Future Prospects for Mapping from Space

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Mapping from Space has become possible through the phenomenal development of space platforms and space sensors during the past generation.

Mapping from Space may be considered a technology driven activity, but it is vitally needed for the provision of basic information required for sustainable development.

1. Global Economic Development and Technical Cooperation

Human activity is based upon economic development. Throughout human history economic development has gone through four different stages from
- nomadic to
- agricultural to
- industrial to
- service oriented.

Due to different conditions in different parts of the world influenced by
- climate
- soil conditions
- mineral resources
- labour
- education
- technical innovation and
- motivation

this economic development has progressed at different rates in different parts of the world.

UN statistical yearbooks list a number of parameters, according to which this progress is usually measured in the countries of the world:
- the percentage of employees in agriculture, industry and services
- the GNP or GDP per inhabitant
- the percentage of food supply
- the inhabitants per medical doctor
- the child mortality.

The countries of the world can usually be divided into three categories:

1) the low level income countries characterized by a GNP/yr under 600 $/inhabitant, a predominance of agricultural economy, and a shadow economy of over 50 %. These countries have recently shown a decline of the GNP/year.

2) the medium level income countries with a GNP/yr between 600 and 3000 $ per inhabitant, a predominance of industrial activity and a shadow economy under 20 %.
   To these count the
   - socialist reform countries with a stagnating GNP/yr
   - the tiger countries of Asia with high foreign investment and the highest GNP/yr growth rates
   - the debtor countries mainly of Latin America with stagnating GNP/yr growth rates.

3) the high level income countries with a GNP/yr of over 3000 $/inhabitant. They are service oriented, and their shadow economy is less than 10 %.
   To these count the donor countries with small GNP/yr growth rates and the oil exporting countries with stagnating GNP/yr growth rate.

One of the major achievements of the United Nations System has been to stimulate high level income countries to share some of their wealth with the countries of lower income to stimulate their economic development through technical cooperation.

Of these four countries alone account for over 50 % of the total economic cooperation of 58 B $/yr for example available in 1991

- the USA 11.3 B $
- Japan 11.0 B $
- France 9.5 B $
- Germany 6.8 B $

Most of the development funding went to Subsaharan Africa with 32.5 %, but a significant portion also went to South East Asia with 27.1 %. This is proof that the system worked.

There have been many mutual discussions to make sure that some of the difficulties encountered, particularly in the poorhouse of the world in Africa, can be overcome.

They stem from institutional, financial, and educational difficulties in the countries, but they sometimes also relate to unsuitable technical issues.

2. Global Trends and Sustainable Development

The major trend in economic development is due to population growth. With the current 6 billion population, mankind will most likely double in number in the next 50 years.

Because of this there is additional need for food production and the need for sustainable development to preserve the global ecosystem with respect to a sustainable water balance, the mitigation of drought, and the preservation of coastal waters.

This leads to the necessity to monitor

- degraded forests
- poor crop yields
- dumps
- drought areas

- floods
- sedimentation
- soil erosion and desertification
- the growth of urban areas

The UNCED-Rio de Janeiro Conference of 1992 in their Agenda 21, Chapter 40 clearly describes the monitoring needs.

Another U.N. conference, Habitat 2 in Istanbul in 1996 has clearly pointed out that this population growth mainly occurs in the poorly developed countries with 2.7 % per year and that it goes hand in hand with urbanization of up to 5 % per year in these countries (see figure 1).

Continent	Population 1996	Population 2025	Growth 1995-2000 %	Urban Population %	Urban Growth 1995-2000 %
Africa	784 M	1496 M	2.7	34	4.3
Asia	3513 M	4960 M	1.5	35	3.2
Europe	727 M	718 M	0.1	74	0.5
Central and South America	490 M	710 M	1.7	74	2.3
North America	296 M	370 M	0.9	76	1.2
Oceania	29 M	41 M	1.4	70	1.4
World	5804 M	8294 M	1.5	45	2.5
developed countries	1171 M	1238 M	0.3	75	0.7
countries under industrialization	4633 M	7056 M	1.8	38	3.3
poorly developed countries	592 M	1162 M	2.7	22	5.2

Figure 1: Population Statistics and Predictions

The urban population is at present about 45 % of the total. 80 % of the world population is expected to be urban by the year 2025.

Most of the highest urban growth rates are expected to be in Asian cities, such as Dhakar (7.8 M) 5.7 %, Jakarta (11.5 M) 4.4 %, Karachi (9.9 M) 4.3 %, Mumbai (15.0 M) 4.2 %, Shanghai (15.1 M) 2.3 %, and Bangkok (7.1 M) 2.2 %.

3. The Need for Basic Data Sets in Geographic Information Systems

In the last 20 years geographic information systems have been developed as computer systems capable of input, storage, manipulation, analysis, and output of geographic data.

In its wider definition a GIS is, however, a data system of managing the environment for sustainable development for

- analysis of data for gaining information
- for planning with information
- for decision making and
- for implementation and monitoring of decisions.

It is to be realized that hard and software of a GIS rarely exceeds 20 % of its cost. The data are the most expensive part with 80 %. Thus a data system needs to be kept up to date.

A GIS due to its data integration capability from various sources has the advantage of being at least 4 times more cost-effective than the simple computer automation of a task.

4. The Need to Provide Timely Base Data Sets at Various Scales

A survey of data acquisition costs for various purposes shows a scale dependence. The larger the scale, the costlier. Costs of less than 100 $/km^2 can only be achieved with satellite imagery. Aerial or ground survey tools, which can supplement such surveys, are in general at least 10 times costlier per km^2 (see figure 2).

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

Figure 2: Survey Costs

Mapping and GIS consist of a base map coverage with integrable thematic layers and references to non-graphic data in data bases in table form (see figure 3).

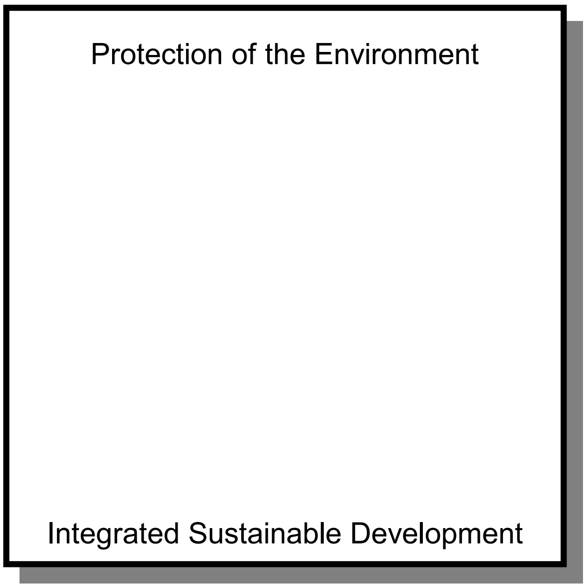


Figure 3: Mapping and GIS

It is this interpretation of information which makes efficient data management possible and affordable.

5. The Need for Satellite Data Systems to Provide the Data

The U.N. Secretariat has tried to monitor existing base map data for the different countries and continents at different scales (see figure 4).

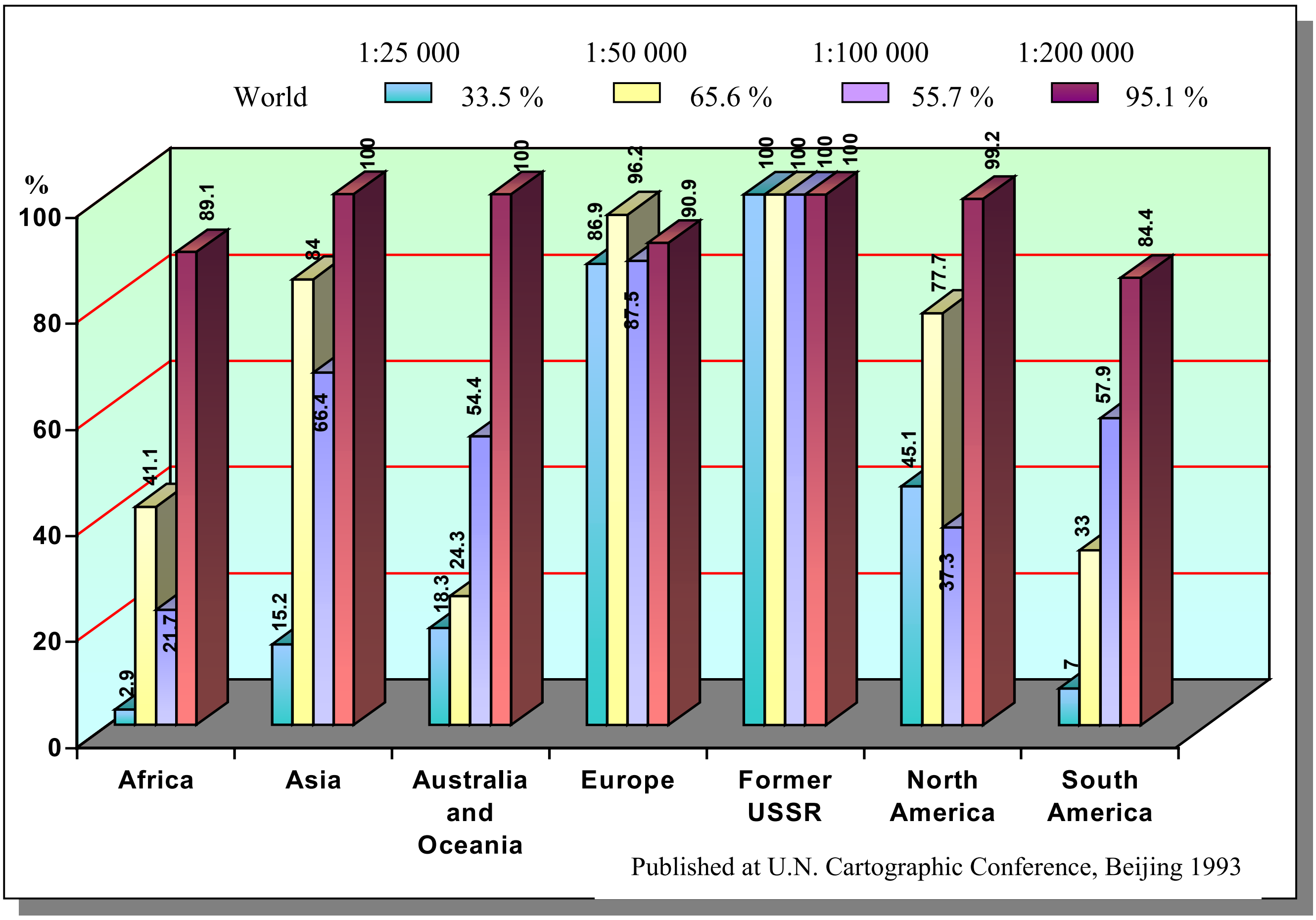


Figure 4: Status of Mapping (U.N. Statistics 1990)

The result has been that a global coverage only exists at scales smaller than 1:250 000. At 1:50 000 about 2/3 of the land area are covered and at 1:25 000 about 1/3.

What is even more alarming is that the present update rate for the 1:50 000 map is only 2.3 % and that of a 1:25 000 map 4.9 %. Thus the average age of a 1:50 000 map is 45 years and that of a 1:25 000 map 25 years (see figure 5).

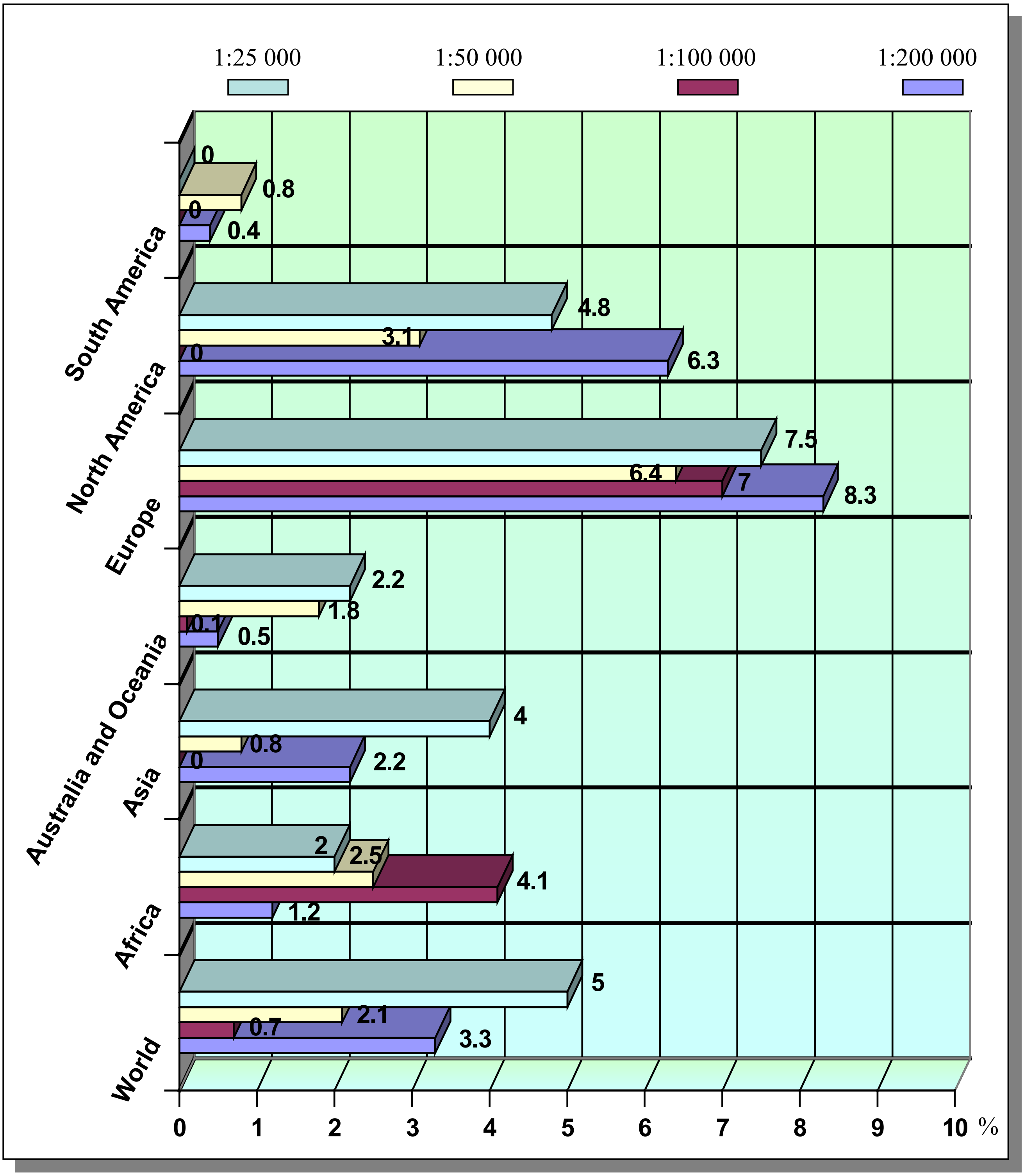


Figure 5: Annual Update Rate

Again, the developing continents have much smaller update rates than Europe or North America.

It becomes clear that the existing map technology based on aerial photography and ground methods is too slow to provide the required data sets. Thus satellite systems must be utilized.

6. Present Capabilities of Optical Satellite Systems

Geostationary low resolution satellites such as GMS, Insat, Goes and Meteosat offer images of the earth’s surface every 30 min at 5 km ground pixels. NOAA satellites offer 1 km resolution at least twice per day. Such data are ideal for global monitoring.

Resource satellites such as Landsat, Spot, JERS and IRS 1A and B offer medium resolution data between 10 and 30 m ground pixels several times per year.

The latest development are high resolution satellites such as IRS-1C and MOMS with about 5 m ground pixels without the present capability to obtain a global coverage as yet (see figure 6).

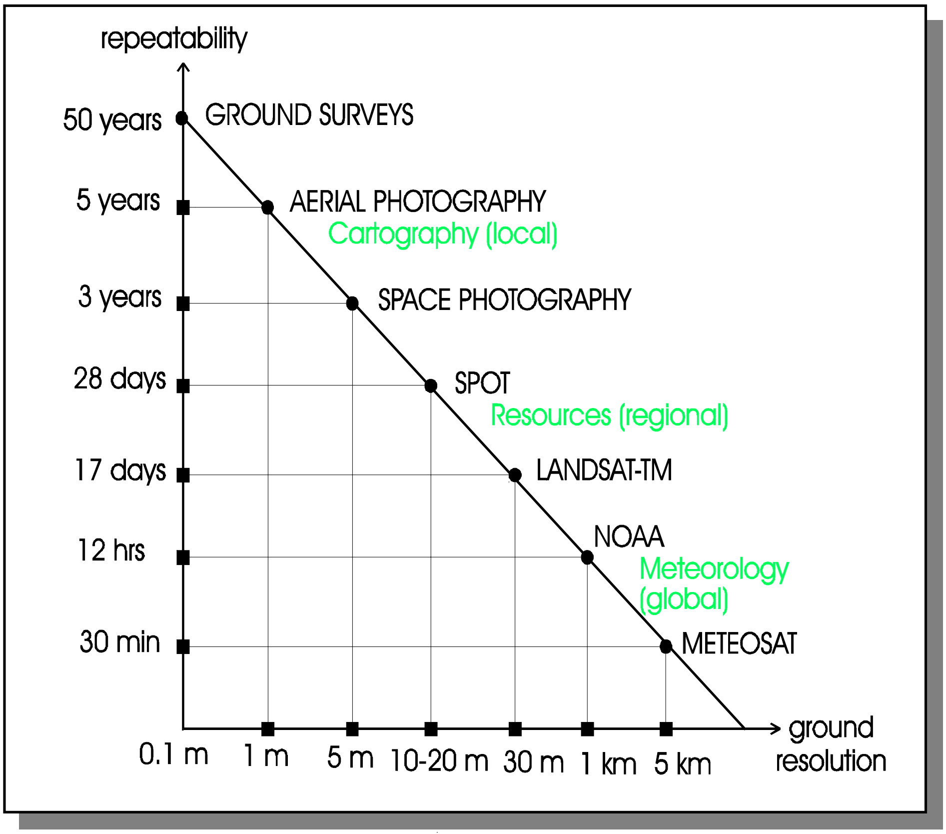


Figure 6: Resolution and Repeatability of Remote Sensing Systems

Experiences with these systems have shown that the use of satellite images for mapping is

- at least four times cheaper than using conventional methods
- but that at present resolutions quality standards must be relaxed
- visual interpretation of these images is still more effective
- but GIS integration is of advantage
- cloud cover is still a handicap opening ways for radar satellites such as JERS-1, ERS 1,2 and Radarsat.

Even 5 m resolution systems cannot compete in quality to aerial photography with 1 m resolution in 1:25 000 mapping (see figure 7).

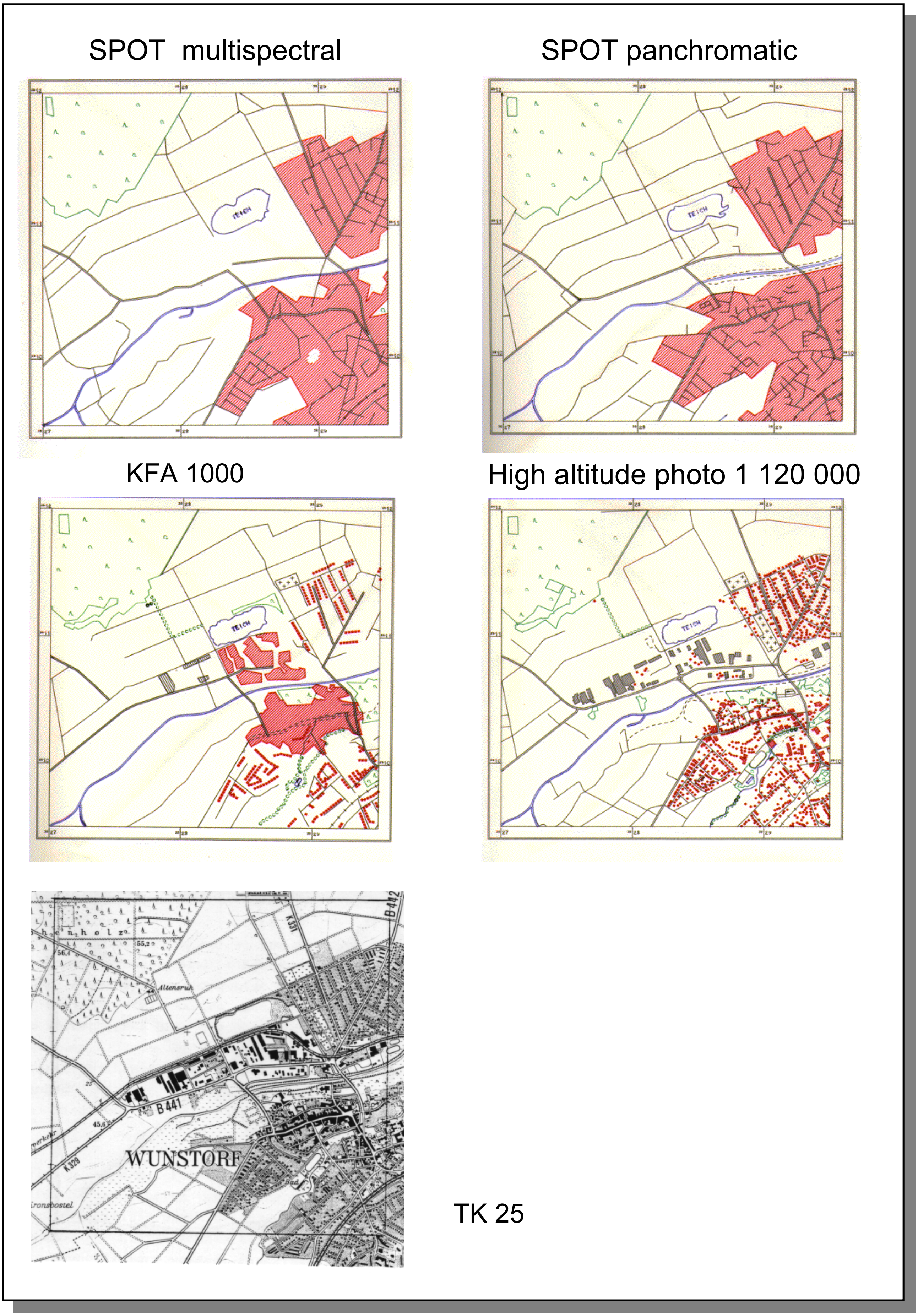


Figure 7: Mapping from Satellite Imagery from Spot MS (France), Spot Pan (France), KFA 1000 (Russia), aerial photography 1:20 000, existing map 1:25 000

The suitability for mapping from a particular type of imagery has already been investigated in the early 1980's. There are three criteria to be met:

- planimetric accuracy, which is scale dependent
- elevation accuracy, which depends on parallaxes created by the different image geometry from two different imaging positions
- detectability, which relates to the spatial resolution, which may be achieved by a particular sensor system.

Even though aerial photography, which has been digitized into different pixel sizes on the ground can hardly distinguish more than 6 bits of grey values as opposed to recent digital sensors with 10 or more bit of grey level distinction these early results are still generally valid:

Planimetric accuracy of a map is generally related to ±0.2 mm at publishing scale according to U.S. mapping standards. This criterion mainly relates to worldwide mapping practices for the original mapping scale, but not for generalized maps at smaller, derived scales, in which the planimetry is often shifted to accommodate conflicts in the depiction of objects. Even in the original mapping scales buildings or building blocks, roads and rivers are shifted in some national map bases for this purpose. But in general this means from the data acquisition side, that the following planimetric standards are usually accepted:

Scale	σ_p
1: 10 000	± 2 m
1: 25 000	± 5 m
1: 50 000	± 10 m
1:100 000	± 20 m
1:200 000	± 40 m

Elevation accuracy is generally a function of terrain slope. Depending on terrain slope a certain contour interval is specified. The reliability of contouring is generally accepted as being 5 times the point measuring accuracy in height, regardless of whether the contours are originally measured in a photogrammetric plotting instrument, or whether they are interpolated on the basis of a measured digital elevation model (D.E.M.) grid.

Contour interval Δh	Point measurement accuracy $\pm \sigma_h$	Terrain type
1 m	± 0.2 m	flood plane
2 m	± 0.4 m	"
5 m	± 1 m	"
10 m	± 2 m	"
20 m	± 4 m	"
50 m	± 10 m	"
100 m	± 20 m	high mountains

The detectability of objects, given sufficient contrast as a function of grey level discrimination, was formerly measured in terms of photographic resolution stated as line pairs per mm (lp/mm). Nowadays this photographic resolution must be compared to 2 to 5 pixels at image scale related to IFOV on the ground.

Early tests with photographic resolutions have been carried out for specific objects to be recognized and identified from the imagery. They established a minimum pixel size for the detectability of the following objects:

Object	Pixel size
urban buildings	2 m
foot paths	2 m
minor road network	5 m
fine hydrology	5 m
major road network	10 m
building blocks	10 m

The highest resolution from space, which is currently accessible on the civilian market is Russian KVR 1000 photography, digitized to 2 m pixels, in which individual houses can still be clearly identified (see figure 8).

Figure 8: Digitized KVR 1000 image (DD5) with 2 m pixels over the city of Hannover, Germany

Such images may be used for the creation of planimetric image maps at the scale of 1:10 000, but the lack of a large number of ground control points to differentially rectify the image maps on account of image deformation to planimetric map accuracy standards at that scale renders the expected planimetric accuracy more to the 1:25 000 level.

Moreover, the height determination from images generally depends on the height-base ratio of the imagery flown:

$$\sigma_h = \pm \frac{h}{b} \cdot \frac{h}{c} \cdot \sigma_{px}$$

with σ_h = point error in elevation
h = orbital height
b = orbital base
c = principal distance (focal length) of the camera objective
σ_{px} = parallax measurement error in the order of the point positioning error σp of about 10 µm in a photographic image, corresponding more or less to the pixel size on the ground with the image scale used.

Due to the very long focal length of the KVR camera of 1 m the stereoscopic overlap conditions of that imagery will not permit a smaller and more favorable height-base ratio than 10, rendering the expected height accuracy of less than ± 20 m.

The present KVR 1000 high resolution images are therefore suitable for planimetric map updates 1:10 000 or 1:25 000, but not for digital elevation model measurements.

Cartographic satellites, which permit a better height determination, even if they do not reach the same detectability are the French panchromatic Spot system with 10 m pixels and the Indian IRS-1C system with 5.8 m pixels. Due to their capability to incline the sensor by a mirror in cross-track direction a favourable height-base ratio of up to 1 may be achieved from subsequent orbits. This, however, is often a handicap due to changing cloud cover, which severely limits stereoscopic coverage for a time period in which the radiometry of the ground has not changed.

The best test result achieved thus far with Spot Pan and IRS-1C stereo imagery are in the order of ± 5 to 10 m in elevation and ± 3 to 5 m in position, making these sensors suitable for 1:50 000 to 1:100 000 mapping in mountainous areas.

Another approach has been provided by the inflight stereo capability of the German Stereo-MOMS system. It consists of a triple line scanner looking forward, vertically down and aft, which has been flown for 10 days on the U.S.-German Space Shuttle mission D2 in 1993 and which since 1996 operates on the MIR-Space Station's Priroda module with interruptions.

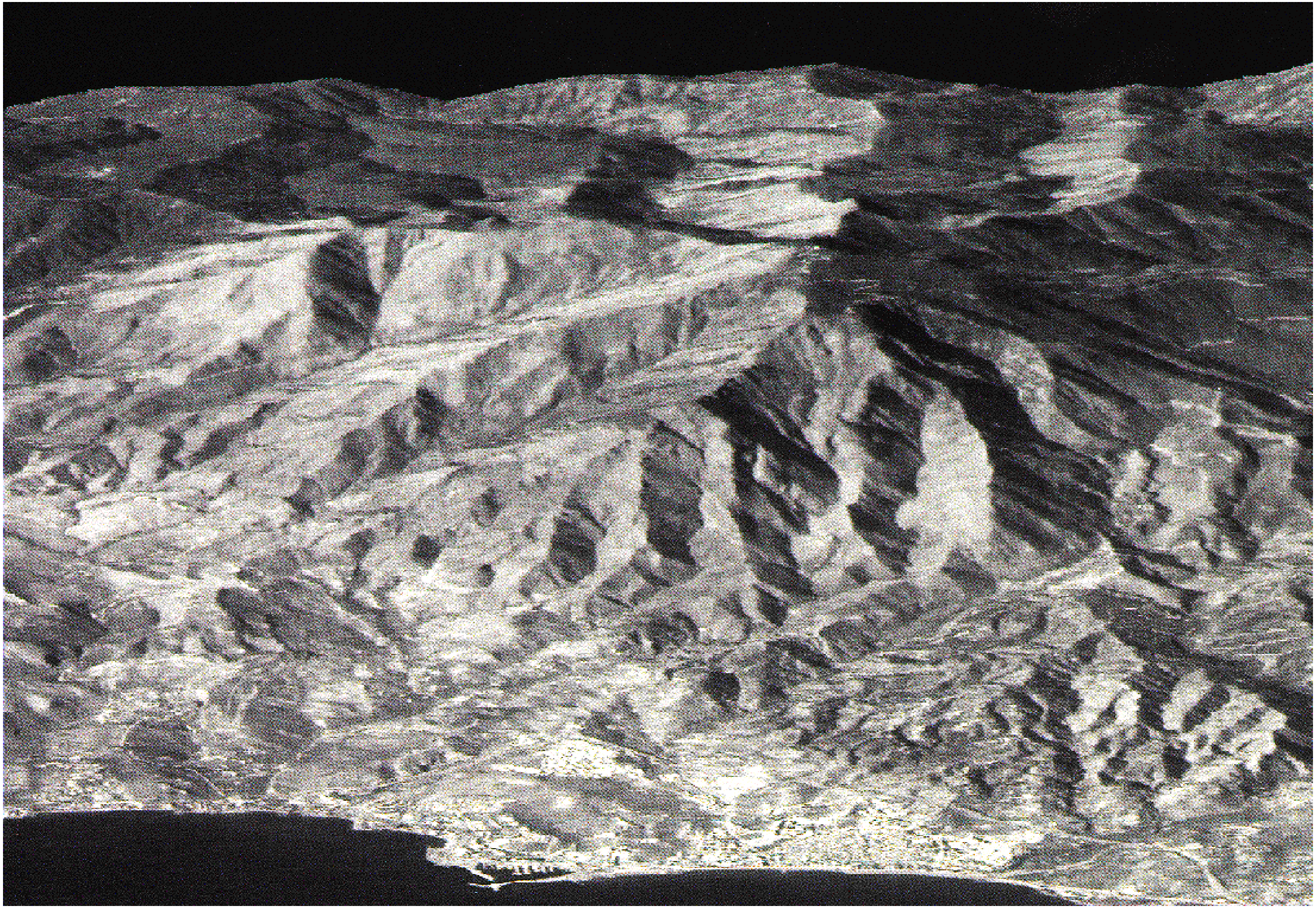
On MIR the vertical sensor yields 5 m panchromatic ground pixels and/or 15 m multispectral ground pixels, and the fore and aft sensors give 15 m panchromatic ground pixels. Figure 9 shows such an image over the German city of Augsburg, in which the vertical panchromatic 5 m pixels have been fused with the vertical multispectral 15 m pixels.

Figure 10 shows an oblique view of three processed fore, down and aft panchromatic stereo images after the generation of a D.E.M. and the resulting orthoimage over the area of Barcelona, Spain.

The advantage of in-track stereo sensing is that all images to create a DTM, orthophotos and oblique views are taken at the same time.

The cartographic requirements for these images show, that planimetric requirements can be met for the 1:25 000 scale, that elevations can be determined with ± 5 to 10 µm accuracy and that the detectability is suitable for 1:50 000 mapping.

Figure 9: MOMS-Priroda image over Augsburg, Germany (5 m pixels)



7. Present Capabilities of Microwave Satellite Systems

Optical satellite systems have sofar shown difficulties with marginal resolution and with cloud coverage. For this reason the European Space Agency ESA has launched the ERS radar satellite series followed by Japan with JERS and Canada with Radarsat.

Radar signals follow a very different geometry from optical devices. The existing satellite systems have also not been designed for land, but for ocean coverage, giving differences in the amount of foreshortening or shadows to be encountered. Moreover, radar backscattering does not behave like optical reflection. Thus the criteria for planimetric accuracy and for detectability of objects from radar images do not easily correspond to pixel size resolution of optical systems. Depending on the grey level differentiation desired radar processing can be executed (e.g. for ERS-1) to 12.5 m or 25 pixels related to the ground.

Thus radar images are more suitable for image fusion with optical images rather than for mapping alone.

Radar, when used in multitemporal mode or multipolarization mode, on the other hand, compares to optical multispectral differentiation capabilities, when classifying area objects. Yet satellite radars have a very distinct advantage, they generate coherent radiation. Coherent radar signals influence radar geometry since the images are reconstructed using phase and Doppler informations. They can only properly be reconstructed if a D.E.M. is used in the reconstruction.

On the other hand phase information may be utilized for D.E.M. generation using interferometry principles. While radar interferometry has been carried out using repeated images from quite different orbits (as for JERS-1 and Radarsat), as long as there is a base between the two imaging stations, the conditions for interferometry were greatly improved during the ERS-1/ERS-2 tandem mission which directed the 2 ERS satellites so that corresponding radar coverages over the same area were obtained one day apart with a small base between orbits.

Radar interferometry requires not only that the base between orbits is known, but that the sensor position and the sensor attitude is accurately determined. In the present satellite systems such possibilities have not been available with sufficient accuracy.

In the Hannover area a digital elevation model generated from radar interferometry has been fitted by a 7 parameter transformation to the few identifiable common control in the radar images. In most areas the comparison with an existing and accurate conventional D.E.M. resulted in average discrepancies of less than 10 m for 90 % of the points, but in hilly areas discrepancies of over 100 m were encountered.

This confirms that radar interferometry may be useful in differential changes of image portions, which are due to dynamic changes of the terrain, but it sofar fails in reliable elevation determinations.

An improvement of this situation has been suggested by the U.S. German SIR-C Space Shuttle Mission in 1999, which not only will use three radar frequencies (X-band, C-band, L-band) to resolve atmospheric ambiguities, but also will have two types of receiving antennas mounted on a 30 m long beam, the positions and attitudes of which are continuously monitored by differential GPS. In this way it is hoped to obtain a system capable of rapid D.E.M. mapping for large areas to ± 10 m.

8. Digital Elevation Models

There are currently at least six alternative methods considered for future generation of digital elevation models, competing in accuracy and price:

- the digitization of existing line maps at 5 to 20 m accuracy, depending on the original map quality, at prices of 1 $/km^2$
- the existing US Military global coverage at 20 m accuracy, obtainable for some portions of the globe, at prices of 1 $/km^2$
- aerial photogrammetric mapping at 5 m accuracy for 40 $/km^2$
- the future use of US commercial optical satellites, following the Stereo-MOMS principles, but at higher resolution with 5 m accuracy for 50 $/km^2$, with the advantage to map areas, when aerial photography is not available
- optical stereo sensors following the Stereo-MOMS or the SPOT/IRS-1C principle with 10 m accuracy at 5 $/km^2$
- interferometric SAR of the SIR-C type with 10 m accuracy at 5 $/km^2$.

9. Use of Satellite Remote Sensing Systems

The use of existing satellite images for monitoring the environment in the largest sense is manifold. The choice of imagery is always a compromise between availability and spatial, spectral and temporal resolution considering repeatability, swath, and pixel size.

All remote sensing conferences in Asia and in other parts of the world show that weather and meteorological dangers (storms, cyclones) can be monitored by global satellites such as Insat. NOAA satellites permit to measure sea surface temperature, pigment and chlorophyll concentration of ocean and coastal areas. But they are also able to monitor the state of vegetation on the basis of the normalized digital vegetation index to follow patterns of drought or floods, the health of tropical forests or the devastation by forest fires.

Resource satellites are useful in monitoring crop patterns in detecting vegetation diseases, to determine erosion risks or to follow uncontrolled growth of industrial activity and urban settlements and their pollution effects on the environment.

There would be no hope to gather the amount of this type of information without satellite remote sensing systems.

These interpreted results together with socio-economic data constitute the needed thematic information which needs reference to the base mapping system in form of a geographic information system.

Noteworthy are the recent activities of the Committee on Earth Observations by Satellites CEOS, an organization of the space agencies formed on the initiative of the 67 group. CEOS propagates the creation of an information locator system which helps the user to find pertinent information via the Internet. This CEOS-ILS is to contain types, locations, and times of satellite sensor images taken, if possible with reduced content quicklooks. In addition value added products such as digitized maps and metadata of various kinds are to be located in the system to offer the user a more complete information potential.

10. Future Capabilities of Medium and High Resolution Sensors

There will be many more satellite systems available in the near future by many nations. The European Space Agency ESA divides them into scientific “Explorer Missions” and operational “Earth Watch Missions”. ESA, for example, plans at least four explorer missions in the 2003 to 2011 time frame, which are directed toward scientific goals

- to measure the earth’s gravity field from space
- to get quantified values for earth radiation
- to explore the spectral capabilities of image spectrometry in a land mission
- to determine missing parameters of the earth’s atmosphere through cloud profiling and the measurement of the wind field.

All these missions are to enable scientists to develop better models for climate, atmosphere and other physical parameters, which could help to explain gaps in scientific understanding. The Earth Watch missions plan to improve the current capabilities of resources and cartographic satellites. To these count the Japanese, Indian, European, and American missions ALOS, IRS-1D, Envisat, Spot 5, and Landsat 7. But of foremost interest are the U.S. commercial ventures for high resolution imagery.

As is usual with planned systems, the details about these ventures change almost every month.

A summary compiled by L. Fritz in October 1997 is shown in figure 11 with relevant parameters.
It has been updated to October 1999. At the end of September 1999 Iconos 2 has been successfully launched by Space Imaging. Also Landsat 7 with a 15m panchromatic sensor is in orbit.

This will vastly improve the present sensing capabilities. The novel approach shall be an end-to-end data provision system including corrections for calibration and reference systems, cataloguing, value added processing and distribution.

Satellite imaging and processing capabilities may become a serious competitor to the traditional aerial survey industry unless the two approaches are merged and used in supplementation. Thus Mapping from Space is by no means a dream. Conceptually and on the experimental level it is now a reality soon to become operational on a competitive basis.

11. Conclusion

If one looks at the global scenario of development from the historical perspective one can conclude:

- The 19^{th} century was the century of interference and control between nations, a time when colonial powers used to introduce their limited mapping systems for their own resource exploitation by inadequate means.
- The 20^{th} century became the century of independence and competition between nations. In this century mapping for national resource management became possible through the World War proven aerial photogrammetric techniques propagated through the United Nations often with the help of donor countries.
- The 21^{st} century is likely to become the century of interdependence and cooperation between nations. In satellite remote sensing their is hope in the coordination activities of CEOS to globally plan satellites for global and regional needs. There is also hope in the recent formation of international consortia to build sensing systems for satellites and to process these products as GIS input in an end-to-end system.

In this scenario mapping from satellites constitutes a contribution to preserve living conditions on this planet by providing the necessary information for it.

Systems	Earth Watch "Quick Bird"		Orbital Sciences "Orb View 3"		Space Imagery "Ikonos"		West Indian Space Ltd. "EROS"		Earth Watch "Early Bird"		Resource 21 "Resource 21"			GEROS		Kodak "Cibsat"		
partners	Ball Hitachi Telespazio MDA		Orbital Sciences		Lockheed Martin E-Systems Mitsubishi		Israeli Aircraft Ind. Core Soft-ware Techn.		Ball Hitachi Telespazio MDA		Boeing Farmland GDE ITD			Geophys. & Env. Res. Corp. Space Vest				
launch	1. 2000 2. 2001		2000		1. Sept 1999 2. 2000		1. failed 2. 2000		failed		1. 2001 (2) 2. 2002 (2)			1.2000 (2) 2. 2001 (2) 3. 20012(2)		cancelled		
mode	Pan	MS	Pan	MS	Pan	MS	Pan		Pan	MS	MS			Pan	MS	Pan	MS	hyper-spectral
quantization	11 bit	11x4 bit	8 bit	8 bit	11 bit	11 bit	10 bit		8 bit	8 x 3 bit	12 bit					11 bit	11 bit	
resolution	0.82 m	3.28 m	1 & 2 m	4 m	0.82 m	4 m	1.3 m		3.2 m	15 m	10 m	20 m	100 m		10 m			
channels	1	4	1	4	1	4	1		1	3	4	2	1			1	5	60
swath	22 km		8 km		11 km		13.5 km		6 km	30 km	205 km					112 km		
pointing in track	$\pm 30^{o}$		$\pm 50^{o}$		$\pm 45^{o}$		$\pm 45^{o}$		$\pm 30^{o}$		$\pm 30^{o}$			-		2 convergent sensors		
pointing cross track	$\pm 30^{o}$		$\pm 50^{o}$		$\pm 45^{o}$		$\pm 45^{o}$		$\pm 28^{o}$		$\pm 40^{o}$			-				
sensor position	GPS		GPS		GPS		GPS		GPS		GPS			GPS		GPS		
sensor attitude	star trackers		2 star trackers		3 star trackers		-		1 star tracker		star trackers			star trackers		2 star trackers		
expected accuracy with GCP's	horiz	vert	horiz	vert	horiz	vert	horiz	vert	horiz	vert	5 m abs.			horiz		horiz	vert	
	2 m	2 m	7.5 m	3.3 m	2 m	3 m	6 m	4 m	6 m	4 m	1 m rel.			3 m		5 m	3 m	
Without GCP's	23 m	17 m	12 m	8 m	12 m	8 m	800 m		150 m		30 m			25 m				

Figure 11: Commercial Earth Observation Satellites