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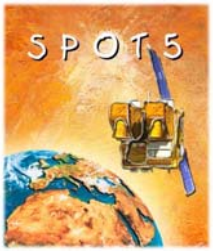

SPOT
IMAGE QUALITY PERFORMANCES

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Prepared by	**Image Quality Team**	**See list**		
Approved by	**Head of High Resolution Department** **C. Valorge** 17/05/04			
For Application	**SPOT IMAGE** **P. Delclaux** 25/05/04			

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SPOT Image Quality Performances

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SUMMARY :
This document provides an overview of SPOT1, SPOT2, SPOT4 and SPOT5 image quality performances.

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STATUS OF DOCUMENT PAGES

Page	Issue	Revised		Page	Issue	Revised

SUMMARY

1 DOCUMENT OBJECT

This document provides an overview of SPOT1, SPOT2, SPOT3, SPOT4 and SPOT5 image quality performances. As the two instruments (HRV, HRVIR, HRG, HRS) on the same SPOT satellite have similar performances we do not distinguish between them here. These performances are updated once a year after the annual SPOT Exploitation Review.

2 RADIOMETRIC PERFORMANCES

2.1 Absolute calibration

After radiometric correction (detector sensitivity and dark current correction), the numerical level in the image Xk is directly proportional to the input radiance Lk:

$$X_k = A_k G_{mk} L_k$$

where:

k is the spectral band,

A_k is the absolute calibration coefficient,

G_{mk} is the electronic gain: $G_{mk} = 1.3^{m-3}$, $m_k \in [1 , 8]$ for SPOT1 and SPOT2, $G_{mk} = 1.5^{m-2}$, $m_k \in [1 , 6]$ for SPOT4, and G_{mk} is given by the following table for the different SPOT5 channels:

m (gain number)	HM, HX	HRS	SWIR
1	0,6	1/2	0,591716
2	0,8	$1/\sqrt{2}$	0,7692308
3	1	1	1
4	1,2	$\sqrt{2}$	1,3
5	1,6	2	1,69
6	2,2	$2\sqrt{2}$	2,197
7	2,8	4	2,8561
8	3,8	$4\sqrt{2}$	3,71293
9	4,8		4,826809
10	6,2		

L_k is the normalized radiance:

$$L_k = \frac{\int L(\lambda) S_k(\lambda) d\lambda}{\int S_k(\lambda) d\lambda} \quad (W.m^{-2}.sr^{-1}.\mu m^{-1})$$

where: $L(\lambda)$ is the spectral radiance and $S_k(\lambda)$ the spectral sensitivity of the sensor.

The absolute calibration of the viewing system consists in estimating and monitoring the parameter A_k ($W^{-1}.m^2.sr.\mu m$). This is done with the following accuracy:

Calibration accuracy	Pa, B1, B2,B3	SWIR
Absolute calibration	**6%**	**7.5%**
Cross-band calibration	**3%**	**5%**
Multi-temporal calibration	**2%**	**2%**

2.2 Signal to noise ratio

The signal-to-noise ratio is representative of the radiometric resolution. The image noise quantifies the variations of the radiometric counts for a uniform landscape. It is the combination (quadratic sum) of two separate noises :

- Columnwise noise, also called instrumental noise : caused by the Poisson fluctuation of the signal delivered by the detector and various constant electronic onboard chain noises.
- Linewise noise, also called normalization noise : following image normalization, the residuals (radiometric model deviations) may cause visible "columns" on a uniform landscape.

Measurements for the different SPOT are done for different radiances according to the viewed landscape, but a noise model depending on the instrument input normalized radiance (L) is used to estimate the signal-to-noise ratio performance for a reference radiance (Lref). This reference radiance corresponds to the same target (reflectance=0.5, solar zenital angle=60°, standard atmosphere: visibility=23km, $[O_3]$=0.35cm.atm, $[H_2O]$=2g.cm^{-2}) seen by the different SPOT instruments. This model also depends on the electronic gain and we use as a reference the lowest operational gain for SPOT1 and SPOT2 and the neutral gain (Gmk=1) for SPOT4 and SPOT5.

The following table gives for the different channels of SPOT instruments

- the reference radiance expressed in W/m^2/sr/µm (the small difference between the different SPOT is explained by the slight spectral sensitivity difference between them),
- the corresponding radiometric count (RC) in the image expressed in LSB for the reference electronic gain,
- the signal-to-noise ratio measured along column and line and computed on images.

The last measurement date is given for each satellite.

					Signal to noise ratio		
			$Lref_k$	RC	Column	Line	Image
SPOT1	HRV	PA	107	61	140	230	120
		B1	119	65	158	233	130
Nov-2001		B2	103	69	130	240	112
		B3	93	62	180	226	140
SPOT2	HRV	PA	108	67	180	250	145
		B1	122	58	160	203	125
Nov-2003		B2	104	58	152	200	125
		B3	95	84	228	303	187
SPOT4	HRVIR	B2M	102	82	170	320	150
		B1	118	74	230	267	175
Nov-2003		B2	102	82	240	290	185
		B3	92	76	250	283	188
		SWIR	18	109	300	317	210
SPOT5	HRG	HM	120	111	153	1500	151
		B1	128	113	187	2500	187
Jan-2004		B2	108	110	197	2000	196
		B3	103	117	226	2000	225
		SWIR	21	108	328	442	263
	HRS	PAN	118	107	190	1070	187

2.3 Modulation Transfer Function (MTF)

The MTF is a way of characterizing the spatial resolution of the instruments. Restitution of the landscape contrasts viewed through the instrument is related to the MTF that is the Fourier transform of the impulse response (response at a point source or PSF). The MTF results from the cumulative effects of the instrumental optics (diffraction, aberrations, focusing errors), integration on a photosensitive surface, charge diffusion along the array and image motion induced by the movement of the satellite during imaging.
The MTF of the different SPOT instruments are provided in the following tables respectively along lines and columns in the image.

MTF - linewise	**f/fe**	0	0,1	0,2	0,3	0,4	**0,5**	0,6	0,7	0,8	0,9	1
SPOT1	Pa	1	0,82	0,64	0,49	0,36	**0,25**	0,16	0,10	0,05	0,02	0
HRV	B1	1	0,92	0,82	0,71	0,58	**0,46**	0,34	0,23	0,14	0,06	0
	B2	1	0,90	0,78	0,65	0,52	**0,40**	0,29	0,19	0,11	0,05	0
	B3	1	0,82	0,64	0,49	0,36	**0,25**	0,16	0,10	0,05	0,02	0
SPOT2	Pa	1	0,84	0,68	0,53	0,40	**0,29**	0,19	0,12	0,06	0,03	0
HRV	B1	1	0,93	0,84	0,73	0,61	**0,49**	0,37	0,26	0,15	0,07	0
	B2	1	0,92	0,82	0,70	0,58	**0,46**	0,34	0,23	0,14	0,06	0
	B3	1	0,89	0,76	0,63	0,50	**0,38**	0,27	0,18	0,10	0,04	0
SPOT3	Pa	1	0,85	0,70	0,55	0,42	**0,31**	0,21	0,13	0,07	0,03	0
HRV	B1	1	0,94	0,85	0,74	0,62	**0,50**	0,38	0,26	0,16	0,07	0
	B2	1	0,92	0,82	0,70	0,58	**0,46**	0,34	0,23	0,14	0,06	0
	B3	1	0,89	0,76	0,63	0,50	**0,38**	0,27	0,18	0,10	0,04	0
SPOT4	M	1	0,86	0,71	0,57	0,44	**0,32**	0,22	0,14	0,08	0,03	0
HRVIR	B1	1	0,94	0,86	0,76	0,64	**0,52**	0,40	0,28	0,17	0,08	0
	B2	1	0,92	0,83	0,71	0,59	**0,47**	0,35	0,24	0,14	0,06	0
	B3	1	0,90	0,78	0,65	0,52	**0,40**	0,29	0,19	0,11	0,05	0
	MIR	1	0,88	0,75	0,62	0,49	**0,37**	0,26	0,17	0,10	0,04	0
SPOT5	HM	1	0,87	0,74	0,60	0,47	**0,35**	0,25	0,16	0,09	0,04	0
HRG	B1	1	0,91	0,80	0,68	0,55	**0,43**	0,31	0,21	0,12	0,05	0
	B2	1	0,87	0,73	0,59	0,46	**0,34**	0,24	0,16	0,09	0,04	0
	B3	1	0,81	0,63	0,47	0,34	**0,24**	0,15	0,09	0,05	0,02	0
	MIR	1	0,94	0,85	0,74	0,62	**0,50**	0,37	0,26	0,16	0,07	0
HRS1	Pa	1	0,84	0,68	0,54	0,40	**0,29**	0,20	0,12	0,07	0,03	0
HRS2	Pa	1	0,85	0,70	0,56	0,43	**0,31**	0,21	0,13	0,07	0,03	0

SPOT MTF along lines as a function of the normalized spatial frequency (f/fe, fe is the sampling frequency).

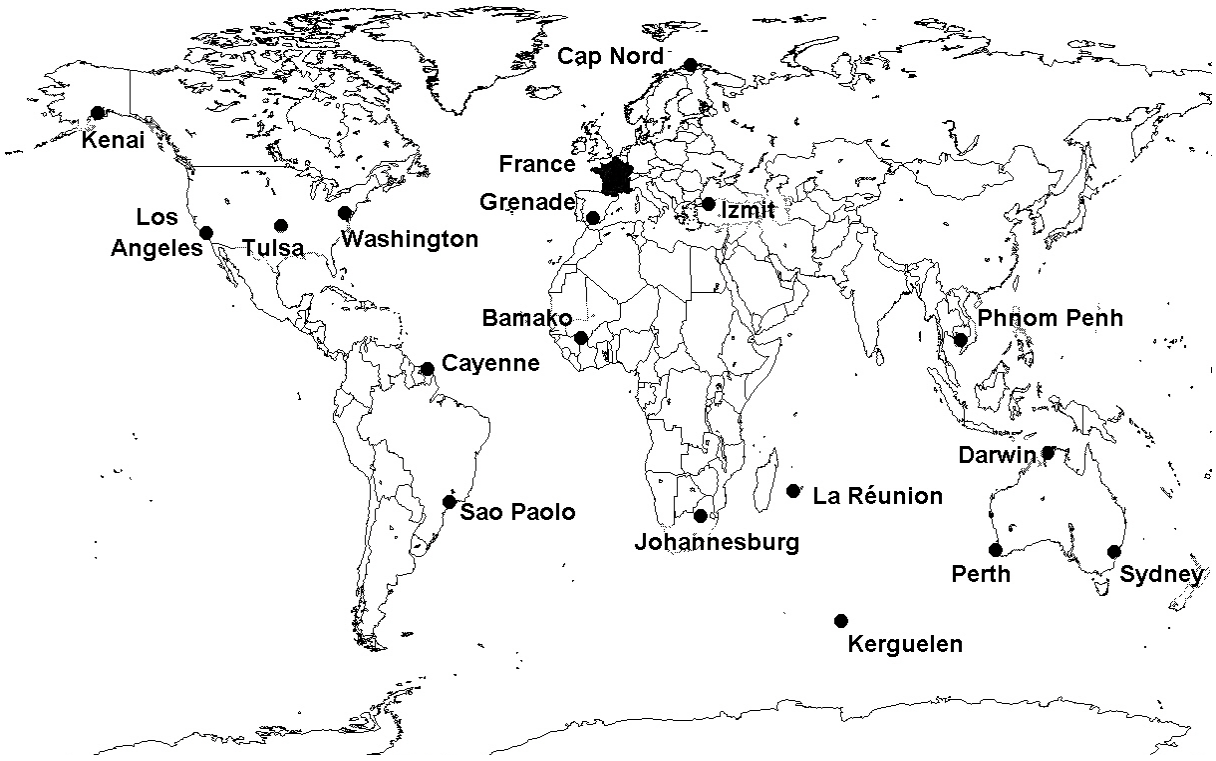
MTF- columnwise	f/fe	0	0,1	0,2	0,3	0,4	**0,5**	0,6	0,7	0,8	0,9	1
SPOT1	Pa	1	0,80	0,60	0,42	0,27	**0,16**	0,08	0,04	0,01	0,00	0
HRV	B1	1	0,91	0,80	0,67	0,53	**0,40**	0,28	0,18	0,10	0,04	0
	B2	1	0,90	0,78	0,65	0,51	**0,38**	0,26	0,17	0,09	0,04	0
	B3	1	0,89	0,76	0,63	0,49	**0,36**	0,25	0,16	0,08	0,03	0
SPOT2	Pa	1	0,85	0,67	0,50	0,34	**0,21**	0,12	0,05	0,02	0,00	0
HRV	B1	1	0,92	0,81	0,69	0,55	**0,42**	0,30	0,19	0,11	0,04	0
	B2	1	0,92	0,81	0,69	0,55	**0,42**	0,30	0,19	0,11	0,04	0
	B3	1	0,91	0,80	0,67	0,54	**0,41**	0,29	0,18	0,10	0,04	0
SPOT3	Pa	1	0,87	0,70	0,53	0,37	**0,24**	0,13	0,06	0,02	0,00	0
HRV	B1	1	0,92	0,81	0,69	0,55	**0,42**	0,30	0,19	0,11	0,04	0
	B2	1	0,92	0,81	0,68	0,55	**0,42**	0,29	0,19	0,11	0,04	0
	B3	1	0,92	0,80	0,68	0,54	**0,41**	0,29	0,19	0,10	0,04	0
SPOT4	M	1	0,85	0,68	0,51	0,35	**0,22**	0,12	0,06	0,02	0,00	0
HRVIR	B1	1	0,93	0,83	0,71	0,58	**0,45**	0,32	0,21	0,12	0,05	0
	B2	1	0,93	0,83	0,70	0,57	**0,44**	0,31	0,21	0,12	0,05	0
	B3	1	0,93	0,82	0,70	0,57	**0,43**	0,31	0,20	0,11	0,05	0
	MIR	1	0,85	0,68	0,50	0,34	**0,21**	0,12	0,05	0,02	0,00	0
SPOT5	HM	1	0,88	0,74	0,59	0,44	**0,31**	0,20	0,12	0,06	0,02	0
HRG	B1	1	0,90	0,78	0,65	0,51	**0,39**	0,27	0,17	0,09	0,04	0
	B2	1	0,90	0,77	0,64	0,50	**0,37**	0,26	0,16	0,09	0,03	0
	B3	1	0,88	0,75	0,61	0,47	**0,34**	0,23	0,14	0,08	0,03	0
	MIR	1	0,88	0,72	0,55	0,39	**0,25**	0,14	0,07	0,02	0,00	0
HRS1	Pa	1	0,83	0,66	0,51	0,37	**0,25**	0,16	0,09	0,05	0,02	0
HRS2	Pa	1	0,87	0,72	0,57	0,43	**0,31**	0,21	0,13	0,07	0,03	0

SPOT MTF along columns as a function of the normalized spatial frequency (f/fe, fe is the sampling frequency).

3 GEOMETRIC PERFORMANCES

3.1 Location accuracy

The location accuracy is the ability to locate a point in the image using its coordinates (row, line) in the image and the viewing model available through ancillary data. The location accuracy is regularly assessed on specific sites world-wide distributed in order to reflect the global accuracy of the system.



Location assessment test sites

Following results of location measurements are given for each satellite :

- number of measures ;
- time period of measures ;
- statistical results : mean, standard deviation (std), root mean square (rms) and maximum for 90% of images are given for across the track, along the track and global location performance.

We also presents 2 types of illustration :

- histograms for across and along the track measurements ;
- distribution of the measurements across the track and along the track : one point represents one image's performance measure. An ellipse centred on the mean performance shows the across the track, and along the track root mean square boundary.

Summary of the global location accuracy for every SPOT satellite is given in the following table :

	SPOT5		SPOT5		SPOT4	SPOT2	SPOT1
	HRG	HRS	HRG	HRS	HRVIR	HRV	HRV
Period	After Sept.04 2003		Before Sept.04 2003		2003		2001-2002
Nb images	75	190	116	246	36	41	62
RMS global	**27 m**	**16 m**	**47 m**	**49 m**	**316 m.**	**488 m.**	**628 m**

Location accuracy summary

Comments :

Two periods are distinguished for SPOT5 because a modification has been brought on board SPOT5 on the fourth of September 2003 which leads to a significant improvement of the location performance. Therefore, we present SPOT5 location performances before and after the modification. A possible way to improve location accuracy for images acquired before the modification is detailed in paragraph 3.1.4.3.

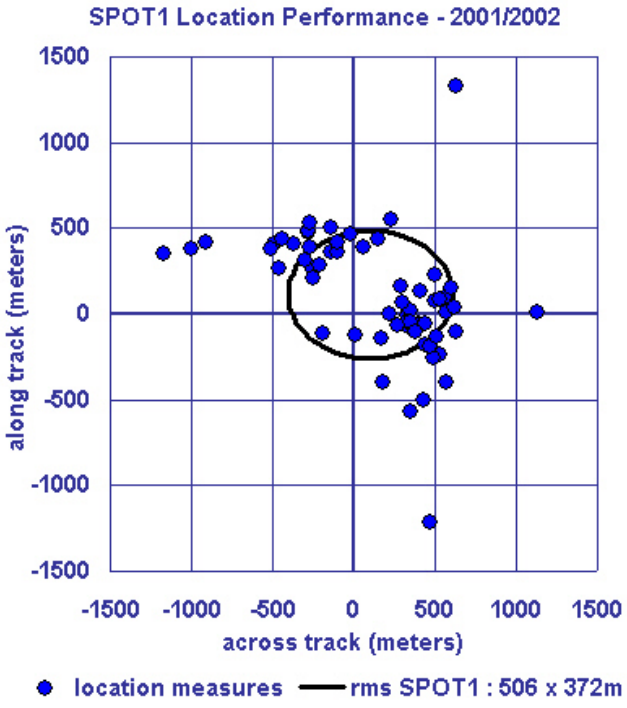
For SPOT5/HRS instrument, we present some monoscopic location performance results. Location performances are computed separately for each camera, with no tie points taken into account. Global HRS figure are computed out of both cameras figures without taking into account the pair.

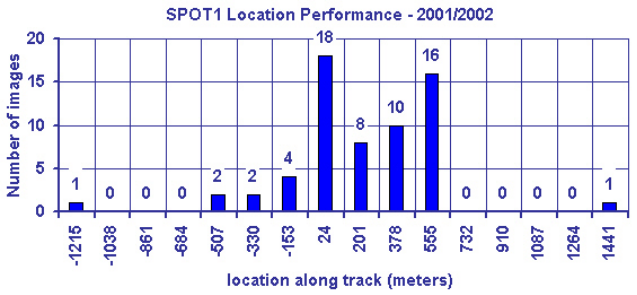
Different periods of measurements are taken into account for the different satellites :

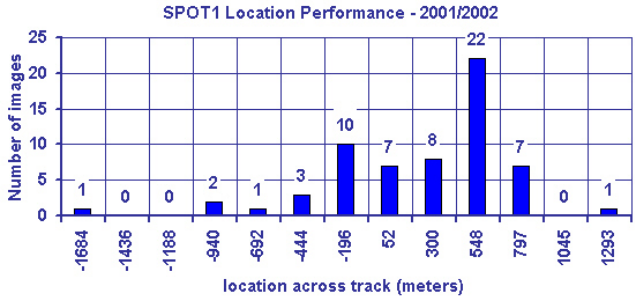
- for SPOT1, latest results before the end of the exploitation are given (January 2001 to February 2002) ;
- for SPOT2 and SPOT4, location assessment is carried out on an annual basis. Figures presented concern year 2003 ;
- for SPOT5, location assessment is carried out on a monthly basis. Figures given covers two period : before and after improvement of the location performance.

3.1.1 SPOT1 location accuracy

Measurements distribution	Across and Along track histograms







Statistical results :

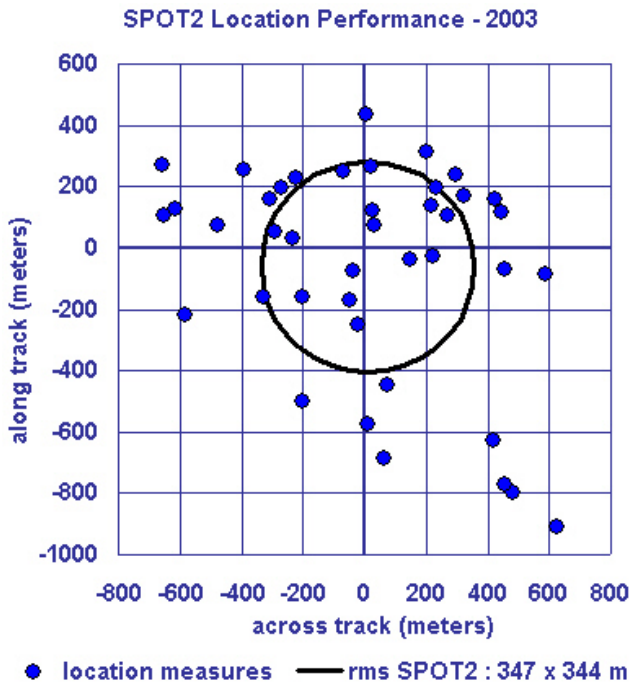
	SPOT1 HRV		
	62 images - 01/2001 to 02/2002		
meters	⊥ track	// track	global
Mean	102	114	152
Std	496	354	610
Rms	506	372	**628**
Max / 90 %	505	629	807

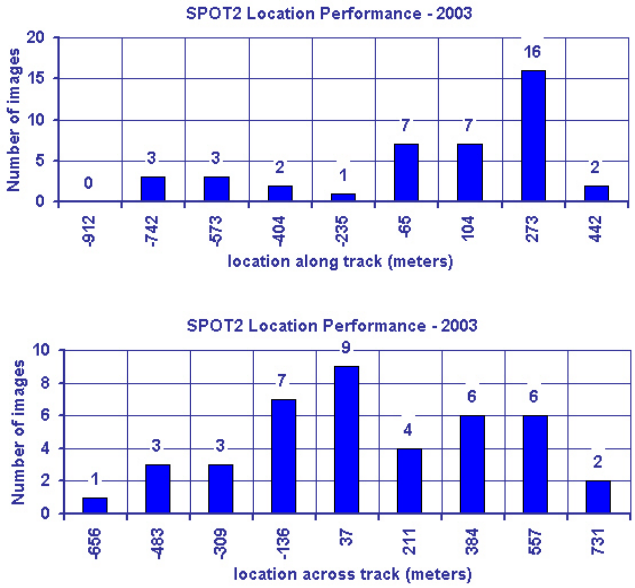
Comment :

Figures given for SPOT1 are related to years 2001 and 2002 measurements. Last location measures were held in February 2002 before the end of SPOT1 exploitation.

3.1.2 SPOT2 location accuracy

Measurements distribution	Across and Along track histograms





Statistical results :

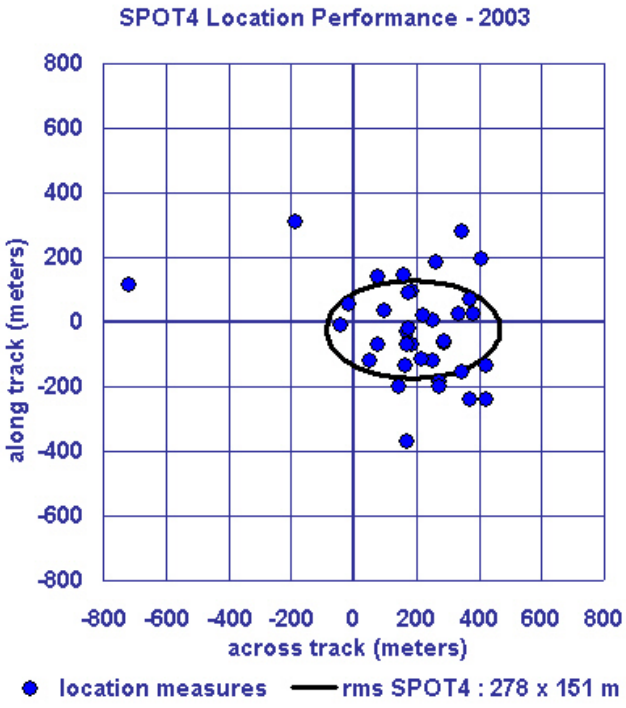
	SPOT2 HRV		
	41 images - 09/2002 to 09/2003		
meters	⊥ track	// track	global
Mean	10	-61	62
Std	347	339	484
Rms	347	344	**488**
Max / 90 %	588	630	862

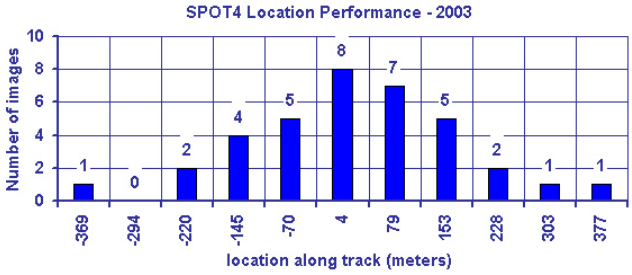
Comment :

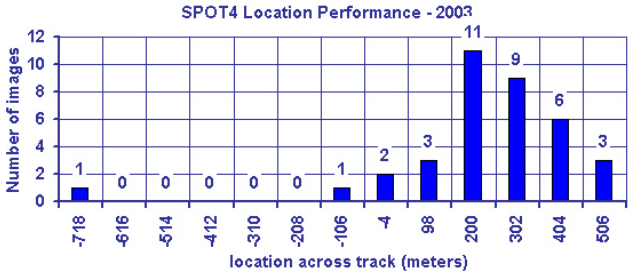
Figures given for SPOT2 are related to measurements held from September 2002 to September 2003. SPOT2 location is assessed on an annual basis for every exploitation review.

3.1.3 SPOT4 location accuracy

Measurements distribution	Across and Along track histograms







Statistical results :

	SPOT4 HRVIR		
	36 images - 09/2002 to 09/2003		
meters	⊥ track	// track	global
Mean	189	-23	190
Std	204	149	253
Rms	278	151	**316**
Max / 90 %	382	239	451

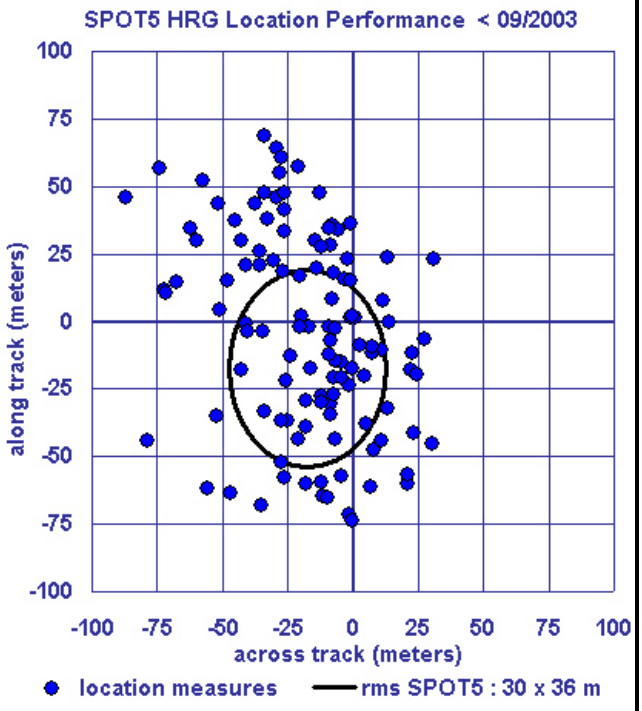
Comment :

Figures given for SPOT4 are related to measurements held from September 2002 to September 2003. SPOT4 location is assessed on an annual basis for every exploitation review.

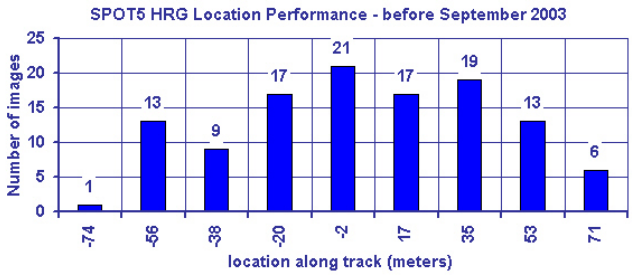
3.1.4 SPOT5 location accuracy before September 2003

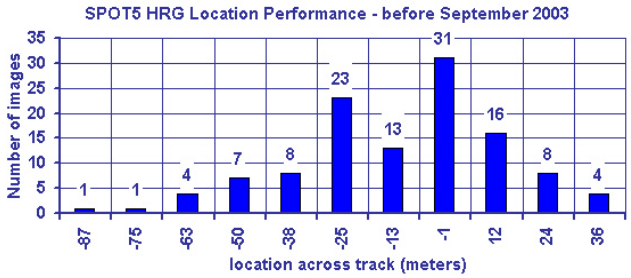
3.1.4.1 SPOT5 HRG location accuracy before September 2003

Measurements distribution



Across and Along track histograms





Statistical results :

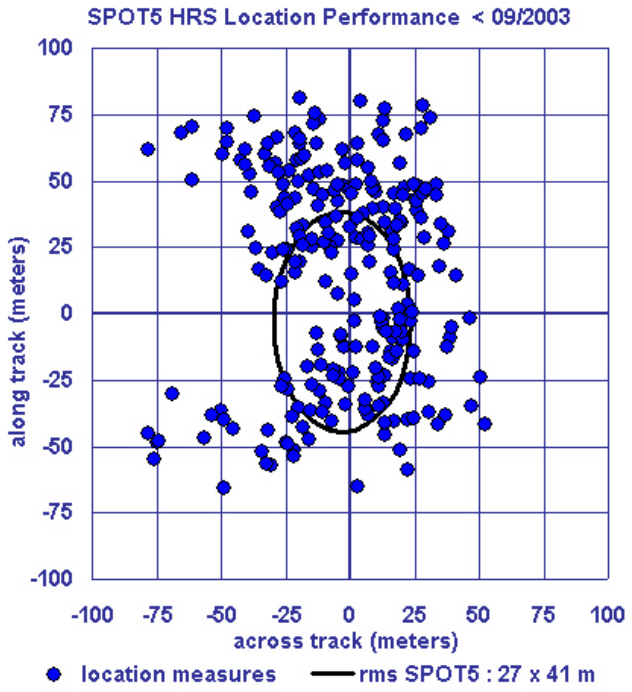
	SPOT5 HRG < 09/2003		
	116 images - 09/2002 to 09/2003		
meters	⊥ track	// track	global
Mean	-17	-4	18
Std	25	36	44
Rms	30	36	**47**
Max / 90 %	51	60	79

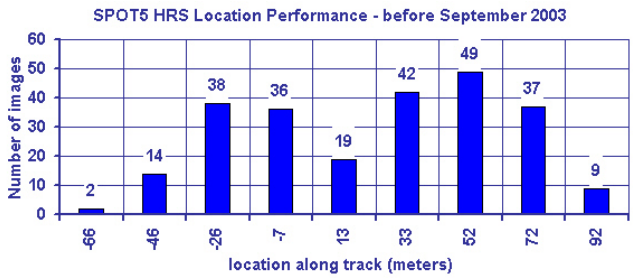
Comment :

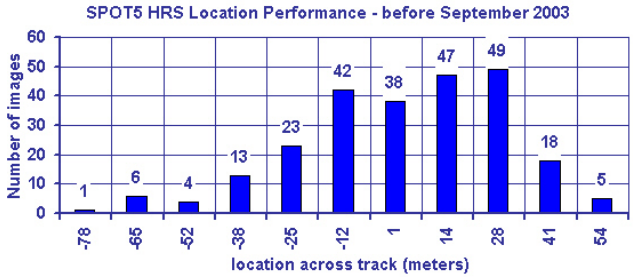
SPOT5 HRG instrument are checked on a monthly basis. These figures are related to measurements held from September 2002 to September 2003. During this period, the location performance has been impacted by a bad initialisation of the on board star tracker's relativist compensation process. This problem is described in paragraph 3.1.4.3.
The average location performance, is not close to 0, especially along track because location has been optimised for latitudes around 20°N.

3.1.4.2 SPOT5 HRS location accuracy before September 2003

Measurements distribution	Across and Along track histograms







Statistical results :

meters	SPOT5 HRS < 09/2003 246 images - 09/2002 to 09/2003 ⊥ track	// track	global
Mean	-3	13	14
Std	26	39	47
Rms	27	41	**49**
Max / 90 %	40	64	75

Comment :

For SPOT5/HRS instrument, we present a monoscopic performance assessment for both cameras. SPOT5 HRS instrument are checked on a monthly basis. These figures are related to measurements held from September 2002 to September 2003. During this period, the location performance has been impacted by a bad initialisation of the on board star tracker relativist compensation process. This problem is described in paragraph 3.1.4.3.
For HRS, the average location performance is close to 0 because it has been world-wide optimised.

3.1.4.3 SPOT5 enhanced location model for images before September 2003

Before September 2003, SPOT5 location performances have been impacted by a bad initialisation of the on board star tracker's relativist compensation process. This problem causes the location performance to vary with satellite position, indeed both with latitude and time.
We give in this paragraph an estimation of the impact of this problem estimated thanks to available measures on location sites. Impact linked with latitude (attitude correction model) and time (Time correction remainders) are given.

Attitude polynomial correction model :

This model allows improvement of the location accuracy before September 2003 down to **30 m rms for HRS** and **40 m rms for HRG** (instead of 50 m rms without attitude correction model).

The model has been designed as a polynomial function of satellite corrected latitude. Satellite latitude corrected from seasonal effect is used in order to reflect an exact time delay after satellite's eclipse exit.
The tuning has been done specifically for HRS. For HRG, an adaptation of the bias is required.

Attitude correction model :

$$\begin{cases} R'(t) = R(t) + R_0 + R_1 \times latcor + R_2 \times latcor^2 \\ P'(t) = P(t) + P_0 + P_1 \times latcor + P_2 \times latcor^2 \\ Y'(t) = Y(t) + Y_0 + Y_1 \times latcor + Y_2 \times latcor^2 \end{cases}$$

where R, P and Y respectively correspond to Roll, Pitch and Yaw.

Corrected latitude estimation :

$$latcor = lat\_sat - 23{,}5 \times \cos\left(\frac{2\pi \times (acq\_date - date\_ref)}{365}\right)$$

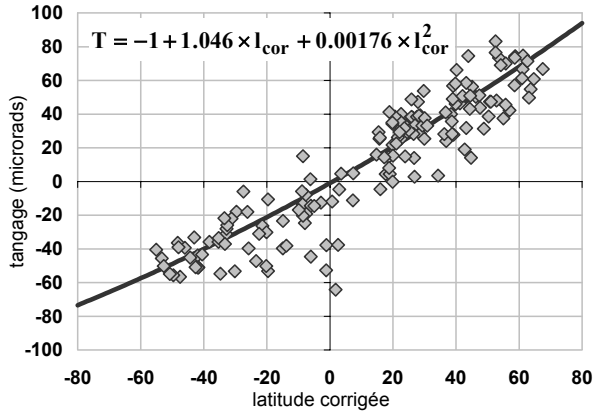
lat_sat : satellite latitude (degrees)
acq_date : acquisition date
date_ref : 21/06/2003

Correction model coefficients :

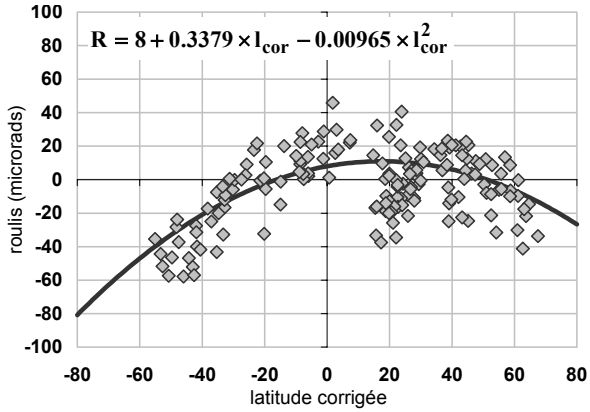
µrad	**Roll**	**Pitch**	**Yaw**
Bias (HRG)	14	29	-39
Bias (HRS)	8	-1	-39
Latcor	0.3379	1.046	1.35933
Latcor^2	-0.00965	0.00176	0.00755

The bias line provides values for R0, P0 and Y0 and should be adapted to HRG or HRS.
The latcor line provides coefficients R1, P1 and Y1
The latcor^2 line provides coefficients R2, P2 and Y2

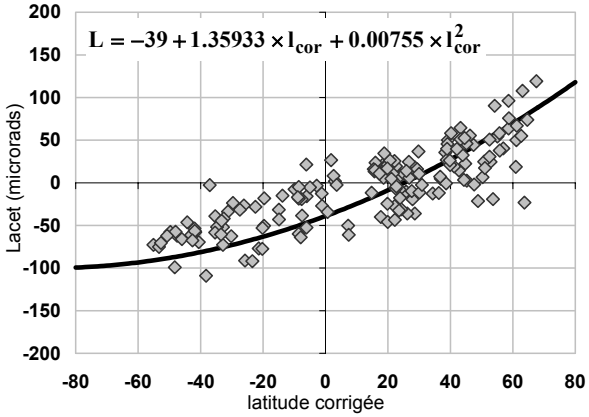
Attitude correction model tunning on HRS measures :



Pitch



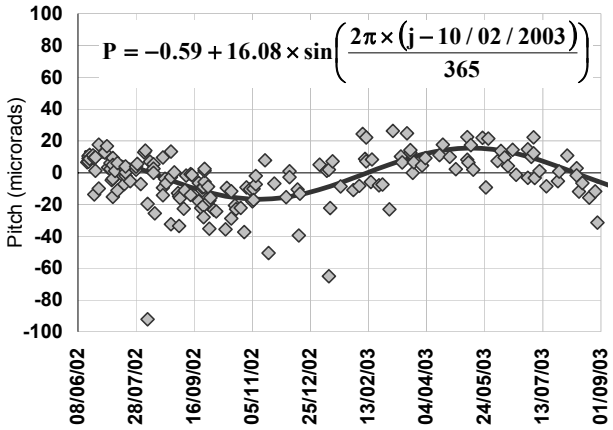
Roll



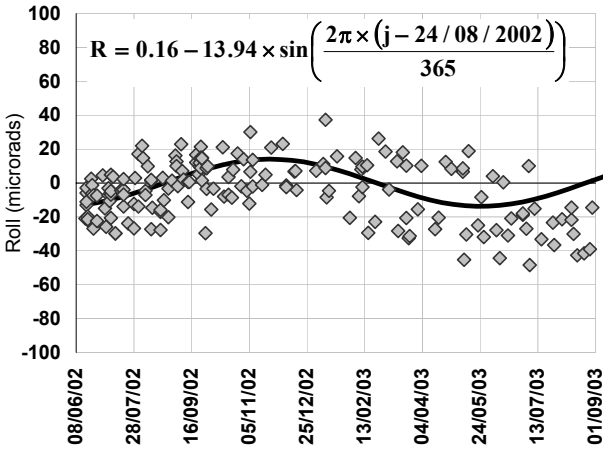
Yaw

Additive time correction model :

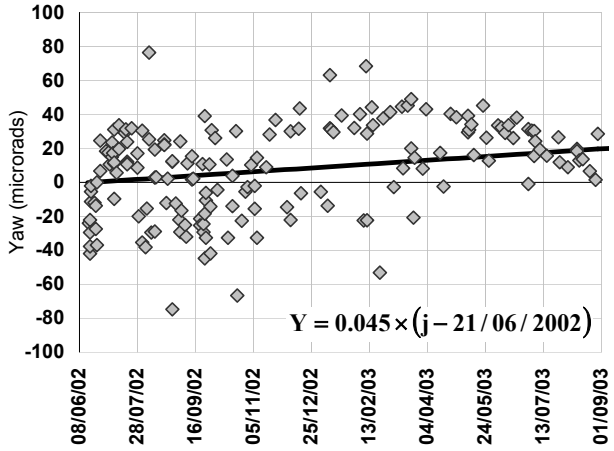
In addition to the attitude model, a correction depending on time can be added for further improvement of the location performance. This correction has not been specifically tuned. We only present remainders of the attitude model measured thanks to HRS pairs.



Pitch



Roll



Yaw

Time Correction remainders after removing attitude correction model for HRS measures

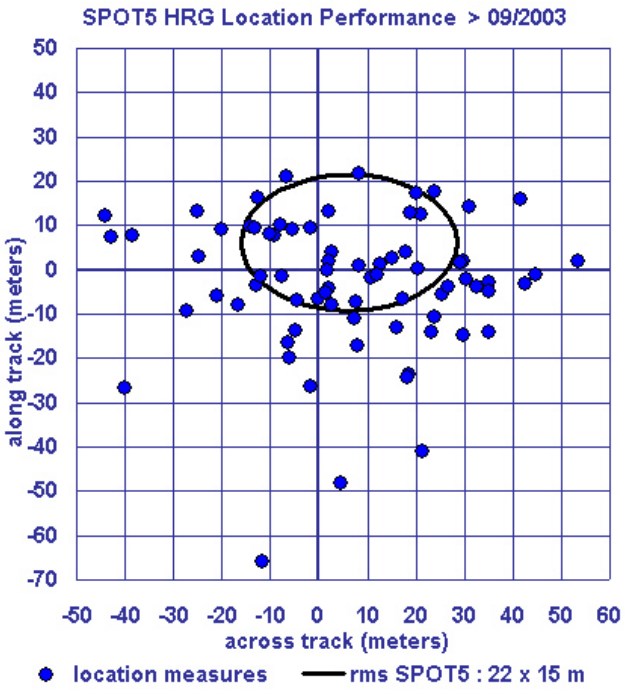
Comments :

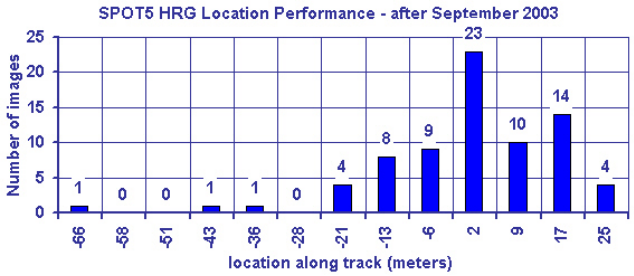
These models do not reflect the real impact of the on-board problem but the best analytic model which can be fit on available measures. Its interpretation may be subject to caution while using it on sites or period which are not covered by our analysis.

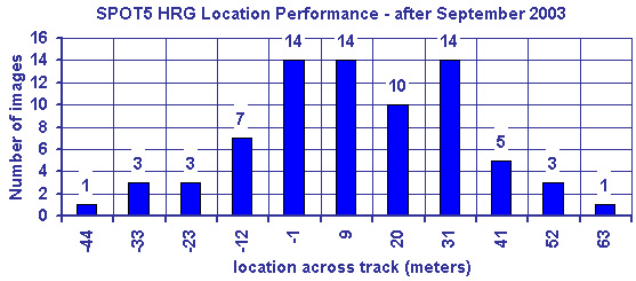
3.1.5 SPOT5 location accuracy after September 2003

3.1.5.1 SPOT5 HRG location accuracy after September 2003

Measurements distribution	Across and Along track histograms







Statistical results :

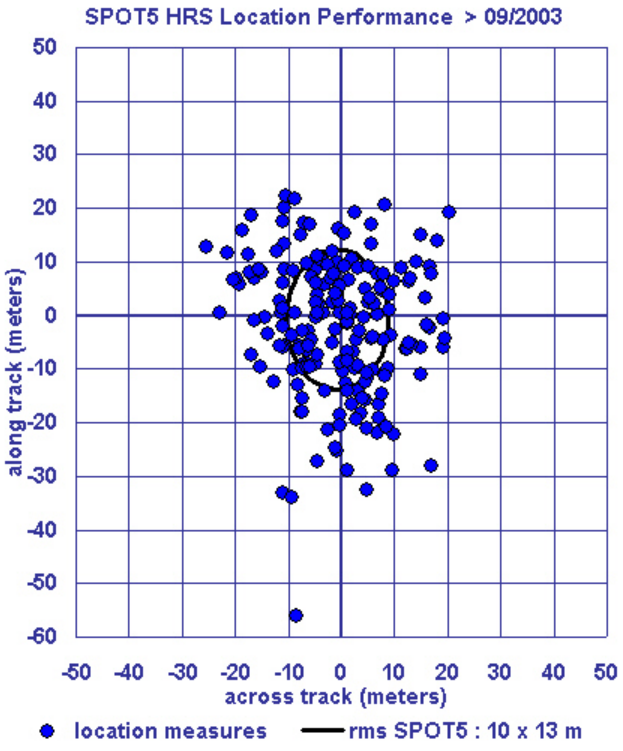
	SPOT5 HRG > 09/2003		
	75 images - 09/2003 to 04/2004		
meters	⊥ track	// track	global
Mean	6	-3	7
Std	21	15	26
Rms	22	15	**27**
Max / 90 %	35	22	41

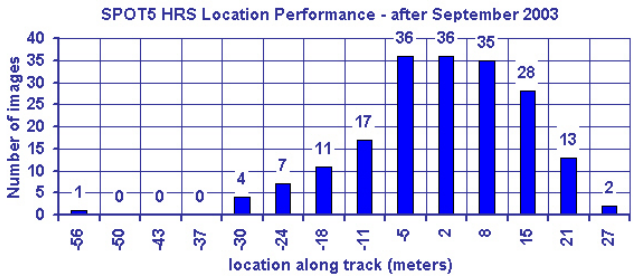
Comments :

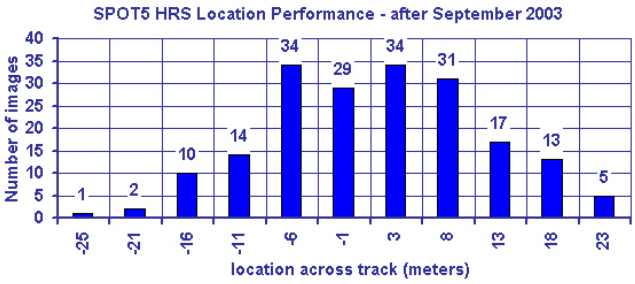
HRG location accuracy across the track accuracy is mainly due to the steering mirror behavior.

3.1.5.2 SPOT5 HRS location accuracy after September 2003

Measurements distribution	Across and Along track histograms







Statistical results :

	SPOT5 HRS > 09/2003		
	190 images - 09/2003 to 04/2004		
meters	⊥ track	// track	global
Mean	-1	-2	2
Std	10	13	16
Rms	10	13	**16**
Max / 90 %	17	21	27

Comment :

No comment.

3.2 Length Distortion

Length distortion is the accuracy of distances measures over images.
It is estimated over a set of images with ground control points by comparison of the real distance between pairs of ground control points (d) with the distance measured on the images (d').

We present 2 types of performances :

- for **distances under 5 km.** : rms of $\delta d = |d-d'|$ in meters ⇔ **measure precision in meters** ;
- for **distances over 5 km.** : rms of $\delta d/d$ in percent ⇔ **measure precision in percent.**

		Length Distortion	
		d<5km δd (meters rms)	**d>5km** δd/d (% rms)
SPOT5 (preliminary results)	HRG	**3.9 m.**	**$0.78.10^{-1}$ %**
	HRS	**2.7 m.**	**$0.54.10^{-1}$ %**
SPOT4	HRVIR	**4.5 m.**	**$0.90.10^{-1}$ %**
SPOT3	HRV	**4.6 m.**	**$0.93.10^{-1}$ %**
SPOT2	HRV	**3.6 m.**	**$0.73.10^{-1}$ %**
SPOT1	HRV	**5.7 m.**	**$1.14.10^{-1}$ %**

3.3 Multi-spectral registration

The multispectral registration performance is the precision of superposition of the different bands of the multispectral mode. It is given by the diameter of the circle containing the centers of every pixel of each band. This performance has been measured during each satellite's commissioning phase and during year 2003 for SPOT2, SPOT4 and SPOT5. Latest figures are given in the following table. SPOT5 performance is given after ground registration.

			Multispectral registration (XS pixel)	
		Résolution	With SWIR band	Without SWIR band
SPOT5 (2003)	HRG	10 m.	**0.23 pixel**	**0.17 pixel**
SPOT4 (2003)	HRVIR	20 m.	**0.39 pixel**	**0.35 pixel**
SPOT3 (1993)	HRV	20 m.	***No SWIR band***	**0.38 pixel**
SPOT2 (2003)	HRV	20 m.	***No SWIR band***	**0.40 pixel**
SPOT1 (1988)	HRV	20 m.	***No SWIR band***	**0.21 pixel**

3.4 Elevation performance

The elevation performance represents the typical performance obtained while producing DTM with SPOT images. It usually depends on the lateral stereoscopy configuration (B/H ratio), of the time elapsed between the two acquisitions of the stereoscopic pair (for exhaustivity) and of the terrain's slopes.
The following table gives the typical performance for a stereoscopic pair with a B/H ratio close to 0.5 for all instruments except HRS, elapsed time lower than 4 months between the 2 images of the pair and medium terrain relief. HRS B/H ratio is slightly higher than 0.8.

		Elevation performance (rms)
SPOT5	HRG 2.5 m./5 m.	**4.9 m.**
	HRG 10 m.	**6.1 m.**
	HRS	**3.7 m.**
SPOT4	HRVIR	**6.7 m.**
SPOT2	HRV	**7.3 m.**
SPOT1	HRV	**7 m.**