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Markets and Opportunities?

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It would be hard to find an *Earth Imaging Journal* reader who didn't know about the Landsat and SPOT satellites. Similarly, the magazine's readers are well aware of the incredible high-resolution satellite imagery available from the three U.S. commercial vendors: DigitalGlobe, ORBIMAGE and Space Imaging. But it would be the rare reader, indeed, who would know about all 66 satellites listed on pages 12 and 13. And how many would believe a country the size of Singapore has plans to launch a global land-imaging satellite?

The satellites listed are worth more than a casual glance by anyone who uses Earth imagery, because they all provide scenes with resolutions better than 39 meters—arguably the resolution that begins to image/map human-scale activities, roads, fields, urban patterns, etc. And, equally important, all are billed as "civil" satellites, implying their data might be available to the masses someday. The sheer number of satellites and the number of countries—21 at last count—using their treasure to own them makes a statement about the status of land-observing satellites in the world economy. But does all of this activity mean the commercial takeoff of a new and vibrant industry or, because most of the satellites are government-funded, something else?

A Brief History

For the moment, let's consider the 54 optical satellites, as radar will be discussed separately. And let's start with a bit of history. Figure 1 provides a quick look at the number of imaging satellites and their government sponsors since the 1972 launch of Landsat 1.

There have been three distinct periods in Earth imaging's history. The first period extends from the original Landsat, which carried the four-band 80-meter-resolution Multispectral Scanner Sensor (MSS), to the launch of Landsat 4 in 1982 with the improved seven-band 30-meter-resolution Thematic Mapper (TM) sensor. The fact that virtually all of the civil satellites flown since then have included multispectral sensors illustrates the technology's value, but it is also a tribute to NASA's efforts in the first period to share and extend multispectral technology to the rest of the world, particularly data-starved Third World countries.

The second period extends from 1978 to 1998, and is dominated by the entry of the foreign systems. Russia (4) was first, but it was followed quickly by France (4), Japan (4) and India (5). The only U.S. launch during the period, Landsat 6 in 1993, was unsuccessful. It was only the miraculous lifetimes of Landsats 4 and 5 that kept the U.S. program alive. Of the four foreign programs only France's SPOT system had any measurable effect in the remote viewing data world. The SPOT program was planned as a commercial venture from the start, providing 10-meter panchromatic and 20-meter multispectral data, stereo images and a 7-day revisit period—characteristics that were responsible for SPOT's $40 million in sales vs. EOSAT's $32 million in 1991.

This period included Landsat's ill-advised commercialization in 1984 and its return to the government in 1992, when Congress declared commercialization a failure and cited Landsat's value to the government for science, applications and national defense. The Landsat Remote Sensing Policy Act of 1992 required Landsat data continuity to be maintained and the data to be sold for no more than the cost of fulfilling user requests—a policy still in place today.

The 1992 act also launched the current set of commercial systems by creating a licensing process for private systems that was managed by the National Oceanic and Atmospheric Administration (NOAA). Lengthy bureaucratic delays to granting a request for a 1-meter license culminated in 1994 at a dramatic meeting of the House Science and Intel committees, during which Congress introduced a 2-meter image of the National Mall purchased commercially from the Russians. It was determined that U.S. industry should be allowed to compete by developing a better product. President Clinton agreed, signing a Presidential Decision Directive to that effect two weeks later. As a result, Space Imaging was born.

And that brings us to the third and still continuing phase. As shown in Figure 1, currently there are 25 satellites in orbit—double the number in 1998—and five more are expected to launch by 2007. But besides the number of satellites, the dramatic change between the two periods is the number of countries paying for them. The five players of the first period have been joined by 12 more. The overview spread on pages 12 and 13 presents the critical discriminating factors of each satellite.

Current and Planned Satellites

To begin to understand the large numbers of satellites, it will be helpful to look carefully at the table on page 13. It provides three critical satellite image features: spatial resolution, image swath (area) and spectral bands. (Due to a lack of information, a fourth feature, radiometry quality, is missing.) Note the wide range of these values and their grouping into two main classes: high-resolution/small-swath and medium-resolution/large-swath systems. Illustrations of these features can be seen in the "Guide to Land-Imaging Satellites," accessible online at *www.asprs.org/asprs/news/satellites/satellites.html.*

Now consider the actual systems composing the numbers in Figure 1. Figure 2 is an on-orbit timeline of current and planned satellites from now until 2011, listing the best resolution of each by color and identifying the commercial systems by slashed patterns. Lifelines are inherently unstable at both ends. The operational timelines are drawn to each satellite's stated design life (traditionally five years, but the latest are designed to last seven). Planned launch dates aren't much more reliable.

Satellite Commercialization

Ten of the 30 satellites scheduled to orbit by 2007 will be commercial—not bad for an industry that was totally government supported a decade ago. But this may be deceiving. Both the U.S. and Israel commercial systems are in the high-resolution market, which Israel believes to be viable only through government sales. Although the three U.S. companies have committed a lot of time and resources to nurture a private market, it has developed slowly. According to one high-resolution company, only 10 percent of last year's sales were to nongovernment users. Airborne imagery providers benefit from the same technologies that bolster the satellite companies—the Global Positioning System, geographic information systems and digital data. The seriousness of this competition was underscored by ORBIMAGE's recent petition to NOAA to let the satellite companies sell the currently restricted 0.25-meter data to the civil market to provide a more level playing field with airborne sensors.

To make matters worse for the U.S. players, several countries are developing high-resolution systems of their own—France, India, Russia and Korea plan to launch systems with 1-meter resolution or better. In addition, Europe announced a "dual use" policy by which various governments will develop and operate satellites because their data are required for defense applications. However, they'll also sell the data commercially.

The case can be made that the Europeans are simply being a little more realistic and honest about their satellite support than the United States. The two recent National Geospatial-Intelligence Agency (NGA) awards of $500 million each to ORBIMAGE and DigitalGlobe for their next-generation satellites were made to ensure a viable industry would be available for vital intelligence needs. Thus, it is reasonable to expect the high-resolution business will continue to be government-sponsored and/or subsidized in one way or another for the foreseeable future.

Another commercial system, Germany's RapidEye, is planning a mostly civil market. RapidEye's total budget to build and launch five satellites is about 150 million euros (30 million from the German government). Compare this with Resource 21's rumored $500 million proposal to NASA for the Landsat Data Continuity Mission and to the two similarly priced NGA awards, all of which were for one satellite each. To keep its investment at its low level, RapidEye is defying conventional wisdom and using six visible and near-infrared bands for its vegetation evaluation function. If RapidEye is a commercial success, its modest startup costs will have played a major part.

Microsatellites and Constellations

This brings the discussion to what could be the most significant change in the imaging satellite world since Landsat 1—microsatellites and constellations. Of the bottom 18 satellites in Figure 2, the U.K's Surrey Satellite Technology Laboratory built or is building most of them—the Disaster Management Constellation (DMC), the RapidEye satellites and TopSat.

The DMC satellites weigh about 100 kilograms—RapidEye's just 150 kilograms. Compare these numbers with the weight of DigitalGlobe's QuickBird and Space Imaging's IKONOS satellites (951 and 728 kilograms, respectively), and it is easy to explain the better than an order of magnitude cost difference between the two satellite types. For comparison purposes, Landsat 7 weighs 2,200 kilograms and cost about $750 million.

The DMC microsatellites cost as little as 10 million euros. Such a price makes satellite constellations affordable, and constellations are the only way to have reasonable resolution and frequent—up to daily—overpass capability. This combination has been sorely needed, but never was possible in the Landsat Cadillac world. (Plus the redundancy inherent in constellations is virtually a requirement for commercial and operational systems.) The DMC constellation data will be sold commercially, and only time will tell if the three VNIR bands are up to all of the tasks they attract because of their daily visit capability. However, their success in the disaster management field is assured, and the results of early quality tests are promising.

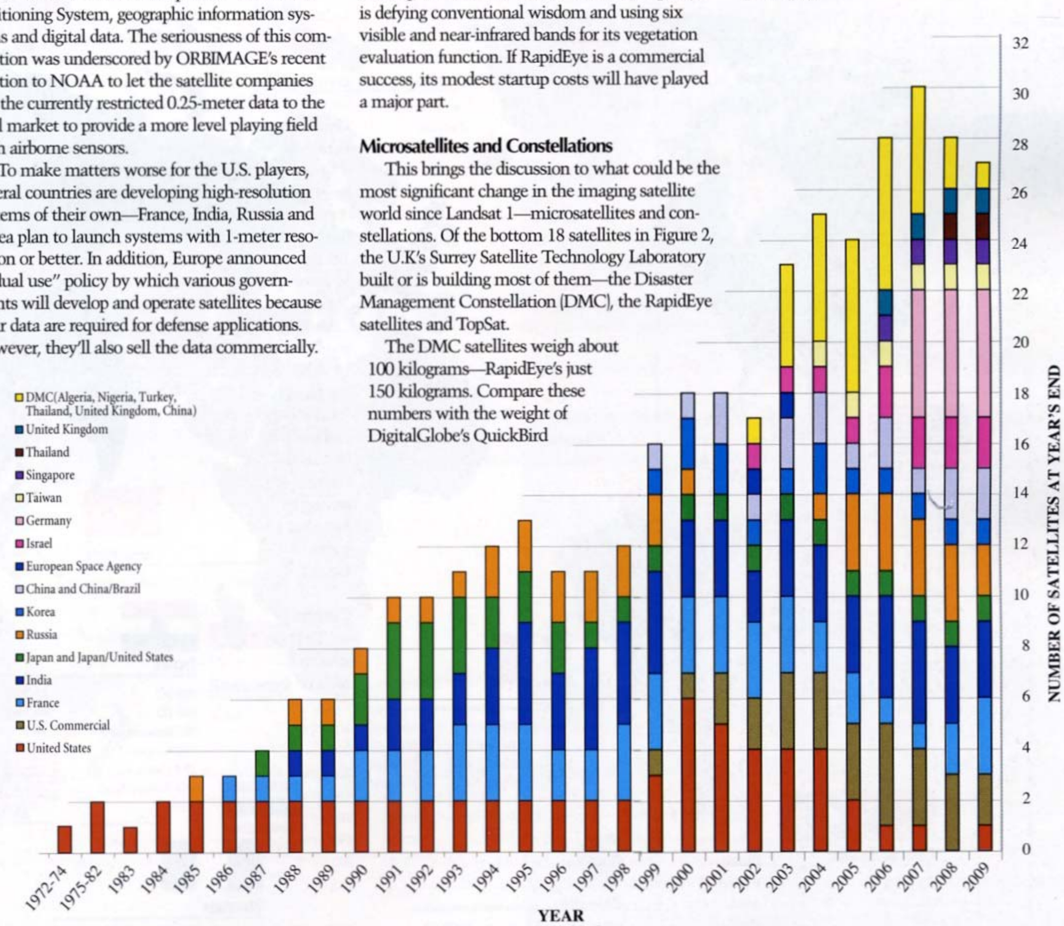


Figure 1. Significant multispectral sensor technology advances were made between the time Landsat 1 launched in 1972 and Landsat 4 launched in 1982. The period from 1978 to 1998 was dominated by the entry of the foreign systems. Now there are 25 satellites in orbit—double the number in 1998—and five more are expected to launch by 2007. Plus a lot more countries are paying for them.

A New Space Race Is On!

This world chart presents the current and planned civil land-imaging satellites with "human scale" resolutions—from a whole football field down to a half-yard line. With the number of satellites, 66, and the number of sponsors, 21, it appears the users community's cup is about to runneth over.

To understand the satellites, look carefully at the table. It provides three critical satellite image features: spatial resolution, image swath (area) and spectral bands for the optical systems, and resolution, swath and frequency band for the radar systems. Although their values vary widely, in general they're grouped into two main classes:

1. High-resolution/small-swath width—offer great detail, but can only cover limited areas such as towns, cities and military installations.

2. Medium-resolution/large-swath width—provide wide swaths that are ideal for recording and understanding natural and manmade changes at country, continent and global scales.

Although it's doubtful the reality will be as bountiful as current plans indicate, it's certain these newly envisioned global datasets will provide Earth observation data to a broader audience than ever. Within the commercial sector, the primary targets are markets associated with mapping, land use, environmental assessment, and utilities planning and management. However, these applications are merely the first wave. Other sectors are expected to come online in the years to come as ancillary users perceive application possibilities.

Black = Operational
Red = Planned
Italics = Radar satellites
★ = Commercial systems

Japan/United States	
Terra (ASTER)	12/15/99

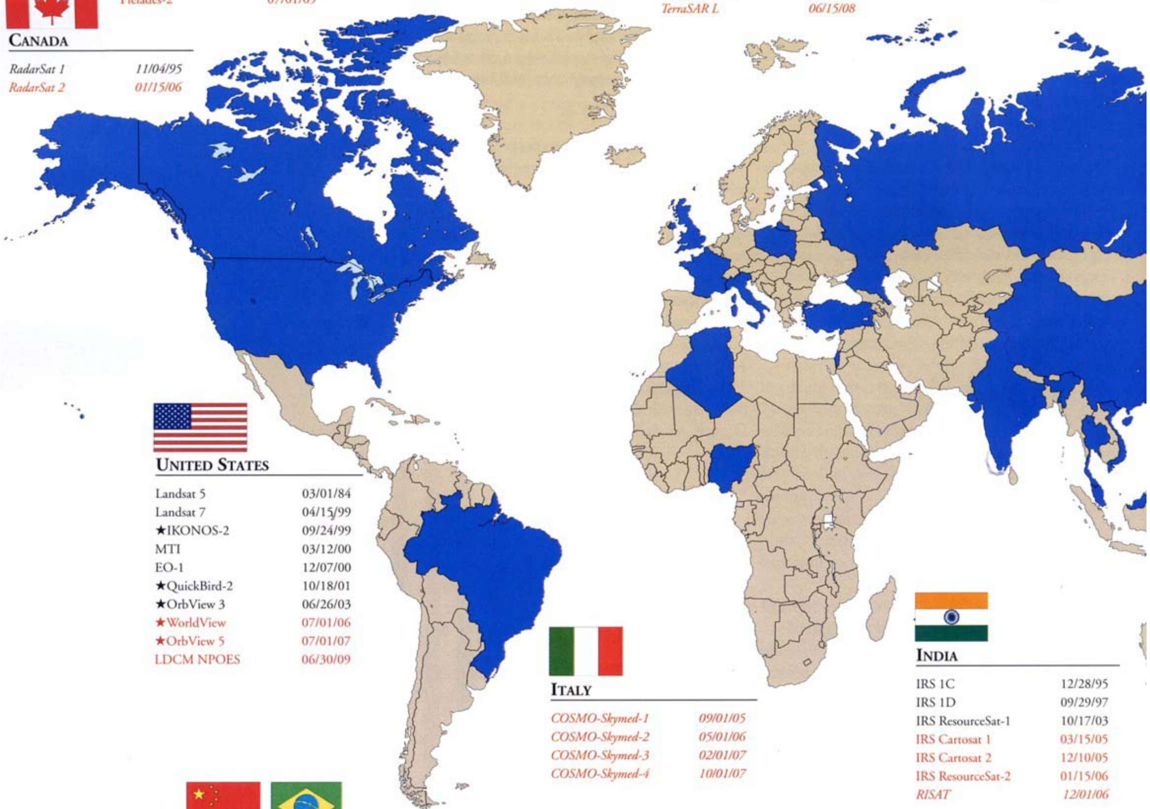
France	
SPOT-2	01/22/90
SPOT-4	03/24/98
SPOT-5	05/04/02
Pleiades-1	07/01/08
Pleiades-2	07/01/09

United Kingdom	
DMC UK	09/27/03
TopSat	03/01/05

Germany	
TerraSAR X	*04/15/06*
★RapidEye-A	06/01/07
★RapidEye-B	06/01/07
★RapidEye-C	06/01/07
★RapidEye-D	06/01/07
★RapidEye-E	06/01/07
TerraSAR L	*06/15/08*

Israel	
★EROS A1	12/05/00
★EROS B	03/01/06
★EROS C	03/01/08

Canada	
RadarSat 1	*11/04/95*
RadarSat 2	*01/15/06*



United States	
Landsat 5	03/01/84
Landsat 7	04/15/99
★IKONOS-2	09/24/99
MTI	03/12/00
EO-1	12/07/00
★QuickBird-2	10/18/01
★OrbView 3	06/26/03
★WorldView	07/01/06
★OrbView 5	07/01/07
LDCM NPOES	06/30/09

Italy	
COSMO-Skymed-1	*09/01/05*
COSMO-Skymed-2	*05/01/06*
COSMO-Skymed-3	*02/01/07*
COSMO-Skymed-4	*10/01/07*

India	
IRS 1C	12/28/95
IRS 1D	09/29/97
IRS ResourceSat-1	10/17/03
IRS Cartosat 1	03/15/05
IRS Cartosat 2	12/10/05
IRS ResourceSat-2	01/15/06
RISAT	*12/01/06*

China/Brazil	
CBERS-2	10/21/03
CBERS-2B	01/15/06
CBERS-3	05/01/08
CBERS-4	06/01/10

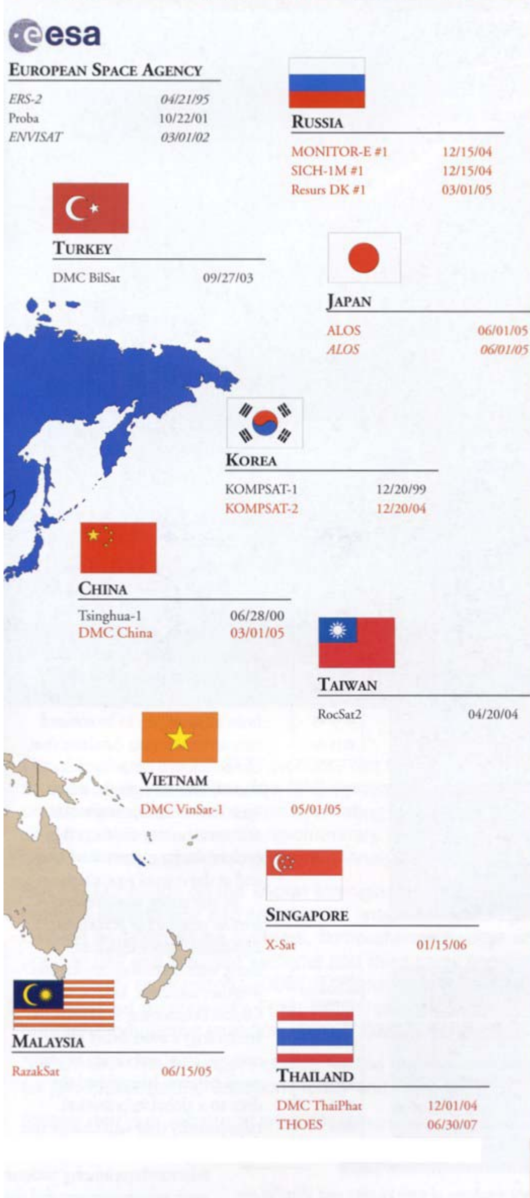
Algeria	
DMC AlSat-1	11/28/02

Nigeria	
DMC NigeriaSat-1	09/27/03

Satellite Sensor Characteristics

Radar Satellites

	Sensor	Resolution in Meters	Band	Swath in Kilometers
ALOS	PALSAR	10-20-100	L	35-50-70-250
COSMO-Skymed-1,2,3,4	SAR-2000	1.0	X	
ENVISAT	ASAR	30.0	C	60-100
ERS-2	GOME	25.0	C	100
RadarSat 1	SAR	8.5-100	C	50-500
RadarSat 2	SAR+	3-28-100	C	20-100-500
RISAT	SAR	10-50	C	10-240
TerraSAR L	LSAR	1.5-30	L	10-200
TerraSAR X	XSAR	1.5-30	X	10-200



Optical Satellites

	Sensor	Resolution in Meters (Number of Bands)					Swath in Kilometers
		PAN	VNIR	SWIR	MIR	TIR	
ALOS	AVNIR		10 (4)				70
	PRISM	2.5					35, 70
CBERS-2	CCD	20	20 (4)				113
CBERS-2B	IRMSS	80		80 (2)		160 (1)	120
	WFI-1		240 (3)				885
CBERS-3 and 4	IRMSS		40 (1)	40 (2)		80 (1)	120
	MUXCAM		20 (4)				120
	PANMUX	5	10 (3)				60
	WFI-2		73 (3)	73 (1)			866
DMC AlSat-1	MSDMC		32 (3)				600
DMC BilSat	MST		26 (4)				52
	PANT	12					
DMC China	MSDMC		32 (3)				600
	PDMC	4					
DMC NigeriaSat-1	MSDMC		32 (3)				600
DMC ThaiPhat	TMS		36 (3)				600
DMC UK	MSDMC		32 (3)				600
DMC VinSat-1	MSDMC		32 (3)				600
EO-1	ALI	10	30 (6)	30 (3)			37
	HYPERION		30 (230)				7.5
	LAC		250 (256)				250
EROS A1	PIC	1.8					14
EROS B	PIC-3	0.7					7
EROS C	PIC-2	0.7	2.8 (4)				11
IKONOS-2	OSA	1	2.5 (4)				11.3
IRS 1C and 1D	LISS-III		23.5 (3)	70.5 (1)			142
	PAN	6					70
	WiFS		188 (2)				810
IRS Cartosat 1	HR-PAN	2.5					30
IRS Cartosat 2	HR-PAN-2	1					10
IRS ResourceSat-1	AWiFS		56 (2)	56 (1)			740
IRS ResourceSat-2	LISS-III +		23.5 (3)	23.5 (1)			140
	LISS-IV	6	6 (3)				23.9/70
KOMPSAT-1	EOC	6.6					17
	OSMI		1,000 (6)				800
KOMPSAT-2	MSC	1	4 (4)				15
Landsat 5	MSS		80 (4)				185
	TM		30 (4)	30 (2)		120 (1)	185
Landsat 7	ETM+	15	30 (4)	30 (2)		60 (1)	185
LDCM NPOES	OLI	15	30 (5)	30 (3)			185
MONITOR-E #1	PANIMAGER	8					94
	MS DA		20 (3)				160
MTI	MTI		5 (4),20 (3)	20 (3)	20 (2)	20 (3)	12
OrbView 3	OHRIS	1	4 (4)				8
OrbView 5	OHRIS+	0.4	1.64 (4)				?
Pleiades-1 and 2	OHRI	0.7	2.8 (4)				20
Proba	CHRIS		18/36 (63)				14
	HRC	8					
QuickBird-2	BGIS 2000	0.6	2.5 (4)				16
RapidEye A-E	REIS	6.5	6.5 (5)				78
RazakSat	MAC	2.5	5(?)				?
Resurs DK #1	HROI	1	3 (3)				28
RocSat2	RSI	2	8 (4)				24
SICH-1M #1	MSU-EU		24 (3)				48
SPOT-2	HRV	10	20 (3)				120
SPOT-4	HRVIR	10	20 (3)	20 (1)			120
	VMI		1,150 (3)	1,150 (1)			2,200
SPOT-5	HRG	2.5	10 (3)	20 (1)			120
	HRS	10					120
	VMI		1,150 (3)	1,150 (1)			2,200
Terra	ASTER (VNIR)		15 (3)				60
	ASTER (SWIR)			30 (9)			60
	ASTER (TIR)					90 (5)	60
THOES	?	2	? (?)				?
TopSat	HIROC	2.5	5 (3)				15/10
Tsinghua-1	?		39 (3)				600
WorldView	?	0.5	4 (8)				16
X-Sat	IRIS		10 (3)				50

Note: PAN = panchromatic VNIR = visible near infrared SWIR = shortwave infrared MIR = mid infrared TIR = thermal infrared
Black = operational Red = planned

Ten of the 30 satellites scheduled to orbit by 2007 will be commercial—not bad for an industry that was totally government supported a decade ago.

The Latest on Landsat

It is fitting to include some remarks on the fate of the program that started it all. After 28 years of cliff-hanging, the current plan is to launch Landsat's replacement sensor, the Operational Land Imager (OLI), late in 2009 as part of NOAA's National Polar-orbiting Operational Environmental Satellites (NPOES) program. As shown in Figures 1 and 2, this means there will be no Landsat in orbit in 2008. It is probable there won't be any in 2007 and 2009 either, given Landsat 7's failing health and the likelihood of a slip in the planned NPOES OLI launch. Now that the operational decision has been made, it is vital for the United States to maintain the lead in broad-area technology so science and applications will get the best data products possible. This will require going beyond the current continuity-only-based specifications to take advantage of the technology gains that already have enabled one company to provide global coverage with daily revisits and six bands at 6-meter resolution two years before the planned NPOES launch. As the coming hiatus in Landsat data proves, scientists can't count on always having a custom-built Cadillac at their disposal and might have to learn to get where they want to go by flagging a taxi or, even better, gangs of rickshaws.

Radar Satellites

Figure 2 provides a look at current and planned radar satellites. The United States started land-imaging radar satellites with the short-lived Seasat in 1978 and hasn't flown a free-flight civil radar since. (The United States did conduct a series of Space Shuttle land-imaging radar tests with Germany and Italy, and on a separate mission obtained interferometric elevation measurements of more than 80 percent of the global land surface.)

It appears from their planning allocations that the European Union countries believe the all-weather 1-meter radar systems will serve their defense needs better than their optical counterparts. The COSMO and TerraSAR systems are being developed under the aforementioned "dual use" philosophy, raising the question of whether the U.S. Air Force's troubled radar satellite program would benefit from the dual-use approach.

Final Observations

Satellites are global by nature. Digital multispectral technology has made it technically and economically possible to monitor the rapidly changing global land surface of our common home with sufficient detail to understand and someday control undesirable changes in forests, farms, villages, cities, countries and continents wherever they're located. Nations have, in their sputtering and chaotic way, recognized this and responded with a sky full of cameras. It is time for the international remote sensing community to get together and plan to share the planet's photo album.

Such a plan is under way. NOAA, with NASA and USGS support, convened an Earth Summit in 2003 that has sponsored international meetings during the last year to help define a system of systems for global satellite observations (see U.S. Plans Call for an Integrated Earth Observation System," page 9). Its goal is to include all Earth observations from space of the air and the land. A final report should be presented in the coming months.

A modest goal for the land part of this effort would be an international agreement that would require all acquired scenes from all satellites to be entered into a virtual meta database that can be queried by everyone, and that all nations agree to make such data available to the scientific community after a period of exclusivity for commercial use and at the cost of reproduction.

In summary, satellite land remote rensing has become a significant "space dividend," along with communications and weather satellites, as well as the Global Positioning System. The technology's availability to all nations, large and small, as well as all citizens, has opened the door to a global information transparency that will change the relationships among nations and even among citizens and their governments. EI

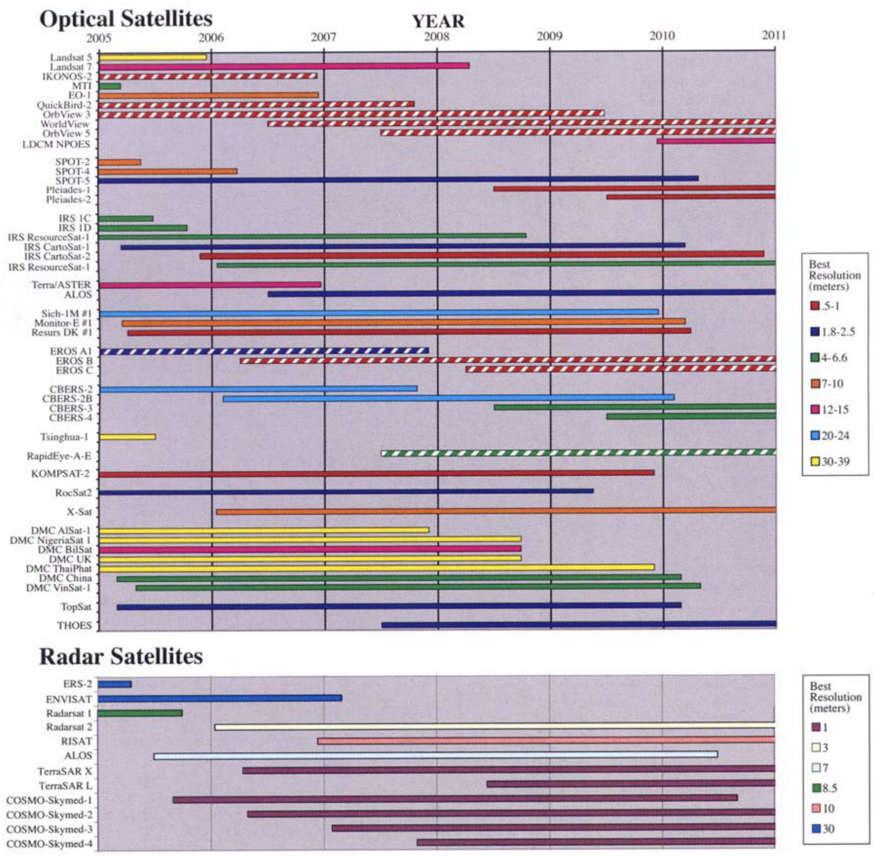


Figure 2. An on-orbit timeline of current and planned satellites from now until 2011 lists the best resolution of each by color and identifies the commercial systems by slashed patterns.