacons to rescuers on the ground. Four of the five low-earth satellites used by the system are American weather satellites, as are two of the geostationary ones; one low-earth orbiting and two geostationary satellites are European weather satellites; and India operates one geostationary weather-communications-TV satellite with synthetic aperture radar sensors.

Beacons have been carried on ships and planes since the programme's inception in 1982, and Personal Locator Beacons (PLBs) are now available to individuals in most countries. The low-earth-orbiting satellites help to determine a beacon's location by measuring the Doppler shift of its transmission, but many modern beacons contain GPS receivers and transmit their location along with their distress call.

In recent years, the system has assisted in rescuing an average of six to seven people per day. Among these was the late adventurer Steve Fossett, who activated his hot air balloon's beacon after it plunged into uncharted waters between Australia and New Caledonia. And just last March, two Norwegians were forced to activate a PLB after falling through the ice into frigid waters while dog-sledding in the northern reaches of the Arctic archipelago of Svalbard. A rescue helicopter arrived 90 minutes later to shuttle the severely frostbitten pair to safety.

"The Cospas-Sarsat beacon was their only means of communication," says Tore Wangsfjord of the Joint Rescue Coordination Centre, North Norway. "If they hadn't had that, it could have been several days before they were reported missing."

Which just goes to show that satellites are indeed never-sleeping eyes in the sky. And in many cases, they are watching over us – not just spying on our military intentions. ■