THIRTY YEARS OF MAPPING FROM SPACE

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ABSTRACT:

International political sensitivity delayed the development of civil systems for mapping the Earth from space. Instead technical advances were directed to lunar mapping. The military and intelligence communities developed the CORONA reconnaissance satellite system in the United States, and the ZENIT system in the Soviet Union. Photography from these systems has recently been declassified. Starting in 1972 electro-optical systems of increasing capability were built: LANDSAT in the U.S., SPOT in France, JERS in Japan, and IRS in India. These were followed by radar systems in the U.S., Japan, European Space Agency, and Canada. Recently high resolution photography from Russian space systems has been made commercially available. A revolution is now under way as commercial organizations are permitted to develop their own high resolution electro-optical imaging satellites, and sell the resulting data to the international market.

THE BEGINNING

When Sputnik 1 was orbited by the USSR in October 1957, it did nothing but emit a "Beep, Beep". But that beep clearly announced the beginning of a new era. Photogrammetrists, cartographers, Earth scientists, environmentalists, all expected that photography from Earth-orbiting spacecraft would result in an increase in the capability and efficiency of collecting information about the Earth comparable to that which occurred when aerial photography replaced ground surveys. Many studies were made and proposals submitted for systems of varying complexity. But it didn't happen! Not in the United States, and not in the USSR, the only two nations then capable of launching space vehicles.

Political sensitivity to the implications of one nation looking at another and making the information openly available inhibited the development of competent Earth-observing spacecraft. In the United States the NASA space program concentrated on developing the capability to support man in space. In the Mercury, Gemini, and early Apollo programs, the astronauts operated nothing more sophisticated than hand-held Hasselblad cameras. These produced beautiful, historic, and fascinating pictures of the terrestrial landscape but photography was only a minor part of the mission objectives. The resulting photographs lacked the scale, resolution, and systematic coverage needed for mapping, resource evaluation, or intelligence.

LUNAR MAPPING

Technological development of space imaging systems by NASA was concentrated on the Race to the Moon between the United States and the USSR. Ranger, Surveyor, and Lunar Orbiter employed systems of increasing complexity and capability. Lunar Orbiter provided the first comprehensive coverage of the far side of the Moon. These systems demonstrated the ability to transmit enormous amounts of high quality image data from space. The Mapping and Panoramic Cameras carried on the later Apollo lunar missions clearly showed that precise topographic mapping information could be produced by competent film-return systems. Nearly a third of the Moon's surface was covered by a photogrammetric control network with 30 meter accuracy, and topographic maps were made for a large part of the area. Those who were involved in the lunar mapping program can rightly be proud of their accomplishments, but in retrospect the lunar program seems to have been merely a diversion. The Apollo program, originally planned for 20 missions, was abandoned after Mission 17. Polar orbits for the Mapping and Panoramic Cameras, contemplated for the later missions, never took place. The Apollo Command-Service Module was diverted to the politically correct link-up with the Soviet Soyuz spacecraft. Handshakes between NASA astronauts and Soviet cosmonauts replaced hard science. This was certainly not all a bad thing, but the objective of precise mapping of the lunar surface remained unfulfilled both in the USA and the Soviet Union.

RECONNAISSANCE SATELLITES

Meanwhile other communities were not inhibited by political sensitivities. The United States and the USSR were locked in the Cold War, and knowledge of each other's offensive and defensive capabilities was critical. Both nations developed reconnaissance satellites, but the system parameters and the data produced were highly classified on both sides. As early as 1963, the USSR acknowledged the principle of space-based reconnaissance, but the U.S. did not openly admit to any capability until 1978. Although there have been many articles speculating on U. S. system capabilities (1)*, and several major security leaks of both data and images, hard information about the early U. S. systems became publicly available only in 1995 with the declassification of the CORONA system (2).

The CORONA program developed a series of increasingly competent panoramic camera systems with the code name KeyHole (KH). The first several systems had a single camera; with KH-4 a pair of convergent cameras were provided to acquire stereoscopic coverage. ARGON (KH-5) was a frame camera used to establish geodetic control by analytical aerotriangulation. These control points were used for targeting

*Numbers in parentheses refer to items in the List of References.

and to control topographic maps made from the high resolution panoramic photographs. LANYARD (KH-6) was a single long focal length panoramic camera to provide better ground resolution. ARGON and LANYARD were only marginally successful. Parameters of the cameras are listed in Table 1.

TABLE 1 - CORONA CAMERA SYSTEMS

System	Operational	Cameras	Focal Length	Format	Resolution
KH-1	Aug 60	1	24 in.	2.2 x 30 in.	40 ft.
KH-2	Dec 60-Jul 61	1	24 in.	2.2 x 30 in.	30 ft.
KH-3	Aug 61-Dec 61	1	24 in.	2.2 x 30 in.	25 ft.
KH-4	Feb 62-Dec 63	2	24 in.	2.2 x 30 in.	25 ft.
KH-4A	Aug 63-Oct 69	2	24 in.	2.2 x 30 in.	9 ft.
KH-4B	Sep 62-May 72	2	24 in.	2.2 x 30 in.	6 ft.
ARGON					
KH-5	May 62-Jul 64	1	3 in.	4.5 x 4.5 in.	460 ft.
LANYARD					
KH-6	Jul 63-Aug 63	1	66 in.	4.5 x 25 in.	2 ft.

Essential contributions of the CORONA program were the development of thin base estar film and the technique of recovering film capsules from space. All photography from the CORONA spacecraft has been declassified and is being digitized primarily as a means of preservation. It is now being made available in both hard copy and digital formats through the EROS Data Center of the U.S. Geological Survey. The published history of the CORONA Program (3) is fascinating reading, not only for the vicissitudes of development but also for the interpretation techniques which are described.

Information about the Soviet counterpart to the CORONA program has recently become available. The ZENIT spacecraft employed the same return capsule as the Soyuz manned program. Instead of cosmonauts the capsule contained cameras. In Zenit-2 there were three film cameras with 1 meter focal length and 30 x 30 cm format. The three cameras were arranged to look relations, and providing the crucial information for negotiating Strategic Arms Limitation Treaties.

DEVELOPMENT OF CIVIL SATELLITE MAPPING SYSTEMS

Political sensitivity could not forever keep the benefits of space systems from the civil scientific community. In 1967, the National Academy of Sciences in the U.S. conducted a Summer Study on "Useful Applications of Earth-Oriented Satellites"(4). Panels on Forestry-Agriculture-Geography, Geology, and Hydrology defined the parameters of a system which was eventually realized in the Landsat program, with the first of five spacecraft launched in 1972.

A Geodesy-Cartography panel defined film camera systems to produce standard topographic mapping at scales as large as 1:25,000. Unfortunately, that report tread on the toes of the Intelligence Community and was classified until 1980. Its recommendations eventually resulted in the Large Format Camera carried on Shuttle Mission 41-G in October 1984. The European Space Agency sponsored the Metric Camera - a modified Zeiss aerial camera - which was carried on a Shuttle Mission in December 1983. Experimental topographic maps at 1:24,000 and 1:25,000 scale with 50 foot or 10 meter contours were produced, and high quality orthophotographs were demonstrated. Though these cameras produced the highest ground resolution and geometric integrity of any civil system, the

vertical, and left and right of the flight line, thus providing a coverage swath of approximately 150km. Ground resolution was about 2 meters. Film load was 1500 frames. A fourth camera of smaller focal length and format (parameters not specified) provided wide angle coverage to tie together the three high resolution photographs. There was also an "electronic reconnaissance antenna", indicating that there may have been a electronic data return system.

In the ZENIT-4 spacecraft, the three long focal length cameras were replaced by two folded optic cameras with 2 meter focal length and the same 30 cm film. Total swath width would be reduced to 50 km, but ground resolution would be improved to about 1 meter. The index camera remains, but the electronic antenna is missing. Both spacecraft could be rolled about the flight axis to acquire photographs left or right of the flight line. When the film load was expended the camera capsule was separated and returned to Earth by parachute. In principle the cameras could have been refurbished and reused, but it is not known whether this was actually done.

It is obvious that these early systems were replaced by higher capability as technology advanced in both countries. In the United States, systems with designation up to KH-12 have been described in the public press, but the actual parameters of these advanced systems remain classified. Enterprising reporters and occasional security leaks indicate that ground resolution of a few centimeters is now possible , and film recovery has been replaced by near real time data transmission. From the former Soviet Union, photographs with parameters similar to those from ZENIT are now commercially available.

Though the techniques of mapping from satellite images were developed in both countries using these systems, there is now general agreement by both sides that the major accomplishment of space reconnaissance has been the stabilizing factor in international

advances in electro-optical sensors, data transmission, and ground processing have made film return systems obsolete, and both cameras were abandoned after only one flight.

Landsat was followed by the French SPOT, the Japanese MOS and JERS, the Indian IRS-1A,B, and C, the ESA MOMS, - all electro-optical data transmission systems operating in the visual and near infrared wavelengths. Some of the characteristics of data currently available from these systems are given in Table 2.

Table 2. DATA FROM EO SATELLITE SYSTEMS

System	LANDSAT	SPOT	IRS-1C	JERS-1
Country	USA	France	India	Japan
Altitude	705 km	832 km	904 km	568 km
Sensor	TM	HRV	LISS-III	VNIR,SWIR
MS bands	7	3	4	4 4
pixel (MS)	30 m	20 m	23 m	18 m
pixel (pan)	X	10 m	6 m	X
swath	185 km	80 km	142 km MS 70 km Pan	75 km

The most useful map products have been made by combining the high resolution panchromatic images with the lower resolution multispectral data to produce maps with various types of color coding. Landsat and JERS images can be usefully enlarged to 1:100,00 scale; SPOT can go as large as 1:25,000 scale. SPOT and JERS provide stereo coverage from which digital elevation data and terrain contours can be compiled. Advanced versions of each of these systems are under development and will undoubtedly provide higher image quality in the near future. International commercial arrangements have been established which now make it possible to order satellite images from any of these spacecraft for any place on Earth, and obtain the data within a reasonable time. Numerous companies will provide value-added processing at competitive prices.

IMAGING RADAR SATELLITES

Radar images have been acquired by the Shuttle Imaging Radar (SIR-A,-B, and-C), but these are experimental only and obtained from short life missions over limited areas. The Russian ALMAZ radar satellite, which provided 15-30 m resolution data over a 60 km swath, is no longer functioning. Operational radar images are being produced by the European Space Agency ERS-1, the Japanese JERS-1, and most recently, by the Canadian RadarSat. Data characteristics for these radar systems are given in Table 3.

Table 3. DATA FROM RADAR SATELLITES

System	SIR-C	JERS-1	ERS-1	RadarSat
country	USA	Japan	ESA	Canada
wavelength	L,C,X	L	C	C
resolution	30 m	18 m	25 m	10-100 m
swath	40 km	75 km	100 km	50-500 km
look angle	variable	35 deg	23 deg	20-50 deg
cycle	X	44 days	35 days	24 days

As with the electro-optical satellites, data from these spacecraft can be purchased from commercial sources. NASA is planning a third mission of SIR-C which will carry a second antenna mounted on an extendable boom, so that interferometric data can be obtained to produce terrain elevation data as well as images. Funds have been requested for a study of a free flying radar satellite with multiband and interferometric capability. Classified radar satellites are reported to have a ground resolution of 1-2 meters, but these date are not available to civil mapping agencies.

RUSSIAN HIGH RESOLUTION PHOTOGRAPHY

In 1988, the USSR released photography from their reconnaissance satellites. In these systems original film is returned to Earth by parachute, and subsequently digitized by scanning. Both hard copy and digital data are offered for sale through several outlets. Characteristics of these photographic systems are given in Table 4.

Table 4. RUSSIAN SPACE CAMERA PARAMETERS

System	MK-4	KFA-1000	TK-350	KVR-1000
Type	Multispect	Multispect	Topographic	Hi-Res
Cameras	4	2	1	1
F.L.	300mm	1000mm	350mm	1000mm
Format	18x18cm	30x30cm	30x45cm	18x72cm
Scale	1:650,000	1:270,000	1:660,000	1:220,000
Res.	6 meters	5-7 meters	10 meters	2 meters

Another camera, designated KFA-3000, with 3000mm focal length, 18x18cm format, providing 2 meter resolution, has been mentioned, but apparently data from this camera are not being sold. In general, pictures over the former Soviet Union, and allied communist government countries, are not made available.

Comparison of the data currently available from commercial sources, as listed in Tables 2,3,and 4, with the capabilities of the early CORONA and ZENIT reconnaissance satellites given in Table 1 shows the remarkable progress that has been made by civil agencies in getting access to high quality image data for mapping and resource evaluation.

COMMERCIAL HIGH RESOLUTION IMAGING SATELLITES

It should be noted that all of the imaging satellites described above have been designed, funded, built, and operated by government organizations, and that it is only a recent development that makes the imagery available through commercial enterprise. But now a new approach is being implemented. After many years of wrangling between the civil federal government agencies, the Department of Defense, the Intelligence Community, the users, and representatives of commercial enterprise, the U.S. government finally approved a set of guidelines under which commercial organizations would be allowed to exploit formerly classified technology and build high resolution imaging satellites, and sell the data as a commercial venture. Several organizations have received licenses to proceed with the construction of high resolution panchromatic and multispectral imaging satellites for launch within the next few years. Among these are:

Space Imaging Inc. is a consortium funded by Lockheed-Martin, E-Systems, and Mitsubishi. Their spacecraft is called Commercial Remote Sensing Satellite (CRSS). The camera system is being built by Kodak. Lockheed and Kodak were major participants in the CORONA system development, and E-Systems is a principal supplier of sophisticated ground processing systems to the Defense-Intelligence community. Space Imaging is planning a two satellite system with first launch in 1997. There will be three ground receiving stations in Denver, Alaska, and Atlanta. In addition they are negotiating with Regional Affiliates in several countries. Space Imaging will supply the receiving and processing equipment to each affiliate, who will then have marketing rights within the sphere of their reception station. Space Imaging will develop a world-wide data base. An extremely agile spacecraft will permit a variety of imaging patterns and very short revisit times.

Orbital Imaging Corporation (Orbimage) is a wholly owned subsidiary of Orbital Sciences Corporation (OSC). Their spacecraft called OrbView will be launched in late 1997 by the OSC Pegasus vehicle. Controlled by ORBIMAGE's existing Center near Dulles, Virginia, the satellite will downlink real-time imagery to receiving and processing stations in the U.S. and other countries with whom the company is presently negotiating. OSC is acquiring MacDonald Detwiler and Associates, a Canadian firm with extensive experience in ground processing of satellite imagery. The highly maneuverable spacecraft will be able to acquire a variety of imaging patterns. A second generation spacecraft with increased capabilities is already in design.

EarthWatch, Inc. is a combination of Ball Aerospace, Worldview, Inc. and several other participants. They are planning two cooperative spacecraft, EarlyBird to be launched in August 1996 and QuickBird to be launched a year later. Data will be recorded on board the spacecraft and downlinked to a central facility in Colorado. EarthWatch plans to retain ownership of all data collected, and sell both images and digital elevation data to customers through local area distributors.

Each of the systems described will be capable of simultaneous panchromatic and multispectral imaging, and can acquire stereo coverage from each pass so that digital elevation data can be derived. They will have Global Positioning Systems and precise attitude sensors to provide exterior orientation to permit topographic mapping with no or minimum ground control points. Sophisticated processing algorithms will be required to assemble the numerous pieces of acquisition which make up a single stereo scene. All systems will provide a variety of products including radiometrically corrected, geometrically corrected, geocoded scenes, image mosaics, orthorectified scenes, multispectral composites, etc. Minimum time between tasking, acquisition, processing, and delivery are essential for all systems. Studies have predicted that the global market for these types of data will be about $8 billion annually by the early years of the next century. Some characteristics of the proposed systems are given in Table 5, derived from information in (5).

Table 5. COMMERCIAL SATELLITE SYSTEMS

System	CRSS	Orbview-1	EarlyBird	QuickBird
Focal length	10 m	2.76 m		
Aperture	70 cm	45 cm		
Altitude	680 km	460 km	470 km	470 km
Inclination	98.1 deg	97.3 deg	97.3 deg	TBD
Detectors	pushbroom	pushbroom	rect. array	pushbroom
Res. pan	1 m	1 and 2 m	3 m	1 m
Swath, pan	11 km	8 km	6x6 km	36 km
Scene, pan	60x60 km	8x8 km	6x6 km	36x36 km
Res. MS	4 m	4 m	15 m	4 m
Bands, MS	4	4	3	4
Swath, MS	11 km	8 km	30x30 km	36 km
Scene, MS	60x60 km	8x8 km	6x6 km	36x36 km
Repeat cycle	14 days	16 days	20 days	20days
Revisit cycle	1-3 days	<3 days	2-3 days	2-3 days

Two other commercial systems which have been announced are:
GDE which will provide 0.7 meter resolution pan data and 2.8 meter resolution multispectral images.
Astrovision, Inc. which plans a geosynchronous spacecraft with a high definition TV camera providing images with 1 km resolution in real time.

All of these companies are struggling to develop commerciallyviable marketing arrangements and realistic pricing regimes for their products. These will obviously be controlled by the level of processing required, the size of areas to be covered, and the amount of repeat business to be expected. These questions will obviously be subject to intense negotiation between potential customers and commercial suppliers, and competition between suppliers of similar data sets will certainly affect the market. A critical point for many customers will be the fact that the U. S. government retains the right to turn off any collection at times of political or military stress. This may well result in agencies of foreign governments promoting the development of comparable systems by their own national organizations rather than buying data from a commercial supplier who may be required to cease operations at a most critical time.

Nations have apparently concluded that secrecy and security are not necessarily synonymous, and the principle of open access to imagery by all nations seems to be accepted. So far as the application of commercial imagery to mapping and geographic information systems is concerned, it is apparent that imagery will be available with the technical ability to resolve most questions of significant importance.

A revolution has begun in the way satellite imagery will be madeavailable to users, and it will be most interesting to see how it develops in the next few years.

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