secrets for sale

How Commercial Satellite Imagery Will Change the World

Yahya A. Dehqanzada and Ann M. Florini

CARNEGIE ENDOWMENT
for International Peace

Additional copies of *Secrets for Sale: How Commercial Satellite Imagery Will Change the World*, as well as the related working paper *No More Secrets? Policy Implications of Commercial Remote Sensing Satellites*, can be obtained from the Carnegie Endowment at the following address and contact numbers:

Carnegie Endowment for International Peace
1779 Massachusetts Avenue, N.W.
Washington, D.C. 20036
Phone 202.483.7600
Fax 202.483.1840
Email pubs@ceip.org
www.ceip.org

Library of Congress Card Number: 99-069173

Design by Manolo Bevia and Travis C. Daub.

table of contents

acronyms and abbreviations

AMI	Advanced Measurement Initiative - program launched by the U.S. Environmental Protection Agency to accelerate the adoption and application of remote sensing and other technologies for environmental monitoring and protection purposes.
AVIRIS	Airborne Visible and Infra-Red Imaging Spectrometer - aerial hyperspectral sensor developed by the U.S. National Aeronautics and Space Administration.
CSA	Canadian Space Agency - the organization in charge of Canadian space programs.
DOD	U.S. Department of Defense.
EOSAT	Earth Observation Satellite Company - a joint venture of RCA Corporation and Hughes Aircraft Company. It was selected by National Oceanic and Atmospheric Administration of the U.S. Department of Commerce to take over the Landsat program in 1985. Space Imaging acquired EOSAT in November 1996.
EPA	U.S. Environmental Protection Agency.
ESA	European Space Agency - the body in charge of space exploration and development of new technologies for fourteen Western European countries.
GIS	Geographic Information System.
HS	Hyperspectral - electro-optical sensor capable of distinguishing fine shades of different colors and thereby providing information on the chemical composition of objects on the ground.
IRS	Indian Remote Sensing satellite.
LEO	Low Earth Orbit - circular orbits typically between 100 and 1,000 kilometers above ground. These orbits are ideal for high-resolution commercial and military remote sensing systems because they lessen the technical demands placed on the satellite sensors.
MDA	MacDonald Dettwiler and Associates - a subsidiary of the U.S. company Orbital Sciences, which was originally selected by the Canadian Space Agency to develop and operate the RADARSAT-2 satellite and market all the resulting data.
MS	Multispectral - electro-optical sensor capable of producing color imagery.
NASA	National Aeronautics and Space Administration - the U.S. agency in charge of research and development relating to space.
NATO	North Atlantic Treaty Organization.
NOAA	National Oceanic and Atmospheric Administration - the branch of the U.S. Department of Commerce presently in charge of licensing and regulating the commercial remote sensing industry.
PC	Panchromatic - electro-optical sensors capable of producing only black-and-white imagery.
RBV	Return Beam Vidicom - similar to a television camera.
RDL	Research and Development Laboratories - this company is currently developing the RADAR-1 commercial satellite.
SAM	Surface-to-air missile.
SAR	Synthetic Aperture Radar - radar sensor capable of collecting imagery at night and in poor weather conditions.
SPOT	Satellite Pour l'Observation de la Terre - although developed and operated by the French Space Agency (CNES), Spot Image manages the SPOT systems on a commercial basis.
SSM	Surface-to-surface missile.
STDC	Space Technology Development Corporation - the U.S. Office of Naval Research is subsidizing STDC in the amount of $60 million to develop and deploy the Naval EarthMap Observer (NEMO) satellite.
TEEMS	Texaco Energy and Environmental Multispectral Imaging Spectrometer - hyperspectral sensor developed by Texaco for fracture analysis and environmental protection purposes.
UN	United Nations.
USGS	United States Geological Survey - the branch of the U.S. Department of the Interior presently in charge of Landsat 7 operations and data distribution.
WIS	West Indian Space Ltd. - a U.S.-Israeli joint venture comprised of the Israel Aircraft Industries Ltd. of Lod, Israel; El-Op Electro-Optics Industries of Rehovot, Israel; and Core Software Technology Inc. of Pasadena, California.

foreword

We are living in a world of fundamental change. Transformations are under way in the meaning and the relevance of national borders; in the relationship of governments to one another; in the roles of other entities, private business and nongovernmental organizations that are capable of governance; and in the meaning of national sovereignty. One of the driving forces behind these changes is the information revolution, by means of which huge masses of information now flow widely around the world. Another is the growing acceptance of transparency, which has led some governments to relax long-held political restrictions on the gathering and dissemination of information. These two trends come together in the subject of this monograph: the advent and the likely impact of commercial high-resolution imaging satellites.

As the monograph makes clear, these satellites promise a quantum leap in the ongoing information revolution. Although satellites have been observing the Earth for nearly forty years, those that could provide highly detailed imagery were operated by secret military/intelligence programs. Governments made some satellite imagery available for sale beginning in 1972, but that imagery showed broad panoramas, not fine detail. Recently, however, governments and commercial firms have begun to sell imagery that discerns objects as small as 1 meter across.

Public availability of timely high-resolution imagery represents a notable break with the past. We are moving from an era in which only a handful of governments had access to high-resolution imagery to one in which every government—and businesses, nongovernmental organizations, and terrorist and criminal groups—will have such access. Nonstate actors will be able to peer behind the walls of national sovereignty, accelerating a shift in power that is already under way.

Yet governments throughout the world are woefully unprepared for the coming era of global transparency. Most countries have chosen to ignore these recent developments. Others have devised flawed policies that will prove unworkable in the long term.

To spur a debate on the possibilities and consequences of this technology, in May 1999, the Carnegie Endowment's Project on Transparency sponsored a conference that brought together a range of specialists, policy makers, journalists, and diplomats from a score of countries. The conference looked both at the implications for specific sectors, such as national security, environment, the media, and humanitarian assistance, and at the broad effects on governance and global politics. This monograph draws from and goes beyond those discussions, providing a breadth of scope and a level of detail beyond what could be covered in a one-day conference.

This is a timely and badly needed analysis of the remote sensing industry while it is still in its infancy. Satellite imagery is a crucial component of an ongoing shift toward greater transparency. Mishandling the technologies and the policies that make such transparency possible would impose heavy costs in missed opportunities and potential threats. But if handled right, the new transparency could offer enormous benefits for nations and peoples around the world.

The Carnegie Endowment is grateful to the Rockefeller Brothers Fund for its support.

Jessica Tuchman Mathews, President
Carnegie Endowment for International Peace

Each chapter opens with satellite images provided by Space Imaging. The two images on the left show lower Manhattan, and the three on the right are of Ronald Reagan National Airport in Washington, D.C.

executive summary

By the year 2003 at least eleven private companies from five different countries expect to have high-resolution commercial remote sensing satellites in orbit. These new satellites have capabilities approaching those of military spy satellites, but with one key difference: their images will generally be available to anyone able to pay for them. This new technology raises a host of policy concerns with which governments, business executives, and analysts around the world are just beginning to grapple. This monograph, inspired by the discussions at a recent conference of the Carnegie Endowment for International Peace, addresses those policy concerns[1].

Key conclusions are that:

- **Increased access to high-resolution satellite imagery will shift power from the former holders of secrets to the newly informed**. Governments that previously had limited or no access to satellite imagery can for the first time see what elite states have observed from the skies for many years. In addition, commercial satellite imagery will provide an independent source of information to groups in civil society. Both state and nonstate actors will employ satellite imagery to monitor and sometimes publicize the activities of various countries and corporations.
- **High-resolution satellite imagery has both beneficial and malign applications**. It can significantly enhance the ability of governmental and nongovernmental organizations to respond quickly to sudden humanitarian emergencies such as in Somalia and Iraq, document and publicize large-scale humanitarian atrocities such as those witnessed in Kosovo and Rwanda, help control environmental problems ranging from impending droughts to deforestation, monitor compliance with international agreements, and assist in managing international disputes before they escalate to full-scale interstate wars. But abundance of information does not guarantee benevolent uses. State and nonstate actors could employ remote sensing imagery to conduct industrial espionage, collect intelligence, plan terrorist attacks, or mount offensive military operations.
- **Attempts to control access to high-resolution satellite imagery are bound to fail**. Since the end of the cold war, technological progress, coupled with a greater appreciation for the military, civilian, and commercial utility of high-resolution satellite data, has persuaded governments and corporations in virtually every region of the world to invest in indigenous remote sensing industries. As a result, both the satellite technology and the necessary support infrastructure have become global. It is unlikely that any one country, regardless of its size or market share,

can by itself curb access to high-resolution satellite imagery. And because of the large number and varied political agendas of the countries that will operate various satellites (Canada, France, India, Israel, Russia, the United States, and possibly China), multilateral agreements on control seem elusive. Governments need to accept this new era of mutual assured observation, take advantage of its positive effects, and find ways to manage its negative consequences.

- **Commercially available high-resolution satellite imagery will trigger the development of more robust denial and deception and antisatellite countermeasures**. Widely available high-resolution satellite imagery will undoubtedly compel governments to develop effective means for keeping their secrets hidden. Many states, especially those with regional adversaries, will invest heavily in denial and deception and antisatellite countermeasures. Such a development could have serious implications for confidence-building and crisis management among mutually vulnerable states.

- **Expected gains from commercial high-resolution satellite imagery may be exaggerated**. Satellite imagery is only one source of data among many. While it can detect large-scale troop movements, mass graves, and deforestation, it cannot reveal what those troops' intentions are, who is buried in the mass graves, or how deforestation can be stopped. Complementary data are necessary to turn satellite imagery into usable information.

- **Good training for imagery analysts is essential. Satellite imagery can be difficult to interpret**. It takes years before an analyst gains the experience and expertise necessary to be able to derive useful information from gigabytes of transmitted data. Junior analysts are wrong far more often than they are right. It is essential that imagery analysts go through extensive training not only at the beginning of their careers, but also every time they shift the focus of their work—analysts who specialize in interpreting and analyzing the activities of ground forces cannot overnight become experts on nuclear testing or environmental issues.

1 introduction

Over the next five years, at least five private companies around the world plan to launch commercial remote sensing satellites able to detect objects as small as one meter across. That level of detail is not as good as that of current government-controlled spy satellites, which by most accounts can achieve a resolution of just a few centimeters, but it is getting close. One key difference renders the commercial satellites far more interesting and possibly far more destabilizing than the state-owned spy satellites: the operators of these systems are not going to hide the imagery in the bowels of intelligence agencies, but are going to sell it to anyone able and willing to pay. The new commercial satellites will make it possible for the buyers of satellite imagery to, among other things, tell the difference between trucks and tanks, expose movements of large groups such as troops or refugees, and determine the probable location of natural resources.

Whether this increased access to imagery amounts to a positive or negative development depends on who chooses to use it and how. On the plus side, governments, international organizations, and nongovernmental groups may find it easier to respond quickly to sudden movements of refugees, document and publicize large-scale humanitarian atrocities, monitor environmental degradation, or manage international disputes before they escalate to full-scale interstate wars. The United Nations, for example, is looking into the possibility that satellite imagery could significantly help curtail drug trafficking and narcotics production over the next ten years. Similarly, the International Atomic Energy Agency is studying the utility of commercial high-resolution satellite imagery for monitoring state compliance with international arms control agreements.

But there is no way to guarantee benevolent uses. Governments, corporations, and even small groups of individuals could use commercial satellite imagery to collect intelligence, conduct industrial espionage, plan terrorist attacks, or mount offensive military operations. Even when intentions are good, it can be remarkably difficult to derive accurate and useful information from the heaps of transmitted data. The media, for one, have already made major mistakes, misinterpreting images and misidentifying objects, including the number of reactors on fire during the Chernobyl nuclear accident in 1986 and the location of the Indian nuclear test sites just last year.

Such bloopers notwithstanding, the new satellite imagery will provide many people with information to which they never before had access. The implications for national sovereignty, international peace and security, the ability of corporations to keep proprietary information secret, and the balance of power among the former holders of information (a few industrialized states) and the newly informed (other governments and global civil society) are serious. Undoubtedly states will attempt to maintain tight controls over this new source of information. Whether their efforts will succeed remains to be seen.

In short, the new form of transparency brought about by the advent of high-resolution commercial satellites raises a host of pressing questions. Does it portend an age of peace and stability, or does it create vulnerabilities that will make the world more unstable and violent? What contributions can emerging remote-sensing technologies make to the fields of news reporting, humanitarian relief, environmental protection, and international security? What policies could the United States and other countries adopt to secure the benefits of growing international transparency while limiting its potential negative consequences?

In addressing these questions, this monograph builds on discussions at a May 1999 conference of the Carnegie Endowment for International Peace entitled *No More Secrets? Policy Implications of Commercial Remote Sensing Satellites*. Chapter 2 describes the range of security, environmental, and humanitarian uses of satellite imagery. Chapter 3 traces the emergence of what has now become a truly global satellite remote sensing industry. Chapter 4 explores the drawbacks to unfettered access to satellite imagery, and shows why satellite imagery by itself will not uncover all secrets. Chapter 5 tackles the pressing policy questions raised by the advent of powerful private remote sensing systems. The report concludes by considering the larger context and broad implications of the emerging era of global transparency.

the technology of remote sensing

An analysis of the implications of the new satellites requires a basic understanding of what the various existing and future systems can see and do, what the jargon used in the remote sensing field means, and what types of sensors exist.[1]

Perhaps the best-known concept is that of *spatial resolution*. Spatial resolution refers to the size of the objects on the ground that the satellite sensor is able to detect. A satellite image is a mosaic. A sensor applies one value (a shade of gray or color) to each square of the mosaic. For a satellite with 1-meter resolution, each square in the mosaic corresponds to one square meter of ground area, while 10-meter resolution corresponds to ten square meters on the ground—a difference of a factor of 100 (see image on page 26).

At present, civilian and commercial satellites carry one of three types of sensors: film, electro-optical, and synthetic aperture radar (SAR).[2]

- Film sensors take actual photographs, with the film returned to Earth either by retrieving ejected film capsules or by recovering the entire satellite. Both U.S. and Soviet spy satellites started off using film, and many Russian satellites still do. Film provides good high-resolution imagery but has two real drawbacks. It can be slow, since it usually has to be physically retrieved and developed, and the satellite becomes useless once it runs out of film, a characteristic that requires frequent launches of new satellites.

- Electro-optical sensors overcome these disadvantages. They measure the electromagnetic radiation reflected off or emitted by objects on the Earth's surface, creating digital images of ground features that are then transmitted to receiving stations on Earth in a matter of minutes. However, these systems, like film, do not produce their own signals and therefore depend on other sources of energy such as the sun to illuminate the objects being observed. This characteristic constrains the use of both types of systems to daylight hours and favorable conditions. Bad weather or smoke can severely limit what these systems can see.[3]

  There are three different types of electro-optical sensors. Panchromatic sensors detect energy reflectance in only one band of the electromagnetic spectrum and thus produce black-and-white imagery. Multispectral sensors can measure electromagnetic reflectance in several different color bands—usually three to seven[4]—and so produce color images. Hyperspectral sensors, through a similar technique, image objects using many different spectral bands. The ability of hyperspectral sensors to distinguish tens and sometimes hundreds of different shades of color allows them to provide a great deal of information about the composition of features on the Earth's surface not discernible by either panchromatic or multispectral instruments.

- With synthetic aperture radar sensors, the systems transmit a signal in the microwave part of the spectrum to the Earth's surface and then detect the characteristics of the return signal after it reflects off objects on the surface. Because radar satellites emit their own signals and operate in longer wavelengths than electro-optical systems, their operations are not limited to daylight hours. Synthetic aperture radar sensors can image any spot on Earth day or night, in any weather, through clouds and smoke. As with the electro-optical systems, they produce digital data that can be downloaded to ground receiving stations moments after the images are collected.

[1]For an overview of existing and emerging remote sensing systems, visit the Carnegie Endowment for International Peace website at www.ceip.org/programs/transparency/RemoteSensingConf/GuptaPage.htm.

[2]The definition of spatial resolution applies to electro-optical and radar systems. Film is different.

[3]The exception is infrared sensors, which detect the thermal infrared radiation emitted by warm objects.

[4]At least three bands - red, green, and blue - are necessary to produce color imagery.

2 applications of emerging remote sensing capabilities

In 1858 the French photographer Gaspard-Felix Tournachon (popularly known as Nadar) pioneered the field of remote sensing when he took the world's first aerial photograph of Paris from his gas balloon, Le Géant, 250 feet above the ground. Two years later Nadar found himself taking aerial pictures of enemy troop movements during the 1870 Franco-Prussian war.[2] What had started as one man's desire to capture the imagination of the world through the lens of a camera suddenly found novel applications in the bloody field of interstate warfare.

Since those early days, many more applications have been discovered for remote sensing data. Although the age of easy access to timely high-resolution satellite imagery is just now dawning, for several decades imagery has been available from aircraft and even (at lower resolutions) from government-operated satellites (see Chapter Three and Appendix B). Over the past thirty years, governments, corporations, and nongovernmental organizations have used aerial and space-based imagery platforms to, among other things, collect intelligence, execute military operations, plan development projects, and monitor the environment. It seems likely that as the availability of high-resolution imagery grows, and especially if the prices drop, governments and non-state actors will find new arenas where remote sensing data can be of value.

Although a discussion of the full range of applications for remote sensing data is beyond the scope of this monograph, the brief overview that follows provides a glimpse of the multi-faceted significance of this powerful form of global transparency.

security applications

Of all the applications of commercial high-resolution satellite imagery, the most controversial and the most lucrative are its security applications.[3] In the short term, nearly half the sales of high-resolution imagery will be made to defense and intelligence organizations worldwide.

High-resolution commercial satellite imagery can help governments, especially those with no indigenous imagery collection capabilities, monitor the activities of neighbors and regional adversaries and expose violations of international norms and treaties (see Table 1). In August 1987, for example, the German foreign intelligence service, the Bundesnachrichten Dienst, used 10-meter resolution SPOT imagery to publicize the construction of a chemical warfare production facility near Rabta, Libya.[4] Space-based reconnaissance is particularly well suited for this type of intelligence collection because it is sanctioned under international law and is considerably less intrusive than either aerial or on-ground surveillance. An added advantage of commercial satellite imagery is that it can be shared. Whereas government officials closely guard spy satellite images to conceal the technical capabilities of national reconnaissance systems, commercial imagery can easily be shared with for-

table 1

Approximate Ground Resolution in Meters for Target Detection, Identification, Description, and Analysis

Target[a]	Detection[b]	General ID[c]	Precise ID[d]	Description[e]	Technical Analysis[f]
troop units	6.0	2.0	1.20	0.30	0.150
vehicles	1.5	0.6	0.30	0.06	0.045
aircraft	4.5	1.5	1.00	0.15	0.045
airfield facilities	6.0	4.5	3.00	0.30	0.150
nuclear weapons components	2.5	1.5	0.30	0.03	0.015
missile sites (SSM/SAM)	3.0	1.5	0.60	0.30	0.045
rockets and artillery	1.0	0.6	0.15	0.05	0.045
surface ships	7.5-15.0	4.5	0.60	0.30	0.045
surfaced submarines	7.5-30.0	4.5-6.0	1.50	1.00	0.030
roads	6.0-9.0	6.0	1.80	0.60	0.400
bridges	6.0	4.5	1.50	1.00	0.300
communications					
radar	3.0	1.0	0.30	0.15	0.015
radio	3.0	1.5	0.30	0.15	0.015
command and control headquarters	3.0	1.5	1.00	0.15	0.090
supply dumps	1.5-3.0	0.6	0.30	0.03	0.030
land minefields	3.0-9.0	6.0	1.00	0.03	--
urban areas	60.0	30.0	3.00	3.00	0.750
coasts, landing beaches	15.0-30.0	4.5	3.00	1.50	0.150
ports and harbors	30.0	15.0	6.00	3.00	0.300
railroad yards and shops	15.0-30.0	15.0	6.00	1.50	0.400
terrain	--	90.0	4.50	1.50	0.750

Notes:
a. The table indicates the minimum resolution in meters at which the target can be detected, identified, described, or analyzed. No source specifies which definition of resolution (pixel-size or white-dot) is used, but the table is internally consistent.
b. Detection: location of a class of units, object, or activity of military interest.
c. General identification: determination of general target type.
d. Precise identification: discrimination within a target type of known types.
e. Description: size/dimension, configuration/layout, components construction, equipment count, etc.
f. Technical analysis: detailed analysis of specific equipment.

Sources: U.S. Senate, Committee on Commerce, Science, and Transportation, *NASA Authorization for Fiscal Year 1978*, pp. 1642-43, and *Reconnaissance Hand Book* (McDonnell Douglas Corporation 1982), p. 125. Table from Ann M. Florini, "The Opening Skies: Third Party Imaging Satellites and U.S. Security," *International Security*, Vol. 13, No. 2 (Fall 1988), p. 98.

Bomb damage assessment photos released by the U.S. Department of Defense on December 17, 1998, of the Baghdad Directorate of Military Intelligence Headquarters.

eign governments and international organizations, a considerable advantage in multilateral operations such as those in Iraq, Bosnia, or Kosovo.

In addition to intelligence collection, high-resolution commercial satellite imagery can help identify enemy vulnerabilities, plan military operations, assess strike effectiveness, and prioritize targets for follow-up missions. There is some evidence that the Iraqi military may have used 10-meter resolution SPOT satellite photographs for attack planning and post-attack assessments both during the eight-year Iran-Iraq war and prior to the invasion of Kuwait in August 1990.[5] SPOT and Landsat imagery later helped the allied forces expel the Iraqi troops from Kuwait.[6]

Technological advances are likely to increase the demand for commercial satellite imagery. With the launch of the world's first hyperspectral sensors on board the OrbView 4, Naval EarthMap Observer, and Aries satellites, all of which are scheduled to begin operations within the next three years, security agencies worldwide will have access to richer data for intelligence gathering and military planning. Hyperspectral imagery can detect any type of camouflage that is not natural and growing. Green plastic and foliage have unique spectral signatures that are easily distinguishable from living vegetation. Military planners can use such information to design and carry out precision strikes against concealed high-value targets. In addition, hyperspectral sensors may be able to identify high concentrations of different chemicals in the soil.[7] It may be possible to employ these sensors to monitor, document, and publicize the production and use of chemical weapons in different parts of the world.

There is no reason to believe that the demand for commercial satellite imagery for intelligence collection and military planning will abate any time in the near future. As long as armed conflicts occur, government demand for remote sensing data is likely to remain high, regardless of what happens to the prices of satellite imagery. If anything, with the launch of new systems with better spatial and spectral resolutions and shorter turnaround times, demand will continue to grow.

humanitarian applications

On August 10, 1995, Madeleine K. Albright, at the time the United States' chief delegate to the United Nations, called the attention of the international community to atrocities committed by Bosnian Serbs against Bosnian Muslims after the fall of the UN "safe area" in Srebrenica.[8] Amb. Albright presented the UN Security Council with American spy satellite images that showed people herded into a soccer field at Nova Kasaba the previous July 13 and 14. Imagery collected several days later revealed an empty stadium but mounds of freshly dug earth in the nearby field (see top of page 8). After the end of hostilities, war crimes investigators exhumed the graves and recovered the bodies of dozens of Bosnian Muslims[9].

The 1995 incident unveiled to the world the power of satellite imagery in monitoring, documenting, and, possibly, deterring large-scale humanitarian crises. On April 1, 1999, as a new chapter of Serbian aggression was being written, this time against Kosovar Albanians, members of ten human rights and religious organizations gathered at the National Press Club in Washington, D.C., to call upon the Clinton administration to "immediately provide the International Criminal Tribunal for the Former Yugoslavia with all available intelligence information that reveals evidence of atrocities in Kosovo, specifically imagery collected by satellites, aircraft, and unmanned air vehicles."[10] Responding to such demands, the United States and the North Atlantic Treaty Organization (NATO) released numerous satellite images of mass graves in different parts of Kosovo, including Glodane, Velika Krusa, Pusto Selo, Glogovac, and Izbica (see bottom of page 8).

The flood of spy satellite imagery made available to the public during the Kosovo crisis was unprecedented. It is not clear, however, whether the United States and its NATO allies will be so open again. Publicizing the egregious acts of the Serbian forces in Kosovo clearly served the political objectives of the Clinton administration, which was trying to win the support of the international community in general and the American public in particular. It seems doubtful that a future U.S. administration would be as forthcoming if releasing spy satellite imagery meant having to take action against states with close ties to the United States or having to consider undertaking a major engagement in less strategically significant parts of the world, such as Rwanda, Sudan, or Afghanistan.

The advent of commercial high-resolution satellites will guarantee that in the future the Milosovics of the world will not be able to carry out their sinister plans unobserved. Satellites can document events in the remotest corners of the world, or in areas where security concerns limit access to international observers and media groups. Such information can later be used to publicize humanitarian emergencies and possibly punish the perpetrators of humanitarian crimes. Commercial satellite operators are generally not restrained by the sort of political constraints that often muzzle the response of state governments. Whereas states may refrain from publicizing acts of humanitarian violence in other friendly

United States surveillance photograph in a handout presented by the chief U.S. delegate to the United Nations on August 10, 1995, showing alleged mass graves in Nova Kasaba, Bosnia (later found to contain bodies of Muslim civilians massacred by the Bosnian Serbs).

(Reuters/Archive Photos)

Aerial imagery from a NATO handout released on April 17, 1999, showing what NATO described as new graves near Izbica, Kosovo.

(Reuters/Archive Photos)

(Space Imaging)

Five-meter-resolution imagery taken by the Indian Remote Sensing satellite (IRS-1D) on May 8, 1999, depicting the destruction left behind in the wake of a powerful tornado near Oklahoma City.

countries or in countries where they do not wish to get involved, commercial satellite operators will readily market such imagery to a host of media and human rights groups. Such widely available satellite imagery might deter states from committing large-scale violence against ethnic minorities and might compel the international community to take action once such acts of violence are committed.

High-resolution satellite imagery can also provide state and nonstate actors with valuable information on how to respond to humanitarian emergencies. Large refugee movements can be tracked using imagery with a resolution of 1 meter or better. Such imagery could help determine the direction of refugee flows, the size of different refugee pockets, ground surface features, and the resources available to humanitarian response teams. Employing high-resolution satellite imagery to plan relief operations could significantly improve the ability of various groups to alleviate human suffering in the wake of large-scale humanitarian emergencies.

environmental applications

For the past twenty-seven years, low- and medium-resolution civilian satellites have provided invaluable data on the status of the Earth's temperature, land cover, water bodies, and atmosphere.[11] For example, satellite imagery has allowed scientists to monitor and document the depletion of the ozone layer over the South Pole, the shrinking of the Aral Sea in the former Soviet Union, and the rate of loss of the tropical rainforests in the Amazon basin. In addition, remote sensing systems have at times played a central role in managing serious environmental emergencies. After the 1990-1991 Persian Gulf

War, the thermal-infrared sensors on board the Landsat 4 satellite provided firefighters with critical information on the exact location of some 529 oil fires in liberated Kuwait.[12] More recently, the Canadian RADARSAT-1 system helped avert a potential disaster by providing timely information on the size and direction of a large oil slick near the water intake pipes of a nuclear power plant on the coast of Japan.

As these examples illustrate, remote sensing systems have for decades satisfied many of the data needs of various government agencies, scientists, and environmentalists. In the future, emerging commercial satellites with higher spatial and better spectral resolutions will supplement and complement (but not replace) existing environmental monitoring capabilities. The primary reason is that most environmental changes are slow, evolving processes that take place across extensive tracts of Earth over lengthy periods. To monitor and document long-term environmental change, scientists need continuous coverage of vast regions. The existing high price of commercial satellite imagery makes it virtually impossible for anyone except the most affluent environmental organizations to purchase large quantities of high-resolution satellite imagery. Whereas the U.S. government provides Landsat 7 pictures for $475 to $600 per scene, commercial satellite operators routinely charge $4,400 for a comparable product. Although these prices may decline as the number of commercial systems in operation increases, that drop is unlikely any time soon, given that the commercial satellite companies are trying to recoup investments on the order of hundreds of millions of dollars.

While existing civilian satellites have a comparative advantage in long-term, wide-area monitoring of the environment, emerging commercial satellites seem to be particularly well suited for periodic assessments of areas of greatest concern. Possible environmental applications of emerging commercial satellites include: studying the impact of land development and energy exploration on wilderness areas, developing more complete wetland inventories, monitoring the health of vegetation in all regions of the world but particularly in remote or inaccessible areas, and detecting toxic discharges from mines and production facilities.

Governments, corporations, and conservation groups are slowly beginning to understand the immense potential of remote sensing data for environmental monitoring and are taking steps to better incorporate such data into their decision making. In 1995 the U.S. Environmental Protection Agency (EPA) conducted a study on the possibility of employing hyperspectral sensors to monitor toxic runoffs from abandoned mines. It conducted the experiment at the CalGulch Mine Superfund site in Leadville, Colorado, which is home to hundreds of relict gold, silver, lead, and zinc mines suspected of contributing acid drainage and heavy metals to downstream supplies of drinking water. Using NASA's aerial hyperspectral sensor, the Airborne Visible and Infra-Red Imaging Spectrometer (AVIRIS), the EPA was able to study the site while saving approximately "80 percent of the time and cost of traditional ground-based analysis."[13] After the success of the CalGulch Mine experiment, the EPA launched an Advanced Measurement Initiative (AMI) to accelerate the adoption and application of remote sensing and other technologies that could provide more timely, accurate, and cost-effective environmental monitoring data. Under the initiative, the EPA has undertaken two new projects involving hyperspectral sensors to monitor the presence of jarosite (a mineral that can contribute to acid drainage and the release of heavy metals into the environment) in the Ray copper mines in Arizona, and to measure the concentration of suspended minerals, chlorophyll, and dissolved organic carbon in the surface waters of the Neuse River in North Carolina. The results of both studies were to be released at the end of 1999.

Mindful of the bad publicity associated with lax environmental practices, a number of multinational corporations have also begun using remote sensing technologies to police their own activities. The Texas oil giant, Texaco, for example, developed an aerial hyperspectral sensor called Texaco Energy and Environmental Multispectral Imaging Spectrometer (TEEMS) to help it pursue environmentally sound policies. Once fully operational, this imaging capability will allow Texaco to, among other things, establish environmental baselines prior to commencing exploration, conduct fracture analysis on its vast network of pipelines, identify oil seeps and oil spills, and, when necessary, take action to minimize and reverse damage done to the environment.

The use of remote sensing data for environmental monitoring is not limited to state governments and large corporations. Environmental nongovernmental organizations have for years made extensive use of existing relatively low-resolution imagery to monitor enforcement of the U.S. Endangered Species Act, document the destruction of coral reefs around the world, and generate plans for ecosystem management.[14] As more sophisticated commercial remote sensing systems become available, and especially if the prices drop, it can be expected that environmental groups will expand their activities, monitoring compliance with existing environmental standards and publicizing violations.

media uses of satellite imagery

On Saturday, April 26, 1986, two explosions destroyed Unit 4 of the Chernobyl nuclear power plant in Ukraine and released 100 million curies of radionuclides into the environment.[15] Hoping to keep the incident secret, the Soviet government immediately sealed off a 100-mile radius around the stricken reactor and banned all foreign travel to Kiev, the largest city nearest the site of the accident.[16] Two days later, as radioactive clouds began setting off radiation alarms throughout Europe, the Soviet news agency Tass confirmed Western suspicions by disclosing that one of its atomic reactors had indeed been damaged.

Within hours of the announcement the United States' top-secret spy satellite, Keyhole (KH-11), began collecting imagery of the Chernobyl power station. By Tuesday, April 29, KH-11 photos were in the hands of U.S. policy makers in Washington, D.C. But this time government officials did not have exclusive access to satellite imagery. Less than twenty-four hours after Keyhole images reached the White House, the American Broadcasting Company (ABC) aired medium-resolution Landsat images of the blazing nuclear reactor.[17] Shortly thereafter, a number of media organizations began broadcasting higher resolution SPOT images of the Chernobyl power plant.

In the decade and a half since the Chernobyl accident, the use of satellite photos by news organizations has increased significantly. Despite the relatively low resolution of publicly available satellite systems, media groups have employed remote sensing technology to report on important events such as the military buildup in the former Soviet Union, the Persian Gulf War, weapons proliferation in the third world, the U.S. assault on Osama bin Laden's hideaway in Afghanistan, the devastation left by a tornado that swept through Oklahoma City, the nuclear tests in India and Pakistan, and, more recently, the humanitarian atrocities in Kosovo.

With the advent of commercial high-resolution satellites, the use of remote sensing imagery by media groups is likely to grow. Imagery, even relatively fuzzy commercial satellite photos, allows news agencies to convey important information visually to their audiences. More important, satellites can go places that are otherwise inaccessible to media groups. These two features alone will ensure the continued use of satellite imagery by news organizations for years to come.

business applications

The full range of commercial applications for satellite imagery is not yet known. A number of factors, including cost, timeliness, and spectral as well as spatial resolution, will ultimately determine how narrowly or broadly remote sensing imagery is employed. However, several commercial applications of satellite imagery are worth noting here.

Satellite imagery has important applications in map making. While 95 percent of the world's land mass is mapped at a scale of 1:250,000, only 33 percent is mapped at 1:25,000. Less than 10 percent of Africa and South America and less than 20 percent of Asia and Australia are mapped at the higher scale. In many cases the maps available at the higher scale are outdated or incomplete. Emerging high-resolution commercial satellites will significantly improve both the scale and quality of maps of the more remote and less developed regions of the world.

Another major commercial application of high-resolution satellite imagery is in the field of agricultural management. Agriculture is a volatile field with pronounced effects on the economic well-being and political stability of nations. Satellite imagery can help take some of the unpredictability out of this important sector. Multispectral and hyperspectral sensors are well suited to predicting crop yields, detecting crop disease and insect infestation, and monitoring thermal stress.[18] Satellite imagery can be used to prepare detailed maps of agricultural fields to determine the best seeding and irrigation patterns, as well as the optimum amounts of fertilizer and pesticides needed to obtain higher crop yields.

Satellite imagery can also help pinpoint the probable location of nonrenewable natural resources, a capability that can dramatically reduce the economic risks of exploration. Radar imagery, for example, has for years helped oil companies identify new offshore oil reserves. According to Roger Mitchell of the Earth Satellite Corporation, nearly 80 percent of offshore oil exploration starts by searching for oil seeps.[19] Oil's viscosity retards wave formation, causing a "calm spot" on the ocean surface. Radar satellites can detect these calm spots and analyze their suitability for future exploration.

Similarly, hyperspectral sensors can inspect the Earth's surface for unique spectral signatures associated with particular resources. Once a signature is detected, mining companies can begin exploration activities with much greater confidence. In the next few years, hyperspectral sensors may revolutionize exploration for natural resources in all corners of the world. Unlike the traditional methods, satellites can image any region on Earth regardless of its accessibility and can provide accurate information at a significantly lower cost. However, for hyperspectral imagery to be useful, additional research is needed to compile a more thorough library of the spectral signatures associated with different natural resources.

Urban planners can also use satellite imagery to improve efficiency and reduce costs. Houses, water tanks, canals, sidewalks, pavements, and parking lots are easily distinguishable on high-resolution satellite imagery. City officials can use such information to plan new development projects and design improved networks of public utilities. Remote sensing data can provide engineers and construction companies with valuable information on soil composition and structural morphology before substantial investments are made.

Finally, remote sensing data provide corporations new opportunities to spy on their competitors. A comparison of archived and more recent satellite imagery can reveal important information about the production capacity of rival companies at dispersed locations around the world. For example, high-resolution satellite imagery can reveal new construction, new types of shipping containers on loading docks, or an increase in the number of rail cars used to distribute products.[20] Although traditionally observers on the ground have obtained such information, commercial satellite imagery may prove to be more cost-effective and significantly less intrusive.

There has never been a ruling on the legality of space-based imagery for competitive intelligence. The only relevant case, which may form the basis for all future litigation, dates back to 1970. In *E.I. du Pont de Nemours & Co., Inc. v. Christopher*, DuPont sued the Christopher brothers for taking aerial pictures of its Texas plant while the plant was under construction to learn DuPont's new process for methanol production.[1] In this case, the court ruled in DuPont's favor, citing the steps taken by the company to protect its trade secrets and the improper means used by the Christopher brothers to uncover those secrets.

The advent of commercial high-resolution satellite imagery may have a profound impact on how cases involving remote sensing imagery are adjudicated in the future. In *DuPont* the court adjudged the actions of the Christophers to be improper primarily because, at that time, the method they used to determine DuPont's secrets was considered so out of the ordinary.[2] Once high-resolution satellite imagery becomes widely available, it will be harder to argue that overhead observation of the production facilities of rivals is an extraordinary and, therefore, improper means for carrying out competitive intelligence. Instead, businesses may have to take additional steps to protect valuable trade secrets.

Even assuming that the use of satellite imagery for competitive intelligence is considered unlawful, it will be difficult for corporations to prove any wrongdoing by industrial competitors. Current statutes do not require satellite operators to disclose either their imagery or the identity of their clients to third parties. Thus, it is nearly impossible for companies to know whether a passing satellite collected imagery of their facilities and, if so, who asked for specific images. This task becomes even more arduous as the number of domestic and, more importantly, international sources of high-resolution imagery increases. Whereas greater regulation and closer government scrutiny can restrain domestic vendors, controlling international vendors is likely to prove far more elusive.

[1]Fred Wergeles, "Commercial Satellite Imagery: New Opportunities for Competitive Intelligence," *Competitive Intelligence Magazine,* vol. 1, no. 1 (April-June 1998), p. 38.

[2]Ibid.

3 growth of the commercial remote sensing industry

Given all these applications, it is perhaps not surprising that since the first launch of a civilian remote sensing satellite in 1972, some twenty-one governmental and private entities in thirteen countries have committed billions of dollars to the development and operation of land observation satellites and have espoused relatively open data distribution practices. Many of these programs have already borne fruit. As of October 1999 there were eight sources of high-resolution film, electro-optical, and radar imagery (see Appendix A).[21] The Russian KVR-1000 camera, for example, provides customers with 2-meter panchromatic photographs of Earth. The Indian IRS-1C and -1D satellites routinely take 5-meter panchromatic and 23-meter multispectral images. The French SPOT-1, -2, and -4 systems provide 10-meter panchromatic and 20-meter multispectral images of objects on the ground. Once system testing and calibration are complete, Space Imaging's IKONOS-2 satellite will, for the first time, provide 1-meter panchromatic and 3-meter multispectral images. At present the Canadian RADARSAT-1 remains the only source of high-resolution radar imagery, providing consumers with 8-meter resolution SAR images.

Over the next five years, however, the number of high-resolution electro-optical and SAR satellites in orbit is expected to explode. By December 2000 at least two more private U.S. companies, EarthWatch and OrbImage, will have launched systems capable of collecting 1-meter panchromatic and 3- to 5-meter multispectral images of Earth. OrbImage's second high-resolution satellite, OrbView 4, will also carry the world's first hyperspectral sensor, the WarFighter. Although access to WarFighter's 8-meter resolution imagery will be restricted to the U.S. government, OrbImage will be able to sell 24-meter hyperspectral images to non-governmental entities. Space Technology Development Corporation is developing, in conjunction with the U.S. Navy, a high-resolution system capable of collecting 5-meter panchromatic and 30-meter hyperspectral images. Southern California's Research and Development Laboratories is currently developing a 1-meter resolution radar system for launch by 2001.

In addition to the United States, many of the countries already active in remote sensing plan to have more capable satellites operational by 2003. India plans to launch IRS-P5, which will be able to detect objects as small as 2.5 meters across, and IRS-P6, which will be capable of providing 5-meter panchromatic and 23-meter multispectral images. France plans to augment its capabilities by adding SPOT-5 to the constellation of SPOT satellites already in orbit. SPOT-5 will provide 2.5-meter panchromatic and 10-meter multispectral images of the planet. Canada will launch a second generation of radar satellites, RADARSAT-2, with a resolution of 3 meters. Russia may launch the more advanced RESURS-DK system, which has the ability to take 2-meter panchromatic and 3-meter multispectral and radar images of objects on the ground.

Also within the next five years a number of new countries will enter the market for high-resolution remote sensing data. Starting in 2000, West Indian Space Ltd., a joint venture of two Israeli and one American firms, plans to launch a constellation of three satellites able to provide 0.8- to 1.8-meter panchromatic images.[22] Japan is currently developing one satellite, ALOS-1, with a 2.5-meter panchromatic sensor and two 10-meter multispectral and SAR sensors. Japan is also considering developing a second satellite, Info-Collectic, with 1-meter panchromatic and 3-meter SAR sensors. Taiwan is constructing a 2-meter panchromatic system that will be ready for launch in 2002. China and Brazil have undertaken a joint effort that may ultimately lead to the development of CBERS III and IV, with the ability to collect 5-meter panchromatic and 10-meter multispectral images. Brazil and Argentina have agreed to develop the SABIA system, which will have a 6-meter multispectral capability, by 2003.

Pakistan, the Republic of Korea (South Korea), and Australia are also eager to enter the business of providing remote sensing data, albeit with lower resolution systems. Pakistan is developing the Badr-C satellite, able to take color images of objects 10 meters or bigger. South Korea is currently developing the Kompsat-1 system with 10-meter panchromatic and 20-meter multispectral resolutions. The South Korean government is also planning to launch Kompsat-2, an improved version of the Kompsat satellite, by 2003. Assuming continuity of funding, Australia intends to develop the Aries satellite, to be equipped with 10-meter panchromatic and 30-meter hyperspectral sensors.

This burgeoning global interest reflects economic, political, and technological trends that have fundamentally reshaped the commercial satellite sector, leading governments and private companies to invest large sums in the belief that the market for space-based remote sensing data will grow exponentially. One is that the market for satellite imagery is already growing. Over the past decade it has more than tripled in size, jumping from $39 million in 1988 to $139 million in 1998.[23] It is estimated that by 2005 the market will reach $420 million, an increase of over 202 percent.[24] Potential customers include farmers, city planners, map makers, environmentalists, emergency response teams, news organizations, surveyors, geologists, mining and oil companies, timber harvesters, and domestic as well as foreign military planners and intelligence organizations. Many of these groups already use imagery provided by existing aerial and space-based imagery platforms, despite the fact that these systems lack some of the unique capabilities of the emerging commercial satellites—better spectral and spatial resolutions, greater timeliness, access to remote areas, non-invasiveness, cost effectiveness, and ease of use. Satellite operators contend that in the next few years the demand for data from emerging space-based remote sensing will grow significantly, at times complementing but often replacing existing sources of remote sensing imagery. This optimism about the future of the remote sensing market, coupled with the desire to capture a larger share of the market, has driven many companies to invest in commercial satellites and associated ground systems.

The collapse of the Soviet Union also aided the growth of the remote sensing industry. Before 1992, both Eastern and Western bloc countries subordinated economic interests to the conduct of the cold war. They often barred investors from developing or employing sensitive dual-use technologies for commercial purposes. After the dissolution of the Soviet threat, many of the political barriers that had stifled private initiatives in high-resolution remote sensing evaporated.

In the United States and Russia, the end of the cold war had the added benefit of making existing sensitive remote sensing technologies available to the private sector. After the collapse of the Soviet Union, Russian firms began marketing 2-meter resolution satellite photographs from the government's KVR-1000 camera, which was designed for and used by the Soviet intelligence community.[26] Discussions are now underway to market even higher resolution photographs (1-meter resolution) from Russian spy satellites. In the United States, military contracting companies, including Lockheed Martin, Ball Aerospace, and Northrop Grumman, which during the cold war had been deeply involved in the development of the highly classified U.S. aerial and space-based reconnaissance programs, were allowed to offer their technical expertise and services to commercial satellite companies.

Another factor facilitating the growth of the remote sensing industry has been the recent technological advances in satellite data acquisition, storage, and processing, along with the ability quickly and efficiently to transfer such data files electronically. In the early 1980s information technology had not yet advanced to the point of providing a robust infrastructure.[27] Since then the situation has changed dramatically. The advent of powerful personal computers capable of handling large files of data, the development of geographic information system software designed to manipulate spatial data, and the growth of mechanisms for data distribution such as CD-ROM disks and the Internet have all facilitated the marketing and sale of satellite imagery.

Last, active government support has tremendously encouraged the growth of commercial sales of imagery in a number of countries. In France, Russia, and India, for example, while governments own and operate the satellite systems, once the imagery is collected, private firms market and distribute the data. In the case of France, the French Space Agency operates and maintains the SPOT satellites, leaving the sale of imagery to the Spot Image Corporation.[28] The Russian and Indian governments maintain control of data distribution through state-controlled agencies (Sovinformsputnik in Russia and Antrix in India), which have separate agreements with U.S.-based companies to expand their marketing capabilities. Sovinformsputnik has entered into a joint venture with Aerial Images, Inc. of Raleigh, North Carolina, and Central Trading Systems, Inc. of Huntington Bay, New York, to establish the terraserver data distribution system, for marketing SPIN-2 products. Antrix has contracted with Space Imaging of Thornton, Colorado, to expand the sale of imagery from India's IRS-1C and -1D satellites.

In Canada, following years of government control over the RADARSAT program, the Canadian Space Agency has agreed to transfer the program to the private sector. In December 1998 Industry Minister John Manley announced that MacDonald Dettwiler of Richmond, British Columbia, would develop and operate RADARSAT-2, the successor to the government-owned and -operated RADARSAT-1.[29] To facilitate the transfer of the RADARSAT program from the public to the private sector, the Canadian government has agreed to provide $225 million of the $305 million (Canadian) needed to construct the satellite. Under the terms of the agreement MacDonald Dettwiler will reimburse the government of Canada with RADARSAT-2 imagery once the satellite is operational.[30]

The support of the Israeli government has been indispensable to the plans of

West Indian Space, an American-Israeli joint venture comprised of the government-owned Israel Aircraft Industries Ltd. of Lod, Israel, El-Op Electro-Optics Industries of Rehovot, Israel, and Core Software Technology, Inc. of Pasadena California. The Israeli government has assisted West Indian Space by permitting the company to use Israeli spy satellite technology for commercial purposes. In addition, it has agreed to purchase all imagery collected by the company's three planned satellites over the Middle East for a period of eight years, providing both a market for West Indian Space products and a means of ensuring that regional rivals do not gain access to the imagery.[31]

In the same manner, the government of the United States has been central to the success of the U.S. commercial land observation satellite industry. Ever since the late 1970s, successive U.S. administrations have enacted legislation to encourage private initiatives in remote sensing. Wary that the customer base for satellite imagery was not sufficiently mature to sustain an entirely private satellite industry, the government initially focused on commercializing NASA's civilian satellite program, known as Landsat (for a comprehensive history of the Landsat program see Appendix B). In July 1984, President Ronald Reagan signed the Land Remote Sensing Commercialization Act (Public Law [P.L.] 98-365), instructing the Department of Commerce, which was then in charge of the Landsat program, to select a private contractor to operate the Landsat systems and market the resulting data. Although the act also established a licensing and oversight mechanism for a commercial remote sensing industry, no such industry emerged. In part the reason was that the law required commercial operators to sell all available imagery to anyone who wanted it at a set, nondiscriminatory price, making imagery less attractive to the many potential users who wanted exclusive access to the imagery they purchased.

In a second attempt to jumpstart private interest in commercial land observation satellites, the Congress passed the Land Remote Sensing Policy Act (P.L. 102-555), which was signed into law in October 1992. The new law allowed satellite operators to sell any given image exclusively to one customer without any restrictions on pricing. To reconcile U.S. domestic law with the 1986 United Nations Legal Principles (see page 31), the act required private companies to make unenhanced data available to the governments of the sensed states. In March 1994, in a further attempt to clarify the regulatory framework and improve U.S. commercial competitiveness, President Bill Clinton issued Presidential Decision Directive 23. The directive, among other things, loosened the restrictions on the sale of high-resolution satellite imagery to foreign entities.[32]

The 1992 legislation and the 1994 directive spurred significant interest in commercial remote sensing. In July 1992, shortly before passage of the Land Remote Sensing Policy Act, WorldView Inc. filed the first application for a license to operate a high-resolution commercial satellite. Since then eleven more U.S. companies have applied for such licenses, investing an estimated $1.2 billion in commercial satellite remote sensing activities[33] (see Table 2). One of these, Space Imaging, successfully launched the world's first 1-meter resolution satellite on September 24, 1999.

The U.S. government has also tried to promote the growth of the U.S. commercial remote sensing industry through direct subsidies to private companies and guaranteed purchases of data. EarthWatch, Space Imaging, and OrbImage have, for example, all been awarded between $2 million and $4 million to upgrade their ground systems to facilitate the transfer of imagery data from their satellites to the National Imagery and Mapping Agency. In addition, the U.S. Air Force has agreed to subsidize OrbImage for up to $30 million to develop and deploy the WarFighter sensor on board its OrbView 4 satellite, which will have both military and commercial applications. Similarly, the Office of Naval Research recently concluded an agreement with the Space Technology Development Corporation whereby the U.S. Navy will provide the company approximately $60 million to develop and deploy the Naval EarthMap Observer satellite.

In addition to direct subsidies to satellite companies, various U.S. national security agencies have reached separate agreements with a number of current and future satellite operators to purchase high-resolution satellite imagery. Since FY1998, for example, the National Imagery and Mapping Agency has "spent about $5 million annually on commercial imagery," and has promised to increase its purchases of data significantly "once the 1-meter commercial imagery systems are available."[34] According to a number of sources, the U.S. intelligence community as a whole plans to spend $1 billion during the next five years on purchases of satellite imagery from private U.S. sources and development of the capability needed to exploit such imagery fully.[35]

the future of the commercial remote sensing market

The market for satellite imagery will, as noted, continue to grow, although the scope and pace are uncertain. Four factors will ultimately determine the size of the market: the extent of government interference; the price of satellite imagery; the timeliness of access to remote sensing data; and the ability of satellite operators to market their products to new customers.

Government Regulation

As of the end of 1999, none of the space-faring nations has allowed the flowering of a truly independent commercial remote sensing industry driven solely by the tides of the free market. Given the dual-use nature of remote sensing data, states have consistently opted to subordinate economic gains to security and political considerations. Most countries, including France, India, and Russia, have chosen to maintain physical control over their country's satellite systems and all the data collected. In contrast, Canada, Israel, and the United States have permitted private companies to launch and operate land observation satellites, with the stipulation that, when necessary, national authorities can temporarily block the collection and dissemination of satellite imagery—a policy commonly referred to as shutter control.[36]

Although some form of government supervision may be essential, commercial operators fear that excessive government interference could stifle the growth of the market for commercial satellite data, both regionally and globally. Potential consumers of satellite imagery need assurances that reliable sources of imagery exist before they alter established procedures or devise new ways to incorporate satellite imagery into their day-to-day activities. In the absence of such assurances, growth of the remote sensing market could suffer.

Cost

Commercial imagery prices currently range from as little as $10 for historic American and Soviet reconnaissance photographs to as much as $10,000 for more recent high-resolution images. On average, however, consumers interested in high-resolution commercial satellite imagery can expect to pay between $1,000 and $4,000 for a single image with a

table 2

Licensed Commercial Systems in the United States (1984-1999)

Company	Date Applied	Date Approved	System
WorldView Inc./EarthWatch	15-Jul-92	04-Jan-93	EarlyBird
EOSAT	06-Oct-92	17-Jun-93	Landsat 6
Lockheed/Space Imaging	10-Jun-93	23-Apr-94	IKONOS-1/2
OrbImage	14-Dec-93	05-May-94	OrbView-1
OrbImage	14-Dec-93	01-Jul-94	OrbView-2
Astrovision	26-Mar-94	25-Jan-95	N/A
EarthWatch/Ball	18-May-94	02-Sep-94	QuickBird
GDE Systems Imaging/ Marconi North America	02-Mar-95	14-Jul-95	N/A
Motorola	31-Mar-95	01-Aug-95	N/A
Boeing Commercial Space	19-Jan-96	16-May-96	N/A
CTA Corporation	06-Sep-96	09-Jan-97	N/A
RDL Space Corporation	01-Mar-97	16-Jun-98	RADAR-1
Space Technology Development Corporation	11-May-98	26-Mar-99	NEMO

Source: National Oceanic and Atmospheric Administration; National Environmental Satellite, Data, and Information Services, May 13, 1999.
N/A=not available.

ground resolution of 10 meters to 1 meter. Generally, the cost of imagery increases proportionally with either higher resolution or greater area coverage. At these prices it is unlikely that anyone except for the most affluent organizations, typically government agencies and large corporations, will be able to purchase large quantities of commercial satellite imagery. Even though many other potential users, such as humanitarian relief agencies and environmental activists, could benefit from the information contained in satellite imagery, few will be able to afford regular purchases at current prices.

Timeliness

At present, it takes anywhere from two days to well over four weeks before customers receive imagery from vendors. This time lapse clearly is a major problem for users of imagery with rigid time constraints. Data providers are well aware of this fact and are preparing to meet the challenge. As Appendix A indicates, most of the new commercial satellites have a revisit cycle (the time it takes to pass twice over any site on Earth) of one to five days. However, with the number of satellites in orbit increasing as existing companies deploy larger constellations of satellites and new companies enter the market, the time it takes to image any location on Earth is likely to decrease considerably. Moreover, satellite operators claim that once the imagery is collected, it can be downloaded, processed, and distributed to customers within one to four hours. The implication is that in the near future on average it could take as little as 25 to 40 hours from the time the customer places an order to receipt of the images.

Marketing

The ability of satellite operators to make the value and utility of space-based data known to new potential consumers will also have a pronounced effect on the

table 3

Estimated Costs of Entering the Market for High-Resolution Satellite Imagery

Component	Payload[b] (to low earth orbit in kg)	Estimated Cost (millions of U.S. dollars)
Satellite Sensor and Spacecraft		$45-300[a]
Ground Segment		$33-65
Primary Ground Station (includes up/downlink terminals and image processing and storage facilities)		$20-35
Backup Ground Station (same as above, but more austere)		$10-15
Remote Tracking Sites (1-3 nominally; relay of satellite commands and telemetry)		$3-5 each
Launch		$12-60[c]
Vehicle Type		
Ariane 42P (French)	6,100	$65-85[d]
Long March 2C (Chinese)	3,200	$20-25[d]
PSLV (Indian)	2,900	$15-25[d]
Athena 2 (United States)	1,990	$22-26
Delta 2 (United States)	1,982	$45-60
Cosmos (Russian)	1,400	$12-14
Taurus 1 (United States)	1,400	$18-20
Pegasus XL (United States)	460	$12-15
Insurance		$7-72[e]
Total		$97-497

Notes:
a. Space segment costs are directly related to key system characteristics such as the number and type of sensors, spatial and spectral resolutions, swath width, platform stability, and satellite agility. These costs also reflect whether existing technologies are used or whether new technologies are developed specifically for the satellite.
b. Low earth orbit - circular orbits typically 100-1,000 kilometers above ground.
c. Launch costs depend on the weight of the satellite and the type of rocket used to deploy the system.
d. The Ariane 42P, Long March 2C, and PSLV launch vehicles are designed for much bigger payloads than the 350-2,000 kg commercial satellites. When used to lift commercial systems, these launchers always carry more than one payload and the cost is divided among several satellite operators.
e. Insurance costs range between 13 percent and 20 percent of the total value of the satellite plus the launch vehicle.
Sources: Commercial Space Transportation, U.S. Department of Transportation, Federal Aviation Administration, Washington, D.C., 1999; Jim Martin, "Key Cost Factors in Commercial Remote Sensing (Ground Segment)," Raytheon Systems Company, Arlington, VA, September 29, 1999; and Clayton Mowry, Satellite Industries Association, Alexandria, VA, September 28, 1999.

growth of the imagery market. One of the main reasons for the relatively slow growth of the remote sensing market has been a lack of knowledge about the potential benefits of satellite imagery. Many businesses, nongovernmental organizations, and even government agencies are for the most part unaware of the different applications of remote sensing data. Aggressive salesmanship is needed to develop the market further and demonstrate the utility of satellite imagery.

globalized ownership?

Developing a single high-resolution commercial satellite costs anywhere between $45 million and $300 million.[1,2] Building the associated ground segment adds another $33 to $65 million to the total cost.[3] A basic insurance package and the launch vehicle raise the price tag by an estimated $19-132 million.[4] In total, commercial companies need to invest between $97 million and $497 million before they collect any revenues (see Table 3).

The exorbitant cost of entering the remote sensing market has compelled many commercial satellite operators to seek a variety of domestic and international sources of funding. For example, Spot Image, although a French company operating under French laws, has several prominent foreign shareholders, including Aerospatiale-Matra group (Italy), Alcatel Space Industries (Spain), and the Swedish Space Corporation (Sweden). Similarly, the U.S. company, Space Imaging, which successfully launched the world's first 1-meter resolution commercial satellite on September 24, 1999, has secured funds not only from U.S. sources, but also from a number of foreign investors, such as Japan's Mitsubishi Corporation, Singapore's Van Der Horst Ltd., South Korea's Hyundai Space & Aircraft, Sweden's Swedish Space Corporation, and Thailand's Loxley Public Company Ltd. Earth Watch, another U.S. company, has obtained funding from the Japanese conglomerate Hitachi Ltd. and the Italian firm Telespazio.

This internationalization of the space industry may present yet another challenge to the ability of nations to pursue the contradictory policy of limiting access to high-resolution satellite imagery for national security purposes while promoting the growth of a profitable remote sensing industry. Whereas domestic investors may be more receptive to the security interests of their state governments, foreign investors are interested only in maximizing their own profits. Consequently, any policy that is likely to reduce sales is also likely to deter foreign investments. This restraint may over time cripple the domestic remote sensing industry as foreign and, perhaps, domestic financiers seek more profitable investments in less restrictive commercial environments.

[1]For a discussion of the globalization of the remote sensing industry, visit the Carnegie Endowment for International Peace website at www.ceip.org/programs/transparency/RemoteSensingConf/WilliamsonPage.htm and www.ceip.org/programs/transparency/RemoteSensingConf/StoneyPage.htm.

[2]Satellite costs are directly related to key system characteristics such as the number and type of sensors, spatial and spectral resolutions, swath width, platform stability, and satellite agility. Moreover, satellite costs also reflect whether a planned system makes use of existing technologies or whether substantial funds are needed for additional research and development activities. Numbers are based on figures provided by commercial satellite operators and aerospace industry officials.

[3]Jim Martin, Raytheon Systems Company, Arlington, Virginia, September 29, 1999, provided the ground segment costs.

[4]In general, insurance costs can be expected to range between 13 percent and 20 percent of the combined value of the satellite and the launch vehicle. Launch costs depend on the weight of the satellite and the type of launch vehicle used to deploy the system. Clayton Mowry, of Satellite Industries Association, Alexandria, Virginia, September 28, 1999, provided the insurance costs. The launch vehicle costs can be found in Commercial Space Transportation, U.S. Department of Transportation, Federal Aviation Administration, Washington, D.C., 1999.

4 drawbacks of commercial satellite imaging

The widespread availability of commercial high-resolution satellite imagery will for the first time reveal to many people and organizations information to which they never before had access. Some have celebrated this new development, calling it the emerging era of global transparency. But transparency has both positive and negative consequences.

In the field of international relations, greater transparency could allay tensions among international rivals and herald a new era of peaceful coexistence. As one observer stated, “Nations that know what their enemies are doing are less likely to increase world tensions through activities born of fear. And nations that know their enemies are observing them are far less likely to threaten international peace through rash behavior.”[37] According to this view, if everyone is constantly watching everyone else, surprise attacks become impossible and aggressive actions unrewarding.

This premise may often be true, but not always. When the success of aggression is dependent on the element of surprise, transparency will indeed reduce the incidence of aggression. But not all aggression requires surprise to succeed. Transparency could aggravate interstate conflicts by removing ambiguities about relative capabilities and allowing states to exploit each others’ weaknesses. To the degree that governments new to remote sensing misinterpret what they see, imagery could create groundless fears.

Even under the best of circumstances, transparency cannot ensure that the right decisions are made. Transparency reveals behavior, but not intent.[38] If enemy troops are detected massing along the border, is that just harmless posturing, or are they preparing for a preemptive strike? If states reach the wrong conclusions, they may find themselves spiraling uncontrollably toward war.

Transparency could also complicate decision making by introducing new participants into the policy process. Widespread availability of high-resolution satellite imagery would allow private citizens, nongovernmental organizations, and particularly the media to take a more active role in policy making. These groups could independently use satellite imagery to monitor state compliance with international agreements, expose environmental degradation, and publicize large-scale humanitarian emergencies. In some situations civil society groups and the media might be able to compel states to take action, even when government officials would much prefer to do nothing.

Here again, there are no guarantees that greater transparency will produce better outcomes. Nongovernmental organizations and the media rarely have the resources, analytical skills, or technical expertise that are more readily available to state governments. It is inevitable that organizations will make mistakes as they begin to increasingly rely on satellite imagery. The media have already made such errors on at least four occasions. During the 1986 Chernobyl accident, in an attempt to be the first with breaking news, a number of media organizations misinterpreted imagery and erroneously reported that two nuclear reactors had melted down.[39] Just a few weeks later, a number of networks in the United States cited SPOT imagery of a Soviet nuclear proving grounds at Semipalatinsk as evidence of Moscow's decision to resume nuclear testing. Further analysis revealed that the networks had completely misinterpreted the imagery, falsely presenting routine activities in a far more pernicious light.[40]

Another error occurred in 1992 when a newspaper called the *European* published SPOT images of what it labeled an Algerian nuclear research complex. Subsequent analysis of the image revealed that the feature in the photo was not a nuclear research facility but a military airbase. To make matters worse, the *European* had published the image upside down and backwards.[41]

More recently, on May 25, 1998, *Newsweek* magazine published a satellite image that it claimed showed the site in the northern desert state of Rajasthan where India had conducted five nuclear tests. *Newsweek* maintained that the image dated from a week before the tests and ran the picture with several captions identifying specific objects and installations. None of the information was correct. It turned out that the imagery had been collected over five years prior to the blasts, and the feature *Newsweek* identified as the hole where one of India's nuclear explosions took place was in fact an animal holding pen.[42]

Fortunately, no grave damage has yet resulted from the erroneous reports that have appeared, but it is optimistic to think that continued carelessness will have no consequences. False reporting, whether deliberate or unintentional, could easily embitter relations among nations and prevent the resolution of outstanding disputes.

Transparency raises major economic concerns as well. Radar, multispectral, and especially hyperspectral sensors may allow extraction companies to know more about a country's natural resources than the country's own government. This disparity in knowledge could place state officials at a considerable disadvantage when negotiating drilling rights and mining agreements. As mentioned, governments are not the only ones that may feel an acute sense of vulnerability. Corporations may find themselves being observed by competitors trying to keep tabs on their construction of new production facilities around the world and estimate the size of their production runs by looking at their emissions.

In short, the emerging global transparency resulting from high-resolution commercial remote sensing satellites promises both benefits and costs. The challenge is to devise policies that harness the benefits of growing international transparency while minimizing its many potential negative consequences.

challenges of acquiring and interpreting imagery

Although a picture may be worth a thousand words, without context it reveals very little. A picture of arid, cracked mud has very different meaning depending on whether the site is a desert riverbed during the dry season or a spot that used to be several feet under the fast-shrinking Aral Sea. Getting useful information out of satellite imagery requires significant prior knowledge about the precise site an image shows and what the image means. If high-resolution satellite imagery is to fulfill its promise, much will depend on the ability of satellite operators to obtain the imagery that addresses the specific needs of different consumers and on the ability of analysts to derive useful information from the mountains of transmitted data. In other words, data acquisition and interpretation are as important as the satellites themselves.

To collect imagery of a particular site or activity, satellite operators need to ascertain the exact coordinates of the target. Satellites, particularly high-resolution systems, cannot find violations of international treaties, signs of humanitarian atrocities, or evidence of environmental contamination unless they are told where and when to look. This precision can sometimes be very difficult, especially if the target is mobile and even more so if the target is concealed through denial and deception techniques. Moreover, it is not always possible to have a satellite at the right place at the right time. Existing commercial satellites can image any spot on earth within 1 to 24 days, depending on the location of the target and the availability of various systems. At present, most of the globe remains hidden most of the time. Continuous global coverage will gradually become available in the next few years as more commercial systems are launched, but until it is available, access to timely satellite imagery will be limited and uncertain.

The technical limitations of emerging systems and the conditions under which they must operate compound the difficulty of collecting useful satellite imagery (see box, page 3). Electro-optical sensors, for example, can provide extremely useful imagery to consumers, but they cannot operate at night or in poor weather. Radar satellites can operate day and night and under all climatic conditions, but few of the new systems provide radar imagery, and radar does not provide the same spatial and spectral information available from the more common systems.

While the advent of 1-meter resolution satellite technology is a gigantic step, it, too, has obvious limitations. As the image on page 26 indicates, considerably more information can be derived from the 1-meter resolution image of this Yannan-class Chinese ship than from the 5-meter resolution image. But even the higher resolution does not show important information, including available weapon systems, onboard cargo, and key features such as the mast and boom. Even if all the planned systems become operational, much will remain hidden from prying eyes.

Assuming that the right imagery is collected by the right satellite, to make sense of it, photo analysts need to understand weather conditions, surface features, seasonal changes, shadows, surroundings, and differing shapes and sizes.[1] In addition, they need a great deal of prior knowledge about what various objects look like from space. It does very little good to acquire an image of a clandestine missile site if the analyst viewing the image does not know what a missile site looks like.

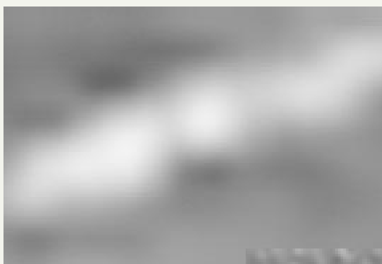
Mastering these challenges requires years of training and experience. In the government sector, analysts undergo sixteen weeks of basic training and work one-and-a-half years before they reach the apprenticeship level.[2] Even so, there is an estimated 90 percent error rate among government imagery analysts during their first three years on the job.[3] To avoid endless debate about what particular images really show, photo analysts must go through extensive training not only in the beginning of their careers but also every time they shift the focus of their work. Analysts who specialize in interpreting and analyzing the activities of ground forces cannot readily become experts on nuclear testing or environmental issues. In addition, peer review must be part of every analyst's daily work to minimize mistakes.

Last and perhaps most important, satellite imagery cannot unlock every secret. While the new high-resolution remote sensing systems will be able to detect large-scale troop movements, mass graves, and deforestation, they will not be able to reveal the intentions of those troops or who is buried in the mass graves, or how the deforestation can be reversed. In virtually all cases, other sources of information will be necessary to unmask what cannot be observed from space.

[1]Robert Osterhout, Director, Spatial Information Customer Support Center, Science Applications International Corporation (SAIC), statement made during the "No More Secrets? Policy Implications of Commercial Remote Sensing Satellites" conference at the Carnegie Endowment for International Peace, May 26, 1999. For transcripts of Osterhout's remarks, visit the Carnegie Endowment for International Peace website at www.ceip.org/programs/transparency/RemoteSensingConf/OsterhoutPage.htm.

[2]Ibid.

[3]Steven Livingston, statement made during the "No More Secrets? Policy Implications of Commercial Remote Sensing Satellites" conference at the Carnegie Endowment for International Peace. May 26, 1999. For RealVideo of Livingston's presentation, visit the Carnegie Endowment for International Peace website at www.ceip.org/programs/transparency/RemoteSensingConf/LivingstonPage.htm.



5 meter

1 meter

20 centimeter

Comparing resolutions: Three views of the same Yannan-class Chinese ship at 5-meter, 1-meter, and 20-centimeter resolutions. (Agence France Presse/downgraded imagery provided by Vipin Gupta, Sandia National Laboratories.)

5 current policy choices

Over a decade ago, an article on the then-nascent commercial satellite industry observed that "the instinct of governments confronted by new technologies is generally to bring them under control (or at least try to), especially when those technologies are related to matters of power and politics."[43] In the case of high-resolution remote sensing satellites this observation has been borne out. Concerned with the consequences of unchecked global transparency, states have considered a number of different options that may or may not prove workable.

unilateral measures

In addition to furthering U.S. commercial competitiveness, Presidential Decision Directive-23 also empowered the Secretary of Commerce to limit commercial satellite operations "during periods when national security or international obligations and/or foreign policies [of the United States] may be compromised, as defined by the Secretary of Defense or the Secretary of State, respectively."[44] This policy of shutter control was the result of the U.S. government's desire to balance its competing interests with respect to commercial satellite imagery.[45]

Satellite imagery represents a classic case of the difficulty of regulating the "export" of dual-use goods (that is, goods with both civilian and military applications). There are powerful incentives working at cross purposes: economic interests want to maintain a major U.S. presence in what could be a large and highly profitable industry that the United States pioneered, whereas national security interests want to prevent potential adversaries from using the imagery against the United States or its allies, and foreign policy interests want to avoid having certain situations publicized. Yet efforts to deny imagery to potential enemies undercut the building of a market for U.S. companies and may leave the field to competitors. As one former government official has observed, "the surest way to lose to increasing international competition is to adopt a restrictive regulatory environment at home which encourages customers to seek out foreign sources."[46] After all, imagery consumers who know access to imagery may be cut off at any time by the vagaries of U.S. foreign policy concerns may prefer to build commercial relationships with other, more reliable providers.

In addition, unilateral measures are likely to be far more harmful to the competitiveness of U.S.-based imagery providers than to the competitiveness of any of their economic rivals. Unlike Canada, France, India, Israel, and Russia, the national security interests of the United States are significantly broader geographically. Unilateral controls could translate into more frequent interruptions in the availability of imagery from U.S. sources, giving consumers yet another reason to seek alternative suppliers.

In the United States, shutter control faces an additional challenge: it may be unconstitutional. As noted, the media have already made extensive use of satellite imagery, and some news producers are eagerly anticipating the emergence of the new high-resolution systems. The Radio-Television News Directors Association argues vehemently that the existing standards violate the First Amendment by allowing the government to impose "prior restraint" on the flow of information, with no need to prove clear and present danger or imminent national harm to an impartial judge.[47] If the U.S. government exercises shutter control in any but the most compelling circumstances, a court challenge is inevitable.

It is also not clear whether shutter control will do much to protect U.S. interests. Although U.S. satellites are more advanced than any of the systems currently in orbit, other than spy satellites, they hardly have the sky to themselves. Canada, France, India, and Russia are already providing high-resolution optical and radar imagery to consumers throughout the world, with Brazil, China, Israel, Pakistan, South Korea, and Taiwan getting ready to enter the commercial remote sensing market. Given the large number of alternative sources of imagery, unilateral shutter control by itself cannot afford the United States any meaningful level of protection.

bilateral and multilateral approaches

An alternative is to try to get other operators of high-resolution satellites to voluntarily restrict the collection and dissemination of sensitive imagery from their systems. Israel has already reached such an agreement with the United States. Following intense lobbying by Israeli officials and a number of pro-Israeli groups, the U.S. government adopted an amendment to the 1997 National Defense Authorization Act (commonly known as the Kyl-Bingaman amendment). It forbids U.S. companies from collecting or selling imagery of the entire country of Israel "unless such imagery is no more detailed or precise than satellite imagery. . . that is routinely available from [other] commercial sources."[48]

Although passage of the Kyl-Bingaman amendment was a clear victory for the supporters of the bilateral approach, this victory will likely be short-lived. The U.S. decision to limit collection of high-resolution commercial imagery of Israel was based on fifty years of close cooperation between the two countries. Israel does not enjoy similar relationships with other space-faring nations. It is rather unlikely that Israel will be able to elicit similar concessions from other actors.

The feasibility of forging a multilateral control regime is even more uncertain. States are unwilling to forgo economic gains unless they are confronted with a clear and overwhelming threat. To most countries, access to high-resolution satellite imagery by third-rate powers does not constitute such a threat. Given that U.S. and Israeli firms will be the first suppliers of 1-meter satellite imagery and in all likelihood will dominate the market, later entrants will have no choice but to compete for the segments that are still untapped.[49] Therefore, while it is conceivable that states might agree to some international regulations (for example, no sale of high-resolution imagery to active combatants), there is little reason to believe that they would jeopardize the future of their commercial satellite industries by operating within a framework that clearly favors U.S. and Israeli political and economic interests.

The prospect of controlling access to sensitive high-resolution satellite imagery through bilateral or multilateral agreements becomes even more dubious as remote sensing technology proliferates further. As mentioned, Canada, France, India, and Russia are already providing high-resolution optical and radar imagery to consumers worldwide. Over the next five to ten years, at least eight more countries (Argentina, Brazil, China, Israel, Japan, Pakistan, South Korea, and Taiwan) are planning to enter the market. Even if the United States can convince existing imagery providers to restrict access to their high-resolution imagery, which seems extremely doubtful, there is no reason to believe that the emerging satellite operators would respect U.S. wishes on what should be disseminated or to whom.

shutter control by other means

In the long run, if it proves unworkable to control the flow of information from satellites either unilaterally or by agreement with other countries, two options remain: take direct action to prevent the satellites from seeing what they would otherwise see, or learn to live with the new transparency.

Direct action requires states either to hide what is on the ground or to disable satellites in the sky. Satellites generally travel in fixed orbits, so that it is easy to predict when one will be overhead and take concealment measures. Hiding assets from satellite observation is an old cold war trick. The Soviets used to deploy large numbers of fake tanks and even ships. Sensitive objects can be covered with conductive material such as chicken wire screening to create a reflective glare that obscures the details of whatever is underneath. Indeed, one concern for the United States is whether countries that currently do not bother trying to conceal their activities from U.S. spy satellites will institute concealment measures once they become aware that commercial operators may sell imagery of them to regional adversaries. In other words, the advent of commercial high-resolution satellite imagery may cause the United States to lose access to information it currently has.

At the same time, although concealment is often possible, it will become harder as the number of eyes in the sky proliferates. The advent of high-resolution radar technology, capable of detecting objects day or night, in any weather and through clouds or smoke, will further reduce the windows in which states can carry out sensitive activities unobserved. Moreover, many of the new systems have the ability to look from side to side as well as straight down, so that knowing when you are being observed is not so easy.

If hiding does not work, are countermeasures against a satellite possible? There are many ways to put satellites out of commission, especially unprotected civilian systems that are of necessity in low earth orbits.[50] Electronic and electro-optical countermeasures can be used to jam or deceive satellites. Satellites can also be spoofed—interfered with electronically and made to shut down or change orbit. The operator may never know whether the malfunction is merely a technical glitch or the result of a hostile action.[51] (And the spoofer may never know whether the target satellite was successfully affected.) Such countermeasures could prove very useful during crises or war to prevent access to imagery of a specific, temporary activity without the legal bother of shutter control or the political hassle of negotiated restraints. During peacetime, they would become rather obvious if carried out on a routine basis to prevent imaging of a particular site.

The more dramatic approach would be either to shoot the satellites down or destroy data-receiving stations on the ground. Short of imminent or actual war, it is unthinkable that any country would bring international opprobrium on itself by destroying civilian satellites or committing acts of aggression against the territory of a sovereign state. Given that the more powerful nations of the world will be developing and operating most commercial satellites, it would be a self-defeating strategy for other, generally weaker, states to take direct action against these systems. The costs of such a strategy would far outweigh any potential gains.

international law and remote sensing of earth

Despite burgeoning interest in civilian and commercial land observation satellites, few internationally recognized and legally binding principles regulate remote sensing activities. Existing standards, the result largely of longstanding U.S. efforts to render legitimate both military reconnaissance and civilian imaging from space, are codified in two UN documents. The 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies declares that "[o]uter space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty"[1] and "shall be free for exploration and use by all states."[2] States cannot exert control over any part of outer space in the same way they do airspace above their national territories, so satellites are free to orbit over them. The treaty stipulates, however, that exploration and use of outer space are to be carried out for peaceful purposes and in a manner that benefits all countries of the world.[3] It also requires that "state parties to the treaty shall bear international responsibility for national activities in outer space…whether such activities are carried on by governmental agencies or by nongovernmental entities."[4]

The UN General Assembly adopted a second document, Principles Relating to Remote Sensing of the Earth from Outer Space, on December 3, 1986. Acceptance of the principles in this document followed intense disagreement between the developed countries, led by the United States, and the developing nations, led by the former Soviet Union. The U.S. camp maintained that collection and distribution of civilian remote sensing imagery should flourish unrestricted. The Soviet camp argued that the acquisition and dissemination of such imagery should only be allowed with the consent of the state that is overflown. The 1986 UN Principles were a clear victory for the U.S. position. Instead of endorsing the right of prior consent, Principle XII of the document merely required that "[a]s soon as the primary data and the processed data concerning the territory under its jurisdiction are produced, the sensed state shall have access to them on a non-discriminatory basis and on reasonable cost terms."[5] The principles did not specify whether a request from the sensed state's government triggers the obligation to make the data available, or whether satellite operators have a responsibility to inform the sensed state that imagery of its territory is available. This lack of precision has allowed satellite operators to interpret the regulations in a manner that is most convenient to them. At present, Principle XII of the 1986 UN document is interpreted to mean that only if a country being imaged knows that it is being imaged and asks for a copy is it entitled to one at the market rate. Even then, it will not know who requested specific images or for what purposes.

Whether the rather lackadaisical regulations of remote sensing activities embodied in the 1967 Outer Space Treaty and the 1986 Legal Principles will continue to satisfy governments whose territories are routinely being observed by large numbers of increasingly sophisticated commercial satellites remains to be seen. It is quite possible that as the number of eyes in the sky increases, so will the demands of governments seeking greater protection for their territorial sovereignty.

[1]Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, Article II, United Nations, New York, January 27, 1967.

[2]Ibid., Article I.

[3]Ibid., Articles I and IV.

[4]Ibid., Article VI.

[5]"Principles Relating to Remote Sensing of the Earth from Outer Space," Principle XII, United Nations General Assembly, New York, December 3, 1986.

6 conclusion

This telephone has too many shortcomings to be seriously considered as a means of communication. The device is inherently of no value to us.

—Western Union internal memo, 1876

Heavier-than-air flying machines are impossible.

—Lord Kelvin, president, Royal Society, 1895

The wireless music box has no imaginable commercial value. Who would pay for a message sent to nobody in particular?

—David Sarnoff's associates in response to his urgings for investment in the radio in the 1920s

I think there is a world market for maybe five computers.

—Thomas Watson, chairman , International Business Machines (IBM), 1943

There is no reason anyone would want a computer in their home.

—Ken Olson, president and founder, Digital Equipment Corporation, 1977

640K ought to be enough for anybody.

—Bill Gates, Microsoft Corporation, 1981

The success rate of prognostications about how new technologies will fare approaches zero. No one really knows whether a thriving satellite commercial remote sensing industry will develop over the next decade, or whether the whole industry will crash, figuratively if not literally.

The only sure prediction is that the industry will change, drastically, in the next few years. Some of those changes may come in the form of technological improvements. Space Imaging, operator of the IKONOS satellite now in orbit, recently announced that it is thinking about follow-ons with even greater capabilities. Chief Executive Officer John Copple noted in an interview that the market has changed notably in the four years since the company was formed. Not only is there competition from other potential satellite operators, but "we're seeing much higher resolution from the aerial companies and would like to be able to participate in that market."[52] Although there is a widespread myth that Presidential Decision Directive-23 limits the resolution of American satellites to no better than 1 meter, in fact there is no constraint on resolution. Indeed, under ideal conditions IKONOS and some of the other satellites scheduled for launch within the next year will achieve resolutions closer to 0.86 meter. Copple says that the U.S. national security industry, likely to be a major customer, is urging U.S. companies to move to higher resolutions in future satellites.[53]

Some of the changes may involve the organization of the industry. Spot Image of France and OrbImage of the United States recently announced plans for a partnership that would market OrbImage's high-resolution imagery (from OrbView 3 and OrbView 4, planned for launch in late 2000) through Spot's well-established global sales network.[54] Such cross-border alliances are becoming emblematic of the globalization of the industry. Not only are there many countries with civilian or commercial operators, the operators themselves are increasingly multinational enterprises.

If commercial satellite remote sensing does take off, the new availability of imagery will raise further questions for government officials and others around the world, questions not easily answered through purely national means. Because information really is power, the spread of this particularly vivid and comprehensive form of information will ripple through all sorts of relationships—those among states, and those between states and other international actors such as businesses and civil society.

The rapidly growing literature and plethora of conferences on the new satellites have mostly focused on what the availability of high-resolution imagery will do to the conduct of war, and in particular whether it will undermine the overwhelming military preponderance of the United States. Certainly it is possible to imagine circumstances in which the United States would benefit militarily from the suppression of such imagery. It is more difficult to imagine military conflicts involving the United States in which France, India, Israel, Russia, and eventually China would all agree to go along with the suppression of such imagery. This battle is already lost.

The more fundamental questions raised by the new satellites have to do with basic issues about the meaning and relevance of national borders, about the relationships of governments not only to one another but also to private businesses and nongovernmental organizations, and about the meaning of national sovereignty. Satellite imagery is only one of a whole series of information technologies that have caused states to lose control over information about what is happening within their borders. From now on, it will not only be the U.S. Ambassador to the United Nations who can show images of atrocities in the UN Security Council and demand action. Any government on the council will be able to do so, or any government or nongovernmental organization that can persuade a council member to present the images. International negotiations on everything from arms control to climate change, already populated by ever-growing numbers of governments, businesses, and nongovernmental organizations, will face new complications caused by their inability to suppress or ignore unwanted information. Because information will be so widely available, crises may become harder to manage, as leaders find themselves under relentless pressure to act quickly.

But this is not the first time the world has had to adjust to a technologically driven jump in the availability of information. Printing presses were once seen as tools of the devil because they removed control over information from the hands of the medieval Catholic Church and spread it across the (literate) populace at large. Every new step from the telegraph to the Internet has been greeted with proclamations of apocalyptic change. Governments that have tried to suppress and control flows of information have, in the long run, suffered for it. The wiser course of action, as well as the only practicable one, is to learn to live with the new transparency.

For the United States in particular, it is most unlikely that the shortsighted policy of shutter control will do good, and it could do harm even to the United States itself by undermining an industry on which the national security community will increasingly have to rely. The United States would be better served by policies that return to the traditional U.S. emphasis on open skies and freedom of information. In the 1960s, U.S. policies helped bring about the legitimacy of satellite reconnaissance. In the 1970s and 1980s, U.S. leadership in both the technology and politics of civilian remote sensing led to global acceptance of unconstrained imaging from space. When the inevitable international disputes arise over the new transparency, and when the United States finds itself facing short-term interests in suppressing imagery, it is crucial that it stick to the long-range policies in favor of transparency that have served it so well.

For the rest of the world, this new form of transparency will do far more good than harm. Countries that now live in fear of one another will be able to learn whether those potentially hostile neighbors are in fact mobilizing for attack, and would-be attackers, at least sometimes, will be deterred by the overwhelming likelihood of detection. The pressing environmental and developmental problems facing poor countries, heretofore unseen and therefore easily ignored by the rich, will become both more visible and better understood.

Most important, the new imagery will contribute to a badly needed shift in perspective. As Oliver Morton wrote in an article on satellite imagery in *Wired* magazine in 1997:

> Like the telephone or the wrist watch, it is the sort of product that gets woven into the fabric of life—in this case, as an assumption that all the world is out there to be seen, that it is all available, comprehensible, and held in common…. With shared eyes we will watch the world carry its cargo of civilization—its roads, its fields, its cities, its landfills—through time and space. This portrait will be an image that can zoom in to the personal and pull out to the geopolitical, a new way to look at borders, a new way to look at news. It will be an illustration of everything: not, in the end, a view from nowhere, but a view from everywhere, for everyone.[55]

notes

1. For the RealVideo, transcripts, and summary of different presentations at the conference, visit the Carnegie Endowment for International Peace website at www.ceip.org/programs/transparency/RemoteSensingConf/Agenda.htm.

2. Ralph Rugoff, "Fame," *LA Weekly*, July 30, 1999.

3. For a discussion of the security implications of commercial high-resolution satellites, visit the Carnegie Endowment for International Peace website at www.ceip.org/programs/transparency/RemoteSensingConf/BakerPage.htm; www.ceip.org/programs/transparency/RemoteSensingConf/BernsteinPage.htm; and www.ceip.org/programs/transparency/RemoteSensingConf/MullenPage.htm.

4. Peter D. Zimmerman, "The Uses of SPOT for Intelligence Collection: A Quantitative Assessment," in Michael Krepon, Peter D. Zimmerman, Leonard S. Spector, and Mary Umberger, eds., *Commercial Observation Satellites and International Security* (Washington, D.C.: Carnegie Endowment for International Peace, 1990), p. 77.

5. It is well documented that during the Iran-Iraq war, images of battle areas were purchased frequently. It is not clear, however, who acquired the imagery or for what purposes. See Peter D. Zimmerman, "From the SPOT Files: Evidence of Spying," *Bulletin of the Atomic Scientists*, Vol. 45, No. 7 (September 1989), p. 24. Further, it has been reported that "before invading Kuwait, Saddam Hussein bought imagery from the French SPOT satellites," although the information could not be corroborated by the authors. See also Robert Wright, "Private Eyes," *New York Times Magazine*, September 5, 1999.

6. Report 102-539, U.S. House of Representatives, Committee on Science, Space, and Technology, May 28, 1992, p. 26.

7. This level of detail is possible only if the sensor has a high enough spatial resolution and can detect objects in the long-wave segment of the spectrum.

8. For more details visit the Carnegie Endowment for International Peace website at www.ceip.org/programs/transparency/RemoteSensingConf/PikePageHumanitarian.htm.

9. David Rohde, "A High-Tech Threat with a Low-Tech Track Record," *New York Times*, April 4, 1999, p. 6.

10. The groups included: Physicians for Human Rights, Refugees International, International Crisis Group, Network Bosnia, Coalition for International Justice, Institute for the Study of Genocide, Freedom House, Network of East-West Women, Balkan Action Council, and Minnesota Advocates for Human Rights. Nora Boustany, "The Heavens Look Down on Kosovo," *The Washington Post*, April 2, 1999, p. A19.

11. For more details, visit the Carnegie Endowment for International Peace website at www. ceip.org/programs/transparency/RemoteSensingConf/HammondPage.htm and www.ceip.org/programs/transparency/RemoteSensingConf/JanetosPage.htm.

12. The retreating Iraqi troops set between 640 and 650 oil wells alight; some, however, were already extinguished by the time Landsat imagery of the oil fields was collected. Peter D. Zimmerman, "The Use of Civil Remote Sensing Satellites During and After the 1990-91 Gulf War," *Verification Report*, VERTIC (1992), p. 239.

13. Frederick P. Hafetz and Gwen M. Schoenfeld, "Advanced Measurement Techniques: Technological Breakthroughs May Usher in Era of Change," *Environmental Compliance & Litigation Strategy*, Vol. 13, No. 3 (August 1997), p. 1.

14. Karen Litfin, "Public Eyes: Satellite Imagery, the Globalization of Transparency, and New Networks of Surveillance," unpublished manuscript, 1999.

15. For more details on the media uses of satellite imagery, visit the Carnegie Endowment for International Peace website at www.ceip.org/programs/transparency/RemoteSensingConf/DubnoPage.htm and www.ceip.org/programs/transparency/RemoteSensingConf/LivingstonPage.htm.

16. Oliver Morton, "Private Spy," *Wired* (August 1997), p. 1.

17. Ibid., pp. 9-10.

18. Pierre C. Robert, "Remote Sensing: A Potentially Powerful Technique for Precision Agriculture," paper presented at the conference titled Land Satellite Information in the Next Decade II: Sources and Applications, American Society for Photogrammetry and Remote Sensing, Washington, D.C., 1997.

19. "Offshore Oil Detection: Radar Imagery Offers a Slick for Locating Rich Reserves at Sea," *Imaging Notes*, Vol. 14, No. 2 (March/April 1999), p. 24.

20. Fred Wergeles, "Commercial Satellite Imagery: New Opportunities for Competitive Intelligence," *Competitive Intelligence Magazine*, Vol. 1, No. 1 (April/June 1998), p. 37.

21. To see William Stoney's presentation on existing and planned land imaging satellites, visit the Carnegie Endowment for International Peace website at www.ceip.org/programs/transparency/RemoteSensingConf/StoneyPage.htm.

22. One of the two Israeli firms involved in the joint venture, Israel Aircraft Industries (IAI), is a government-owned company.

23. The figures include revenues from the sale of satellite imagery and ground station fees; they do not include

revenues from the sale of geographic information system software. Karen Kaplan, "An Eye in the Dark: Radar 1 Satellite to Sell Unobstructed Views of Earth," *The Austin American-Statesman*, September 21, 1998, p. C1. See also Space Business Indicators (Washington, D.C.: U.S. Department of Commerce, Economics and Statistics Administration and Office of Space Commerce, June 1991), pp. 31 and 55.

24. Adrian Murdoch, "Pie in the Sky," *Worldlink* (September/October 1999), p. 1. For the full article, visit www.worldlink.co.uk/articles.

25. Statement by the Press Secretary, The White House, Office of the Press Secretary, Washington, D.C., March 10, 1994, p. 1.

26. Vipin Gupta, "New Satellite Images for Sale," *International Security*, Vol. 20, No. 1 (Summer 1995), p. 98.

27. Ray A Williamson, "The Landsat Legacy: Remote Sensing Policy and the Development of Commercial Remote Sensing," *Photogrammetric Engineering & Remote Sensing*, Vol. 63, No. 7 (July 1997), p. 883.

28. Spot Image's main shareholders are the French Space Agency (35 percent), the French National Geographic Institute (10 percent), Matra Marconi Space (23 percent), and a number of government and private entities in Belgium, Sweden, and Italy (11 percent).

29. MacDonald Dettwiler and Associates, "Government of Canada Successfully Negotiates RADARSAT-2 Agreement with MacDonald Dettwiler: A New Earth Observation Satellite for Canada," Vancouver, B.C., December 18, 1998.

30. Ibid.

31. Peter B. de Selding, "Israel Approves Sale of Images from Spy Satellite," *Space News*, Vol. 10, No. 25 (June 28, 1999), p. 7.

32. Statement by the Press Secretary, The White House, Office of the Press Secretary, Washington, D.C., March 10, 1994, p. 1.

33. Courtney A. Stadd and Ronald J. Birk, "No Strings Attached? Commercial Remote Sensing Companies Hope That U.S. Government Policy Will Keep Pace with the Industry's Rapidly Expanding Needs," *Imaging NOTES*, Vol. 14, No. 4 (July/August 1999), p. 20.

34. Statement made by the National Imagery and Mapping Agency, Office of Congressional and Public Liaison, May 20, 1999. This figure does not include funds spent by other organizations such as the U.S. Army and Air Force.

35. "United States Negotiates Sale of Turnkey Remote Sensing Systems," *Geo Info System*, Vol. 9, No. 7 (July 1999), p. 18.

36. The Canadian government has not yet released its regulations for the Canadian remote sensing industry. It has indicated, however, that its laws will be very similar to those of the United States and that it will release them before the first privately owned and operated Canadian satellite, RADARSAT-2, begins operations in 2002.

37. R. Jeffrey Smith, "High-Tech Vigilance," *Science* (December 1985), pp. 26-33.

38. Ann M. Florini, "The End of Secrecy," *Foreign Policy*, No. 11 (Summer 1998), p. 60.

39. Dino A. Brugioni, "Satellite Images on TV: The Camera Can Lie," *The Washington Post*, December 14, 1986, p. H1.

40. Ibid.

41. Vipin Gupta, statement made during the Carnegie Endowment for International Peace conference entitled No More Secrets: Policy Implications of Commercial Remote Sensing Satellite, Washington, D.C., May 26, 1999. To watch the RealVideo of Vipin Gupta's presentation, visit the Carnegie Endowment for International Peace website at www.ceip.org/programs/transparency/RemoteSensingConf/GuptaPage.htm.

42. Statement made by Steven Livingston at the Carnegie Endowment for International Peace conference entitled No More Secrets: Policy Implications of Commercial Remote Sensing Satellites, Washington, D.C., May 26, 1999. See also "Correction" in the August 31, 1998 issue of *Newsweek*. To see more of Steven Livingston's presentation, visit the Carnegie Endowment for International Peace website at www.ceip.org/programs/transparency/RemoteSensingConf/LivingstonPage.htm.

43. Robert P. Merges and Glenn H. Reynolds, "The News Media Satellites and the First Amendment: A Case Study in the Treatment of New Technologies," *High Technology Law Journal*, Vol. 3 (Spring 1988), p. 31.

44. Application to Operate a Commercial Land Observation System, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Washington, D.C., Section B, part 1.

45. To learn more about U.S. policy on shutter control, visit John Barker's page on the Carnegie Endowment for International Peace website at www.ceip.org/programs/transparency/RemoteSensingConf/BarkerPage.htm.

46. Scott Pace, testimony before the Committee on Science, Space, and Technology and the Permanent Select Committee on Intelligence, U.S. House of Representatives, Washington, D.C., February 9, 1994.

47. To learn more about the Radio-Television News Directors Association's position, visit Barbara Cochran's page

on the Carnegie Endowment for International Peace website at www.ceip.org/programs/transparency/RemoteSensingConf/CochranPage.htm.

48. “Prohibition on Collection and Release of Detailed Satellite Imagery Relating to Israel,” National Defense Authorization Act for Fiscal Year 1997, P.L. 104-201, Sec. 1064(a), Washington, D.C., 1996.

49. Russia may begin marketing 1-meter resolution satellite imagery in the near future. However, given the unreliability of Russian vendors, it is unlikely that they will be able to capture a significant portion of the remote sensing market.

50. Michael M. May, “Safeguarding Our Military Space Systems,” *Science*, No. 232 (April 18, 1986), pp. 336-40.

51. The U.S. Air Force Research Laboratory’s Space Vehicles Directorate is developing a system called Satellite Threat Warning and Attack Reporting (STW/AR) designed to detect intentional interference with U.S. and allied satellites. William B. Scott, “New Satellite Sensors Will Detect RF (Radio Frequency), Laser Attacks,” *Aviation Week & Space Technology*, August 2, 1999, p. 57.

52. Warren Ferster, “After IKONOS, Space Imaging Plans Even Better Satellite,” *Space News*, Vol. 10, No. 36 (September 27, 1999), p. 3.

53. Ibid.

54. Warren Ferster and Peter B. de Selding, “Spot Image, Orbital Plan Reciprocal Sales Deal,” *Space News*, Vol. 10, No. 36 (September 27, 1999), p. 3.

55. Oliver Morton, “Private Spy,” *Wired* (August 1997), p. 9.

appendix a: selected commercial and civilian imaging satellites

north america

Satellite	Launch (end of service)	Operator	Capability (meters)	Swath Width (kilometers)	Revisit Time (days)	Status
Landsat 3	1978 (1983)	NASA/NOAA	30RVB/80MS	185/185	18	retired
Landsat 4	1982	EOSAT/Sp. Imaging	30MS/80MS	185/185	16	operational[a]
Landsat 5	1984	EOSAT/Sp. Imaging	30MS/80MS	185/185	16	operational
Landsat 6	1993 (1993)	EOSAT	15PAN/30MS	185/185	16	failed
Landsat 7	1999	USGS	15PAN/30MS	185/185	16	operational
IKONOS 1	1999 (1999)	Space Imaging	0.82-1PAN/4MS	13/13	3 to 5	failed
IKONOS 2	1999	Space Imaging	0.82-1PAN/4MS	13/13	3 to 5	operational
EarlyBird	1997(1997)	Earth Watch	3PAN/15MS	3/15	1 to 5	failed
QuickBird 1	2000	Earth Watch	1PAN/4MS	22/22	1 to 5	planned
QuickBird 2	2000	Earth Watch	1PAN/4MS	22/22	1 to 5	planned
OrbView 3	2000	OrbImage	4MS/8HS	8/8	3	planned
OrbView4	2000	OrbImage	1PAN/4MS/8HS[b]	8/8/5	3	planned
NEMO	2001	STDC	5PAN/30HS	30/30	1 to 7	planned
Resource21	2001	Boeing	10PAN	200	7	planned
RADAR 1	2002	RDL	1SAR	4	1	planned
RADARSAT-1	1995	CSA	8SAR	50-500	3 to 24	operational
RADARSAT-2	2002	MDA	3SAR	50-500	3 to 24	planned

a. Data transmission from the 30-meter sensor failed in August 1993.
b. OrbImage will be able to sell only 24-meter hyperspectral images to nongovernmental entities.

russia

Satellite	Launch (end of service)	Operator	Capability (meters)	Swath Width (kilometers)	Revisit Time (days)	Status
SPIN-2[a]	Periodic[b]	Russia	2PAN/10PAN	180/200	N/A	N/A
RESURS-F	Periodic[c]	Russia	5-8MS/15-30MS	N/A	N/A	N/A
RESURS-DK	2000	Russia	2PAN/3MS/3SAR	N/A	N/A	N/A

a. SPIN-2 is the product of KVR-1000 and TK-350 cameras on board the Kometa spacecraft.
b. SPIN-2 satellites are presently launched about once each year and have a mission life of 45 days.
c. RESURS-F satellites are launched throughout the year and have a mission life of 25 days.

western europe

Satellite	Launch (end of service)	Operator	Capability (meters)	Swath Width (kilometers)	Revisit Time (days)	Status
SPOT 1/2	1986/90	Spot Image	10PAN/20MS	60/60	1 to 4	operational[a]
SPOT 3	1993 (1996)	Spot Image	10PAN/20MS	60/60	1 to 4	failed
SPOT 4	1998	Spot Image	10PAN/20MS	60/60	1 to 4	operational
SPOT 5	2002	Spot Image	2.5PAN/10MS	60/60	1 to 4	planned
ERS-1	1991	ESA	30-50 SAR	100-500	3 to 35	operational
ERS-2	1995	ESA	30-50 SAR	100-500	3 to 35	operational
ENVISAT 1	2000	ESA	30 SAR	100	3 to 35	planned
ENVISAT 2	2003	ESA	N/A	N/A	N/A	planning

a. Although still operational, SPOT 1 was withdrawn from active service at the end of 1990.

FINALreport.qxd 2/17/00 6:54 PM Page 39

southeast asia and south america

Satellite	Launch (end of service)	Operator	Capability (meters)	Swath Width (kilometers)	Revisit Time (days)	Status
JERS-1	1992 (1998)	Japan	18MS/18SAR	75/75	44	retired
ADEOS1	1996 (1997)	Japan	8PAN/16MS	80/80	41	failed
ALOS-1	2003	Japan	2.5PAN/10MS/10SAR	70/70/70	46	planned
Info-Collectic	2003	Japan	1PAN/3SAR	N/A	N/A	planning
Kompsat-1	1999	South Korea	10PAN/20MS	40/40	2 to 3	operational
Kompsat-2	2003	South Korea	1PAN/4MS	N/A	2 to 3	planned
Rocsat 2	2002	Taiwan	2PAN	N/A	1	planning
CEMD	2003	China	4SAR	700	N/A	operational
CBERS I	1999	China/Brazil	20MS/80-160MS	120/120	26	planned
CBERS II	2001	China/Brazil	20MS/80-160MS	120/120	26	planning
CBERS III	N/A	China/Brazil	5PAN/10MS	N/A	N/A	planning
CBERS IV	N/A	China/Brazil	5PAN/10MS	N/A	N/A	planning
SABIA	2003	Brazil/Argentina	6MS	400	N/A	

australia

Satellite	Launch (end of service)	Operator	Capability (meters)	Swath Width (kilometers)	Revisit Time (days)	Status
Aries	2003	Australia	10PAN/30HS	15/15	6 to 7	planned

middle east

Satellite	Launch (end of service)	Operator	Capability (meters)	Swath Width (kilometers)	Revisit Time (days)	Status
EROS-A1	2000	WIS	1.8PAN	13	2 to 3	planned
EROS-A2	2000	WIS	1.8PAN	13	2 to 3	planned
EROS-B1	2001	WIS	0.8PAN	13	2 to 3	planned

south asia

Satellite	Launch (end of service)	Operator	Capability (meters)	Swath Width (kilometers)	Revisit Time (days)	Status
IRS-1C	1995	India	5PAN/23MS	70/150	5 to 24	operational
IRS-1D	1997	India	5PAN/23MS	70/150	5 to 24	operational
IRS-P5[a]	2000	India	2.5PAN	30	5 to24	planned
IRS-P6[b]	2001	India	5PC/23MS	750/750	5-24	planning
CartoSat-2	2003	India	1PAN	N/A	N/A	planning
Badr-C	2000	Pakistan	10MS	205	N/A	planned

a. IRS-P5 is also known as CartoSat-1.
b. IRS-P6 is also known as Resource Sat-1.

appendix b: policy history

In grappling with the policy implications of high-resolution satellite imagery, it is helpful to have a good understanding of how current policies came about. Because civilian remote sensing has been so heavily dominated by the United States until quite recently, in both technological and policy terms, much of the history occurred there.

The history begins with the U.S. National Aeronautics and Space Administration (NASA), which developed the first civilian remote sensing satellite, Landsat. The launch of Landsat 1 in 1972 gave the global public its first glimpse of satellite images of Earth. However, Landsat 1's relatively low resolution (80 meters multispectral) was too coarse for most commercial purposes. During these early years research scientists, educators, and government agencies were the principal users of Landsat imagery.

To expand the user base for Landsat data and set the stage for the eventual commercialization of the civilian remote sensing industry, the Carter administration issued Presidential Decision Directive-54 in July 1979. The directive transferred the operation of the Landsat systems to the National Oceanic and Atmospheric Administration (NOAA) in the U.S. Department of Commerce and directed NOAA to "seek ways to further private sector opportunities in civil land remote sensing activities … with the goal of eventual operations of these activities by the private sector."[1] The administration hoped that under NOAA the management cost of the Landsat program would decline significantly, improving the prospects for its eventual commercialization. Moreover, it was believed that the future availability of 30-meter resolution imagery from Landsats 4 and 5 (planned for launch within the next five years) would dramatically increase the revenue earned from the sale of Landsat imagery.[2] These two factors, it was reasoned, would ultimately lead to the creation of an affordable and robust market for remote sensing data. That market in turn would encourage the growth of a commercial satellite industry that could develop and operate remote sensing systems for government and private markets.[3]

the unpromising start of commercialization

Following the election of President Ronald Reagan in 1980, the government abandoned the Carter administration's gradual approach to commercialization of the Landsat program in favor of a far more accelerated plan. To cut federal spending by privatizing government programs, the Reagan administration ignored evidence that suggested that the remote sensing market was not sufficiently mature to sustain an independent commercial industry. That evidence included four feasibility studies commissioned by the U.S. government between 1982 and 1983. The first, undertaken by the Civil Operational Remote Sensing Satellite Advisory Committee of the Department of Commerce, found that the commercial market for Landsat data was seriously underdeveloped and recommended that "commercialization of the Landsat program should be done gradually."[4]

The other three studies supported the committee's conclusions. Following an in-depth analysis of the satellite imagery market, ECON Incorporated concluded that "full transfer of the civil land remote sensing system to the private sector, with the expectation of a viable self-sustaining enterprise, is premature."[5] Similarly, Earth Satellite Corporation declared that "No option was found that would permit the [Landsat] program to be commercialized, today or in the near future, without substantial subsidies or government-guaranteed data purchases."[6] Using a much harsher tone, the National Academy of Public Administration argued that the Reagan administration's decision to transfer operations of the Landsat program to the private sector "fails to meet sensible criteria of preservation of the national security" and represents a "forced premature privatization of these responsibilities."[7]

Despite these cautionary words, the Reagan administration pressed ahead. Faced with the likelihood that funding for the Landsat program would soon be discontinued, Congress quickly approved the Land Remote Sensing Commercialization Act (P.L. 98-365), which was signed into law on July 17, 1984. The act directed the secretary of commerce to select a contractor to operate the Landsat system; instructed system operators to market the resulting data on a nondiscriminatory basis; required the Department of Commerce to maintain an archive of land remote sensing data for historical, scientific, and technical purposes; and established a licensing and oversight process for new entrants into the anticipated private remote sensing industry.

In September 1985, NOAA selected the Earth Observation Satellite Company (EOSAT), a joint venture of RCA Corporation and Hughes Aircraft Company, to operate the Landsat satellites and market the resulting data for a period of ten years. According to the terms of the contract, the U.S. government would continue to cover the operational costs of the Landsat program through the three-year expected lifetime of Landsats 4 and 5. In addition, because the market for remote sensing data was considered underdeveloped, the U.S. government agreed to subsidize EOSAT in the amount of $295 million over a five-year period to develop and launch two new Landsat spacecraft, Landsats 6 and 7. Upon the launch of Landsat 6, EOSAT would assume full responsibility for all operational costs of the Landsat program. Policy makers and EOSAT executives believed—or hoped—that during the lifetime of Landsats 6 and 7, EOSAT's revenues would grow sufficiently to allow the company to finance the development, launch, and operation of future land remote sensing systems.[8]

The government transferred responsibility for the operation of the Landsat program to EOSAT in October 1985. It then failed to keep its end of the bargain. The Reagan administration deleted additional subsidies for EOSAT from its FY1987 budget proposal, arguing that the remaining $125 million called for in the EOSAT-NOAA contract would have to come from EOSAT or other private sources. In December 1986, EOSAT began laying off employees and ceased all marketing and spacecraft development. Congress again intervened to ensure the survival of the Landsat program beyond Landsat 5: in FY1987 it appropriated $62.5 million to continue the development of Landsat 6. However, the funds could not be released until NOAA drafted and Congress approved a new Landsat commercialization plan.

In June 1987 NOAA submitted its new commercialization proposal to Congress. It called for EOSAT to develop only one additional Landsat satellite, and funds were provided for a feasibility study for a second satellite that might include more advanced and commercially oriented sensors. Congress initially rejected the proposal but acquiesced in October 1987.

Between November 1987 and April 1988, NOAA renegotiated its contract with EOSAT. The revised contract directed EOSAT to develop Landsat 6 and all associated ground systems. The government agreed to subsidize the project up to $220 million; EOSAT was to absorb any additional costs. Under an innovative "payback" arrangement, EOSAT agreed to refund $10.8 million to the government over a period of approximately four years. In addition, EOSAT waived all rights to data from follow-on civil remote sensing spacecraft beyond Landsat 6. With this agreement in place, Congress finally released the $62.5 million appropriated for the development of Landsat 6 in the FY1987 budget.

No sooner was the Landsat 6 dilemma resolved than the Landsat program faced yet another crisis. The 1984 Land Remote Sensing Commercialization Act had instructed NOAA to finance the operations of Landsats 4 and 5 through the expected lifetime of the two satellites, which was projected for 1987, and the support was due to expire at the end of that year. NOAA, which had no particular institutional interest in continuing the Landsat program, made no arrangements to fund either satellite after the expiration date, regardless of whether the satellites were still operational. Thus NOAA did not request any funds for the Landsat program in its FY1989 budget even though the satellites were still functioning. Congress quickly appropriated $9.4 million to fund Landsats 4 and 5 for the first half of the fiscal year and asked NOAA to secure funding for the second half. Unable to obtain sufficient funds, NOAA directed EOSAT to turn the satellites off in April 1989. This proposal drew strong protests from Congress, foreign governments, and data users in the United States and around the world. In response to the outcry, the National Space Council, chaired by Vice President Dan Quayle in the Bush administration, drafted an interim funding plan that asked government agencies that used Landsat imagery to provide money to NOAA. Moreover, the council recommended that the federal government ensure the operation of Landsats 4 and 5 so long as the satellites were the only source of civilian remote sensing data.[9] NOAA rescinded the shutdown order in March 1989.

The same routine played out during fiscal years 1990 and 1991. In both years Congress provided $9.5 million for the first six months of the each year and asked other government agencies that used Landsat imagery to provided the remaining funds. Finally, on June 1, 1989, President George Bush "approved funding for continued operations of Landsat satellites 4 and 5 and for the completion and launch of Landsat 6."[10] In addition, President Bush "directed the National Space Council and the Office of Management and Budget to review options with the intention of continuing Landsat-type data collections after Landsat 6."[11]

the undoing of landsat commercialization

By the early 1990s, several developments made it clear that the U.S. government needed to review the Land Remote Sensing Commercialization Act of 1984. First, the forced commercialization of the Landsat program had faltered badly. Instead of spending $295 million to acquire and deploy two Landsat satellites, the U.S. government had committed itself to spending $245.7 million to develop and launch only one. Moreover, commercialization of Landsat had dramatically increased the price of imagery. Between 1982 and 1985, the prices of data from Landsat's multispectral scanner and thematic mapper instruments more than doubled.[12] The hike in prices led many of the former customers of Landsat imagery, including large numbers of scientists and academics, to stop using Landsat products.

Second, the emergence of foreign competitors to Landsat imagery eliminated the United States' comfortable position as the sole provider of remote sensing data.

Following the successful launch of the French SPOT-1 satellite in February 1986, Spot Image began marketing 10-meter panchromatic and 20-meter multispectral images of the Earth. A year later a Soviet firm, Soyzkarta, initiated limited sale of 5-meter panchromatic photographs from its Cosmos KFA-1000, MK-4, and MFK-6 cameras.[13] These developments led many in the United States to worry that foreign companies might come to dominate the remote sensing market. This concern gained new urgency as SPOT's sale of remote sensing imagery surpassed that of EOSAT by 1989.[14] Many within and outside the U.S. government began to question the wisdom of a policy that allowed foreign countries to surpass the United States in an industry it had pioneered.

Third, Landsat imagery proved remarkably useful during the planning and execution of the 1990-1991 Persian Gulf War. As D. Brian Gordon of the Defense Intelligence Agency testified, "There were significant contributions by Landsat … to the success of Operation Desert Storm."[15] According to some estimates, the U.S. Department of Defense spent $5 to $6 million on Landsat imagery during the Gulf War.[16] Throughout the conflict, allied forces used Landsat imagery for terrain analysis, operational planning, and concealment detection.[17]

All these pressures led the U.S. Congress to pass the Land Remote Sensing Policy Act (P.L. 102-555), which was signed into law by President George Bush on October 28, 1992. The act recognized that "the continuous collection and utilization of land remote sensing data from space are of major benefit in studying and understanding human impacts on the global environment, in managing the Earth's natural resources, in carrying out national security functions, and in planning and conducting many other activities of scientific, economic, and social importance."[18] The act further acknowledged that "despite the success and importance of the Landsat system, funding and organizational uncertainties over the past several years have placed its future in doubt and have jeopardized United States leadership in land remote sensing."[19] The act rejected full commercialization of the Landsat program "within the foreseeable future"[20] and transferred control of the Landsat system to NASA and the DOD. Authority for licensing any new private remote sensing satellites remained with the secretary of commerce, as it had been under the 1984 act, with advisory roles given to the secretaries of state and defense. The act repealed the obligation established by the earlier act that compelled private companies to make all raw data available to all potential users at the same cost and terms. Instead, the new law merely required that satellite operators "make available to the government of any country (including the United States) unenhanced data collected by the system concerning the territory under the jurisdiction of such government as soon as such data are available and on reasonable terms and conditions."[21]

Shortly after passage of the Land Remote Sensing Policy Act, disagreements arose between NASA and the DOD over what type of sensors to place on the Landsat 7 satellite. NASA favored the cheaper Enhanced Thematic Mapper Plus, capable of acquiring 15-meter images of Earth. The DOD pushed for the new High Resolution Multispectral Stereo Imager sensor, which could collect 5-meter resolution data of particular interest to it.

The disagreement had not been resolved when disaster struck. At approximately 11:08 a.m. Pacific Standard Time on October 5, 1993, nearly 13 minutes after the launch of Landsat 6, a ruptured hydrazine manifold prevented fuel from reaching the satellite engine, and the $256.5 million spacecraft plunged into the Pacific Ocean.[22] Following the failure of Landsat 6 to reach orbit, NASA concluded that the high cost of developing the High Resolution Multispectral Stereo Imager sensor could undermine the timely development and deployment of Landsat 7. It therefore rejected placement of the sensor on board the new Landsat satellite. Consequently, the DOD pulled out of the Landsat program.

With the DOD out, the question of which agency or agencies should develop and operate the Landsat system and market the resulting data once again came to the forefront. The White House finally resolved the issue in Presidential Decision Directive-3 of May 10, 1994: NASA would be responsible for developing and launching Landsat 7, NOAA would operate the spacecraft and all relevant ground systems, and the Department of the Interior would archive and distribute the data at the marginal cost of reproduction.

As this monograph went to press, yet another rearrangement of responsibilities for the Landsat program was underway. A new Presidential Decision Directive was drafted that would transfer all operational responsibility for the Landsat 7 program from NOAA to the Department of the Interior's U.S. Geological Survey (USGS). Given that USGS had a more obvious interest in pursuing land remote sensing activities than NOAA, the transfer was expected to be approved in the very near future.

With the successful launch of Landsat 7 on April 15, 1999, the United States came full circle, restoring a significant government subsidy to civilian remote sensing, although now with a substantially improved satellite. Landsat 7 is providing 15-meter panchromatic and 30-meter multispectral images of Earth and is expected to continue functioning until 2004. It has the ability to re-image areas of interest every 16 days with its more accurate Enhanced Thematic Mapper Plus sensor. More important, Landsat 7 images are available to all consumers of satellite imagery "at the cost of fulfilling user requests,"[23] and anyone who buys an image is free to pass it on at no extra charge. As of the end of 1999, prices were $475 per scene for minimally processed data and $600 per scene for radiometrically and geometrically corrected data (over 50 percent cheaper than any comparable commercially available civilian or private satellite imagery).[24]

Although it might seem that the government is subsidizing a competitor to commercial operators, the Landsat 7 sensors are sufficiently different from the commercial sensors that direct competition is unlikely. Indeed, by helping build a market for satellite imagery in general, the Landsat program may in fact help the commercial prospects of private satellite operators.

The Landsat story nonetheless raises important red flags. The commercial success of the satellite remote sensing industry is by no means assured. Nations that try to privatize their government-controlled civilian systems may find themselves with neither a civilian nor a commercial system, as the United States almost did in the early 1990s.

1. Announcement of the President's Decisions Concerning Land Remote Sensing Activities, The White House, Washington, D.C., November 20, 1979.

2. "Remote Sensing and the Private Sector: Issues for Discussion," U.S. Congress, Office of Technology Assessment, Washington, D.C., March 1984, p. 62.

3. Ray A. Williamson, "The Landsat Legacy: Remote Sensing Policy and the Development of Commercial Remote

Sensing," *Photogrammetric Engineering & Remote Sensing*, Vol. 63, No. 7 (1997), p. 879.

4. David P. Radzanowski, "The Future of Land Remote Sensing Satellite System (Landsat)," U.S. Library of Congress, Congressional Research Service, Washington, D.C., September 16, 1991, p. 3.

5. "Commercialization of the Land Remote Sensing System: An Examination of Mechanisms & Issues," ECON Inc., Princeton, NJ, April 1, 1983.

6. "A Study to Examine the Mechanisms to Carry Out the Transfer of Civil Land Remote Sensing Systems to the Private Sector," Earth Satellite Corporation, Rockville, MD, March 28, 1983.

7. "Space Remote Sensing and the Private Sector: An Essay," National Academy of Public Administration, Washington, D.C., March 1983.

8. U.S. House of Representatives, Committee on Science, Space, and Technology, Report 102-539, May 28, 1992, Washington, D.C., p. 20.

9. National Landsat Policy Act of 1992, Report 102-539, U.S. House of Representatives, Committee on Science, Space, and Technology, Washington, D.C.: GPO, May 28, 1992, p. 23.

10. "Statement by the Press Secretary," The White House, Office of the Press Secretary, Washington, D.C., June 1, 1989.

11. Ibid.

12. National Landsat Policy Act of 1992, Report 102-539, footnote #48, U.S. House of Representatives, Committee on Science, Space, and Technology, Washington, D.C.: GPO, May 28, 1992, p. 29.

13. Gerald M. Steinberg, "Dual Use Aspects of Commercial High-Resolution Imaging Satellites," The Begin-Sadat Center for Strategic Studies, Bar-Ilan University, Ramat Gan, Israel, 1998, p. 8.

14. "Space Business Indicators," U.S. Department of Commerce, Office of Space Commerce, Washington, D.C., June 1991.

15. D. Brian Gordon, testimony before the U.S. House of Representatives Committee on Science, Space, and Technology and the Permanent Select Committee on Intelligence, Washington, D.C.: GPO, June 26, 1991, p. 28.

16. National Landsat Policy Act of 1992, Report 102-539, U.S. House of Representatives, Committee on Science, Space, and Technology, Washington, D.C.: GPO, May 28, 1992, p. 26.

17. Donald J. Kutyn, prepared statement, Hearings before the U.S. Senate Armed Services Committee, Washington, D.C., April 23, 1991, p. 733, and D. Brian Gordon, testimony before the U.S. Congress Committee on Science, Space and Technology and the Permanent Select Committee on Intelligence, Washington, D.C.: GPO, June 26, 1991, p. 29.

18. Land Remote Sensing Policy Act of 1992, Section 2(1), Washington, D.C., October 28, 1992.

19. Ibid., Section 2(7).

20. Ibid., Section 2(6).

21. Ibid., Title II, Section 202(b)(2), Washington, D.C., October 28, 1992.

22. "Landsat 6 Failure Attributed to Ruptured Manifold," U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Washington, D.C., March 10, 1995. The price includes all costs borne by the U.S. government and EOSAT to develop and launch Landsat 6.

23. Land Remote Sensing Policy Act of 1992, Section 2(13), Washington, D.C., October 28, 1992.

24. "Landsat 7 Data Prices Announced," U.S. Department of Commerce, U.S. Geological Survey, Washington, D.C., October 31, 1997.

THE CARNEGIE ENDOWMENT FOR INTERNATIONAL PEACE is a private, nonprofit organization dedicated to advancing cooperation between nations and promoting active international engagement by the United States. Founded in 1910, its work is nonpartisan and dedicated to achieving practical results. Through research, publishing, convening and, on occasion, creating new institutions and international networks, Endowment associates shape fresh policy approaches. Their interests span geographic regions and the relations among governments, business, international organizations, and civil society, focusing on the economic, political, and technological forces driving global change. Through its Carnegie Moscow Center, the Endowment helps develop a tradition of public policy analysis in the states of the former Soviet Union and improve relations between Russia and the United States. The Endowment publishes *Foreign Policy,* one of the world's leading journals of international politics and economics, which reaches readers in more than 120 countries and in several languages.