Current status and future possibilities for topographic mapping from space

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ABSTRACT

An overview of developments in photogrammetry and topographic mapping is given. Mapping is still very inadequate in many parts of the world. It is concluded that topographic mapping from space is on the verge of becoming an operational reality.

1. DEVELOPMENT OF PHOTOGRAMMETRY

The development of photogrammetry is intimately linked with the tasks of topographic mapping. Photogrammetry and photo-interpretation are the first remote sensing applications, which commenced soon after the invention of photography in 1839.

In the period from 1850 to 1900 topographic surveys were still made by plane table. Interpretation of objects on photographs and their measurement on the images led to the phase of plane table photogrammetry, which was applied in mountainous, inaccessible terrain as a substitute for terrestrial plane tabling, in which measured angles led to graphic reconstruction of object points to be depicted on a map sheet.

The inventions of the airplane and of stereo-measurement in overlapping photographs, taken from different exposure stations led to a more systematic way of terrain imaging and to mechanical or optical reconstruction of the imaging process and its terrain reconstruction by analogue photogrammetric plotters. The era of analogue photogrammetry started shortly after the year 1900. It still prevails in most developing countries as the standard method of topographic mapping.

After the invention of the electronic computer in the 1940's, the 1950's marked the first introduction of computer aided mapping in the form of analytical photogrammetry, which is now the standard method of topographic mapping in the developed world.

Digital processing of satellite remote sensing images introduced in the 1970's gave an impetus to digital photogrammetry, in which the pixels of stereo-satellite imagery, available since Spot in 1986 could be processed; likewise it became possible to digitise analogue aerial and satellite photographs by scanners, and to process them by digital means into terrain information in form of digital orthophotos and digital terrain models.

The current coexistence of analogue, analytical and digital photogrammetric restitution methods is governed by economic considerations and by accuracy and interpretation quality requirements: While analogue instruments are no more produced by manufacturers, they still exist in most mapping organisations. On the other hand the quality of aerial photos in terms of resolution is very superior to current digital sensors, so that their scanning at the high resolution required leads to presently non-competitive computer processing times. This will, however, be overcome as computer development in the 1990's leads to faster and more economical computer processing.

The competition between analog, analytical and digital photogrammetry has been furthermore challenged by new improvements in technology in each of the fields.

2. ADVANCES IN ANALOGUE SENSING

An interest in using photogrammetric cameras from space has been sparked by the German funded ESA experiment from the European Spacelab on the Space Shuttle in 1983: the "Metric Camera", a Zeiss RMK 30/23. It photographed 10 million km^2 of the land surface of the Earth with a resolution of 30 lp/mm. The NASA "Large Format Camera" 30/24 x 48, flown from the Space Shuttle in

1984 reached a resolution of 45 lp/mm. Both camera systems with a focal length of 30 cm provided imagery with ground resolutions better than 15 m pixel equivalents. The Russian cameras KFA 1000 flown on short duration Kosmos satellites and the orbital platform MIR between 1987-1993 also reached 30 lp/mm resolution, but with a 1 m focal length reached ground pixel equivalents of better than 8 m. This was surpassed by the KWR 1000 and KFA 3000 cameras on Kosmos satellites reaching 70 lp/mm and ground pixel equivalents between 1 to 5 m. These advances were made possible by the use of image motion compensation permitting to use longer exposures with fine grain, low sensitive, high resolution films.

Aerial survey cameras benefited from this development. The Zeiss LMK, the Zeiss RMK TOP and the Leica RC 30 permitted to obtain high resolution high altitude photography at 70 lp/mm as opposed to previously reached resolutions of 30 lp/mm.

For use of low altitude photography these forward motion compensated cameras were further equipped with a stabilised platform to permit low altitude resolution of 60 lp/mm. Thus aerial photography became more competitive by a factor of 2 to 2.5 to the square, by permitting to fly at higher altitudes to achieve the same resolution, increasing the area coverage by a factor of 4 to 6.

Other advances have come about by the in-flight use of GPS-positioning, permitting to determine the coordinates of the exposure stations to ± 0.15 m. This brought about much less stringent specifications for overlap conditions and a significant reduction in ground control requirements for blocks of aerial photography.

3. ADVANCES IN ANALYTICAL RESTITUTION

A key to the reduction in costly ground control requirements for aerial photography was aerial triangulation. In conjunction with airborne GPS data the requirements for ground control in position and elevation were reduced to the 4 corners of the block, while previously up to 100 control points were used for a block to achieve the same accuracy.

The standard instrument to be used for measurements of aerial triangulation was and is the analytical plotter, by which the tedious procedures of orientation and measurement on analogue plotters were simplified and partially automated. This concerns semi-automatic point transfer according to image coordinates for aerial triangulation measurement, semi-automatic orientation according to bundle block adjustment data; semi-automatic relative and absolute orientation, DTM raster measurement, correction of systematic errors, adaptation to other than usual model geometry (e.g. SPOT), analytical orthoprojection and vector data acquisition for geographic information systems.

4. ADVANCES IN DIGITAL SENSING

Attempts to construct digital area sensors have so far only been successful in near range sensing from stable platforms, where there was sufficient time for readout of the sensed information. Moreover economic considerations have led to a restriction in sensor size to about 1500 x 1000 pixels.

For moving platforms, when digital data are required to be gathered at high acquisition and readout rates, one dimensional scanners are more effective in performance and cost. The early scanners, like that of the Landsat programme since 1977, were electro-mechanical, for which a rotating mirror directed the ground radiation to a single detector element. Several elements could receive multispectral signals, if the radiation was diffracted by a prism. About 3000 pixels per scan could be generated for each detector. The electro-optical scanner MOMS-01 flown for the first time from the Space Shuttle in 1983, followed by the Spot Satellite in 1986 permitted the collection of ground radiation as an optical image onto a linear array consisting of up to 6000 linearly spaced detector elements.

While imaging in the thermal range is still restricted to electro-mechanical scanners, electro-optical systems were successfully utilised in the visual and near infrared ranges to generate stereo images. Spot permitted to do so by deflecting mirrors from two orbits, while MOMS-02 in 1993 utilised multiple arrays pointing optically forward, down and aft along one orbit.

Another digital system is the imaging radar. For satellites it was introduced on Seasat in 1978, but was successfully applied on the European ERS-1 or the Japanese JERS-1. Since the radar pulses are coherent in nature, signals from different satellite orbits permit the generation of interferograms for radar signals received from the same ground location at different phases.

5. DIGITAL IMAGE RESTITUTION

Digital image restitution offers unprecedented possibilities for quality improvements and for partial or total automation of the restitution process.

Contrary to the restitution in analog or analytical plotters, in which standard photographic material with all its limitations is utilised, digital data may be subjected to online image processing operations involving

- grey level adaptation
- filtering
- geometric rectification
- multispectral, multitemporal and multi-sensoral classification (after data fusion) e.g. by maximum likelihood, fuzzy logic or neural network techniques
- image restoration.

DTM derivation becomes possible by digital image correlation in image or object space using maximisation of the correlation coefficient applied to search areas arranged in image pyramids either for the whole image or for features derived by filtering processes. Subpixel correlation is usually achieved by least squares matching allowing for terrain slopes.

Attempts have even been made to include automatic pattern recognition using image segmentation and knowledge based systems in which objects and their relations are modelled.

Stereo workstations permit to interactively start the required automation modules and to correct the computed results by manual intervention. They are applicable to derive digital orthophotos and DTM's with a high degree of automation, and they are able to aid in interactive feature extraction.

Monoscopic systems are particularly suitable for the overlay of digital orthophotos derived from the most recent image data with partially outdated map data contained in vector or raster geographic information systems. This provides a rapid interactive capability for map updating.

The generation of digital orthophotos has become operational in the last few years. It involves the following tasks:

- generation of a DTM either manually via aerial triangulation plus raster measurements in the stereo model, or by digitisation of existing maps, or by digital image correlation
- geometric rectification of the image with respect to image geometry and image orientation and the DTM.

While the traditional aerial photography permitted to evaluate the imagery with a magnification between 4 (low altitude) to 8 (high altitude), image motion compensated cameras now permit magnifications of 12 to 14. The current limitation rests in storage and data processing speeds.

A CD-ROM containing 12 photographic images scanned at 25 µm pixels at 85 MB storage can be operationally processed in PC's or workstations. Higher resolutions (15 µm) can currently only be operationally used on workstations, while optimal resolutions (7.5 µm) still await more efficient processing capabilities.

The data storage requirements for digital orthophotos are listed in Table 1.

The table illustrates that aerial photographic sensors have a much higher data extraction capability than current satellite sensors.

Table 1 - Data Storage Requirements for Digital Orthophotos

Imagery	resolution	pixel equivalent without image processing (1 lp = 2 √2 pixel)	pixel equivalent with image processing (1 lp # 2 pixel)	pixels per image
B/W photographic prints	10 lp/mm	35 µm	50 µm	21 MB
B/W low altitude flight diapositive	20 lp/mm	18 µm	25 µm	85 MB
B/W high altitude diapositive	30 lp/mm	12 mm	17 m	183 MB
B/W IMC camera low altitude diapositive	60 lp/mm	6 µm	8 µm	827 MB
B/W IMC camera high altitude diapositive	70 lp/mm	4.5 µm	6.5 µm	1252 MB
Landsat TM				
1 channel			(30 m ground)	38 MB
7 channels				230 MB
SPOT-P 1 channel			(10 m ground)	36 MB
SPOT-MX 3 channels			(20 m ground)	27 MB

6. STATUS OF WORLD TOPOGRAPHIC MAPPING

The U.N. Secretariat regularly publishes figures on World Topographic Mapping. The last survey, contained in Table 2, has been presented at the U.N. Cartographic Conference in Beijing in May 1994.

Table 2 - Status of World Topographic Mapping 1993

Area	% in 1:25 000	% in 1:50 000	% in 1:100 000	% in 1:250 000
Africa	2.9	41.1	21.7	89.1
Asia	15.2	84.0	66.4	100
Australia and Oceania	18.3	24.3	54.4	100
Europe	86.9	96.2	87.5	90.9
North America	45.1	77.7	37.3	99.2
South America	7.0	33.0	57.9	84.4
former USSR	100	100	100	100
World 1993	33.5	65.6	55.7	95.1
World 1987	17	59	56	90
Annual progress 1987-1993	2.8	1.1	0	0.9
Map updating progress 1987	4.9	2.3	0.7	3.4

From this official survey it becomes clear that the status of topographic mapping is still rather inadequate in the developing continents of Africa, Australia and Oceania and South America. The world annual progress of 2.8% for 1:25 000 and 1.1% for 1:50 000 is very inadequate, considering that these maps form the basis of geographic information on the environment and as a tool for sustainable development. The world map updating progress for areas already mapped amounts to 4.9% for 1:25 000 and 2.3% for 1:50 000. This means an average age of maps of over 20 years for 1:25 000 and of over 40 years for 1:50 000. This is proof that only satellite remote sensing methods are capable to provide the needed information within a reasonable time period.

Figure 1 shows the relationship of the trade-offs between achievable ground resolution and repeatability for low resolution meteorological satellites with high repeatability for global environmental monitoring tasks, for medium resolution and repeatability resource satellites for regional monitoring tasks, and for high resolution cartographic

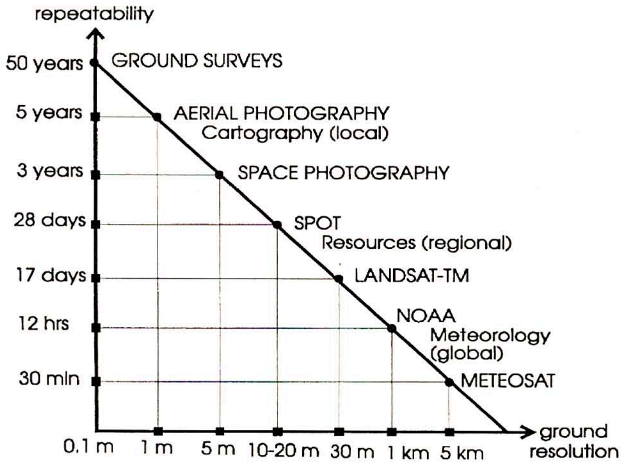


Figure 1 - Resolution and Repeatability of Remote Sensing Systems

satellites with low repetitivity for topographic mapping tasks as compared to the more tedious aerial photographic and ground survey mapping methods.

7. CARTOGRAPHIC REQUIREMENTS

There are 3 criteria to judge the suitability of imagery for cartographic uses:

- planimetric accuracy achievable
- elevation accuracy achievable
- detectability of objects from the imagery.

Planimetric accuracy requirements are ± 0.2 m at publishing scale of the maps. This means:

± 5 m for 1: 25 000

± 10 m for 1: 50 000

± 20 m for 1:100 000, and

± 40 m for 1:200 000.

Elevation accuracy requirements depend on the terrain: For flat areas a contour interval of 20 m is required. According to map accuracy standards the point measurement accuracy in elevation should be 1/5 of the contour interval, requiring ± 4 m point accuracy in height. For mountainous regions a 50 m contour interval will suffice, requiring a point determination accuracy of ± 10 m in height.

Detectability requirements depend on the nature of objects to be shown in the map. The relation of photographic resolution in lp/mm and pixel size is 2 to 3 pixels per line pair.

Urban buildings and footpaths require a pixel size of 2 m. Such objects are contained in European maps. The minor road network and fine hydrological features require a pixel size of 5 m. Such objects are depicted in North American and Asian maps. In maps of Africa and South America only major roads and building blocks are shown. They require a pixel size of 10 m.

With aerial photography the requirements for 1:25 000 and 1:50 000 mapping of ± 5 m to ± 10 position accuracy and of ± 5 m for elevation accuracy as well as object detectability of 2 to 5 m can be easily reached.

8. TESTS OF MAPPING AND MAP UP-DATING FROM SATELLITE IMAGERY

Figure 2 lists the result of tests carried out at the University of Hannover for different types of cartographic satellite imagery available before 1992 for positional and elevation accuracy.

Thus only experimental space camera systems such as MC (Spacelab 1) and LFC (Space Shuttle) as well as Spot-P marginally meet cartographic requirements for 1:50 000 mapping. Russian space imagery (KFA 1000) meets positional, but not elevational requirements.

Regarding detectability of objects only the Russian space photographic images marginally meet cartographic requirements (see Figure 3).

In Figure 4 the results of a test for completeness of 1:25 000 mapping are shown over a North German area (Stadthagen) with KFA 1000 and SPOT-XS images. Only a part of the minor streets and field paths as well as drainage details have been mapped, while roads could be nearly fully depicted.

Figure 5 shows the graphic results of a map 1:25 000 compiled from KFA 1000 imagery as compared to the existing map.

Figure 6 shows the attempt to update an East German Topographic map 1:25 000 with the help of KFA 1000 imagery.

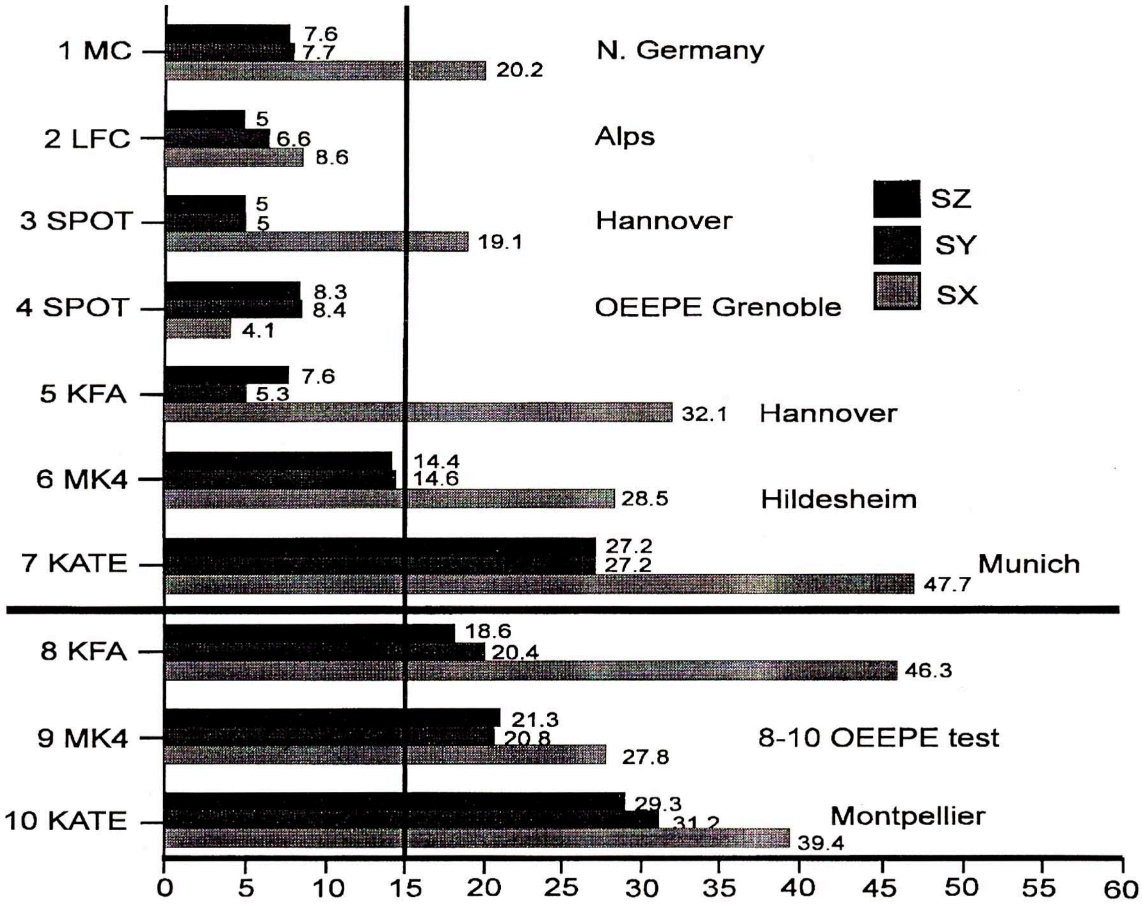


Figure 2 - Accuracy of Point Determination with Space Images by Bundle Block Adjustment with Program System BLUH

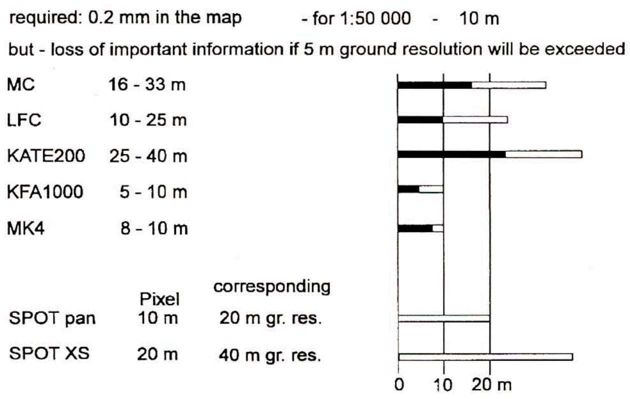


Figure 3 - Ground Resolution with KFA 1000 and Spot-XS images

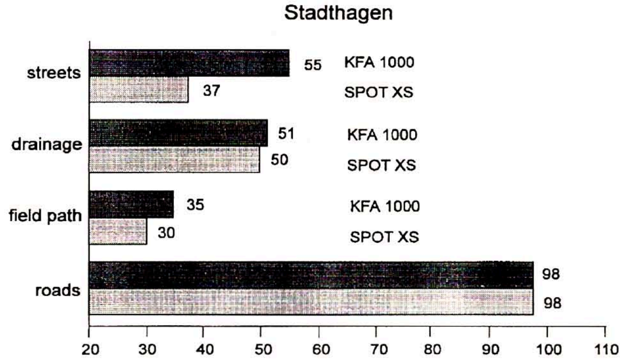


Figure 4 - Completeness of Mapping with Space Images

The mapping and updating procedures using satellite imagery, despite marginal performance as compared to aerial photography, appear to be four times more cost effective. Therefore mapping and updating of 1:50 000 maps in Africa has been successfully demonstrated.

9. SPACE MISSION FUNDING

Worldwide currently 22 space remote sensing missions are operating in the world. With 56 further missions planned for the next ten years there will be altogether 78 missions by 2004. Of these currently 12 are land and ocean oriented. For the next 10 years further 31 missions are planned, making it a total of 43 land and ocean oriented missions by the year 2004.

At an average cost of 450 M US$ per mission the cost of present and future land and ocean oriented missions for the next 10 years amounts to 19.4 billion US$. It is more than warranted to ask the question, whether the user needs are satisfied by the huge mission funding cost.

Figure 7 illustrates the current approach in development of remote sensing satellites as a top down approach from

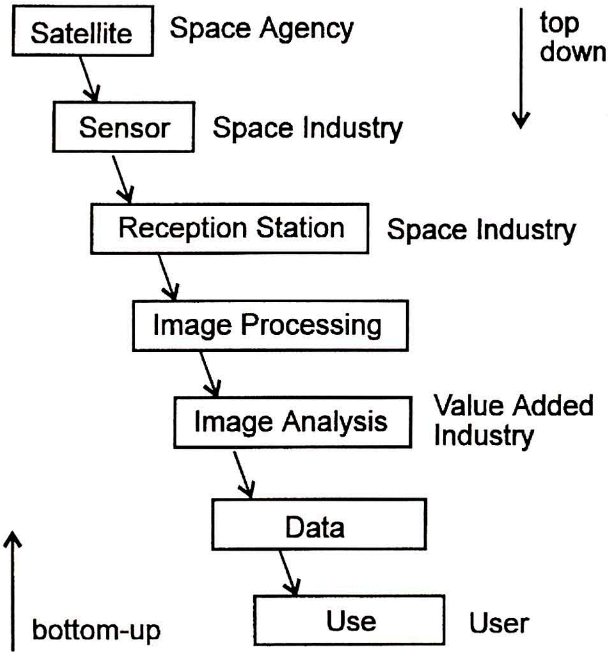


Figure 7 - Development of Remote Sensing Satellites.

satellite to sensor to data reception to data analysis to provision of information to the user.

Various restrictions imposed on the top-down process prevent the user from obtaining optimal information within the capabilities of the total information provision system.

The user generally prefers a bottom up approach for the design of remote sensing systems.

Figure 8 illustrates the weak points of the information provision chain.

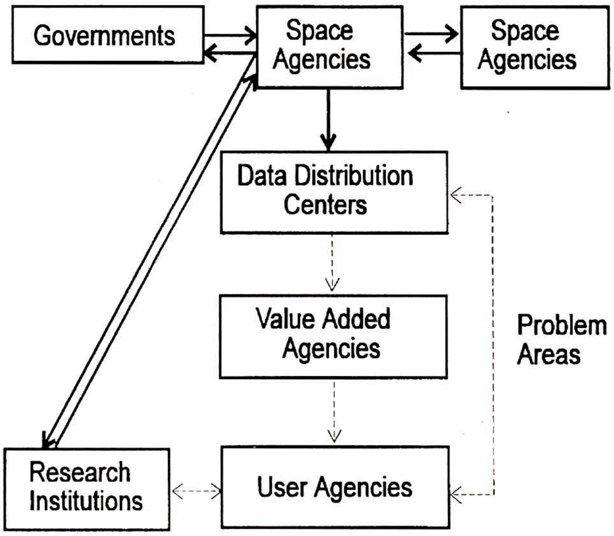
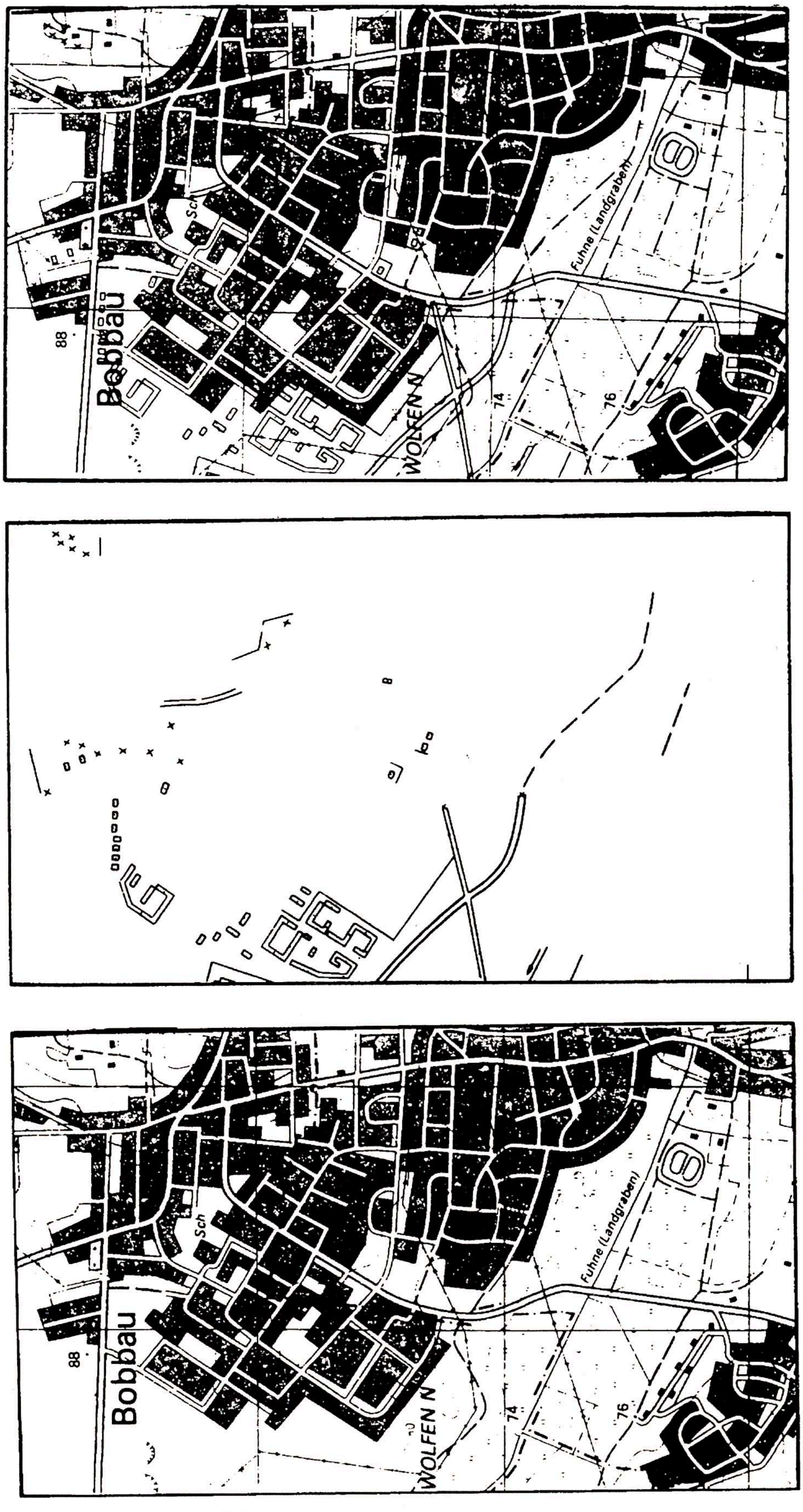


Figure 8 - Satellite Remote Sensing Development.

Figure 5 - Map 1:25 000 compiled from KFA imagery as compared to existing topographic map.



(c) updated map (1988) combining (a) and (b)

(b) new information (1986) derived from KFA 1000 image

(a) existing topographic map 1980

Figure 6 - Updating of a map with KFA 1000 imagery.

Governments fund space agencies. These contract platform and sensor design to space industry. To verify potential usefulness they also fund research agencies, which identify potential uses of the systems without regard to a user agency infrastructure. Space agencies limit themselves to provide data distribution centers. Unless the data are transformed into information by value added procedures, user agencies find no justification to deviate from their current more costly alternatives for information provision.

To enhance the potential for use of satellite data a closer cooperation between data distribution centers, user and research agencies and value-added information agencies is therefore urgently required, for which a funding effort is overdue.

This is further illustrated by tables 3, 4 and 5.

Table 4 - Aerial Photography and Aerial Mapping Prices

Aerial Photography Prices

Image Scale	Cost/km²
1:60 000	4 $
1.30 000	8 $
1: 3 500	16 $

Mapping Prices from Aerial Photography

Map Scale	Image Scale	Cost/km²
1:25 000	1:60 000	42 $ desert & rural
1:25 000	1:30 000	165 $ rural & urban
1: 5 000	1:30 000	1 000 $ desert
1: 5 000	1:30 000	3 000 $ rural
1: 1 000	1: 6 000	12 000 $ urban
1: 500	1: 3 500	16 000 $ urban
digital orthophoto 1:25 000	1:40 000	24 $ digital record only
digital orthophoto 1:10 000	1:30 000	120 $
digital orthophoto 1: 5 000	1:30 000	240 $

10. COST OF DATA VERSUS COST OF INFORMATION

Table 4 shows that aerial photography, irregardless of scale, is more costly per km² than satellite imagery.

Yet, the bulk of the cost arises from converting image data into information. Mapping prices are 1 to 3 orders of magnitude higher than the provision of imagery.

The further development and use of digital orthophoto production offers a cost-effective alternative to make the mapping process faster and less costly. The use of this technique in the user agencies is, however, not yet well established and needs to be strengthened.

Table 5 is a summary of thematic survey compiled from development projects of the German Technical Cooperation agency GTZ. It again shows, that costs are per magnitude higher than the provision of information.

The sale of imagery alone therefore constitutes an imperfect market. The commercialization of image sales without information extraction therefore remains a myth.

11. SUMMARY OF PRESENT AND PLANNED INTERNATIONAL SATELLITE REMOTE SENSING SYSTEMS

Table 6 shows the present international efforts in operational remote sensing satellite systems with regard to meteorology, resources, and cartography.

Details of present and future developments are shown in the subsequent tables. Table 7 lists the progress from Landsat 1 in 1972 to the most recent Landsat 5. Due to the failure in launch of Landsat 6 a serious gap in data continuity has arisen until 1999.

Table 3 - Cost of Satellite Imagery

Sensor	cost per image (US$)	ground resolution	ground area (km²)	area per image (km²)	cost $/km²
Landsat MSS	1000	79	170 x 185	31 450	0.03
Landsat TM	4400	30	170 x 185	31 450	0.14
Spot-XS	ca. 2100	20	60 x 60	3 600	0.58
Spot-Pan	ca. 2650	10	60 x 60	3 600	0.74
KFA 1000	ca. 1150	7.5	120 x 120	14 400	0.08
MKF-6MA	ca. 880	20	175 x 260	45 500	0.02
MK-4	ca. 1200	10	150 x 150	22 500	0.05

Table 5 - Thematic Survey Costs

Field	Type	Scale	Imagery	Cost/km²
AGRICULTURE	Phenol. Change	1:1 000 000	NOAA	80 $/km²
BIO-MATERIAL	Biomass. Change	1:1 000 000	NOAA	80 $/km²
FORESTRY	Forest Mapping	1: 250 000	MSS	6 $/km²
GEOLOGY	Reconnaissance	1: 100 000	TM	20 $/km²
FORESTRY	Forest Development	1: 100 000	TM	20 $/km²
IRRIGATION	Watershed Mapping	1: 100 000	TM	10 $/km²
REGIONAL PLANNING	Planning Study	1: 100 000	TM	25 $/km²
LAND USE	Land Use Mapping	1: 100 000	TM	13 $/km²
BIO-MATERIAL	Biomass Inventory	1: 100 000	TM	20 $/km²
EROSION	Vegetation Cover	1: 100 000	TM	20 $/km²
DESERTIFICATION	Change Detection	1: 100 000	TM	35 $/km²
FOOD SECURITY	Cultivation Inventory	1: 100 000	TM	25 $/km²
ENVIRONMENT	Environment Inventory	1: 100 000	TM	50 $/km²
REGIONAL PLANNING	Feasibility Study	1: 50 000	Spot-XS	40 $/km²
ENVIRONMENT	Risk Zone Mapping	1: 50 000	KFA 1000	150 $/km²
URBAN DEVELOPMENT	Urban Change	1: 50 000	KFA 1000, Spot-P	45 $/km²
TOPOGRAPHY	Base Map	1: 50 000	aer. phot.	120 $/km²
GEOLOGY	Photogeology	1: 25 000	aer. phot.	150 $/km²
TRANSPORT	Road Design	1: 20 000	aer. phot.	180 $/km²
TOPOGRAPHY	Orthophoto	1: 12 000	aer. phot.	24 $/km²
WATER SUPPLY	Base Map	1: 10 000	aer. phot.	800 $/km²
FORESTRY	Forest Inventory	1: 10 000	aer. phot.	350 $/km²
LAND USE	Land Use Mapping	1: 10 000	aer. phot.	520 $/km²
BIO-MATERIAL	Energy Study	1: 10 000	aer. phot.	250 $/km²
TRANSPORT	Photogr. Map	1: 10 000	aer. phot.	700 $/km²
CADASTRE	Orthophoto Map	1: 10 000	aer. phot.	400 $/km²
TOPOGRAPHY	Base Map	1: 5 000	aer. phot.	2 000 $/km²
TOPOGRAPHY	Orthophoto	1: 5 000	aer. phot.	78 $/km²
CADASTRE	Photogr. or Survery Map	1: 2 000	aer. phot.	10 000 $/km²
CADASTRE	Orthophoto	1: 2 000	aer. phot.	1 000 $/km²
TOPOGRAPHY	Orthophoto	1: 1 000	aer. phot.	800 $/km²
URBAN CADASTRE	Base Map	1: 1 000	aer. phot.	20 000 $/km²
URBAN CADASTRE	Multipurpose Cadastre, Utilities, Topography	1: 500	aer. phot.	40 000 $/km²

Table 6 - Operational Satellite Remote Sensing Systems

	Meteorology	Resources	Cartography
USA	GOES NOAA	LANDSAT	(LFC)
CIS	METEOR	MKF 6	KFA 1000
France		SPOT-MX	SPOT P
ESA	METEOSAT	ERS-1	
Japan	GMS	MOS	
India	INSAT	IRS-1	
China		Satellite Photography	
Germany			(MC) STEREOMOMS

Landsat 7, which originally was to combine efforts of the US-DOD and NASA in launching an ETM for continuity together with a high resolution stereo instrument HRSMI has now due to funding difficulties been limited to launch ETM by NASA alone improving the multispectral resolution from 30 to 15 m. NASA also makes preparations for an experimental system EOS AM-1 on the polar platform in 1998 with enhanced multispectral capabilities (15 m visual-NIR 4 channels, 30 m SWIR 5 channels, 90 m TIR 5 channels) with inflight stereo (see table 8).

The French SPOT system operating since 1986 will be continued with SPOT 4 when required. Spot 5 in 1999 will be improved with a 10 m multispectral resolution and a 5 m in-track stereo capability (see table 9).

Table 7 - The US Landsat Program

	Landsat 1	Landsat 2	Landsat 3	Landsat 4	Landsat 5	Landsat 6	Lansdat 7
period of operation	1972	1975	1978	1982	1986	failed 1993	1999-2000
spatial resolution	79 m	79 m	(1-6) 30 m (7) 120 m	(1-6) 30 m (7) 120 m	(1-6) 30 m (7) 120 m		(1-6) 15 m (7) 60 m
channel (1)	0.45-0.52	like	like	like	like		0.45-0.52
channel (2)	0.52-0.60	Lansdat 1	Landsat 1 & 2	Landsat 3	Landsat 3		0.52-0.60
channel (3)	0.63-0.69						0.63-0.69
channel (4)	0.76-0.90						0.76-0.90
channel (5)	μm		1.55-1.75				1.55-1.75
channel (6)			2.08-2.35				2.08-2.35
channel (7)			10.4-12.5				10.4-12.5
stereo	--	--	--	--	--	--	--
swath	185 km	185 km	185 km	185 km	185 km	185 km	185 km

Table 8 - EOS AM-1, USA

Year	**1998-2003**	**resolution**
bands VIS	0.52-0.60 μm 0.63-0.69 0.76-0.86 1.6-1.7	15 m
SWIR	2.145-2.185 2.185-2.225 2.235-2.285 2.295-2.365 2.360-2.430	30 m
TIR	8.125-8.475 8.475-8.825 8.925-9.275 10.25-10.95 10.95-11.65	90 m
stereo	in track NIR	
addit. instrum.	MODIS	
addit. instrum.	MISR	
swath	60 km	

Table 10 - ESA

	ERS-1	**ERS-2**
year	1991	1994
swath	100 km	
C Band VV	SAR Wave	

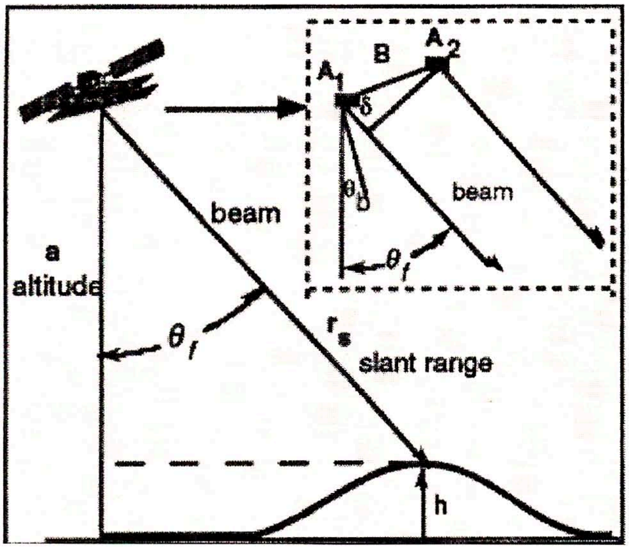


Figure 9 - SAR-Interferometer Geometry.

ESA, which launched the first operational radar satellite ERS-1 in 1991 has provisions for launching ERS-2 when required (see table 10). ERS-1 not only provides radar imagery, but from different orbits it also provides interferometric capabilities, which prove to be most interesting for derivation of surface deformations and for generation of DTM's when methods for the elimination of systematic error influences can be developed.

ESA now considers operating ERS-1 and ERS-2 in a limited duration tandem mission which would facilitate the use of radar interferometry. Figure 9 illustrates the SAR-interferometry principle.

Japan started its remote sensing program in 1987 with MOS-1a. It now, with JERS-1 has an 8 channel multispectral system with in-track stereo capability (however with an inadequate base-height ratio) for 18 m pixels.

Table 9 - Spot, France

	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5	Spot 6
period of operation	1986-1993	1990-1994	1993-1996		1999-	like Spot 5
spatial resolution	XS 20 m P 10 m	20 m 10 m	20 m 10 m		10 m (G, R, IR1) 20 m (IR2)	
channel X56	0.50-0.59	0.50-0.59	0.50-0.59	0.50-0.59		
channel R	0.61-0.68	0.61-0.68	0.61-0.68	0.61-0.68		
channel IR1	0.79-0.89	0.79-0.89	0.79-0.89	0.79-0.89		
channel	µm	µm	µm	1.58-1.75		
stereo	cross	cross	cross	cross	in track	
inclination	± 27°	± 27°	± 27°	± 27°	± 27°	
swath	60 km	60 km	60 km	60 km	60 km	

In conjunction with NASA Japan wishes to launch another cross-track 8 m pixel stereo system with 16 m multispectral capability (see table 11).

India, as the first developing nation to maintain an operational space remote sensing programme, has successfully launched IRS 1A and B with 36 m pixels. It wishes to

Table 11 - Japan

	MOS-1a	MOS-1b	JERS1		ADEOS	TRMM
launch	1987	1990	1992		1996-1999	1997
height	909 km (sun-synchr.)		570 km (sun-synchr.)		800 km (sun-synchr.)	350 km
inclination	99°		98°			35°
	MESSR:		OPS:			in track
	0.51-0.59 µm		λ (µm)	Δλ	0.42-0.50 µm	
	0.61-0.69		0.56	0.08	0.52-0.60	
	0.72-0.80		0.66	0.06	0.61-0.69	
	0.80-1.1		0.81	0.10	0.76-0.89	
			0.81	0.10		
			1.655	0.11		
			2.065	0.11		
			2.190	0.12		
			2.335	0.13		
res. (IFOV)	50 m		18 m		16 m, pan 8 m	
swath	100 km		75 km		80 km	
stereo			15.33°, b/h 0.3		cross track, ±40°	
	VTIR:		SAR:			
	0.5-0.7		L Band (1275 m)			
	(res. 900 m)		H-H			
	6-7					
	10.5-11.5					
	11.5-12.5					
res. (IFOV)	2.7 km		18 m			
swath	327 km		75 km			
	MSR:				global env.	precipitation radar
	23.8 6 Hz				changes	(rainfall in trop.
	31.4 6 Hz					areas)
res. (IFOV)	32 km					
swath	327 km					

reach a panchromatic resolution of 10 m on IRS 1C and D shortly (see table 12).

Germany has successfully launched the MOMS-02 sensor on Space Shuttle D2 in 1993 (see table 13).

The so-called "Stereo-MOMS" is a multipurpose electro-optical scanner with a nadir looking panchromatic high resolution channel (4.5 m), two forward and aft looking stereo channels (13.5 m) and four multispectral vertical channels (13.5 m). During the 9 day shuttle mission 7 M km^2 of data were acquired up to ±28° latitude. With a base to height ratio of nearly 1:1 it is the first in-flight stereo instrument with expectations to reach ±5 m height accuracy. The 4.5 m panchromatic vertical channel also provides a superior cartographie resolution for topographic mapping from space.

Of great interest is its sensibility on the Russian MIR-Priroda module 1995, with an inclination of 51°. It should be able to provide high resolution stereo imagery before Spot 5 is ready to do so in 1999. The MOMS-02 recording geometry is shown in figure 10, and the stereo coverage in figure 11.

Table 14 lists the Russian space missions flown from short duration platforms (Resurs F, Kosmos), from meteorological orbits (Meteor, Resurs O-N) or from orbital platforms (MIR).

Of particular interest are the Russian high resolution camera systems KFA 1000, KFA 3000, and KWR 1000 flown both from Resurs satellites and from MIR (table 15).

Figure 12 shows the coverage of a KFA 1000 mission on Resurs F1.

Table 16 shows the parameters of the Canadian Radarsat 1 expected to be launched in 1995 in comparison to the parameters of ESA's ERS 1 and 2.

The summary is still to be supplemented by the Chinese efforts shown in table 17.

Table 18 shows the current commercial plans for launch of high resolution panchromatic satellites with a pixel size up to 1 m.

Table 12 - India

	IRS-1A & 1B	1C / 1D		IRS-2	WIFS
year	1988-1991	1994-1996			
height	904 km	871 km			
	LISS 0.45-0.52 0.52-0.59 0.62-0.68 0.77-0.86	 0.52-0.59 (t) 0.62-0.68 (t) 0.77-0.86 (t) 1.55-1.70 (s)	 Pan better than 10 m		
IFOV	I: 72.5 m II: 36.25 m	23.5 m (t) 71 m		SAR 25 m	108 m
swath	I: 148.48 m II: 146.98	148 km			770 m

Table 13 - MOMS-02, Germany, 1993

channel	mode	direction	wave length	resolution	swath
1	M/S	Nadir	440-505 µm	13.5 m	78 km
2	M/S	Nadir	530-575	13.5 m	78 km
3	M/S	Nadir	645-680	13.5 m	78 km
4	M/S	Nadir	710-810	13.5 m	78 km
5	H/R	Nadir	520-760	4.5 m	37 km
6	stereo	±21.4°	520-760	13.5 m	78 km
7	stereo	±21.4°	520-760	13.5 m	78 km

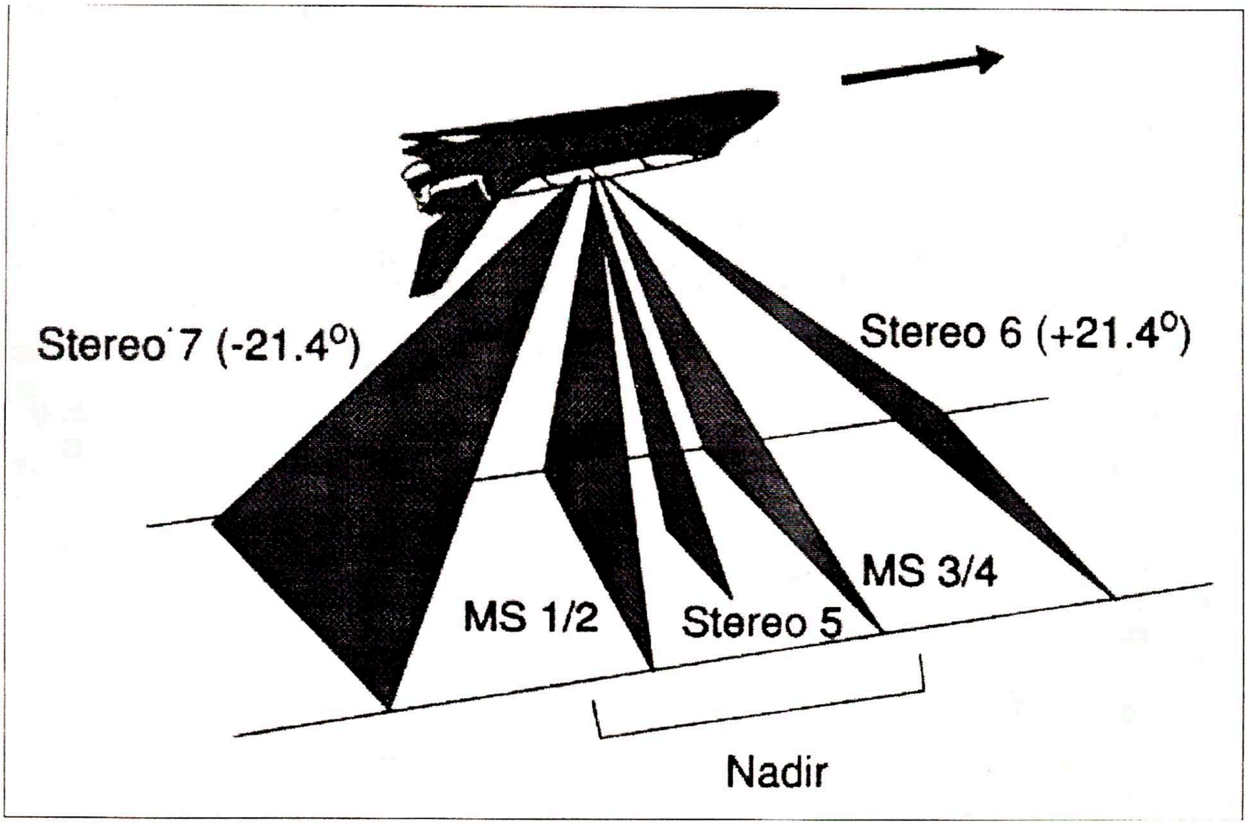


Figure 10 - MOMS-02/D2 Recording Geometry.

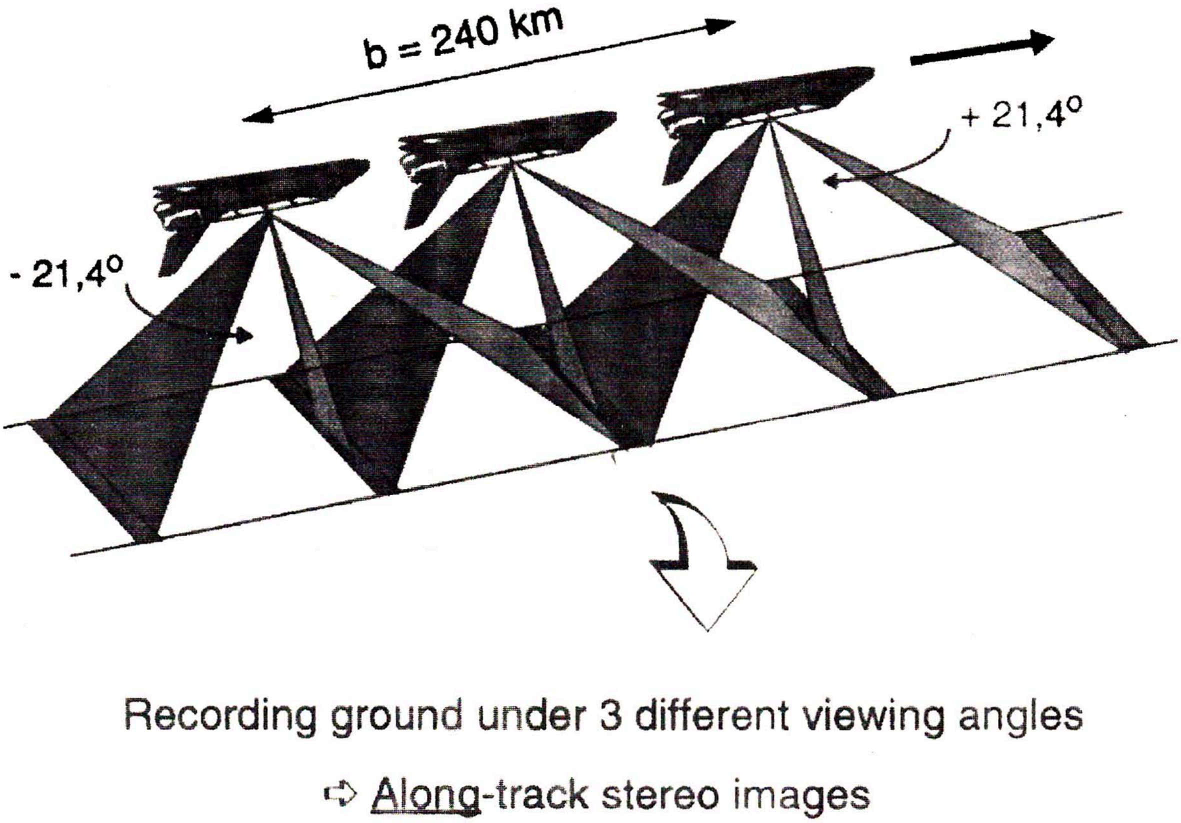


Figure 11 - MOMS-02/D2 Stereo Imaging Mode.

Table 14 - Russia, space missions

	height	duration	camera	resolution	swath
Resurs F1	250-400 km	11-14 days	2 KF 1000	5 - 12 m	147 km
			3 KATE 200		225 km
Resurs F2	170-450 km	20-30 days	MK4	5 - 12 m	150 km
Kosmos	175-350 km	1-2 months	3 KWR 1000	2 m	40 km
4th gen.			TK 330	10 m	180 x 270 km
Kosmos 5th gen.	180-355 km	5-9 months	digital system		
MIR Kvant	350-430 km		MKF 6MA	20 - 25 m	260 km
			Kap 350	40 m	200 km
Kristal	350-430 km		2 KFA 1000	8 m	232 km
Base Block	350-430 km		Kate 140	50 - 70 m	515 km
Meteor 2	950 km	2-3 years	scan. photometer	1 km	2 600 km
			IR radiometer	8 km	2 800 km
			IR spectrometer	90 km	1 000 km
Meteor 3	1 200 km	2-3 years	scan photometer	1 km	3 200 km
			IR radiometer	3 km	3 100 km
			IR spectrometer	42 km	1 000 km
			UV spectrometer	4 km	2 000 km
Resurs O-N2	650 km	3-5 years	2 MSU-E	45 km	2 x 45 km
			MSU-SK conical	V170 m	600 km
			MW spectrom.	17 - 90 km	1 200 km
			SAR	200 m	100 km
Okean	640 km	2 years	MSU-S	350 m	1 280 km
			MSU-M	1 500 m	2 000 km
			MW radiometer	6 - 15 km	600 km
			SLAR	1 - 2 km	450 km
			SAR		
GOMS 166°E, 14°W		1966-			
Almaz 1A		1992-1994			
Kwant-2	350-430 km	-1998	MKS-MS	1° x 0.09°	
			Telespectrometer	1' x 1'	
			MW radiometer	12' x 12'	
Base Block	350-430 km	-1998	256 Z spectrum	8° x 16°	
				0.87° x 0.17°	
			KL 103W Pan		
			Video System		
Priroda	350-430 km	1995-1998	IR spectrometer (64)	6.5' x 6.5'	
				0.7 x 2.8 km	
			MW radiometer	6 km	60 - 750 km
			MSU-SK	120 x 300 m	350 km
			MSU-E	25 m	45 km
			MOS obsor A	2.9 km	83 km
			MOS obsor B	0.7 km	83 km
			MOMS 2 P	5 - 14 km	

Table 15 - Russia, Camera Systems

	KFA 1000	**KFA 3000**	**KWR 1000**	
height	220 – 350 km	210 – 350 km	200 – 350 km	CIR 66 – 105 km
inclination	60°	60°	60°	CIR/pan 21 – 36 km
resolution	8 – 10 m	3 – 5 m	(0.75) 2 – 5 m	pan 13 km
satellite	Resurs F1	Resurs		available as DD5
German missions	1982 – 1989	1993	1993	digit 1.5 m pixels
1992-1994	2 missions perhaps		pan camera (scan across flight direction)	
	30 x 30 cm^2 first generation	30 x 30 cm^2 second generation	18 x 18 cm^2 third generation	
	MKF 6 MC 23 x 23 km^2 LFC 24 x 48 cm^2	KFA 1000 MK4	KWR 1000 (40 x 40 km^2)	

Table 16 - Canada

Radarsat	1995 – 2000	C-Band 10-50 m res. swath 50-500 km multi	HH
ERS-1/2	1991 –	C Band 25 m	VV

Table 17 - China

Chinese Academy of Space Technology (CAST)

Operational Systems

Nov 26, 1975 –
At least 10 recoverable satellites
3 – 8 day missions
Photos with high resolution, panchromatic cameras

Future

1. Earth Observation Satellite CBERS Joint Project: Brazil (INPE) – China (CAST)
   1995? CAST – INPE
   26d cycle,
   20 m multispectral, 5 bands vis & near IR
   1 far IR 80 m
   swath 120 km
2. Recoverable satellite with panoramic camera
   to be continued

Table 19 lists the publicly not too well known parameters of classified military satellites.

Table 18 - Future High Resolution Plans up to 1 m.

Lockheed-Martin, USA
1 m panchromatic
4 m multispectral, 4 channels
swath 37 km
in flight stereo, use of RAID technology

Ball Aerospace
1 m panchromatic
6 m multispectral, 4 channels
swath 30 km
in flight stereo

Eyeglass

Worldview launch intended 1995
3 m panchromatic
12 to 15 m multispectral, 3 channels

Greensat
South Africa
2-3 m panchromatic
10 m multispectral
altogether 6 satellites

NEC
Japan
1 m panchromatic

Table 19 - Classified Military Systems

• US Military	K11 & K12 satellites flown 15 m pixels?	swath 1 km?
• France	Helios satellite launch 1995 first 4 m pixels, later 1 swath 10 km	
• France (Germany?)	Osiris X-SAR	sofar studies only

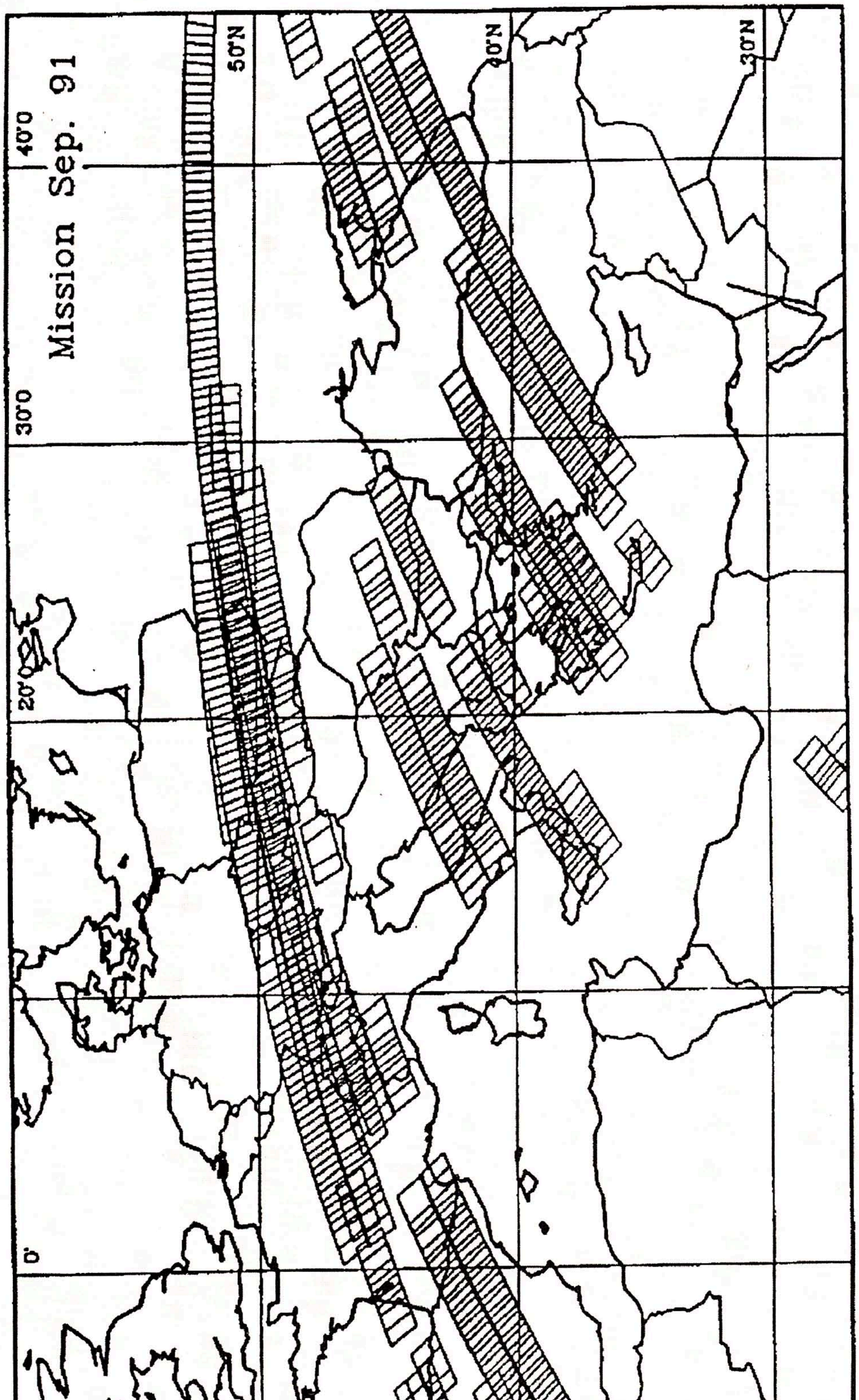


Figure 12 - Coverage of a KFA 1000 mission on Resurs F1.

12. CONCLUSION

The international developments presented in chapter 11 justify the conclusion that topographic mapping from space is on the verge of becoming an operational reality.

The capabilities of using this type of imagery are under development and investigation. Already now it can be concluded that there are no serious technical limitations for a vast improvement in the performance of the mapping process. Financial incentives may speed up this process.

The sooner this happens, the sooner satellite imagery will be able to meet global, regional and local information needs for resource management and for sustainable development as foreseen by Agenda 21, Chapter 40 of the Rio de Janeiro UNCED Conference of 1992.