SPOT IMAGERY, FUTURE PRODUCTS AND POTENTIAL APPLICATIONS

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ABSTRACT : SPOT will provide Earth images with 10 m ground resolution in black and white or 20 m in the multispectral mode, at vertical or off-nadir viewing and in single frame or stereopairs. In addition a variety of image preprocessing and processing levels will be made available according to the precision and quality required by users. The many innovative SPOT features combined with well adapted products should provide the user community with high value information in a variety of application fields as demonstrated by analysis completed with SPOT simulated data, in cartography, agriculture, town planning, environment studies and geology. The overall impression is that SPOT images may well be the alternative to medium and small scale aerial photographs for numerous thematic applications. The inherent acquisition flexibility of the SPOT system will be an important additionnal advantage in the case of programs requiring multitemporal data.

RESUME : SPOT fournira des images de la surface de la Terre avec 10 mètres de résolution en mode panchromatique et 20 mètres en mode multispectral, en visée verticale ou oblique, en scènes simples ou par couples stéréoscopiques. De plus, un large éventail de traitements sera proposé, pour répondre aux divers besoins des utilisateurs en termes de précision et de qualité. La conception originale de SPOT combinée avec des produits bien adaptés devrait fournir à la communauté scientifique des informations de haute valeur dans de nombreux domaines d'application comme le démontrent les évaluations réalisées sur des données simulées en cartographie, agriculture, urbanisme, environnement et géologie. L'ensemble des résultats permet de penser que les images SPOT pourront se substituer aux photographies aériennes à moyenne ou petite échelle pour de nombreuses applications, en particulier thématiques. La souplesse d'acquisition des données spatiales sera un atout supplémentaire pour la réalisation des études nécessitant des informations multitemporelles.

INTRODUCTION

The SPOT program has been planned and designed as an operational and commercial system. Decided by the French government in 1978, with the participation of Sweden and Belgium, the program is managed by the French Space Agency (CNES) which is responsible for the program development and satellite operations. SPOT 1 will be launched in May 1985 and SPOT 2, to be available for launch in early 1986 as a back up for SPOT 1, is also under construction. Plans are being made for the launch of SPOT 3 and 4 in 1988 onwards in order to ensure the necessary service continuity expected from an operational spaceborne remote sensing program. Actually, it is essential that current programs be followed up over a sufficiently long period (at least 10 years) to allow the development of applications in those areas where remote sensing is not yet widely used. This is also necessary to implement adequate procedures for operational aspects, involving training activities and equipment.

The organizational structure adopted for the management of the SPOT program clearly distinguishes between the functions of technical system management, executed by CNES and the responsability, assigned to SPOT IMAGE, a commercial corporation, for relations with the user community and the data distribution. This structure should ensure the efficient management of both satelitte image acquisition capacity and data transmission, by the ground network of SPOT data receiving stations, in accordance with user requirements. In addition, the conditions of image distribution on a commercial basis go hand-in-hand with the necessity to move towards the complete auto-financing of the program. This policy should make it possible to ensure continuity of service beyond the first two satellites.

I - BRIEF RECALL OF THE SPACECRAFT CHARACTERISTICS

The SPOT spacecraft carries two identical sensors, called HRV (Haute Resolution Visible), made of static solid state arrays of detectors (CCD) and operating in the visible and near infrared part of the spectrum. Among the innovative features of SPOT are the relatively high ground resolution of the imagery it will produce (10 m in the panchromatic mode, 20 m in the multispectral mode) and the ability of its sensors to point up to 27 degrees East and West of the local vertical axis. This latter feature offers interesting possibilities to increase the number of opportunities to obtain views of a given area. It also permits stereoscopic observations by combining views taken at different angles from the vertical and therefore opens up the possibility of third dimension (or altitude) determination, an important requirement for cartographic applications. The principal characteristics of SPOT are summarized in table I.

Swathwidth

Two identical sensors (HRV) are onboard the Satellite and can be activated independently. Each instrument has a swathwidth of 60 km. When the two instruments operate in adjacent covering field, the ground coverage is 117 km.

Imaging Modes

SPOT operates in two modes: multispectral mode and panchromatic mode.
In the multispectral mode, observations are made in three spectral bands with a pixel size of 20 meters.

- a green band from .50µm to .59µm
- a red band from .61µm to .68µm
- a near infra red band from .79µm to .89µm

SPOT : PRINCIPAL CHARACTERISTICS	
ORBIT	Circular at 832 km Inclination : 98,7 degrees Descending node at 1Oh 30mn A.M. Orbital cycle: 26 days
HAUTE RESOLUTION VISIBLE (HRV)	Two identical instruments Pointing capability: ± 27 degrees East or West of the Orbital plane Ground swath: 60 km each at vertical incidence Pixel size: . 10 m in panchromatic mode . 20 m in multispectral mode Spectral channels: . panchromatic: .51 to .73 µm . multispectral: .50 to .59 µm .61 to .68 µm .79 to .89 µm
IMAGES TRANSMISSION	Two on board recorders with 23 minutes capacity each Direct broadcast at 8 GHz (50 Mbits/sec)
WEIGHT	1750 kg
SIZE	2 x 2 x 3.5 m plus solar panel (9 m)

Table 1

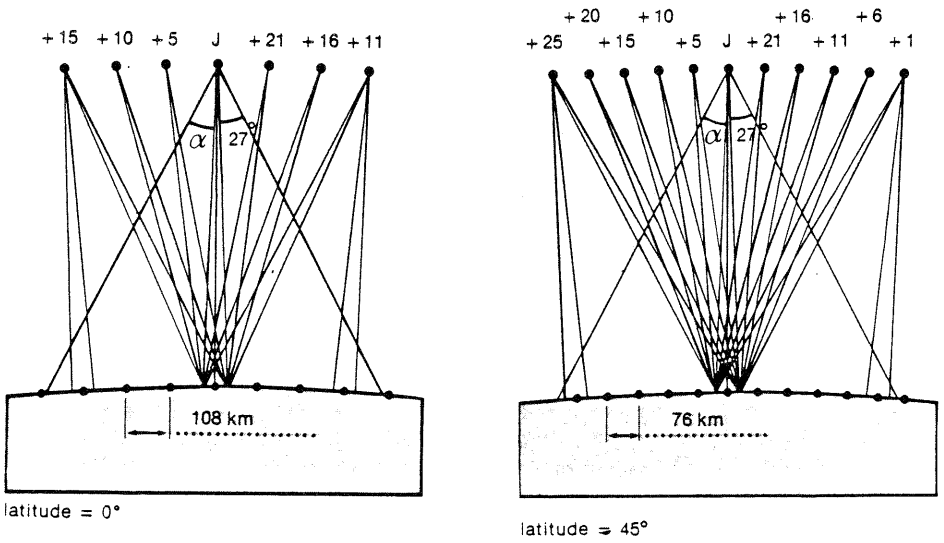


Figure 1 : Typical sequence of acquisition at the Equator and at latitude 45°

In the panchromatic mode, observations are made in a single broad band, from .51µm to .73µm with a pixel size of 10 m.
The multispectral bands have been selected to take advantage of interpretation methods developed over the last ten years; they have been designed to allow the best discrimination among crop species and among different types of vegetation using three channels only.
The panchromatic band will offer the best geometric resolution (10m) and will make possible to comply with cartographic standards for maps at a scale of 1:100,000 and/or to update at a scale of 1:50,000 and in some cases 1:25,000 for thematic applications.

Field pointing flexibility, Nadir and off nadir viewing

One of the key features of SPOT is the steerable mirror which provides off nadir viewing capability.The instrument can be titled sidewards (to the East or to the West) step by step from 0 to 27 degrees allowing scene centers to be targeted anywhere within a 950 km wide strip centered on the satellite track. This technique provides a quick revisit capability on specific sites. For instance, at the Equator, the same area can be targeted 7 times during the 26 days of an orbital cycle i.e. 98 times in one year with an average revisit of 3.7 days. At latitude 45, the same area can be targeted 11 times in a cycle i.e. 157 times in one year, with an average of 2.4 days, a maximum timelapse of 4 days and a minimum timelapse of 1 day (Fig. 1).
The revisit flexibility allows

1. to monitor phenomena which rapidely vary over time, such as crops, environmental stresses, natural disasters.
2. to improve the possibility of obtaining timely data required in many studies
3. to improve the rate of area coverage by minimizing the effects of weather conditions.

Figure 2 illustrates the variability to obtain a complete coverage of France using cross-track viewing capability. At vertical viewing the coverage is obtained in 313 days, and in 100 days if 27° depointing mode is used.

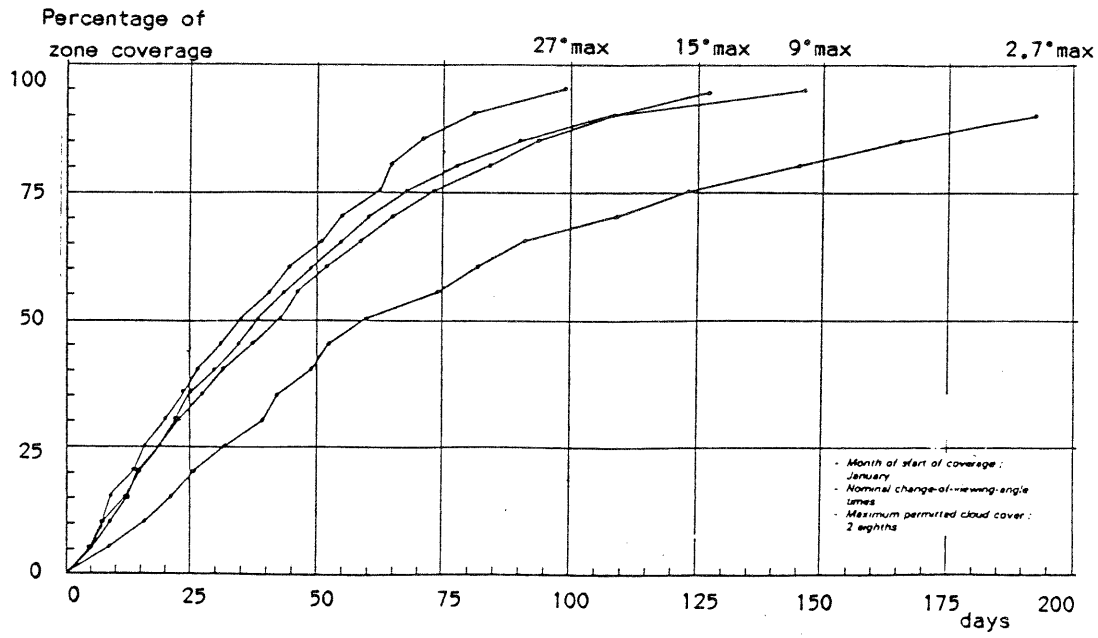
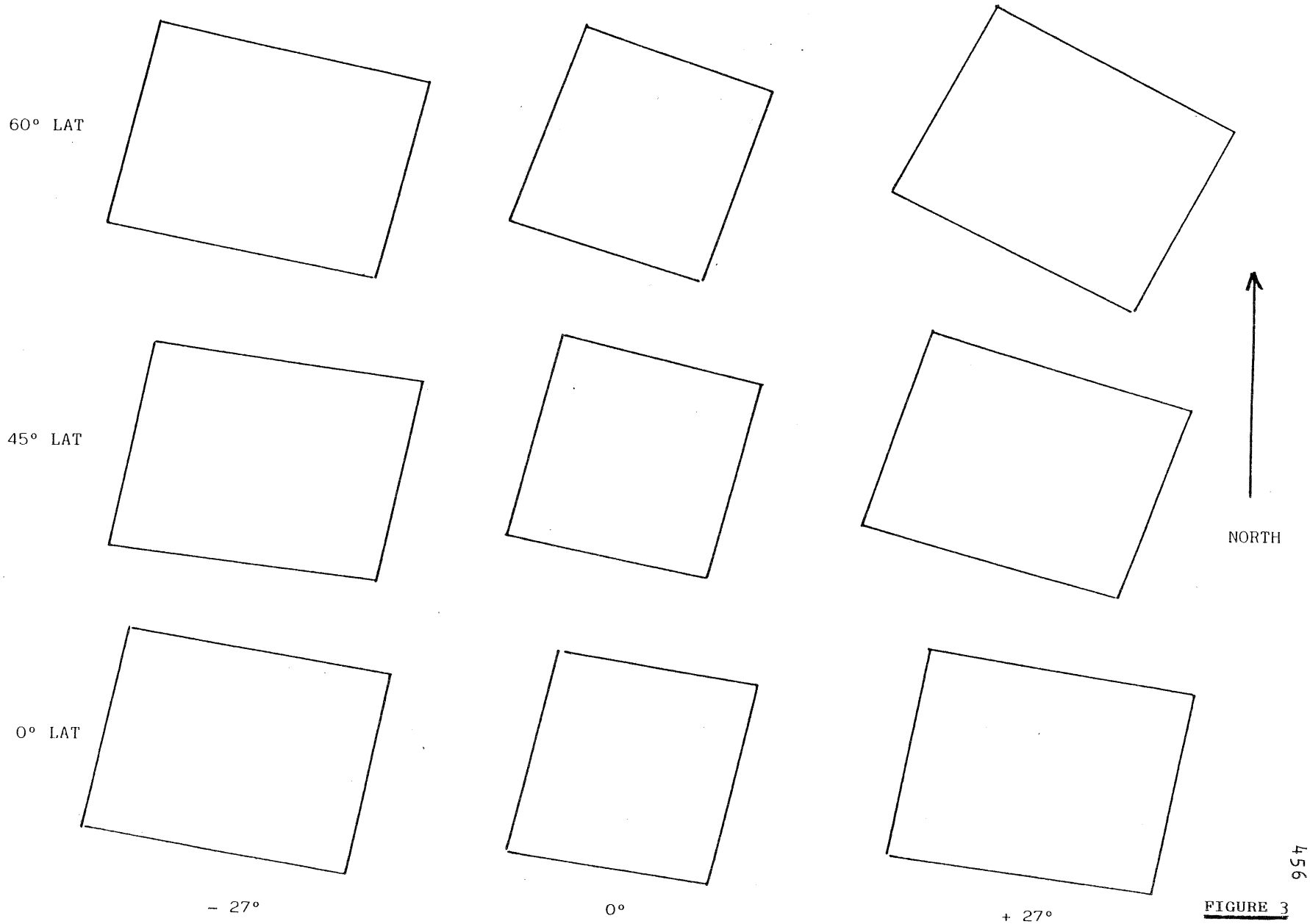


Figure 2: Time required to obtain a complete coverage of France for different maximum cross-track viewing capabilities

SIZE AND ORIENTATION OF A SPOT SCENE

ACCORDING TO LATITUDE AND VIEWING ANGLE



456

FIGURE 3

Stereoscopy

Stereo pairs can be obtained by combining two images of the same zone but recorded during different orbits and at different HRV viewing angles. Stereo pairs can be recorded with mirror pointing angles anywhere between -27 and +27°. For a pair comprising one image recorded at -27° (HRV looking East), and another recorded at +27° (HRV looking West), the B/H ratio is 1.

The longitudinal axis (axis defined by the middle of the lines of the image) of two scenes forming a stereo pair are not parallel. The angle between the axes of two scenes forming a stereo pair increases as the pointing angle of the HRV mirror increases and also as the latitude of the scene center increases (figure 3). Stereopairs are an important requirement in many cartographic applications: geomorphical, geological or soil maps and of course for topographic maps. SPOT will provide the opportunity to map anywhere in the world with a mapping accuracy corresponding to the 1:100,000 standards.

Images transmission

Direct broadcasting operates at 8 GHz at a rate of 50 Mbits/sec. The satellite carries two on board recorders with a 23 minutes capacity each. On board data recording will be used over areas where no ground receiving facility occurs.

II - SPOT PRODUCTS

SPOT will provide Earth images with 10 meters ground resolution in black and white or 20 meters in the multispectral mode, at vertical or off-nadir viewing and in single frame or stereopair. In addition, a variety of image prepocessing and processing levels will be made available according to the precision and quality required by users for "SPOT data" which applies to scenes with standard processing and "SPOT products" which refers to any product derived from the above data.

Data transmitted by the SPOT satellites will be received:

- at both the Toulouse (France) and Kiruna (Sweden) main stations in direct read out mode for data taken over Europe and Polar zones. These two stations will also received the worldwide data dumped from the onboard recorders. Each of them has a receiving capacity of 250,000 scenes per year.
  The preprocessing centers attached to both stations and operating in Sweden and in France, have a capacity of 70 system corrected (level 1) scenes per day or 20 precision processed (level 2) scenes per day. A level 1 scene can be preprocessed within 48 hours from its acquisition at the ground station in standard procedure, when a precision processed scene requires 5 to 7 days.
- at other receiving stations in the world which will receive only real time data over the stations visibility range.
  The distribution of SPOT data and products will be made by the receiving stations within the station's distribution zone which generally correspond to the country or countries operating the station. Elsewhere the distribution will be ensured by SPOT IMAGE and a network of national distributors.
  Therefore, users will have various possibilities for information purposes or for product ordering:
- to contact the national receiving station acting as a distributor when they are resident in such a country.
- to contact the national distributor(s) in those countries that do not possess a receiving station.
- or to contact directly SPOT IMAGE in Toulouse.

Information availibility through easy and quick access to data and products is a very important factor in operational procedures. The system implemented for data acquisition as well as data ditribution has been conceived to meet the user needs and SPOT customers are given an active part in the system.

1- Review of specifications for data and product basic preprocessing levels.

The basic unit for segmenting the image data streams at the ground receiving and preprocessing stations will be the "scene" which corresponds to the totality of image data for an area 60 Km in length (along the ground track) and 60 to 80 Km in width (in the cross track direction) depending on the instrument viewing angle. This corresponds, for vertical (nadir) viewing to 6000 x 6000 pixels per scene in the panchromatic mode and 3000 x 3000 pixels in the multispectral mode. (Table 2)
In the case of cross-track viewing (i.e. for mirror pointing angles between 0° and the maximum value of 27°), the length of a scene in the ground track direction is always 60 km, but the width, in the cross-track direction, is a function of the mirror pointing angle and ranges between 60 and 80 km.
When the two HRVs are operated in the so-called "twin mode" with the mirror pointing angles near 0°, the result is termed a "bi-scene". Such SPOT bi-scenes cover 60 km x 117 km with 3 km overlap between the two.

SPOT IMAGE and stations operators will deliver basic image data preprocessed in a number of different ways to make them unable. This applies to radiometric corrections taking into account the calibration factors for the detectors and the optical and telemetry systems and to geometric corrections to take account of the viewing conditions and of the precision required for specific applications. Four main levels of preprocessing are anticipated roughly corresponding to system corrected (level 1B) and precision processed (level 2 and S) data.

Level 1A

This is essentially a "raw" data, the only processing performed being the equalization of the response of the CCD detectors. Neither interband calibration nor geometric correction is applied. Level 1A data are intended for users requiring imagery that has undergone a minimum of preprocessing and in particular for stereo plotting purposes.

Level 1B

This level involves radiometric and geometric system corrections (compensation of: rotation of the earth, satellite perspective effects, viewing angle, and effects of satellite forward motion (desmearing). The location accuracy is 1500 m (rms), for vertical veiwing, and the relative error 10^{-2}. This is the basic preprocessing level for photointerpretation and thematic analysis. Stereoscopic pairs, with different B/H ratios depending on instrument viewing angles, are available at this level.

BASIC CHARACTERITICS OF SPOT SCENES		
Scene dimensions (nadir viewing) :	60 km x 60 km	
	XS MODE	P MODE
Pixel size :	20 m x 20 m	10 m x 10 m
Number of spectral bands :	3	1
Dimensions of preprocessed scenes :		
. number of pixels per line : (raw scene to level 2 scene)	3 x (3000 to 5200)	6000 to 10400
. number of lines per scene : (raw scene to level 2 scene)	3 x (3000 to 4900)	6000 to 9800
. volume (8-bit bytes) :	27 to 76.5 Mb	36 to 100 Mb

TABLE 2

Level 2

This is a precision processed level. Radiometric correction is as for level 1B. Geometric corrections involve bi-dimensional computation based on 6 to 9 ground control points (GCPs) per scene. The image is rectified according to a given cartographic projection: Lambert Conformal, Transverse Mercator, Oblique Equatorial, Polar Stereographic, or Polyconic. The location accuracy is 50 m (rms) for vertical viewing. But this level does not take account of distortions due to relief. Thus, the closer the viewing angle to the vertical and the less pronounced the relief, the more accurate the final product. Film reproductions of level 2 data are oriented with geographic North corresponding to the "Y-axis" of the film.

Level S

This level of preprocessing involves scene rectification relative to landmarks to ensure registration with another scene used as a reference to within 0.5 pixel, i.e. to within 5 or 10 m depending on the imaging mode. Level S products are typically used in multidate studies.

These basic standard preprocessing levels are performed by the preprocessing centers at Toulouse (CNES) or Kiruna (SATIMAGE) or at other preprocessing centers attached to local receiving stations.

In addition to these basic preprocessing levels, a number of further processed and value added products will be made available. These products include most of the multispectral enhancement and processing techniques commonly used at the moment as well as geometric processing for cartocgraphic purposes :

- cartographic precision processed SPOT scenes: level 3 (orthophotography using a DTM) and level 4 (production of contour level maps) such as those which will be produced by Institut Geographique National
- radiometric enhancements: stretching, edge enhancement, etc.
- channel combinations: ratios, PCA, color composites of basic or new computed channels, etc.
- mixed products such as SPOT panchromatic and multispectral scene or SPOT scenes merged with other sources of information
- geocoded products
- multispectral classifications

2- Media and formats

SPOT products will be available, by full scene or sub-scene, recorded on the following media: CCT, floppy disk, photographic film or print.

2.1- Magnetic Media

. Computer Compatible Tapes (CCTs)
The SPOT CCT format belongs to the "CCT Family of Tape Formats" as defined by the Landsat Ground Station Operators Working Group (LGSOWG). SPOT CCTs may be recorded at 6250 ou 1600 bits per inch (bpi). Recall that a single SPOT scene comprise from 27 to 100 million bytes depending on the imaging mode and the processing. This means that one full SPOT scene can be recorded on one 6250-bpi tape or on two or three 1600-bpi tapes each with a maximum capacity of 32 M bytes. The image record length will be, depending on the case, 5400, 8640 or 10,890 bytes (of 8 bits). The recording format will be band-interleaved-by-line. (BIL) (TABLE 2).

A tape will contain five files: a volume directrory, leader file, imagery data file, trailer file, and null volume directory. The leader file contains ancillary information concerning the satellite, the recorded scene and preprocessing (ephemeris data, attitude; calibration coefficients and previously computed histograms, etc.).
Radiometric levels will be encoded using 254 levels. Level 0 corresponds to non-significant values (borders, losses of synchronization) and level 255 is reserved for future applications.

. Floppy disks
Each floppy disk will only be able to store a small part of a scene. The format for the recording of floppy disks has yet to be determined.

2.2- Photographic Media

The basic photographic medium is the 241 mm x 241 mm format film corresponding to a full SPOT scene preprocessed to level 1B and at a scale of 1:400,000. However, in view of the very fine detail in such imagery, it is not directly usable at this scale, i.e. it needs to be enlarged. The basic film format for level 2 products will be 350 mm x 350 mm. In this case, North-oriented images will require yet another format because of their "skewness". Level 1B, 2 and S film products will be available in black & white (panchromatic or three spectral bands), or as color composites, with the following scales and formats

Level	Film format	Scale	Content
1B	24 cm x 24 cm	1:400,000	1 full, 60 km x 60 km, scene
	24 cm x 24 cm	1:200,000	1/4 scene
	50 cm x 50 cm	1:200,000	1 full scene
	50 cm x 50 cm	1:100,000	1/4 scene
	50 cm x 80 cm	1:100,000	1/2 scene
2	35 cm x 35 cm	1:400,000	1 full, 60 km x 60 km, scene
	35 cm x 35 cm	1:200,000	1/4 scene
	70 cm x 70 cm	1:200,000	1 scene
	70 cm x 70 cm	1:100,000	1/4 scene

Level 3 film products will be available in two formats:
50 cm x 50 cm and 100 cm x 100 cm.

SPOT IMAGE

SPOT PRODUCTS

EACH 60 × 60 KM SPOT SCENE WILL BE AVAILABLE :

- AS PANCHROMATIC DATA (ONE BAND, 10 M.)
  OR AS MULTISPECTRAL DATA (THREE BANDS, 20 M)
- AT FOUR PROCESSING LEVELS :

  1A EQUALIZATION OF DETECTOR RESPONSE NO GEOMETRIC CORRECTION

  1B RADIOMETRIC CORRECTION AND GEOMETRIC CORRECTION INDUCED BY THE ACQUISITION SYSTEM

  2 RADIOMETRIC CORRECTION PLUS PRECISION GEOMETRIC CORRECTION TO MAP THE IMAGE INTO A CARTOGRAPHIC PROJECTION

  S REGISTRATION WITH A REFERENCE SCENE
- IN SINGLE FRAME (AT NADIR OR OFF NADIR VIEWING) OR IN STEREOPAIR
- ON PHOTOGRAPHIC FILM AT SCALES RANGING FROM 1/400,000 TO 1/25,000 OR ON CCT (1600 OR 6250 BPI)

Paper prints will be available with scales starting at 1:200,00. Level 1 quarter-scenes will use the 24 cm x 24 cm and level 2 the 35 cm x 35 cm format. Quarter and full scenes will also be available at 1:100,000 using correspondingly larger format.

Quick-look images

Quick-look images can be briefly characterized as follows:
- gross geometric and radiometric correction,
- panchromatic mode data subsampled at the rate of 1 pixel in 6 and 1 line in 6.
- multispectral mode data subsampled at the rate of 1 pixel in 3 and 1 line in 3.

Quick looks will be available as photographic paper prints at a scale of 1:400,000 (format: 24 cm x 24 cm), unless ordered on a subscription basis, in which case they can be recorded on videocassettes.

III - POTENTIAL APPLICATIONS

In 1979, it was decided as part of the preparation for and the promotion of the SPOT program, to conduct a series of campaigns aimed at simulating the types of imagery that will be recorded by the SPOT earth observation satellites. At first this exercise was simply intended to meet the requirements of users who had participated in the drawing up of the specifications for the SPOT system and to ensure the compatibility of SPOT products with the intended applications in such areas as cartography, agriculture, geology, land use, the environment, and so on.

In view of the interest created by the first simulated images, this program, which was open only to French laboratories during the first year, was quickly extended to cover a number of foreign countries and made open to all users. Thus, all potential users had (and still have) an opportunity to become acquainted with simulated SPOT data, to assess the technical qualities of the products, and to evaluate the usefulness of the data for different applications.

To date, 400 simulated scenes, covering 23,000 km^2 and 130 sites, including a wide variety of geographical zones, have been prepared. Some fifty or so organizations and laboratories have participated financially or technically in the campaigns.

The first analyses completed have yielded promising results suggesting that SPOT data should be well suited to a wide range of applications from which some examples have been selected to illustrate this paper.

1- LAND USE AND AGRICULTURE

With regard to land use studies in rural environments, it appears certain that the high resolution of SPOT images will prove to be a major advantage.

An interesting case in point is the visual interpretation study conducted by the Bureau pour le Développement de la Production Agricole (B.D.P.A.) of several areas of Corsica. This work revealed that, without doubt, SPOT imagery is particularly suitable for thematic mapping in highly complex regions such as the Mediterranean basin and similar regions in other parts of the world, characterized by a complex pattern of landscapes.

In these areas, currently available satellite remote sensing data has been of little use due to insufficient resolution.

The potential usefulness of SPOT data for such applications is due to the judicious choice of spectral bands which, associated with the high resolution (10 m) of the panchromatic mode, greatly facilitates the identification and location of major features, despite their frequently small dimensions. The excellent accuracy of feature location also greatly facilitates the use of ground truth data and the mapping of the results. With regard to mapping, it should be noted that the use of standard level 2 SPOT products will completely bypass the problem as these will be conformed to cartographic projections.

Given the richness of textural and structural information contained in the simulated data, SPOT imagery would appear to be fairly comparable to small-scale aerial photography (1:60,000 to 1:100,000).

Analysis of the results obtained for the types of terrain studied reveals that the 20 m resolution multispectral and 10 m resolution panchromatic modes are complementary and that the corresponding data should thus be used in association or in combination : panchromatic data is nearly always required to bring out textural and structural features, while multispectral data provides complementary information on vegetation, soil and rock types, water bodies, and so on.

In image digital processing and automatic classification, the pixel size compared with field, parcel or plot size is of capital importance.

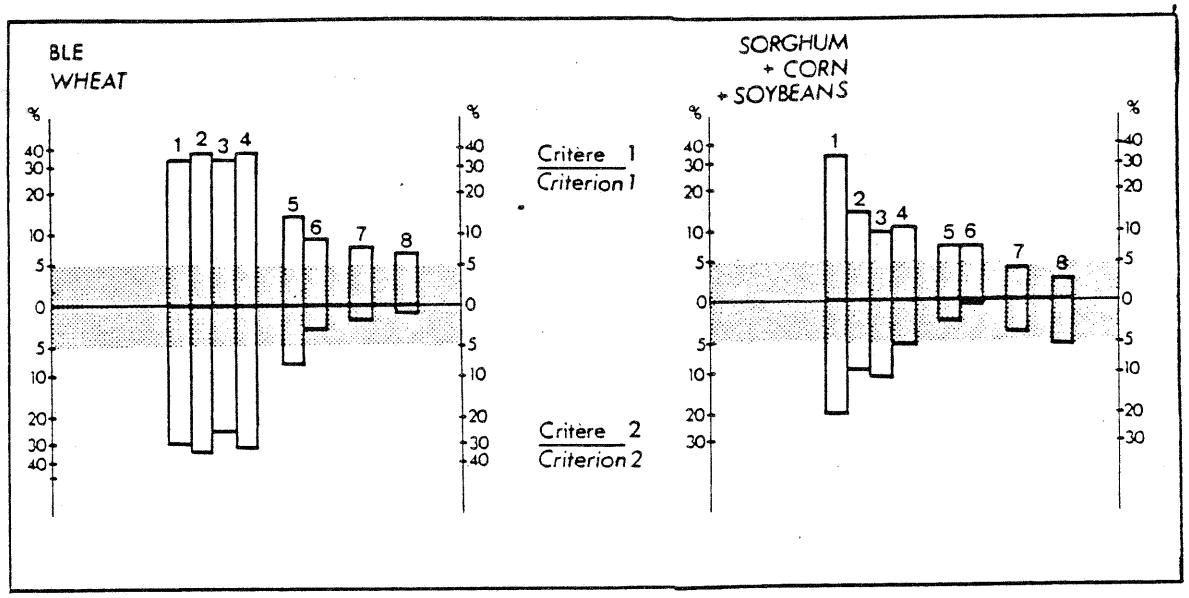
With Landsat MMS 80 m resolution, a field needs to be 2.56 ha in area before it surely contains one pure pixel... and this for a total of 8 overlapping border pixels. With 20 m resolution, the corresponding area is 0.16 ha while with 10 m resolution, it is 0.04 ha. If we consider the case of a field of 2.5 ha and 20 m resolution imagery, we find, on average, 49 pure pixels (i.e. fully within the parcel) and 15 border mixed pixels. Thus, the ratio of pure to mixed pixels is approximately 4 to 1. This means that it should be possible to unambiguously distinguish between the two in virtually every case.

Since 1981, the Centre National d'Etudes Spatiales (C.N.E.S.) and the Service Central des Enquêtes et Etudes Statistiques (S.C.E.E.S.) of the French Ministry for Agriculture have been using simulated SPOT data of a number of test sites in the Lauragais region of SW France (approx. 50 km SE of Toulouse), to study the possibility of incorporating remote sensing data into the agricultural statistics system. Each year this system estimates the areas of land under different crops, the data being derived from the annual TERUTI statistical survey which, in turn, is based on aerial photographs and ground truth. In addition, there is a general agricultural census (RGA) once every ten years. This is a much larger operation as it takes into account various socio-economic parameters.

The Lauragais area can be considered as representative of many parts of Europe as regards the average field size (2 ha) and the wide variety of crops grown : wheat, corn, sorghum, rape, and sunflower, not to mention interspersed uncultivated fields and woods. Despite the technical difficulties associated with this simulation exercise, and particularly with the registration of airborne scanner data acquired on four different dates, the results obtained are significant.

They reveal, for instance, that data acquired on two dates (May 6 and June 30) can result in a better than 90% correlation between pixels classified according to crop type (cartographic quality) and ground truth data, and that the error associated with the estimation of the corresponding crop areas (overall ratio of estimated area to actual area) is less than 5%. (Figure n° 4)

This study has also demonstrated the importance of a judicious choice of acquisition dates relative to the different crop cycles. The difficulties associated with unreliable weather at that time of year (May- June) in Western Europe mean that users requiring data collection at such periods should draw benefit from the inherent flexibility of the SPOT system as regards the revisit capabilities. In this connection, for instance, a change of just 5° pointing angle of the swatch selection mirror of the HRV instrument results in the doubling of the acquisition capacity over a given area.



Combinations of dates *:

*dates expressed in the form: month/day/year

1: 05.06.1981
2: 06/16/1981
3: 06/30/1981
4: 08/12/1981
5: 05/06/1981+06/16/1981
6: 05/06/1981+06/30/1981
7: 05/06/1981+06/16/1981+06/30/1981
8: 05/06/1981+06/16/1981+06/30/1981+08/12/1981

1) Mapping criterion: correctly classified pixels compared with ground truth

2) Statistical criterion: ratio of calculated area (for each crop) to true ground area

FIG. 4: RESULTS OF CLASSIFICATIONS

expressed as percentage differences relative to optimum value

2- URBAN AND PERI URBAN PLANNING

The efficient planning and management of urban areas can only be achieved through access to accurate and continuously updated information concerning land use and changes therein. Today, aerial photographs are still the prime source of such data.

Naturally, the high-resolution is appreciated, but aerial surveying is an expensive exercise, particulary when it comes to the analysis of multidate photos. Attempts to use 80 m and even 30 m resolution space imagery in this area have only yieled modest results, as the resolution is not comparable with the typical sizes of urban objects, particularly in the case of old pattern cities with complex structures. The simulated SPOT imagery of such cities as Paris and Toulouse in France, or Dakar, Senegal, and Ouagadougou, Upper Volta, in West Africa reveal that 10m resolution is about sufficient for the identification of the main features of a typical urban pattern. For instance, comparison of the simulated SPOT imagery of Paris with maps at different scales prepared by the Institut d'Amenagement et d'Urbanisme de la Région Ile de France (I.A.U.R.I.F.) reveals that the images are richer in detail and more accruate than 1:100,000 maps and that there is perfect correlation, as regards the road network, between the images and 1:50,000 maps. (Figure N° 5).

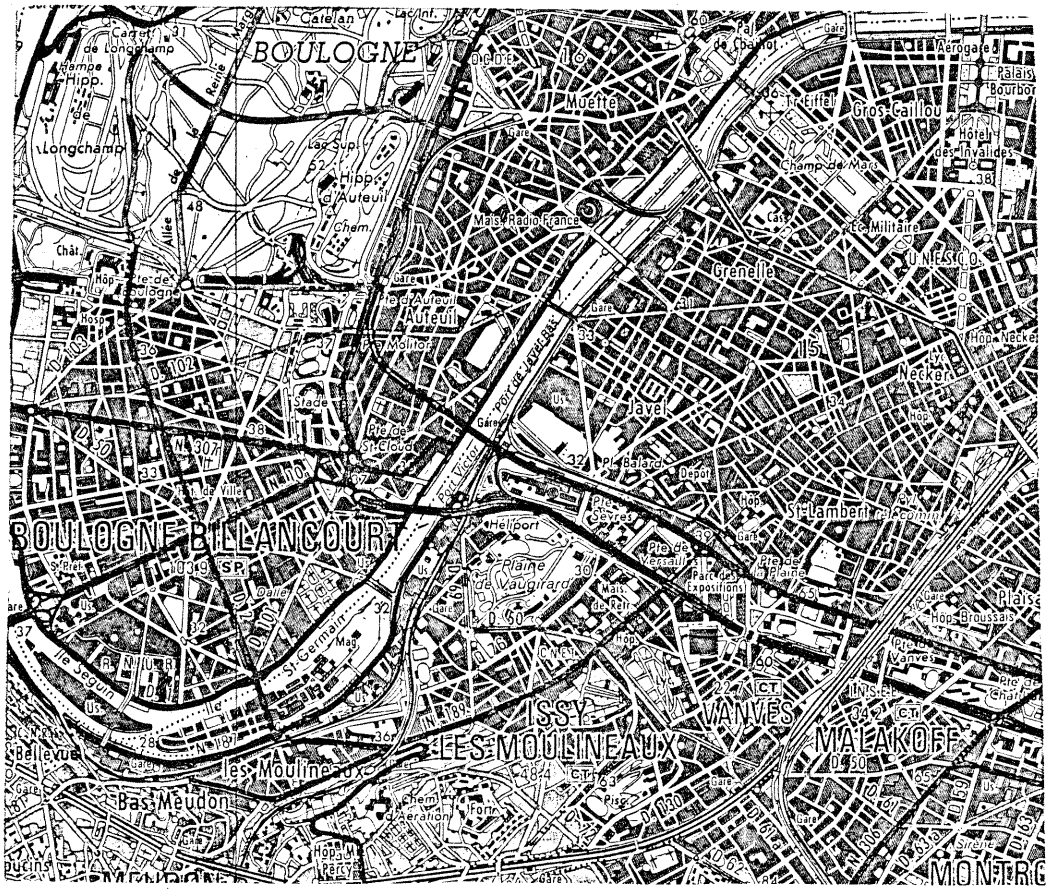
This in turn indicates, among other things, that the plotting of the road network at 1:50,00 corresponds to a sampling interval of about 10 m. However, maps at this scale prove better than the simulated images in suburbs featuring narrow winding streets, although the accuracy of the images could cetainly be improved by contrast and edge enhancement..., something which has yet to be performed for this type of application.

The IAURIF experiments on Paris also included the merging of 20 m resolution multispectral data with 10 m resolution panchromatic data by resampling the XS1 and XS2 channels at 10 m intervals. This confirmed that the thematic content of SPOT images processed in this way is greater than that of maps at 1:50,000, and practically equivalent to that of maps at 1:25,OOO as regards sizes and shapes of buildings, distribution colors and hence types of materials, etc. However interpretation must be performed with caution, particularly with regard to aberrations, wherever the object dimensions approached pixel dimensions.

An automatic classification experiment was implemented after the statistic survey entitled "Mode d'Ocupation des Sols (MOS)", or Modes of Land Use. The experiment was confined to classes having a physical representation. The following classes were identified: woods, lawns and grass-covered areas, private houses, low-apartment-type buildings, tall apartment-type buildings, freeways and major roads and streets, and, finally, water bodies and waterways. These results suggest that it may well be possible this way, in the near future, to automatically update French MOS-type surveys of urban areas.

Quick analysis of the simulated images of the two African cities reveals that 10 m resolution SPOT imagery is sufficient to gain an appreciation and to differentiate between various urban areas that cannot be distinguished with a lower ground resolution, as a result of the fact that, in certain areas of these cities, the radiometric response is scarcely different from that of the surrounding natural terrain. The poorer areas of Dakar and Ouagadougou jand the major part of Agadès (Niger) are dominated by such raw natural building

SPOT simulated image - Paris West
Scale 1/62500 - Panchromatic channel - Resolution 10m



Extract of the map at 1/50000

FIGURE 5

materials as rammed earth, thatch and straw, not to mention the unpaved roads, - all of which have spectral responses that are scarcely different from each other or from that of the surrounding environment. However, with simulated 10 m resolution images, it is possible to identify the different structures and types of urban organization and hence to identify the various types of human settlements.

Finally, the inherent flexibility of SPOT data acquisition should permit the recording, even in the least favorable cases, of the one or more images per year that are necessary for monitoring the evolution of urban phenomena and for regularly updating the corresponding maps.

3- COASTAL STUDIES

Coastal zones are particularly sensitive, from several points of view, and frequently characterized by a fragile equilibrium. Thus, it is especially important that they be monitored constantly and that the development planning process take special account of a number of environmental parameters. In coastal environments, characterized as they are by continuous change and such time-varying factors as shore currents and sedimentation process, remote sensing clearly has a special role to play.

Although the SPOT system was not designed specifically for coastal studies, the first simulated images of Corsica to include a portion of coastline were soon found to be particularly rich in detail. For instance, the 10 m resolution documents clearly depicted swells approaching the shore while the XS1 band turned out to offer a useful degree of water penetration. Further coastal studies have since been conducted in Senegal, Bengladesh, and in France (Loire estuary and North Brittany).

In each case, the results obtained have confirmed the original encouraging results. The main organizations to participate in these campaigns were : the Centre National pour l'Exploitation des Océans (C.N.E.X.O.), the Ecole Nationale Supérieure de Jeunes Filles de Montrouge (E.N.S.J.F.), the Office de la Recherche Scientifique des Territoires d'Outre-Mer (O.R.S.T.O.M.), and the Institut Scientifique et Technique des Pêches Maritimes (I.S.T.P.M.).

One theme studied in some detail was the intertidal zone. Data analysis showed, for instance, that the intertidal zone can be extracted by a relatively simple method, that its area can be readily computed, and that distinction can be made within the zone between vegetation (algae), hard bare substrate (rock), and sand and mud. The next step was to determine the vegetation index which, in turn, yielded an accurate estimate of the total area occupied by algae. Principal component analysis of all pixels, corresponding to intertidal vegetation followed by the compilation of a color composite of the results, made it possible to differentiate between beds of predominantly Ascophyllum Nodosum, those of predominantly Fucus Serratus and those of predominantly either Fucus Vesiculosus and Spiralis or else Pelvetta Canaliculata. The significance of this achievement is apparent when it is realized that some of these species are used in the manufacture of alginates which, in turn, are used in processed foods and cosmetics industries.

When the same analytical procedure is applied to "non-vegetation" portions of the intertidal zone, it is possible to discriminate between bare rock (schists), sand, and other types of cover. Comparison of the results achieved by processing simulated SPOT imagery and those obtained by conventional

planimetry on aerial photographs reveals differences of less than 10%. In the case of conventional false-color photographs, it is not possible to distinguish visually between the different types of algae.

The combination of the SPOT spectral bands plus both 10 m and 20 m resolution data would thus appear to be most suitable for coastal studies. The campaign, to take place this year, covering certain coral sites, should provide further information concerning the potential use of SPOT imagery for coastal mapping applications in such areas.

A further noteworthy point likely to be of direct interest to hydrographers is that SPOT should be capable of yielding instantaneous shorelines with an accuracy of 10 to 20 m.

4- CARTOGRAPHY

Standard preprocessing levels 1 and 2 might possibly prove insufficient for certain applications requiring a very high quality level of geometric correction.

Level 1 preprocessing includes only system corrections (precision of localization : 1 500 m) and level 2 corrections are made using 6 to 8 control points per scene to present an image in a cartographic projection (precision of localization : 50 m). These preprocessing levels do not take into account displacements due to terrain relief. These distorsions are negligible in the case of vertically-acquired image over flat terrain, but can be substantial in the cases of oblique views or mountainous regions.

Level 3 preprocessing uses known relief information to correct for all distorsions from an existing map of the SPOT image, so that it can be overlaid on a cartographic reference model (a U.T.M. for example) to an accuracy on the order of half a pixel (10 m or 5 m), whatever the acquisition angle and whatever the terrain relief.

Where maps are available, level 3 uses control points (crossroads, small lakes, etc...) clearly visible on the image, the coordinates of which are well known (within a few meters) in the three dimensions (X, Y, Z); these control points, along with orbit and attitude data, permit to calculate the image geometry. Images are then rectified pixel by pixel, based on an equidistant X, Y grid. The digital elevation model provides the Z (altitude) coordinate for each point on the grid. The radiometric value of a pixel on a corrected image is then calculated by interpolating the radiometric values of the raw image. Processing can be performed on entire image segments (up to ten consecutive scenes), thereby reducing the number of control points necessary. An orthophotography is produced with a position accuracy of 0.5 pixel.

Use of Level 3 imagery : Images corrected to level 3 are of interest, on one hand, for topographic or thematic map-making and updating, and on the other hand, for any users wishing to integrate SPOT imagery with other geographic data (geocoded data) or other space imagery (e.g. radar). Level 3 corrected images are indispensable in studying and utilizing stereoradiometry effect of the angle of view on the spectral signature of a terrain).

Level 4 preprocessing uses two SPOT stereo images to measure terrain relief deformation and thus, to deduce and plot contour level maps.

This preprocessing level is, in a way, inversely related to level 3, for the result of level 4 is simply a representation of the relief, in the form of a digital terrain model (DTM), while that of level 3 is a corrected image.

Method: In order to determine the exact geometry of each image covering a zone to be mapped, one must calculate the precise geographic position of certain points on the ground. When the precision of existing maps is inadequate, geodetic measurements become necessary. This is effected by measuring points on the SPOT image itself, through the process of spatial triangulation, comparable to the process used in aerial photogrammetry.

Ground relief can be derived from the stereo imagery in digital (D.E.M.) or graphic (contour levels) form. This information can be derived from photographic film using stereoplotters, or by automatic correlation procedures currently being developed.

The expected precision of altitude determination is approximately 10 m in panchromatic, for example and 20 m in multispectral.

Cartographers will be the principal users of level 4 preprocessing, as it will aid them in mapping new regions and in obtaining digital relief files more easily than by digitizing existing maps.

Nonetheless, numerous other users may find the need for digital relief data, to correct images (see Level 3) and to aid in interpretation : for example, in order to correct for slope and sun exposure effects in land use studies of mountain areas.

CONCLUSION

The results of the simulated data studies conducted to date clearly suggest that SPOT data may well be the alternative to medium- and large-scale aerial photographs in numerous thematic applications.

The inherent acquisition flexibility of the SPOT system will be an important additional advantage in the case of environmental studies requiring multitemporal data. Moreover, the possibility of obtaining data on a cartographic projection will make it possible to go directly from data analysis to map representation. Where necessary, SPOT data will effectively permit the compilation of base maps, from the plotting of stereo pairs acquired during different passes with the imaging instrument operating in the cross-track (oblique viewing) mode. The production of maps with elevation contours accurate to within 20 m will require only 1/25th as many stereo pairs as would map production using aerial photographs at 1:100,000.

Moreover, the space imagery can be implemented using considerably simpler and cheaper equipment. Finally, the availibility of image data in digital form will considerably facilitate the setting up of geocoded data banks which, in turn, will be used to generate various types of documents directly in map form.

By the time it is completed, the SPOT simulation program will have provided scientists, over a period of three years prior to the launching of SPOT 1, with data representing the full spectrum of possibilities to be offered by SPOT imagery. All of the major themes of remote sensing will have been dealt with in a wide variety of biogeographical environments, and many users will have had an opportunity of becoming acquainted with SPOT data and its potential applications.

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