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WORKSHOP ON REMOTE SENSING TECHNIQUES WITH APPLICATIONS TO AGRICULTURE, WATER AND WEATHER RESOURCES

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SPOT AFTER THREE YEARS IN OPERATION, AN APPRAISAL OF RESULTS AND A REVIEW OF SELECTED APPLICATIONS

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INTRODUCTION

SPOT has been in orbit for three yearsand 662 000 images of the Earth have been acquired during this period of time. Users progressively grew familiar with this new and performant spaceborne multispectral sensor and research or routine applications have developed accordingly. The research and assessment phase culminated with the SPOT 1 International Conference in November 1987 where more than 150 papers demonstrated the usefulness of SPOT Data in all remote sensing fields of activity.

The programme is now well established with SPOT 2 ready to be launched in early 1989, SPOT 3 under construction and SPOT 4 at the end of the development phase. The market share taken by SPOT products has steadily increased during these first two years and the SPOT specific capabilities have attracted new customers yet not used to this source of information.

This paper firstly analyses the data acquisition and distribution results and secondly presents a review of significant achievements in selected fields of applications.

1. - DATA ACQUISITION

Since February 23rd, 1986, SPOT has satisfactorily operated, with the exception of the loss of one tape recorder in September 1986. The image quality has been praised by the users community and the few minor occuring radiometric defects have now been removed.

By February 22nd, 1988, two years after SPOT 1 launch, 662 000 SPOT scenes were acquired. They are distributed as follows (table 1A).

Toulouse station (visibility circle and worldwide) 233 000
Kiruna station (visibility circle and worldwide) 207 000
Prince Albert and Gatineau, Canada (station visibility circle) 217 000

The Indian station (Hyderabad) started operations in May 1987 but stopped receiving during the moonsoon period and thus acquired only few hundreds of scenes. The ESA Station (MAS PALOMAS, Spain) has just started to receive SPOT Data in November 1987 over the Western part of Africa, South of the Toulouse visibility circle (about 4000 scenes acquired on February 22nd, 1988).

Among receiving stations anticipated to begin reception in 1988 are: Cuiaba (Brazil), Ryadh (Saudi Arabia), Islamabad (Pakistan), Dhaka (Bengladesh), Bangkok (Thailand), Beijing (China), and Hatoyama (Japan) (Fig. 1 and Table 2). Other stations will be completed beyond 1988. The Nairobi (Kenya) and Quito (Equator) sites are also under consideration.

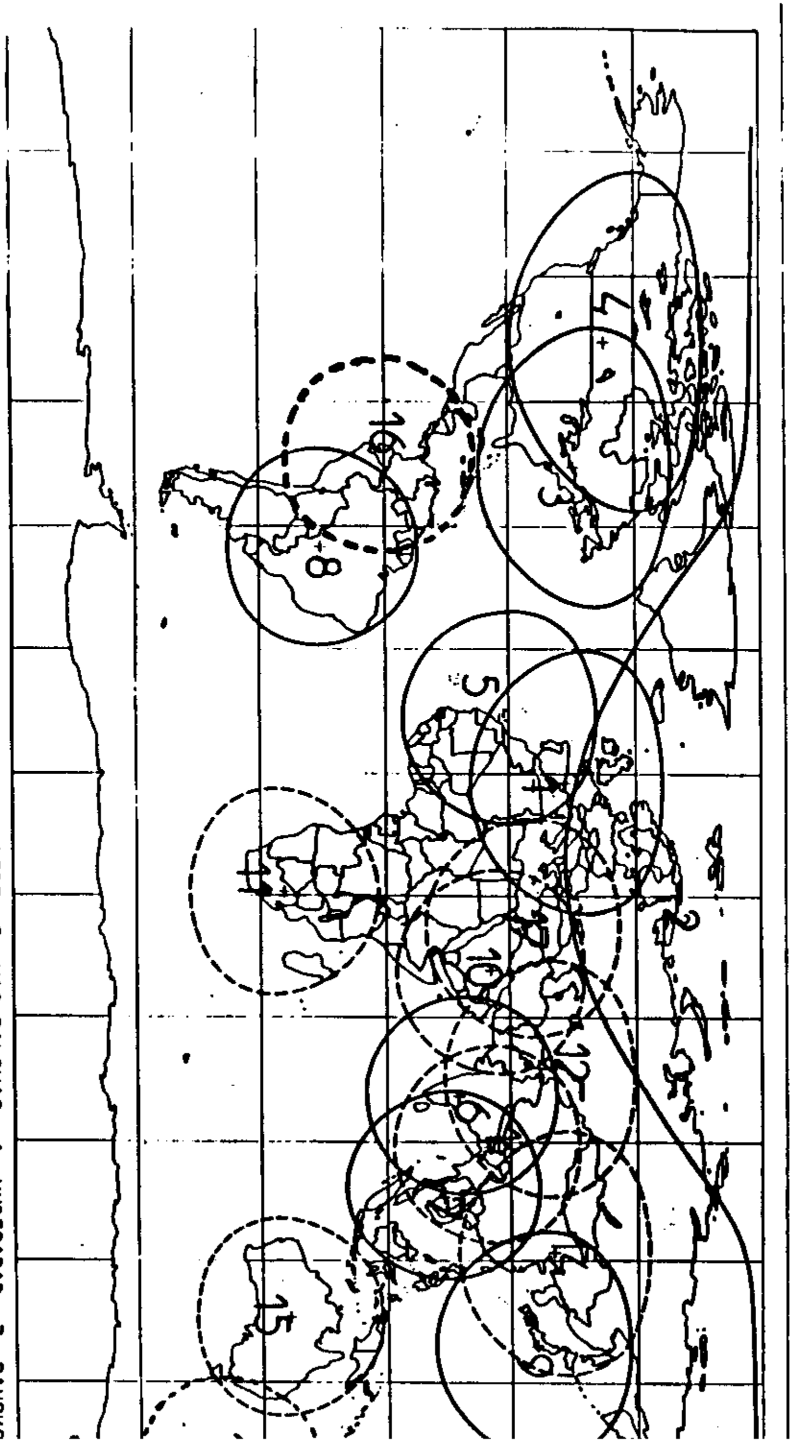
The increased number of stations in 1988 will ease the burden put on the on board tape recorder and facilitate acquisitions which were hampered over some parts of the world by recording capacity and programming conflictual situations.

Out of the total 662.000 archived scenes, about 25% are usable and present a cloud cover under 10% (table 1) while 50% are not usable at all (cloud cover > 7/8).

Table 1B gives a typical SPOT coverage obtained over 3 countries: Spain, France and the United Kingdom and Figure 2 illustrates the seasonal effect on SPOT Data acquisition.

In Europe and Asia Pacific regions and to a lesser extend in North America, acquisitions come from user requests and demands saturate the system capacity. On the contrary, over Latin America and Africa, where the user demand is lower, a systematic acquisition policy has been implemented to use the system capacity and to build up a data archive.

Table 3 gives the breakdown of user requests by geographical areas and the percentage of successful acquisitions obtained during the year 1987.



IN OPERATION: 1. TOULOUSE, 2. KIRUNA, 3. GATINEAU, 4. PRINCEALBERT, 5. MAS PALOMAS, 6. HYDERABAD, 7. BANGKO
8. CUIABA, 9. HATOYAMA.

TO BE OPERATIONAL IN 1988 OR LATER: 10. RIYADH, 11. PRETORIA, 12. ISLAMABAD, 13. BAKNA, 14. PEKIN, 15. ALIC
SPRING, 16. QUITO, 17. TEL AVIV, 18. AUCKLAND.

SPOT DIRECT RECEIVING STATIONS

SPOT DATA ACQUISITION
TOTAL NUMBER OF SPOT SCENES
ACQUIRED FROM FEBRUARY 23, 1986
TO FEBRUARY 22, 1988

ARCHIVING CENTER	NUMBER OF SCENES
TOULOUSE (FRANCE)	233 000
KIRUNA (SWEDEN)	207 000
PRINCE ALBERT (CANADA) GATINEAU	124 000
RESTON (U.S.A.)	93 000

CLOUD COVER BREAKDOWN	
0 - 10% CC	25%
0 - 25% CC	30%
0 - 50% CC	50%

SPECTRAL MODE BREAKDOWN	
P MODE	46%
XS MODE	54%

TABLE 1A

SPOT DATA ACQUISITION
EXAMPLES OF DATA ACQUISITION
AVER 3 COUNTRIES IN EUROPE
(CC < 25 %)

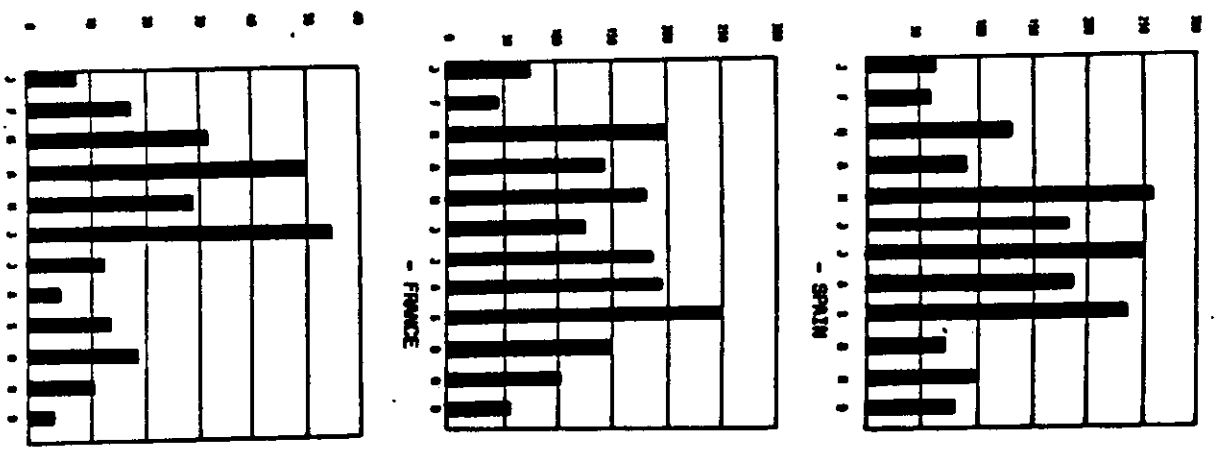
	NUMBER OF KJ NODES	NUMBER OF XS SCENES	NUMBER OF P SCENES
SPAIN	304	1240	446
FRANCE	377	1229	487
U.K.	171	168	101

TABLE 1B

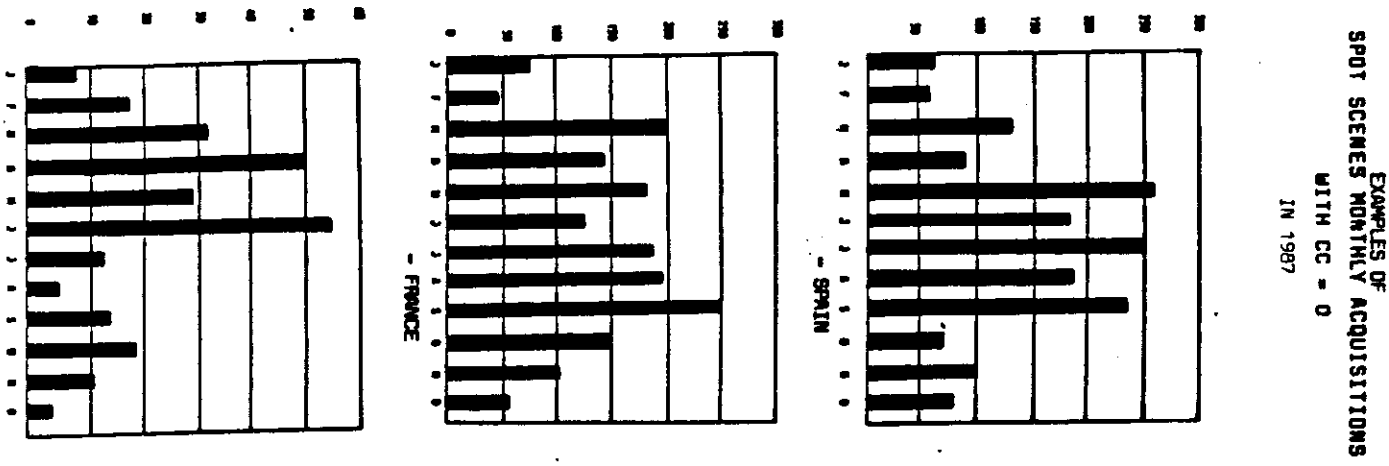
STATUS OF SPOT DIRECT RECEIVING STATIONS

LOCATION OF THE S.D.R.S.	COUNTRY	ORGANIZATION	DATE OF OPERATION	ESTIMATED DATE OF OPERATION
PRINCE ALBERT-GATINEAU	CANADA	C.C.R.S.	JUNE 5, 1986	
HYDERABAD	INDIA	N.R.S.A.	MAY 5, 1987	
MASPALOMAS	SPAIN	E.S.A.	NOVEMBER 4, 1987	
CUIABA	BRAZIL	I.N.P.E.	APRIL 1, 1988	
MONGKUT	THAILAND	N.R.C.T.	MAY 1, 1988	
HATOYAMA	JAPAN	N.A.S.D.A.	OCTOBER 1, 1988	
PRETORIA	SOUTH AFRICA	C.S.I.R.		1ST QUARTER 1989
ISLAMABAD	PAKISTAN	SUPARCO		4TH QUARTER 1988
ALICE SPRINGS	AUSTRALIA	NATMAP		1ST QUARTER 1989
AUCKLAND	NEW ZEALAND	S.C.S.		4TH QUARTER 1989
TEL AVIV	ISRAEL	I.S.A.		4TH QUARTER 1989
RIYADH	SAUDI ARABIA	K.A.C.S.T.		?
BEIJING	CHINA	S.S.T.C.		?

TABLE 2



EXAMPLES OF SPOT SCENES MONTHLY ACQUISITIONS WITH CC = 0 IN 1987



EXAMPLES OF SPOT SCENES MONTHLY ACQUISITIONS WITH CC = 0 IN 1987

1987 SPOT PROGRAMMING REQUESTS PERCENTAGE OF SUCCESSFUL ACQUISITIONS

REGION	N° OF P.R. COMPLETED	N° OF SCENES REQUESTED	AVERAGE PER P.E.	N° OF SCENES ACQUIRED	% OF SUCCESSFUL ACQUISITION
FRANCE	69	169	2.5	84	50.0 %
EUROPE OUTSIDE FRANCE	145	541	3.7	292	54.0 %
MIDDLE EAST	77	405	5.3	355	88.0 %
ASIA PACIFIC	315	931	3	726	78.0 %
AFRICA EQUATORIAL AREAS	54	270	5	128	47.0 %
REST OF AFRICA	174	888	5.1	613	69.0 %
AMAZONAS + ANDES	24	196	8.1	16	8.0 %
REST OF LATIN AMERICA	109	287	2.6	97	34.0 %
SCANDINAVIA	28	333	11.9	197	59.0 %
TOTAL	995	4020	4.5	2510	62.5 %

TABLE 3

III. - DATA PROCESSING AND MARKET DISTRIBUTION

By the end of october 1987, stored processed Data in SPOT IMAGE (G. BRACHET, SPOT 87) amounted to over 20 000 products. This volume comprises both processed data following user orders (60%) and anticipated processing (table 4).

Table 5 gives the distribution by type of products sold by SPOT IMAGE in 1987. 43% are CCTs and 57% photographic products. In terms of income the CCT share represents 68%. The P and XS modes ratio which is 45% and 55% respectively, tends during the last months of 1987, towards a fifty-fifty level. Preprocessing at standard level 1B takes by far the largest part of users demand with 86%, while level 1A represents only 9% and precision processed level 6%.

Looking at the market distribution by geographical areas, table 6 shows that Europe represents 50% of the total market, a little less than half of this amount coming from the French user community.

A consistent and increasing part is taken by North America users with 24%, the Asia Pacific region accounts for 14% of the market. Middle East levels at 11% and Africa and Latin America have the lowest part with 5% cumulated. The situation in this last two regions is explained by two factors:

1) Financial constraints and administrative barriers hamper the development of the market and,
2) Most of the sales for data occuring over those regions are made by users (services companies and international organizations) from outside these regions.

The market statistics by application is more difficult to grasp as more than half the sales are made through the distributors network that does not allow to identify the end users. As far as the French market is concerned table 7 gives the statistics according to main fields of activity. Among the trends that have been noticed in 1987, a steady increase occured in cartography, mining and oil exploration, civil engineering and the TV-Media sectors.

The SPOT market is still in a development phase characterised by a traditional remote sensing market but also by a penetration towards new applications due to the SPOT characteristics in terms of ground resolution and stereovision. This is confirmed by the fact that, apparently, the market share taken by SPOT IMAGE does not seem to have a significant impact on the Landsat sales.

SPOT PRODUCTS

NUMBER OF PROCESSED PRODUCTS (CCT OF FILM) STORED AT SPOT IMAGE ARCHIVE (OCTOBER 1987)

	XS MODE	P MODE	TOTAL
CCTs	10400	5500	15900
FILMS	2900	2000	4900

TABLE 4

BREAKDOWN OF PRODUCTS SOLD BY SPOT IMAGE IN 1987

MEDIA

	INCOME	QUANTITY
CCTs	68,6 %	43 % (US 58 %)
FILMS	26,3 %	40 %
PAPER PRINTS	5,1 %	17 %

P MODE 45 %

XS MODE 55 %

PROCESSING LEVEL

1A : 9 %

1B : 85 %

2B : 6 %

TABLE 5

SPOT PRODUCTS

MARKET SHARE BY GEOGRAPHICAL AREA 1987

FRANCE	23,2 %
EUROPE (outside France)	27,5 %
MIDDLE EAST	9,4 %
ASIA, PACIFIC	11,7 %
NORTH AMERICA	24,1 %
LATIN AMERICA	1,7 %
AFRICA	2,3 %

TABLE 6

MARKET SHARE BY APLICATION (FRANCE 1987)

ACADEMICS, SCIENTIFIC RESEARCH	25 %
CARTOGRAPHY, SURVEILLANCE	22 %
VEGETATION, FORESTRY, AGRICULTURE	19 %
NON RENEWABLE RESOURCES	16 %
CIVIL ENGINEERING	6 %
MEDIA	6 %
COASTAL STUDIES	2 %
OTHERS	4 %

TABLE 7

III - TOPOGRAPHIC MAPPING WITH SPOT DATA

It is not the purpose of this presentation to develop the mathematical principles upon which are based the various methods using SPOT imagery for cartographic works but rather to briefly present the main results obtained to date by users in terms of accuracy and reliability.

Stereoscopic vision is obtained with SPOT by taking two oblique views of the same area from two different orbits. The B/H ratio can vary as the pointing mode possibilities range from + 27° to - 27° (B/H from 0 to 1.1). Among the differences between aerial photographs and SPOT images are: the two images making a pair are not taken at the same time (1 day time lapse minimum), one image is taken with an oblique view towards the East, the other one towards the West, and the projection is pseudo cylindrical.

The key advantages of SPOT imagery in topographic mapping are the following:

1) data acquisition flexibility,
2) large ground coverage,
3) improved spatial resolution which allows to identify most of the ground features required for mapping at a scale of 1:50 000 and in some cases 1:25 000 and,
4) good geometric performances: a geographic localization accuracy of 500 m RMS for system corrected images (no control points) and internal distorsion measured at 0.05 10^{-2} (G. BEGNI, SPOT 87e).

SPOT imagery is adequate for image maps production, digital elevation models, orthophotos and line maps compatible with standards currently in use. Figure 8 illustrates the typical flowchart of cartographic products which can be derived from SPOT data.

For planimetric information, image maps in quadrant sheets can be obtained in any cartographic projection. They are prepared from level 2 precision processed data using control points taken from existing maps or ground control points (obtained by GPS for instance). The RMS localization error is about 40 m with vertical images and elevation differences within the image not exceeding 1200 m.

On flatter terrains, the error can be less than 20 m. This error comes from the fact that this technique does not take into account the parallax effects (slope distortion). When no control points are available, the product can be achieved in a given projection with an excellent relative accuracy. An XY translation is then necessary for absolute localization.

Altimetric information is obtained with a SPOT stereopair processed either in an analytical plotter or by computer automatic correlation. SPOT softwares for analytical stereoplotters are now available on Matra Traster, Kern DSR plotters, Zeiss Planicomp - Orthocomp and Intergraph and is beeing developed for the Wild Aviolyt (I.J. Dowan, SPOT 87). Those equipments make use of films as input. Some other softwares have been directly implemented on existing image processing systems

Digital elevation model can also be obtained with SPOT by automatic correlation. Several softwares are already available and many more are in the experimental or implementation phase. The technique involves the matching of a pair of images in order to determine parallax difference from which a DEM is constructed. Orbital information, ground control points and a geometric model are needed. Image correlation is based on feature points or edges structured along epipolar lines. IGN, INRIA-ISTAR and SEP, France, Mac Donald Dettwiler and DIGIM, Canada, University College London, UK, SATIMAGE's Terragon System, Sweden, Geospectra and Welch, USA, are currently producing DEM with automatic correlation techniques.

SPOT accuracy performances were firstly checked by a team of the Institut Geographique National, France, (V. RODRIGUEZ A.C., DE GAUJAC, P. GIGORD, P. MUNIER, 1986). The results demonstrated that the expected accuracy in terms of planimetry and altimetry were met. The assessment was performed on 60 stereopairs with 3 viewing configurations (+ 27° and - 27°, B/H = 1 - 0° and 27° and + 13° and - 13°, B/H = 0.5). 177 check points and control points were determined with an accuracy of:

3 m in X, Y and 1.5 in Z.

The stereopairs were processed on a Matra-Traster equipement for:

- plotting ground control points (GCPS) and modelling the SPOT view,
- calculation of deviation from true positions.

Practically 6 to 10 points from the topometric network were sufficient to establish the model for one stereopair, the remaining points being then used for stereoplotting. The raw results (G. BRACHET, P. DENIS, W. Nordberg Symposium, 1987) for all stereopairs indicate a RMS residual error for each point of:

8.0 m in X - 6.6 m in Y and 7.1 m in Z.

After filtering, the RMS residual errors were reduced to:

4.6 m in X - 4.4 m in Y and 5.3 m in Z, with a B/H of 0.5 m in Z.

The most significant results are presented in Table 9.

R.M.S.	X	Y	Z
RAW RESIDUES	8.0 m	6.6 m	7.1 m
FILTERED RESIDUES	4.6 m	4.4 m	5.3 m
CONFIGURATION + 27°/-27 ° RAW RESIDUES	8.1 m	5.5 m	4.3 m
CONFIGURATION + 27°/-27 ° FILTERED RESIDUES	3.8 m	4.2 m	3.5 m
CONFIGURATION 0°/+27 ° RAW RESIDUES	7.8 m	7.2 m	8.3 m
CONFIGURATION 0°/+27 ° FILTERED RESIDUES	4.6 m	4.4 m	6.7 m

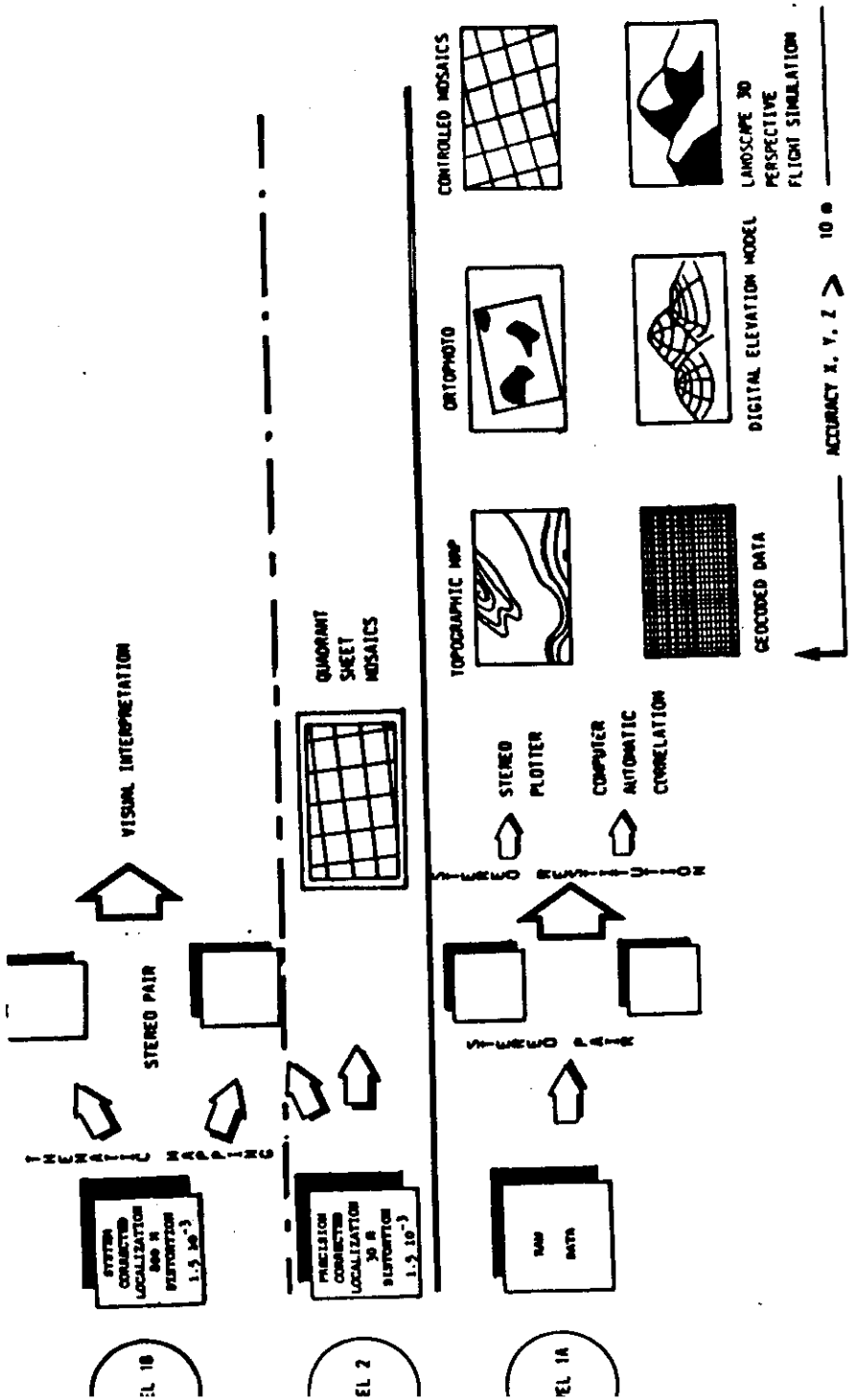
Professor G. KONECNY from the Instutute for Photogrammetry and Engineeting Surveys, University of Hannover, (G. KONECNY : The use of SPOT Imagery on analytical photogrammetric instruments, SPOT 87) developped a mathematical model which avoids high correlations between the unknowns and is based on the used of photo coordinates. The unknowns of the orientations are approximated by the use of orbit data and in the course of adjustment, are partly formulated as additional parameters. The method has been implemented on Zeiss Planicomp and orthocomp hardware and a bundle adjustment programme BINGO has been modified to handle SPOT geometry. The results of test are given in figure 10 :

NUMBER OF ADJUSTED POINTS	NUMBER OF CONTROL POINTS	ADD. PAR. LEFT/RIGHT		ZYMAX	INTERNAL ACCURACY XYMEAN	Z MAX	ZMEAN
66	18	4/3	8.4	8.7	6.2	10.8	8.5
66	34	3/3	7.9	6.1	4.5	8.8	7.1
66	83	4/5	6.1	4.5	3.0	5.8	5.9
NUMBER OF INDEPEND. CHECK P.	NUMBER OF CONTROL POINTS	X	MEAN DIFFERENCES Y	Z	X	MEAN SQUARE DIFFERENCES Y	Z
66	18	7.9	10.4	4.8	10.9	13.7	8.5
52	34	8.3	10.5	4.6	11.3	13.8	8.2

TABLE 10

Similar results are obtained by University College London (Gugan, Dowman) MDA, Ordnance Survey (Hartley) on analytical plotters or by automatic correlation techniques (INRIA-ISTAR, MDA, Geospectra), which gives figures around 10 to 15 m in planimetry and better than 10 m in altimetry. I.J. Dowman in his extensive review of SPOT prospects in cartography (I.J. Dowman, the prospects for topographic mapping using SPOT DATA SPOT 87) concluded that the necessary accuracy for mapping at 1:50.000 scale with 20 m contours is possible with SPOT and that organizations are prepared to produce image maps at scale 1:25.000 (orthophotos).

Apart from topographic line maps and orthophotos, DEM are also used to generate 3D landscape perspectives in computers for site locations, environment studies, flight simulations. They are also used as an input in Geographical Information Systems.



SPOT APPLICATIONS IN CARTOGRAPHY
TABLE 8

In addition, cost of mapping with SPOT is reduced compared to aerial photographs. Although it is too early to have precise figures from large surveys, IGN France reported a ratio of 1 to 3 in favor of SPOT data acquisition, 3 to 9 for SPOT for ground control points (maximum when SPOT segments up to 10 scenes can be used) and 4 to 8 for SPOT for photogrammetric plotting, while ground completion is in favor of aerial photos in a ration 1 to 2. Ordnance Survey (Hartley) has worked out a cost reduction of 66 % for data acquisition, ground control points, and 20 % for plotting. The companies ISTAR (France) and NPA (UK), representing Geospectra, are currently proposing DEM for a price ranging from 12 to 20 French Francs per Square km according to grid precision. In any case it is certain that gain in time and money is obtained for topographic map making with SPOT and that this will still improve as more experience is gained and more sophisticated software developped.

IV. - SPOT APPLICATIONS IN GEOLOGY - a review of some test cases

Geology is probably the field of activity which has most benefited from space imagery since satellite data were made routinely available in 1973.
The synoptic view of the earth surface brought by Landsat has been a milestone in geological knowledge as large portions of the globe could be visualized at a glance and regional trends or inter regional relationship directly analyzed. The most obvious contribution was first in structural analysis and regional interpretation with the discovery of large regional linear or sub linear features (lineaments) generally linked to surface or deep seated faulting. Interpretation improved for rock discrimination with the use of multispectral analysis best performed with Landsat T.M. multichannel scanner.

However many photogeologists were still disappointed by satellite data that were found too coarse in ground resolution to resolve local problems and more significantly by the lack of stereoscopic capacity for terrain interpretation. Landscape morphology is directly controlled by geology through differential erosion and weathering processes acting according to rock physical properties and structural organization. Therefore a large part of the surface geology information is deducted form morphology and landform study, which is in turn fully grasped only with relief perception.

SPOT is the first satellite with stereocapability. In addition, an improved ground resolution : 10 m in panchromatic mode and 20 m in multispectral mode gives SPOT imagery the combined advantages of conventional aerial photographs (stereo, good resolution) and satellite images (synoptic view, multispectral data, worldwide repetitive coverage).

As a matter of fact most of SPOT users in geological mapping and mining and oil exploration praise SPOT for :
- Stereo capability for landform analysis,
- Ground resolution for semi-detailed studies and field work localization,
- excellent geometric precision.

SPOT is usually favourably compared to aerial photography, and multispectral capabilities, although limited compared to Landsat TM, are seen as sufficient to solve most of the geological problems.

A typical example of SPOT performances has been obtained in geological mapping along the Gregory Rift in Kenya (Chorowicz and Vidal, 1986). Various processing techniques have been applied to the Data : stretching, anamorphosis, filtering and spectral band decorrelation. The decorrelation technique is particularly useful in geological mapping as it gives a striking discrimination between image textural elements linked to rock types and geomorphic features associated to the structural pattern. SPOT acquisition time (10.30 a.m.) is ideal to generate precise, but not too large shadows enhancing the structural and fault pattern.

In addition, stereo capability improves the confidence and reliability in image analysis and mapping as altitude differences as small as 3 meters can be detected. Finally, field checking is facilitated by a precise ground localization with high resolution images used as a field survey document.

Among the main results of the study are : a perfect delineation of the two major regional structural trends running N-S and NW-SE, the detection of still unknown tensional fractures (as small as 3-5 m in width on the ground) with an orthogonal direction, and an improved mapping of volcanic units compared to existing documents. The study gives a spatial and historical understanding of the existing relationship between a typical rifting system (North Kenya, Cenozoic) and a preexisting transverse lineament zone (Aswa, Precambrian). The structural pattern composed of rhomb-shape sub-systems, strik slip faulting and tensional gashes is consistent with the transform character attributed to the Aswa lineament between the two rift system branches.

Pr. J. GUILLEMOT, IFP (la géologie de la région de Damas, Syrie, d'après les images stéréoscopiques de SPOT 1, revue photointerprétation 87.2/1) made an outstanding visual interpretation of the Damas area using a SPOT multispectral stereopair, leading to a structural pattern of the Anti-Lebanon, the Palmyrids ridges and the arabic platform. Among the main advantages of SPOT data, are listed:

- an excellent ground resolution for details perception (hydrographic network, surface texture),
- confident structural analysis through stereo vision,
- large synoptic coverage.

The same conclusions are expressed by G. GESS and Al (Méthodologie d'utilisation de l'imagerie SPOT pour l'exploration pétrolière : exemple du permis du Bas Languedoc SPOT 87)* who used a SPOT stereopair made of one image in the P mode and the second one in the XS mode, over an oil exploration block in the Southern part of France. A structural map at a scale of 1:000 000 was carried out in a very short time. The image analysis performed by conventional visual interpretation complemented by image processing (ACP, filtering and classification)

resulted in a good understanding of the structural relationship between basement tectonics and sedimentary overlying units. Lithological units discrimination, bedding, dipping and feature pattern analysis were performed. Results were confronted with seismic data to test exploration modelling. Authors highlighted particularly the confort in interpretation brought by simultaneous detailed information and synoptic view.

A similar type of work was performed by Institut Français du Pétrole and BEICIP (J. BURNS and Al, contribution de l'imagerie SPOT à la connaissance des structures géologiques de l'Atlas Tunisien central, SPOT 87) in central Tunisia where SPOT data were used to produce at a scale of 1:000 000 a stratigraphic and structural mapping. The map was used firtsly for field work and in a second stage as an aid to prepare seismic surveys in the region.

*Many examples in this review are taken from papers published in the SPOT 1 International conference, Paris, Novembre 1987. They are referred to as SPOT 87.

Also worth to mention is the work carried out by BRGM France (J.Y. SCANVIC) in the Poukoussa basin, Guinea. SPOT imagery was used to study a fresh water reservoir contained into Plioquaternary sands and Ordovician quartzites located in a mangrove area. The aquifer, controlled by faulting, is invaded by salted water. In this vegetation-covered area of difficult access, SPOT data proved to be efficient using a specific digital processing techniques (sinusoïdal stretching). The quartzitic horst was clearly identified and mapped as well as an yet unknown prolongation to the North and the fault system which controls the area was well delineated.

In the field of mining exploration, noticeable findings using SPOT data are reported. In Zimbabwe BRGM (J.Y. SCANVIC) carried out a survey with SPOT data aiming at reactivating an ancient copper-gold bearing mining district. Conclusions were: the discovery of a dome structure, a new possible gold prospect and a perfect delineation of gossan alterations using the spectral ratio 2/3 R, 1/3 G, 1/2 B.

Similarly C. ROQUIN from CNRS (C. ROQUIN and Al, SPOT and Geochemical mapping of lateritic covers in Southern Mali, SPOT 87) found a good relationship between processed SPOT multispectral data and rock composition with a good separation between Silica content units and iron/alumium content units. Spectral response allowed to differentiate between lateritic shields from bauxites and pure bauxites from ferugineous bauxites. The rock differenciation can also be expressed in terms of relative proportions of estimated minerals: quartz, kaolinite, gœthite, hematite and gibbsite after normative calculation.

In Nevada (USA) J. TARANIK from the Mackay School of Mines (Reno) applied SPOT data to regional structural geology in the Walker Lane region. The conclusion of the study, using panchromatic, multispectral and stereo images were that SPOT was particularly useful for this type of work due to its geometric accuracy and stereo capability. The study demonstrated a good correlation between SPOT lineaments and aeromagnetic lineaments and a significant improvement in mapping structural features in surficial deposits subject to neotectonism. This was achieve thanks to an easy landform and drainage analysis.

Active tectonics was also studied with SPOT by P. TAPPONIER (Institut de Physique du Globe de Paris) along the Altyn Tagh fault in Northern Tibet. In this area with huge alluvial and colluvial fans and moraine deposits, evidence of block displacements of 100 m to 300 m in magnitude were found by a detailed interpretation of panchromatic data. As these deposits are from the Holocene period (10000 years) an average annual movement was derived.

Finally applications in the field of civil engineering for the oil and mining industry have to be mentioned. Accurate maps including contour levels or DTM can be derived from SPOT data. In areas where cartographic documents are lacking, SPOT images can be used for:

- preparation of ground or airborne geophysical surveys (airmag, seismic)
- site selection and access routes for equipment transportation,
- road or pipe line prefeasibility study,
- oil well localization.

In conclusion, for all applications relatied to geology (regional and semi detailed mapping oil, mining and geothermal exploration, hydrogeology, geomorphology, geotechnics) SPOT appears as very efficient means of information gathering. It fills the gap between arerial photograph and other satellite data in combining most of the advantages of both mehods. this is clearly demonstrated by the increasing use of SPOT data in geology.

V. - CIVIL ENGINEERING AND URBAN PLANNING

SPOT Data provide information on relief, hydrography, geology, soils, land cover and land use. In civil engineering applications, SPOT can therefore be used for:

- feasibility studies of transportation network: roads, railways, canals, pipelines, power lines.
- site selection for civil works implantation: plants, dams, new urban settlements etc...
- work progress monitoring.

The projects can involve small areas of a few square kilometers as well as large surveys such as road laying out where optimized outlines can be determined.

From SPOT imagery can be derived:

1) up dated land cover and land use maps at scales ranging from 1:100 000 to 1:25 000 which are used for impact studies and best site location.

2) precise hydrographic network and watershed or catchment surfaces to work out water run off and then estimate subsequent drainage works and engineering work (bridges) size.

3) geology and soils maps for material discrimination, rock and surficial formation physical properties assessment, erosion and weathering risk evaluation.

4) Digital elevation modelling which is one of the main contribution of SPOT image in this field of application. SPOT DEMs, performed either on stereoplotters or by computer automatic correlation give an accuracy around 10 m in planimetry and sligtly better in altimetry, which is sufficient in a feasibility study phase.

From the DEM, several other products can be derived:

- slope maps,
- excavation/embanking volume computation,
- cross sections,
- sun illumination models,
- intervisibility maps,
- environment and landscape perspectives.

The registration of a DEM with SPOT imagery allows to visualize the landscape in 3D and to interactively modify the views and perspectives on a computer display leading to an infinity of simulated situations.

In addition, the excellent SPOT geometric performances in terms of absolute localisation and internal distortion give SPOT data a clear advantage in remote or inaccessible areas for parameters computation, (surfaces, length, positionning, localization).

In urban planning and related applications, SPOT 10 meters resolution brings a new type of information which was previously only available with aerial photographs. SPOT Data are usefull for:

- urban and periurban land use mapping,
- monitoring of urbanization,
- impact studies of planning policies on natural environment and cultivated lands,
- analyses of urban structures and change detection,
- continuous maps up dating.

Several examples of conventional visual interpretation of large cities such as Mexico (J.M. Eberhard, 1987) or Lubumbashi (J. Flouriot, SPOT 87) have already demonstrated the large quantity of information which is taken out of SPOT images analysis. In the Lubumbashi project , two maps at scales 1:100 000 and 1:50 000 were produced showing the various density and land use classes of the urban (7 classes) and suburban areas (10 classes). An automatic extraction of the urban area was also performed.

Various methods of computer aided analysis are also used in urban studies. They range from radiometric algorithms (vegetation index, classifications) to textural and structural analysis (filtering, pattern recognition, morphological mathematics).

As a matter of fact, thanks to the excellent ground resolution, the structures such as the roads network is particularly well expressed on SPOT images but the automatic extraction of this information is not possible when based only on radiometric parameters. Textural analysis algorithms currently in use are not fully operational and development are still in progress in this field of activity.

However significant results have been obtained for instance by A. Michel (Ministère de l'Equipement, du Logement, de l'Aménagement du Territoire et des Transports, France) on the Quito test site where a large part of the roads network was extracted by automatic edge detection.

Finally, worth to mention, the excellent project carried out by the Toulouse City Council to determine the impervious areas of the town and the water run off factor on each urban watershed. This is obtained by automatic detection of vegetated areas and registration with the watershed map. Results are within 5% of conventional methods and obtained quasi instantly. This information is used to size water sewage pipes.

VI. - WATER RESOURCES MANAGEMENT, AGRICULTURE, FORESTRY

In the field of vegetation and agriculture, numerous operational applications have been or are being carried out taking advantage of the combination of SPOT excellent revisit capability and high spatial resolution. Several studies emphazised SPOT's spatial and temporal resolution. Table 11, for example, illustrates the image acquisition probability over a flooded area in Marocco.

Operational methodologies for water management applications were developped by CEMAGREF in France (Centre d'Etudes du Machinisme Agricole du Génie Rural et des Eaux et Forêts). A first lake inventory was implemented upon request from Fishersmen Union in Southern France using SPOT XS band 3. Such information on small lakes location, surface and nature was not available on regular basis by other means. Lakes were numbered and located in terms of latitude and longitude directly from SPOT image and water surface were computed. These informations were entered into a data base and thus could be crossed with other external data.

The localization accuracy was estimated better than 100 meters and up to 10 meters. Smallest lake detected range from 0.01 to 0.27 hectares. All lakes above 0.3 hectares were detected (D. LEPOUTRE, 1987, to be published).

A study on flood monitoring in irrigated lands is also under progress at CEMAGREF on an annual basis in Marocco over the Gharb region. The goal is to evaluate accurately the flood direct impact over irrigated schemes. By combining a detailed land use map obtained before the floods from a SPOT image and the actual flood map, it is possible to anticipate the flood impact on crop production. Drainage pattern improvement and irrigation planning works can also be decided from image

PROBABILITY OF ACQUIRING A CLOUD FREE IMAGE OVER AN AREA IN MAROCCO

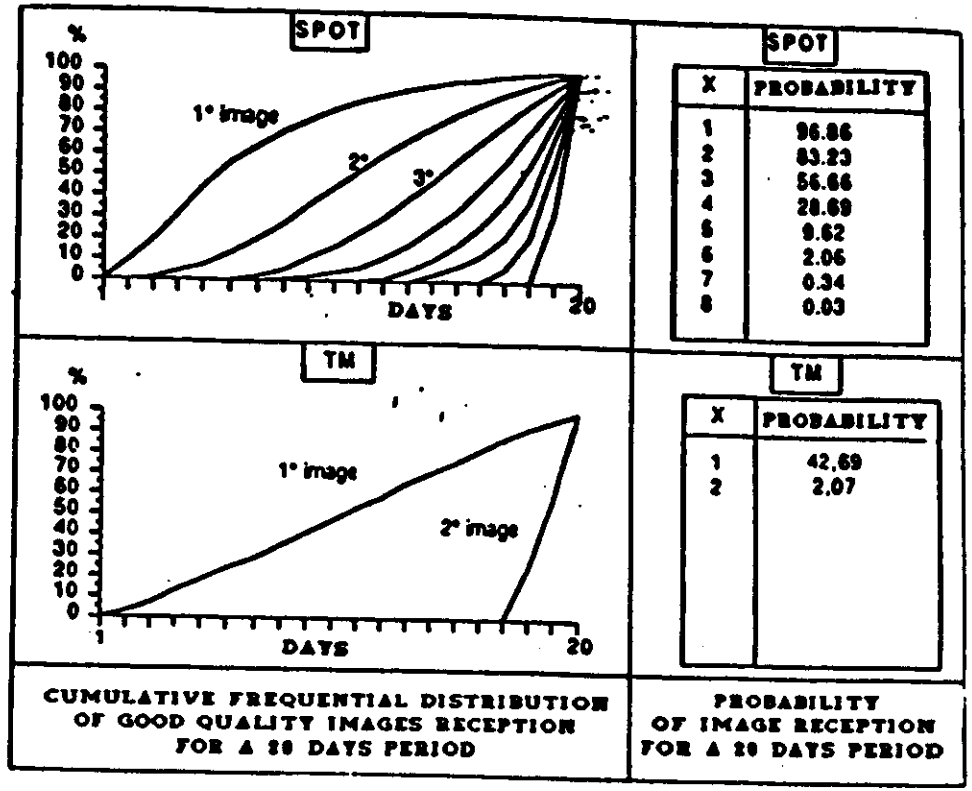


Table 11

from D. LE POUTRE, 1986

analysis (D. LEPOUTRE, 1986 ; S. JOVENIAUX, 1986). The major and unique advantage of SPOT identified in this case is the high revisit capability (see Table 6). In addition, SPOT allows to implement a complete flood monitoring study even in case of lack of basic data, including the plotting of contour lines with SPOT panchromatic stereo pairs, the drawing of flood maps, computation of flood water depth and final integration within a GIS.

The management of irrigated schemes has also, through the Gharb example, been studied by CEMAGREF. Through multitemporal SPOT acquisitions, land use changes are identified and their relation to water management regulation can be pointed out. Irrigation detection is performed by using crop phenological criterions. Successful results were obtained by digital classification. These results may be used for irrigation management and control of irrigation fee payment.

Other application studies are developped for instance at the Toulouse School for Agriculture (ESAP) where basic detection change maps on irrigated rice schemes were updated with traditional photo interpretation techniques using SPOT XS images in Northern Cameroun. Map of land use changes were drawn at a scale of 1/50 000. Maximum localization error was 60 m.

Single crop land use maps (maize) were also implemented by ESAP with conventional digital classification over the areas of influence of agricultural cooperatives in Southern France. The information provided with SPOT multispectral image in August is easy to get as at that time of the year all the winter crops have been harvested and only spring crops like corn, root beets, sunflower, rapeseed and sorghum are remaining, with spectral response rather different from one to the other.

Results such as corn surfaces in a given area are crucial to economic management : when to sell corn? is it better to stock or to sell according to the estimated production derived from SPOT, prices at a given moment and potential evolution of the market. Such studies are now requested by similar farming organizations for winter crops, such as winter wheat or barley.

Beyond these operational agricultural applications many experimental studies are implemented, based on SPOT images.

The French Ministry of Agriculture, is carrying out the last steps of a study that aims at preparing an operational integrated system for the early 90's, combining SPOT and ground truth data for agricultural statistics, giving the crop surfaces at national level. Statistical cursus surveys are replaced by a spatial inventory which gives statistical results as well as crop maps. Current studies apply to large fields in the Beauce area as well as small fields in the Haute Garonne (Toulouse district).

The same technique can be used in forest inventories. Forest stands are readily identified as well as isolated large individual trees and monitoring seems to be feasible with a fair degree of confidence. Forest plots, logging tracks are clearly identified with 10 or 20 meters resolution. SPOT imagery would then appear to be competitive with aerial photography for analysis and in particular for continuous monitoring and updating a forest inventories. Experimental forest studies with SPOT are presently implemented in many countries including Sweden, Finland, Poland, USA, Canada, Belgium and France. First results are expected by the end of 1987.

VIII - SPOT APPLICATIONS IN COASTAL STUDIES AND OCEANOGRAPHY

Although initial objectives of the SPOT system were mainly directed to land resources applications, many coastal and oceanographic studies have been carried out during the first two years of operation in the framework of the PEPS program.

Four main areas are covered :

- Coastal and environmental studies,
- Coastal management,
- Coastal mapping and near shore charting
- Oceanography

For all of these applications, SPOT performances and potential were evaluated and compared to conventional means, or to other remote sensing sensors ; operationality and cost effectiveness were also considered.

- Coastal and environmental studies

Due to the complexity and dynamic changes of coastal environment, coastal vegetation and shallow water studies have very stringent requirements. Although, as Klemas says (V. Klemas and al. SPOT 87), no remote sensing system can answer to all the marine sciences, SPOT has two major assets in this field of application : ground resolution and revisit capability. The combination of the two allows to detect small changes occuring in short time lapses.

The relationship between resolution and time sequences for change detection is well illustrated in a multisensor comparative study for mapping coastal areas (F.VERGER, P. REBILLARD, 1987), where it is showed that sand drifts on the dunes and on the beaches can be detected with two SPOT panchromatic images acquired at 40 days interval, emphazing the interest of SPOT revisit.

In this study, two representative coastal areas for geomorphological applications were selected : a rapidly changing sand headland, the Arçay headland, and an extremly muddy estuary, the Cove of Aiguillon, both located in a 20X20 km flat area, North of La Rochelle on the French Atlantic coast. SPOT data were compared to the MMS, TM and Seasat data acquired in 1974, 1984 and 1978. A SPOT image of August 86 was registered to a 1/25.000 topographic map. Then three other SPOT images of other dates were registered to the first SPOT image using

about 20 GCPs and polymonial of the order of 3 to 4, bi cubic resampling.

Results demonstrated that for the Arçay headland, the beach and spit change generally take place over a period of one to several months, whereas the level of image resolution provided by the MSS (79X55 Meters) only allowed change detection taking place over a period of years (Wang et al., 1985). Although the resolution provided by SEASAT radar data (25 meters) and TM (30X30 Meters) has already greatly improved this change detection potential, none of the other sensors had a revisit capability such as SPOT (12 possible attempt over this study area per orbital cycle, 26 days, illustrated by the acquisition of images for this study at specific periods).

Guillemot (Guillemot et al, 1987), studied the inter seasonnal coastal changes in the Province of Huelva, Andalucia, South West of Spain. A first image acquired on June 10, 1986, in Multispectral and Panchromatic modes was compared with other Multispectral images, acquired respectivedly on August 18, 1986 and February 04, 1987.

Standard processing techniques were used :
- vegetation index : XS3 - XS2 / XS3 + XS2),
- brighteness index (XS3 + XS2)
- colour composite
  (X S3 = Red ; X S2 = Green ; X S1 = Blue
  B.I. = Red ; V.I.=Green ; X S1 = Blue),

and binary stretching of the shore line using X S3.

By combining ground radiometric measurements, using SPOT spectral bands and the processed SPOT data it was possible to carry out a dynamic study on the two areas : tidal marshes and shore line ; sand dunes and beaches. For the first area the important transformation of the natural environment by human activity was established : local drainage modification, embankement of islands, localization and measurement of industrial waste spreading within the salt marshes, as well as the aquaculture ponds structure. Paleo shorelines and sand banks were also identified. Shoreline dynamic modification between summer 1985 and winter 1987 was also stressed. Inter seasonnal morpho sedimentary conditions were looked at : opening at wintertime and closing at summertime of the fairway linking in between the banks, along with the erosion of the beaches during wintertime, by spreading of the materials, and acretion in summertime of the same areas.

Working also on coastal zone waters and wetland vegatation in the Delaware bay, Del. U.S.A., V. KLEMAS carried out a complete comparative study betwenn landsat TM and SPOT over the same area (V. KLEMAS et al. 1987).

The objectives were twofold : discriminating estuaries water masses and measuring and detecting changes in the Vegetation Index of areas of salt marsh grass like the evolution of the Spartina Alterniflora, including changes in biomass and productivity. The TM image was acquired on September 21st 1984, the SPOT images on September 13th, 1986. These images were selected because they were generally comparable. Bands used on TM were 2, 3 and 4 , which are very similar to bands 1, 2 and 3 of SPOT.

For the analysis of water features only raw data were used, on which an unsupervised classification was applied after masking of the land through band 3. Most of the classes were on both images located in tidal creeks. Many of the features in the bay waters were visible on the SPOT image, while they were not obvious on the TM data. Besides the SPOT's resolution advantages, V. KLEMAS explains this SPOT detection superiority throuth its better image quality.

Analysis of changes in the vegetation distribution was performed on both TM and SPOT images rectified to a UTM grid. A ten class supervised classification was then applied to the images for analysis of the salt marsh vegetation, including one class for spartina alterniflora, using a maximum likelyhood classifier. TM pixels were resampled at 20 X 20 m. Vegetation indexes were also generated for both images. A composite image was then created for both sensors, providing vegetation index value.

Then, a multitemporal vegetation index of Spartina Alterniflora was made by overlaying the SPOT and TM processed images. It was therefore possible to map the multitemporal changes by classifying the Vegetation Index value differences. The results of the classification shows comparable accuracy of both systems : 14 668 pixels were classified in S. alterniflora with TM, against 13 129 with SPOT. Vegetation index values are generally similar, except when die back phenomenon happened.

- Coastal Management

One of the more immediately operational field of application is the use of SPOT data for acquaculture site selection (LOUBERSAC SPOT 1987). The quick development of tropical prawns culture (macrobrachium rosenbergi) in the world during the past years has gone far beyond the expected figures : the 1983 forecast of a 170 000 tons/year in 1990 is already overcome as the 1986 production was established at 310 000 tons ; actual forecasting for 1990 beeing 475 000 tons (source USDC/noaa/NMSF/Nov. 87). The Asia Pacific area has a leading role for prawn culture, but its potential for developing surfaces has not been estimated. In this context, IFREMER, the French Institute of Oceanographic and Coastal Studies launched a feasibility study to assess, with SPOT data, the aquaculture development potential, site localization and acreage in New Caledonia. The processing of a SPOT image and the addition of external information required for the decision making were anticipated a useful methodology for providing products and optimising the site selection, thus leading to a better planning of the activites.

Two scales were selected :
- the 1/150,000 allowing the global inventory over a region of the size of a SPOT image.
- the 1/25,000 where the potential of a series of sites is evaluated, within a 10 x 10 km window.

In the Northen part of New Caledonia where the study took place, where the following figures were obtained :

- 1332 ha of bare soils corresponding to the total potential develpment zones.
- 394 ha, among the first 1332, representing a potential easy to develop in a first step.
- a huge site, superior to 150 ha, was discovered, and many in smaller size were inventoried.

These figures, on the basis of a production of 2 tons per hectare and per year, provide a gross potential revenue after development standing above 30 million French Francs / Year for the first 394 ha.

Where aerial photographs are not available, SPOT data superiority, compared to other investigation means, is demonstrated specially for :
- localization
- identification and acreage estimation of potential areas to be developped.
- synoptic view of the areas to be developped.

The methodology is now well established for such products, and has proved to be operational.

Other applications in costal managements concerned the inventory and stock evaluation of marine vegetation (T. BELSHER, SPOT 1987). Northern Brittanny in France is the main production region for seaweeds in France. Using ground control, including lateral sonar, submarine automatic photographic and video surveys, low altitude aerial photographs and radiometric measurements, Belsher demonstrated the SPOT accuracy for seaweed mapping. The image processing methodology used is a well known : vegetation index and pigmentary index (X S1 / X S2). Seaweeds were sensed up to ... 15 meters. A map at 1/25,000 scale was produced, and results pointed out that previous seaweeds acreage estimation in this region, obtained by conventional means, were - when they are available - over estimated by a factor 2.

- Coastal mapping and near shore charting

Hydrographic and bathymetric survey or charting with conventional means are expensive and time consuming. Very few of the coastal remote areas in the world, such as small islands and archipelagos are properly and accurately mapped. As an example, 50 % of the French overseas territories in Polynesia have no map at all and this fugure rises to 95 % in the Indian Ocean.

The French Hydrographic and Oceanographic Survey (Service Hydrographique et Océanographique de la Marine) carried out a study in order to evaluate SPOT's bathymetric and hydrographic potential (M. LE GOUIC, SPOT 1987). The OUVEA atoll (Loyalty Islands) was selected as a test site.

SPOT data geometric accuracy was evaluated as adequate for hydrographic mapping up to 1/50,000. The first advantage of SPOT for this kind of large scale survey is of course to provide the immediate shore line and to identify with a good accuracy the isolated emerged rocks or coral reefs. Sea bottom can be estimated with a bathymetric methodology using a light extinction coefficient, computed from SPOT spectral bands. As a matter of fact, the sun light is selectively absorbed by the water according to the wavelength, and the distance between the sea surface and the bottom. Several environment factors do affect the measurement : water turbidity, chlorophyl, bottom reflectance, surface specular reflexion, atmosphere. By an equation integrating the different physical and environmental elements, Le Gouic showed that it was possible with SPOT images to achieve a bathymetric accuracy better than 90 % up to 25 meters depth, with SPOT band 1. The theoretical maximum depth reached for the area was estimated at 40 meters, in particularly clear waters.

	PRICE PER KM2	STAFF	CONVENTIONAL COMPLEMENTARY GROUND SURVEY	TOTAL DURATION	COST
CONVENTIONAL SURVEY	1,150 US $	Charting : 5 Surveying : 30 Mapping : 5	0 %	6 months	575,000 US$
AERIAL BATHYMETRIC SURVEY	170 US $	Surveying : 3 Mapping : 1	10 % of conventional survey / km2 (115 US $)	5 months + 1 month (**)	142,500 US$
SPOT BATHYMETRIC SURVEY	45 US $	2	10 % of conventional survey / km2 (115 US $)	0,5 month + 1 month (**)	80,000 US $

Compared cost of different techniques for a mapping coastal zone of 500 km2
from FOURGASSIE and LE GOUIC, 1987

(*) to check and complete the results of airborne or space remote sensing studies
(**) ground truth

Table 12

The usefulness of the SPOT data can therefore be recommended as a preliminary document, to be completed by conventional survey (around 10%). For shoals and shallow waters mapping, SPOT has, compared to conventional surveys, two major advantages :

- quick processing of large surfaces (Table 12)
- very low cost effectiveness (Table 13)

AVAILABLE POTENTIAL	COASTAL SURFACE COVERED IN ONE YEAR
2 vessels equiped with a vertical sonar (survey at a scale 1/10 000)	1 000 km2
Mapping of 20 x 20 minutes sheet at a scale of 1/10 000	1 400 km2
Use of 10 SPOT scenes at a scale of 1/50 000	20 000 km2

Compared potential means of SHOM France (Service Hydrographique de la Marine) for marine charting of French Pacific Territories from FOURGASSIE and LE GOUIC, 1987
Table 13

Figures given in table 12 and 13 give only magnitude as they derive from estimates of typical work type. Present work completed by SHOM only applies to one island (Ouvea) of the LOYALTY archipelago. Some additional experiments however, are still needed to conclude on the actual potential of SPOT for shallow water mapping. This potential is maximum in cleaar waters (carbonated sea - floor of tropical and subtropical areas) at a scale of 1/50,000.

- Oceanography

An unexpected field of applications is developping in oceanography and sea studies. Stricking examples in the Gibraltar straight or off the Eastern coast of India, near Madras, demonstrate the SPOT ability, under specific conditions of acquisition, (namely with a viewing angle oriented Eastward and close to the sun glint) to detect sea surface features almost similar to what is seen with an imaging radar system. (A. Wadsworth and al, SPOT a satellite for oceanography? IGARSS 87, Ann Arbor).

In the Coast of India case, the image shows at sea, large banded structures running roughly N.S. in the right and uppper part which are likely to correspond to internal wave packets progagating towards the coast. Wavelength is estimated at 300 to 500 meters and each packet contains between 6 and 12 waves. They disapear at distance of 10 to 15 km from the cost, due to decrease in sea botton depth.

Swell and waves with a much smaller wavelength and with crests trending N.W. and N.N.W. are also crearly detected. White patches at sea North of Madras correspond to man-made oil slicks. Structure of oil slicks demonstrates that wind is blowing from the South West. In addition, the river plumes along the coast indicate that currents are trending northward.

Various other examples of similar phenomena have been recorded in different places. All of them show that, when images are taken with a looking angle close to the sun glint, valuable sea surface information can be derived from SPOT imagery analysis : sea state, wave trend and direction of propagation, internal wave structure, wind and coastal current direction, and oil spills location.

- Pollution

SPOT data can also be widely used for coastal management and particularly for disaster prevention in case of hydrocarbon pollution. On coastal areas, vulnerability maps can be established that will be used, if necessary, for disaster preparedness and disaster relief. Such an oil spill contingency plan was achieved in the Mohakam delta, Eastern Kalimentan (J. Denis et al. SPOT 87) to assess and control an eventual oil pollution of the coastal areas.

Information derived from SPOT are :

- Shore line, topography, hydrographic network, shoals and coral reefs, tranportation network, human settlements, vegetation units, physiographic units, land use maps, human activity, etc...

- From these data, the vulnerability map will actually define the various eco-zones, and the potentially high risk zones, these information being used for preparedness and relief strategies.

CONCLUSION

After 18 months of operation, many encouraging results have been obtained with SPOT data. As a new tool, SPOT data require new processing techniques, new methodologies and studies enter to new fields of applications filling the gap between other satellite data and aerial photographs. Many operational projects are already undergone in service companies, research laboratories and industrial organizations. They prove that SPOT images are efficient in most fields of application where space or airborne remote sensing is used.

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