SPOT IMAGE QUALITY PERFORMANCES

	Grade And Name	Date	Signature
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MODIFICATIONS

ISSUE	REV	DATE	MODIFIED PAGES	SIGNATURE
0	0	20/02/2003	Document creation	
1	0	15/05/2004	2003 Spot Exploitation Review update - HRS radiometric performance addition - HRG FTM in-flight measurement	
2	0	15/01/2006	2005 performances update Add of absolute calibration coefficients values	
3	0	15/04/2007	2006 performances update	
4	0	15/01/2008	2007 performances update	
5	0	15/01/2009	2008 performances update	
6	0	30/11/2009	2009 performances update	
7	0	17/12/2010	2010 performances update	

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. The results presented in this issue correspond to November 2010. We can notice that the SPOT1 and SPOT2 performances are presented but naturally no more updated, since SPOT1 and SPOT2 have been put out from their orbit respectively in November 2003 and in June 2009.

2 GLOSSARY

HRG	Large Field High Resolution	(SPOT 5)
HRS	Stereoscopic High Resolution	
HRV	High Resolution in Visible	(SPOT 2)
HRVIR	High Resolution in Visible and Infra-Red (SPOT 4)	
MTF	Modulation Transfer Function	
PSF	Point Source Function	
RC	Radiometric Count	
SNR	Signal to Noise Ratio	

3 REFERENCE DOCUMENTS

DR1 : S5-NT-76-9739-CN, “Note technique de livraison de PSTS géométriques HRS, Juin 2007” (CNES internal document).

DR2 : S5-NT-76-10793-CN, “Note technique de livraison de PSTS géométriques HRS, Novembre 2010” (CNES internal document).

4 RADIOMETRIC PERFORMANCES

4.1 Absolute calibration

4.1.1 Definitions

The absolute calibration coefficient is used to deduce a physical quantity from the image numerical level.

After radiometric correction (detector sensitivity and dark current correction), the numerical level in the image X_k is directly proportional to the input radiance L_k through the radiometric model :

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

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/√2	0,7692308
3	1	1	1
4	1,2	√2	1,3
5	1,6	2	1,69
6	2,2	2√2	2,197
7	2,8	4	2,8561
8	3,8	4√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 value of the absolute calibration coefficient is not used to correct final products: they are in Radiometric Count (RC) and not in radiance. Nevertheless, the value of the product $A_k.G_{mk}$ is given to final users through the auxiliary data file :

- The corresponding field is “PHYSICAL_GAIN” for DIMAP Spot scene format.
- It is the “Absolute Calibration Gain” in the Header Record of the Header file, bytes 1765 to 2276

4.1.2 Specifications

The specifications are the following :

- determination of the absolute calibration with a precision better than 10%
- determination of the cross-band calibration better than 3%
- determination of the multi-temporal calibration better than 10%.

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%**

The calibration accuracy is fully compliant with the specifications, except for the SWIR cross-band calibration (estimated value 5% for 3% specified value).

4.1.3 Results

The coefficient value applicable to the image is always given in it auxiliary data file (see 3.1.1). Hereafter, results from last campaigns and their evolution since launches.

4.1.3.1 Last results

The last update of the absolute calibration coefficients values and the corresponding date are given in the following table.

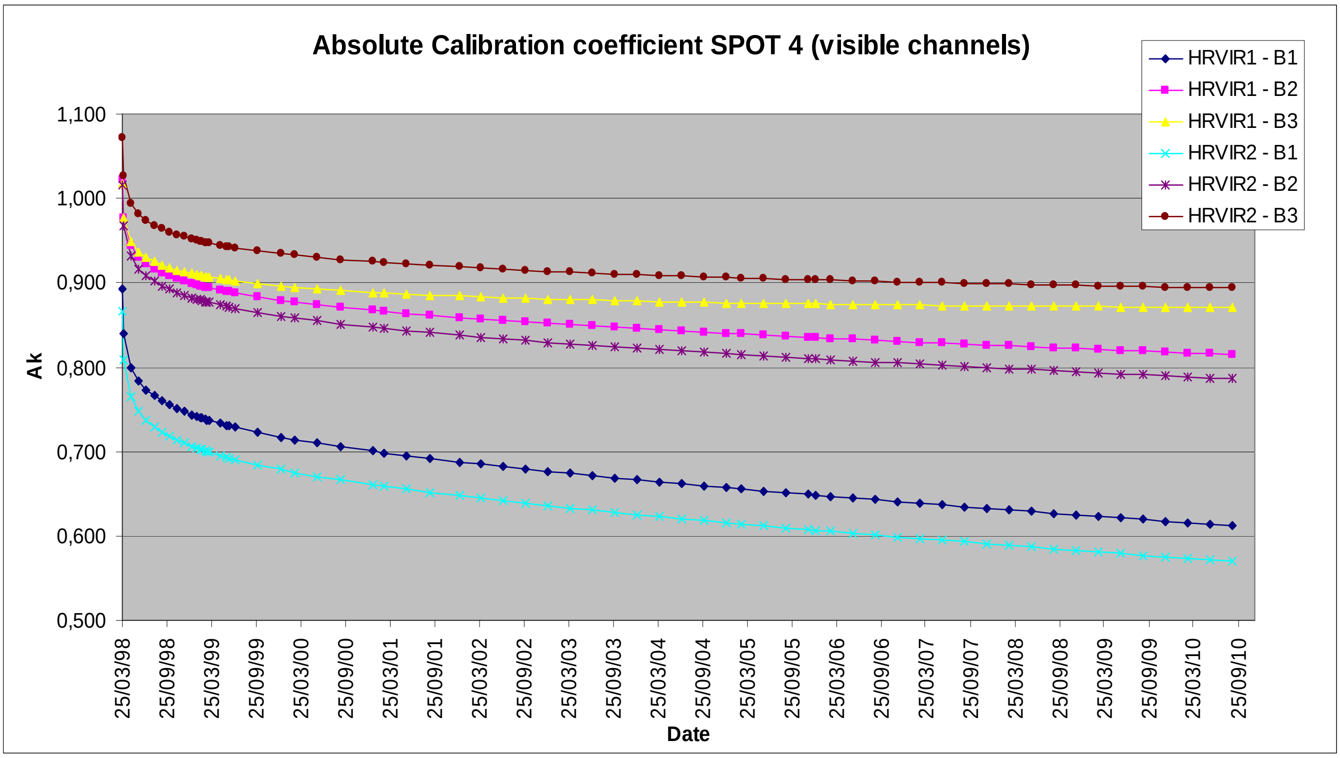
		Pa	B1	B2	B3	SWIR
SPOT1 Oct-2001	HRV1	0,4690	0,3290	0,2690	0,4890	
	HRV2	0,4430	0,3220	0,3040	0,5100	
SPOT2 Dec-2008	HRV1	0,437	0,449	0,359	0,733	
	HRV2	0,546	0,388	0,358	0,735	
SPOT4 Sept-2010	HRVIR1		0,612	0,815	0,871	6,041
	HRVIR2		0,570	0,786	0,894	5,347
SPOT5 Sept-2010	HRG1	0,859	0,781	0,977	1,081	6,265
	HRG2	0,853	0,713	0,994	1,062	6,236
	HRS1	0,9040				
	HRS2	0,9070				

Updated absolute calibration coefficients

The underlined values are not monitored and don't vary any more from one year to another.

4.1.3.2 Temporal evolution

The graphs below give the temporal evolution of the SPOT4 and SPOT5 absolute calibration coefficients since the launch.



Absolute Calibration coefficient SPOT 4 (visible channels)
HRVIR1 - B1
HRVIR1 - B2
HRVIR1 - B3
HRVIR2 - B1
HRVIR2 - B2
HRVIR2 - B3
Ak
1,100
1,000
0,900
0,800
0,700
0,600
0,500
25/03/98
25/09/98
25/03/99
25/09/99
25/03/00
25/09/00
25/03/01
25/09/01
25/03/02
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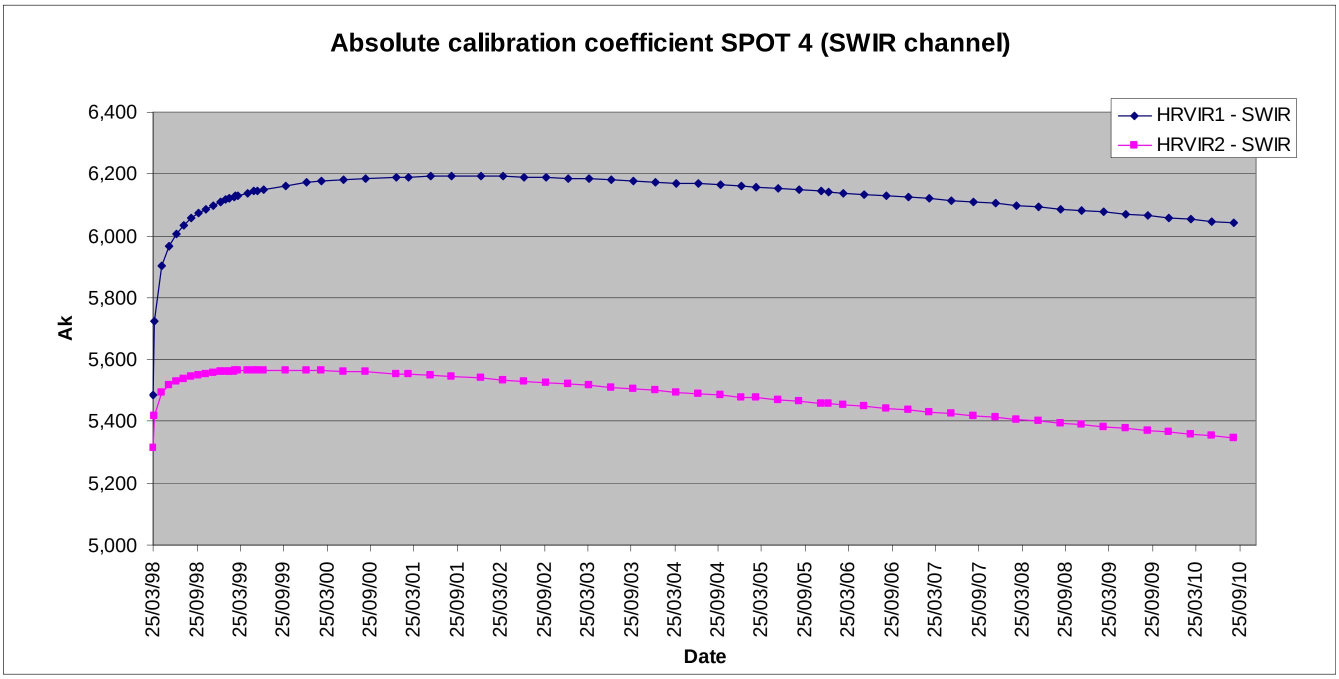
25/03/10
25/09/10
Date



Absolute calibration coefficient SPOT 4 (SWIR channel)
HRVIR1 - SWIR
HRVIR2 - SWIR
Ak
6,400
6,200
6,000
5,800
5,600
5,400
5,200
5,000
25/03/98
25/09/98
25/03/99
25/09/99
25/03/00
25/09/00
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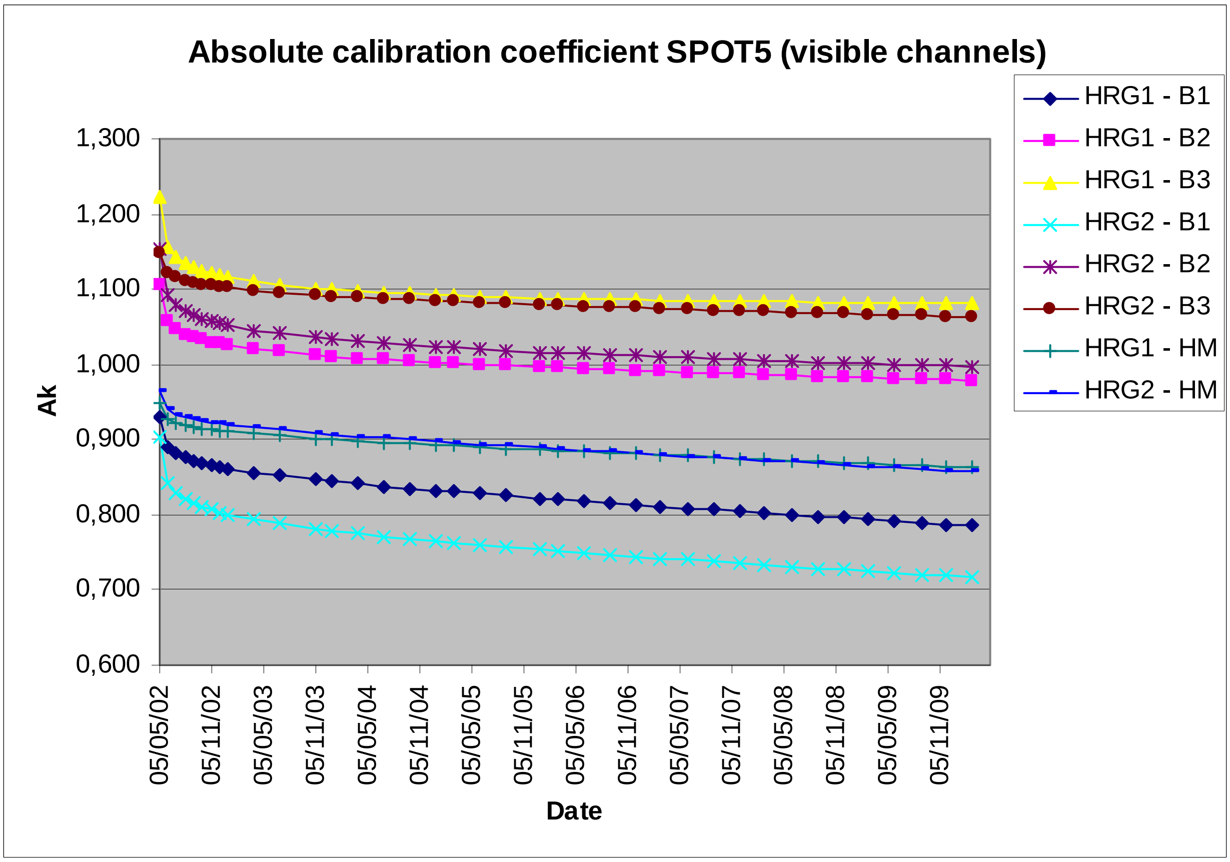
25/03/10
25/09/10
Date



Absolute calibration coefficient SPOT5 (visible channels)
HRG1 - B1
HRG1 - B2
HRG1 - B3
HRG2 - B1
HRG2 - B2
HRG2 - B3
HRG1 - HM
HRG2 - HM
Ak
1,300
1,200
1,100
1,000
0,900
0,800
0,700
0,600
05/05/02
05/11/02
05/05/03
05/11/03
05/05/04
05/11/04
05/05/05
05/11/05
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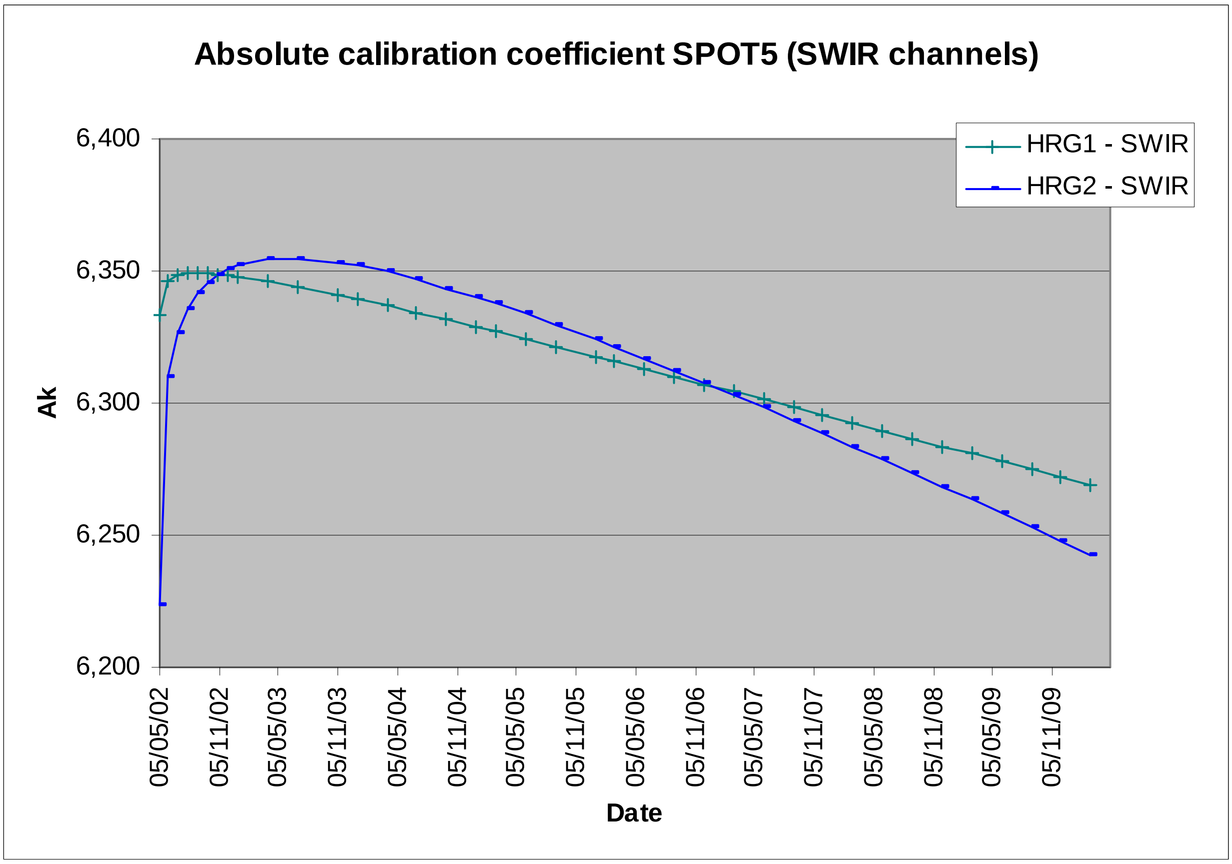
05/05/09
05/11/09
Date



Absolute calibration coefficient SPOT5 (SWIR channels)
HRG1 - SWIR
HRG2 - SWIR
Ak
6,400
6,350
6,300
6,250
6,200
05/05/02
05/11/02
05/05/03
05/11/03
05/05/04
05/11/04
05/05/05
05/11/05
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05/11/08
05/05/09
05/11/09
Date

4.1.4 Synthesis

The temporal evolution of the Absolute Calibration Coefficient is regular for all the satellites and all the channels : the evolution is similar for 2 instruments on a same satellite and it corresponds to a usual loss of sensitivity about 1% maximum per year for each value, representative of the ageing of the detectors.

4.2 Signal to Noise Ratio

4.2.1 Definitions

The Signal-to-Noise Ratio is representative of the radiometric resolution. We distinguish different noises :

- The *columnwise noise*, also called instrumental noise, is representative of the noise along the column and can be seen as a temporal noise along the detector. This noise is caused by the Poisson fluctuation of the signal delivered by the detector and various constant electronic onboard chain noises.
- The *linewise noise*, also called the equalization noise, is representative of the quality of the equalization through possible equalization residuals (radiometric model deviations). It may cause visible "columns" on a uniform landscape.
- The *image noise* quantifies the variations of the Radiometric Count for a uniform landscape. It is the combination (quadratic sum) of two separate noises : the columnwise noise and the linewise noise. The image noise is usually calculated on a 50x50 pixels image.

The linewise noise is estimated regularly when equalization parameters (radiometric model) are updated : calibration coefficients of the radiometric model (inter-arrays and inter-detectors parameters) are adjusted in order to minimize residuals. Consequently, linewise noise is not presented in this document, there is no specification about this noise and it is well-known after adjustment of calibration parameters.

Concerning the method, measurements for the different SPOT are done for different radiances according to the viewed landscape. Then, a noise model depending on the instrument input normalized radiance (L) is used to estimate the Signal-to-Noise Ratio (SNR) performance for a reference radiance (L_{ref}). 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 (G_{mk}=1; gain number 3) for SPOT4 and SPOT5. These measurements of SNR are then compared to the specifications.

Practically, the used SPOT 2-4 images are realized with on-board calibration system : a lamp with well-known radiance. The columnwise noise is calculated on these images and then modelized in function of the gain and radiance. The image noise is calculated by adding the linewise noise.

For SPOT 5, images over uniform landscapes (snow deserts) are used : the radiance is estimated over the scenes thanks to the absolute calibration coefficient. The same scene is seen with the two instruments of the satellite and the columnwise noise is estimated with removing the landscape component in the image. The columnwise noise model is then estimated and the image noise is calculated by adding the linewise noise.

4.2.2 Specifications

The following table gives :

- the reference radiance expressed in $W/m^2/sr/\mu m$ (the small difference between the different SPOT is explained by the slight spectral sensitivity difference between them),
- the specified Signal-to-Noise Ratio for column and for images.
- the reference electronical gain number.

			$Lref_k$	Specification SNR Column	Specification SNR Image	Reference gain number
SPOT1	HRV	PA	107	122	119	2
		B1	119	142	142	2
		B2	103	130	130	2
		B3	93	200	201	2
SPOT2	HRV	PA	108	122	119	2
		B1	122	142	142	2
		B2	104	130	130	2
		B3	95	200	201	2
SPOT4	HRVIR	M	102	133	133	3
		B1	118	219	219	3
		B2	102	186	186	3
		B3	92	214	214	3
		SWIR	18	179	179	3
SPOT5	HRG	HM	120	148	120	3
		B1	128	168	119	3
		B2	108	142	100	3
		B3	103	175	123	3
		SWIR	21	210	150	3
	HRS	PAN	118	129	129	3

Signal to Noise Ratio: specifications

4.2.3 Results

4.2.3.1 Last results

The following array gives the last results for the different channels of SPOT instruments. They correspond to the last on-board measurement (calibration lamp) for Spot2, in March 2009, for Spot4, in September 2010. For Spot5, they correspond to the last acquisitions over uniform sites (snow deserts), in December 2009.

The following table gives :

- the reference radiance expressed in $W/m^2/sr/\mu m$,
- the corresponding radiometric count (RC) in the image expressed in LSB for the reference electronic gain,
- the Signal-to-Noise Ratio measured along columns,
- the Signal-to-Noise Ratio Image, computed on 50x50 pixels images.

The last measurement date is given for each satellite. The underlined values don't vary any more from one year to another.

Remark : HRS results correspond to the ground measurements : on-board measurements are not applicable to this instrument because it is not possible to have acquisitions on the same landscape simultaneously with HRS1 and HRS2.

			$Lref_k$	RC	Column	50x50 pixels Image
SPOT1 Nov-2001	HRV	PA	107	61	140	120
		B1	119	65	158	130
		B2	103	69	130	112
		B3	93	62	180	140
SPOT2 Mar-2009	HRV	PA	108	67	195	162
		B1	122	58	192	151
		B2	104	58	164	134
		B3	95	84	244	**197**
SPOT4 Sept-2010	HRVIR	M	102	82	172	150
		B1	118	74	261	**184**
		B2	102	82	252	194
		B3	92	76	310	216
		SWIR	18	109	274	**52**
SPOT5 Dec-2009	HRG	HM	120	111	**135**	134
		B1	128	113	**160**	160
		B2	108	110	178	178
		B3	103	117	203	201
		SWIR	21	108	247	201
	HRS	PAN	118	107	190	187

Signal to Noise Ratio: measured performances

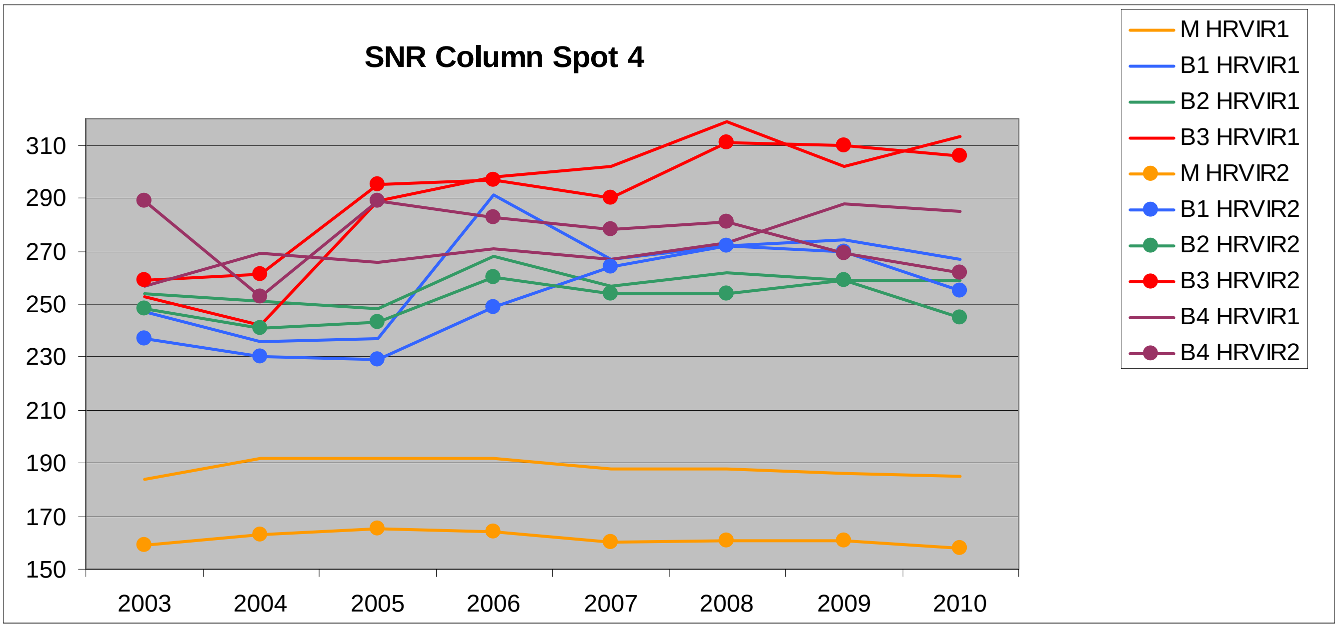
Values under the specification are in bold characters.

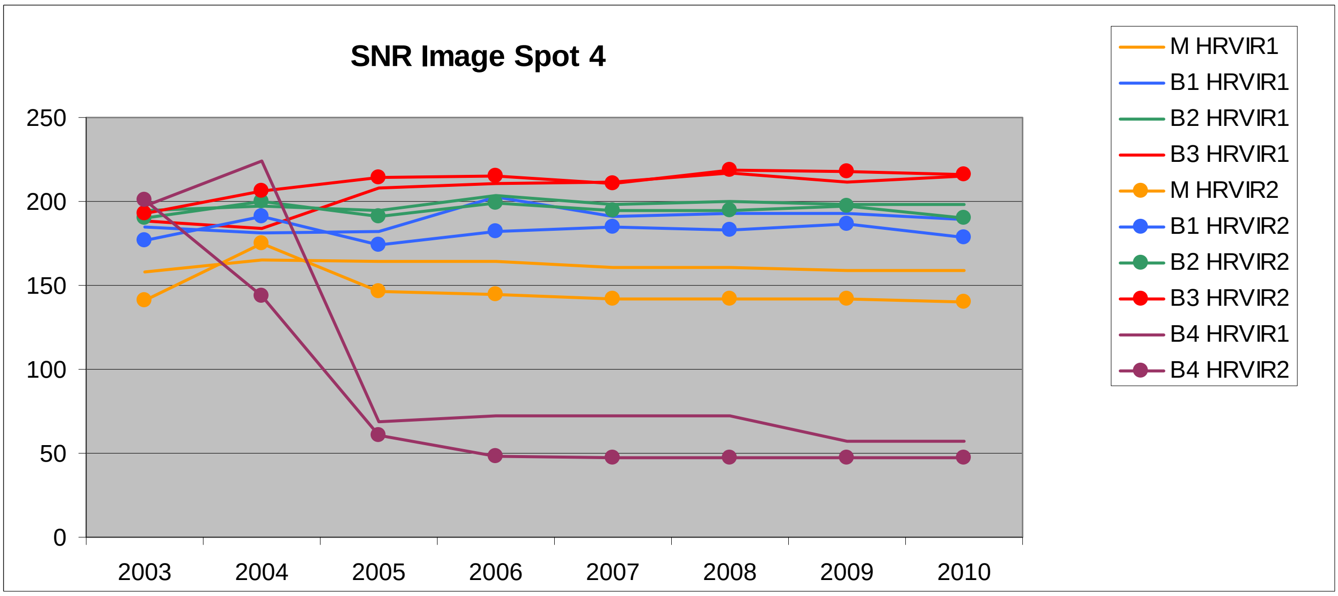
The *Signal to Noise Ratio for column* is correct and above the specifications for all the satellites and all the channels, except slightly for B1 channel for SPOT5 (specification: 168, measured value: 160). and for Panchromatic channel also for SPOT5 (specification: 148, measured value: 135). The values can slightly vary from one year to another because the measured values are sensitive to the compression noise: the compression noise is removed to estimate the columnwise noise but the results can be better if this noise is weak.

Concerning the *Signal to Noise Ratio for image*, which includes the linewise noise, results are strongly out of the specifications for the SWIR channels (SPOT4 satellite) : it is due to the increase of the number of aberrant detectors (sensibility to the radiation effects). Results are correct for the other channels and satellites (value for HRVIR/B1 is slightly out of the specifications).

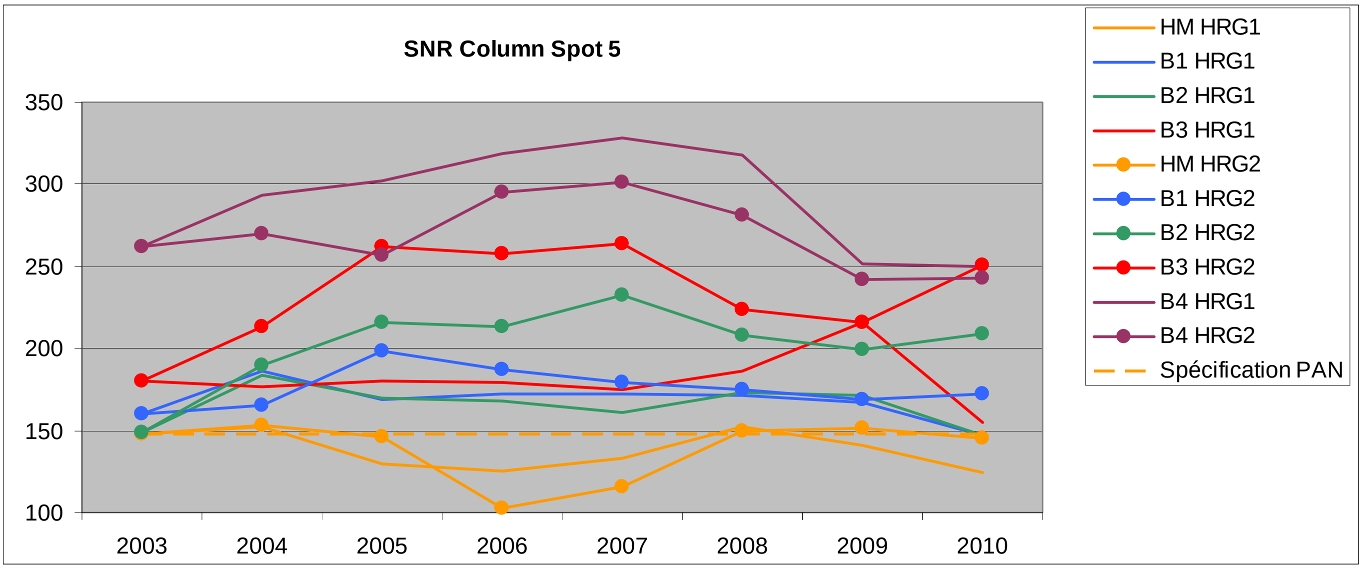
4.2.3.2 Temporal evolution

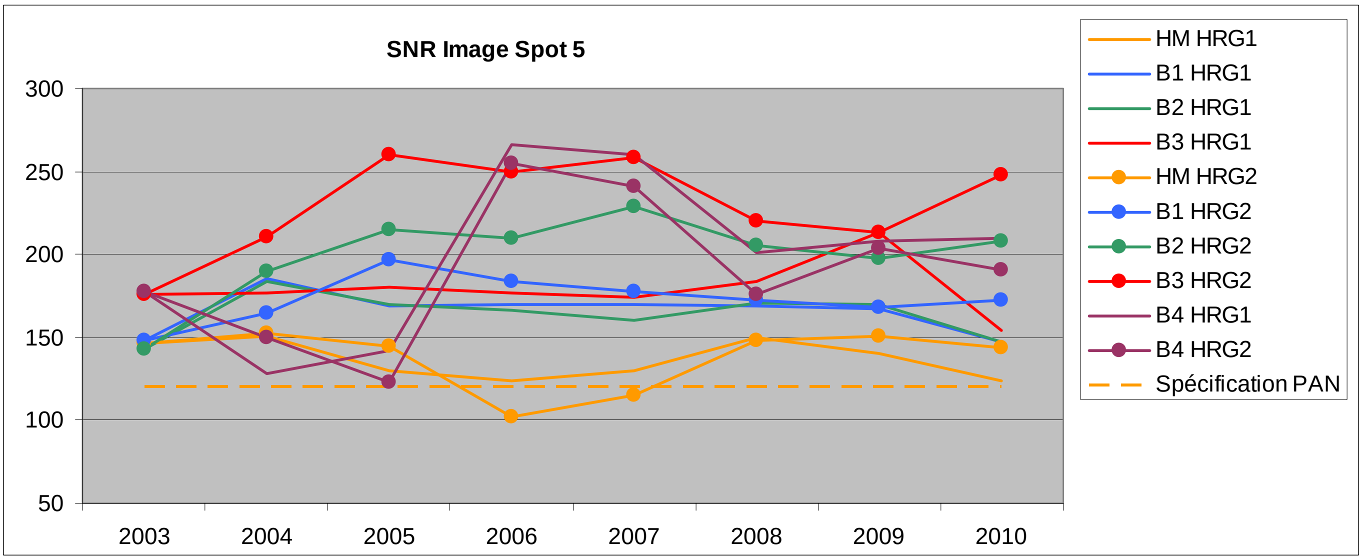
The following graphs present the results for columnwise noise and image noise since 2003 for SPOT 4 and 5. The measurements for SPOT4 are realized using on-board images and have very regular variations. The variations for SPOT5 can be explained by the choice of the uniform images (number, gain, level of radiance, compression characteristics).





SPOT4 Signal to Noise Ratio: temporal evolution





SPOT5 Signal to Noise Ratio: temporal evolution

4.2.4 Synthesis

The performances for SNR column and image are very good for all satellites and globally compliant with the specifications, excepted for Spot4 SWIR channels, which is explained by the great number of aberrant detectors of this channel.

4.3 Modulation Transfer Function (MTF)

4.3.1 Definitions

The MTF is a way of characterizing the spatial resolution of the instruments, it corresponds to the image sharpness. 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.

4.3.2 Specifications

The specifications are expressed for absolute MTF values, along lines and columns in the image. The following array gives the specifications for all the satellites and channels. The specification is expressed at the frequency $f_e/2$ (f_e : sampling frequency).

MTF - linewise	**f=fe/2**	Specification linewise	Specification columnwise
SPOT1	Pa	0,35	0,35
HRV	B1	0,35	0,35
	B2	0,35	0,35
	B3	0,35	0,35
SPOT2	Pa	0,35	0,35
HRV	B1	0,35	0,35
	B2	0,35	0,35
	B3	0,35	0,35
SPOT3	Pa	0,35	0,35
HRV	B1	0,35	0,35
	B2	0,35	0,35
	B3	0,35	0,35
SPOT4	M	0,3	0,2
HRVIR	B1	0,3	0,3
	B2	0,3	0,3
	B3	0,3	0,3
	SWIR	0,3	0,15
SPOT5	HM	0,25	0,23
HRG	B1	0,3	0,3
	B2	0,3	0,3
	B3	0,2	0,3
	SWIR	0,3	0,15
HRS1	Pa	0,18	0,18
HRS2	Pa	0,18	0,18

4.3.3 Results

4.3.3.1 Last results

The absolute MTF values of the different SPOT instruments are provided in the following tables respectively along lines and columns in the image. We can notice that the values which vary each year correspond to the SPOT 5 measurements (HRG, HM). Other values come from the ground measurements before flight or during the Calibration/Validation period : because of the spatial resolution, the edge method with the Salon target can be used only with SPOT 5 HRG instruments, panchromatic channels.

Nevertheless, the relative evolution of the MTF between two instruments on the same satellite is measured on flight once a year, over urban sites for all the satellites: the same target is acquired simultaneously with the two instruments. The analysis gives the relative value of the MTF between the two instruments for line and column. The interpretation of this value is difficult because of the relative measurement. However, it gives an indication if the focus vary for one instrument. There is no specification for the relative value. Practically, for SPOT 5, the relative value can vary (for example for the B3 channel): the variation is different depending on the HX channels, the column/line values and the location in the focal plane: the relative decrease appears more clearly for the B2 and B3 channels and for the right part of the focal place.

Concerning the HM values (SPOT5), mean values are stable since two years: nevertheless, the decrease since the beginning of life indicates a slight defocusing for both instruments (see §4.3.3.2), particularly along line and on the right part of the image.

4.3.3.1.1 MTF along lines

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
	SWIR	1	0,88	0,75	0,62	0,49	**0,37**	0,26	0,17	0,10	0,04	0
SPOT5	HM	1	0,84	0,68	0,54	0,40	**0,29**	0,20	0,12	0,07	0,03	0
HRG	B1	1	0,91	0,80	0,68	0,55	**0,43**	0,31	0,21	0,12	0,05	0
Nov. 2010	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
	SWIR	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).

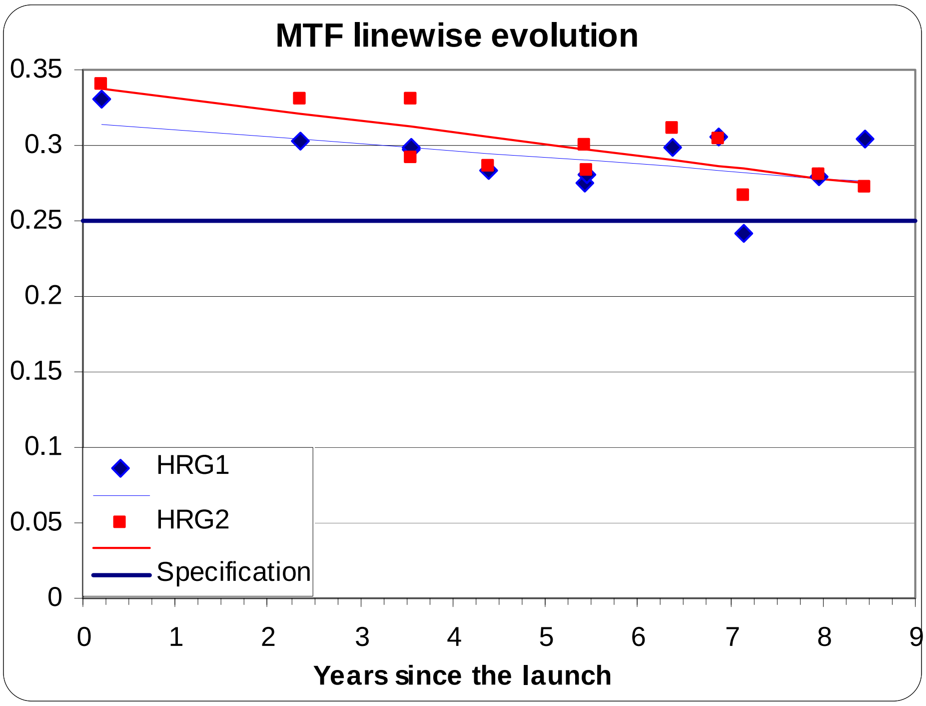
4.3.3.1.2 MTF along columns

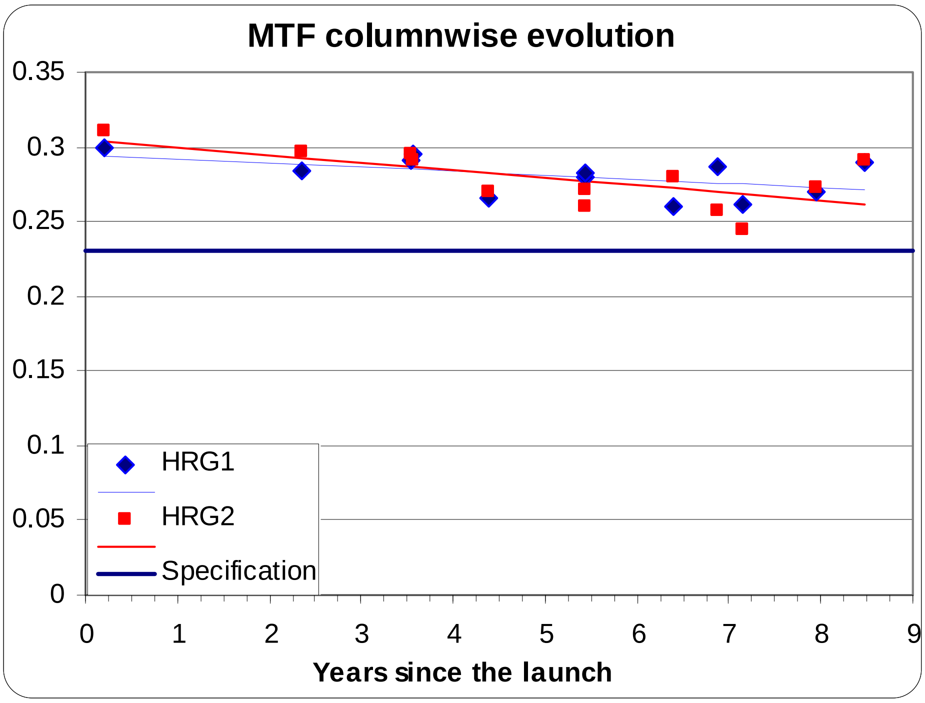
MTF- columnwise	**f/fe**	0	0,1	0,2	0,3	0,4	**0,5**	0,6	0,7	0,8	0,9	1
SPOT1	Pa	1	0,80	0,60	0,42	0,27	**0,16**	0,08	0,04	0,01	0,00	0
HRV	B1	1	0,91	0,80	0,67	0,53	**0,40**	0,28	0,18	0,10	0,04	0
	B2	1	0,90	0,78	0,65	0,51	**0,38**	0,26	0,17	0,09	0,04	0
	B3	1	0,89	0,76	0,63	0,49	**0,36**	0,25	0,16	0,08	0,03	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
	SWIR	1	0,85	0,68	0,50	0,34	**0,21**	0,12	0,05	0,02	0,00	0
SPOT5	HM	1	0,86	0,70	0,54	0,39	**0,27**	0,17	0,10	0,05	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
Nov. 2010	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
	SWIR	1	0,88	0,72	0,55	0,39	**0,25**	0,14	0,07	0,02	0,00	0
HRS1	Pa	1	0,84	0,68	0,52	0,38	**0,25**	0,16	0,08	0,04	0,00	0
HRS2	Pa	1	0,88	0,74	0,59	0,44	**0,31**	0,20	0,11	0,05	0,01	0

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

4.3.3.2 Temporal evolution

The variations of the MTF at the frequency fe/2 and for the SPOT5 HM channels are the following, respectively for column and line. Variations are represented in function of the number of years since the launch. The specification value is represented through the blue continuous line.





SPOT5 HM MTF along lines and columns temporal evolution

4.3.4 Synthesis

The MTF values are stabilized for the last years. Nevertheless, since values are compliant with the specifications, we notice that values are decreasing since the launch. It can be due to a slight defocusing for the two instruments: the defocusing is more important for HRG2 instrument and should be corrected at the beginning of 2010.

5 GEOMETRIC PERFORMANCES

5.1 Location accuracy

5.1.1 Introduction

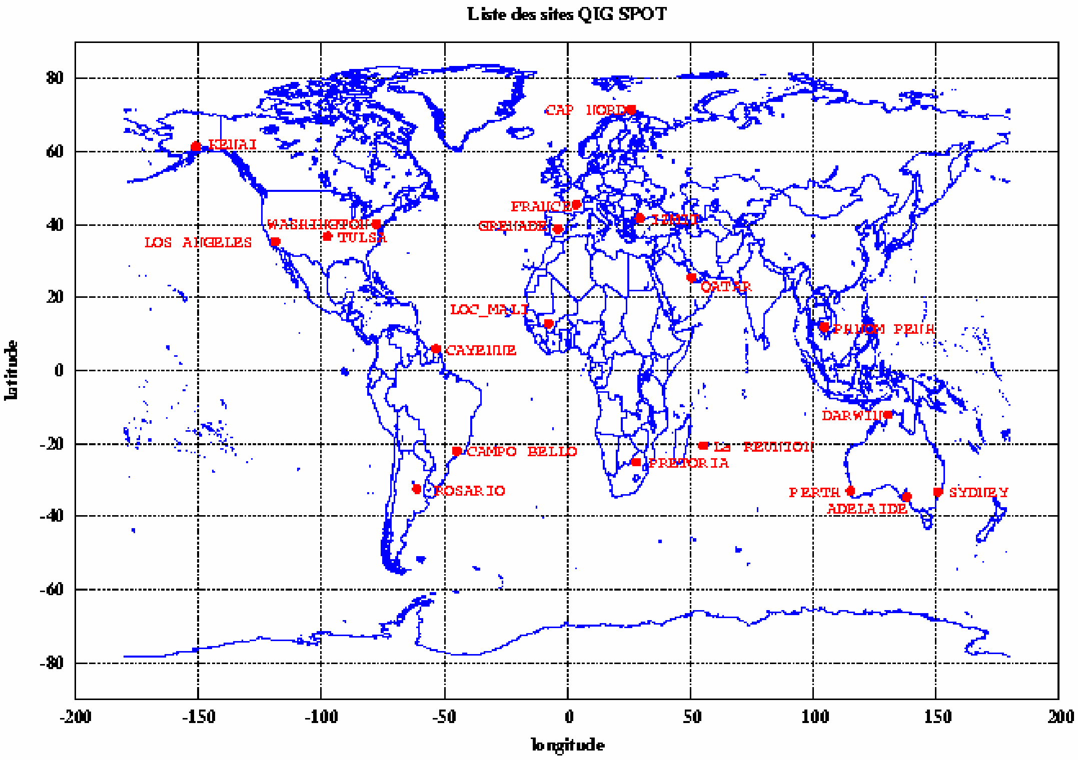
Definition :
The location accuracy is the ability to locate a point in the image using its coordinates (row, line) in the image and the viewing model available through ancillary data, without using ground control points. The location performance results presented in this document have been estimated by considering that the altitude is perfectly known (potential errors due to relief are not taken into account)

Specifications :
For SPOT5, the specification of location accuracy is :

- for HRG images : 65 meters RMS,
- for HRS images : 50 meters RMS.

These specifications are required in nominal mode, with ULS and DORIS data (for other modes see Annex A3).
For SPOT1, SPOT2 and SPOT4, the specification of location accuracy is 1500m RMS.

The location accuracy is regularly assessed on specific sites world-wide distributed in order to reflect the global accuracy of the system (cf. following figure).



Location assessment test sites

Following results of location measurements are given for SPOT4 and SPOT5 :
- 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 present for both satellite the graph of the distribution of the measurements across the track and along the track : one point represents one image's performance measure.

In the following paragraphs, we present the location performance results estimated on images acquired between September 2009 and August 2010. But we also recall the results since the launch in order to show a potential evolution function of time. In particular, we have to distinguish two periods for SPOT5 results, 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 performance after the modification in the following paragraphs, and the detailed results performed on images acquired before the modification are presented in annex A1, as well as a possible way to improve the location accuracy for these images.

Finally, a synthesis of the performance is presented for SPOT1, SPOT2, SPOT4 and SPOT5.

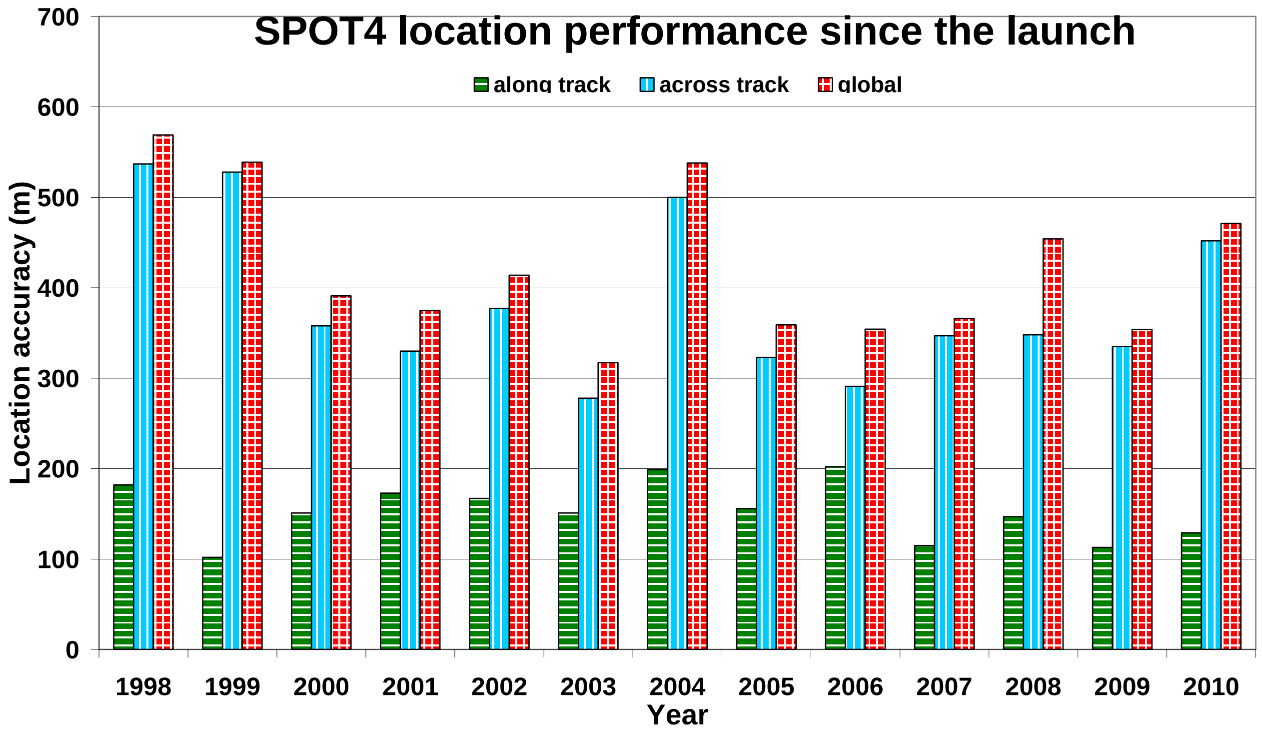
For SPOT5, we also present in annex A2 the synthesis of residuals alignment biases and their evolution function of different parameters such as time, latitude and so on…

It must be noticed that all the results have been processed in nominal mode, with ULS and DORIS data. An estimation of location performance without ULS and DORIS data is given in annex A3.

5.1.2 SPOT4 location accuracy

5.1.2.1 Evolution since the launch

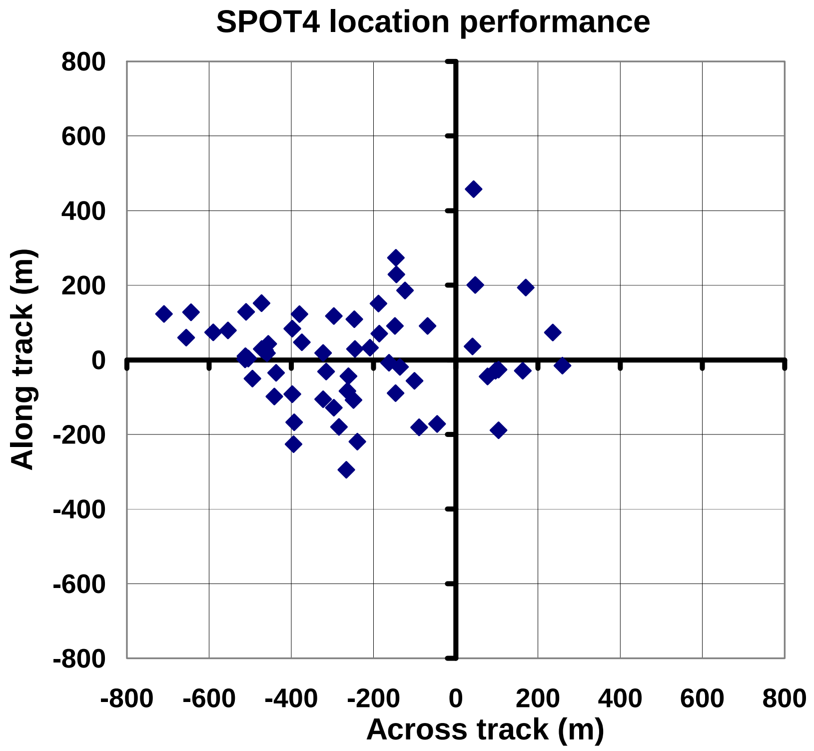
The following graph shows the evolution of SPOT4 location accuracy since the launch in 1998.



The graph shows stable results in 2010 compared to previous years.

5.1.2.2 Results estimated between September 2009 and August 2010

SPOT4 location accuracy is assessed on an annual basis for every exploitation review.
The following graph shows the distribution of the measures estimated on images acquired between September 2009 and August 2010. One point corresponds to the location accuracy of one image.



The following table shows the detailed statistical results estimated on images acquired between September 2009 and August 2010.

	SPOT4 HRV 2010		
	66 images - 09/2009 to 08/2010		
meters	**across track**	**along track**	**global**
Mean	**-243**	**16**	
Std	**382**	**128**	
RMS	**453**	**129**	**471**
Max for 90 %			**594**

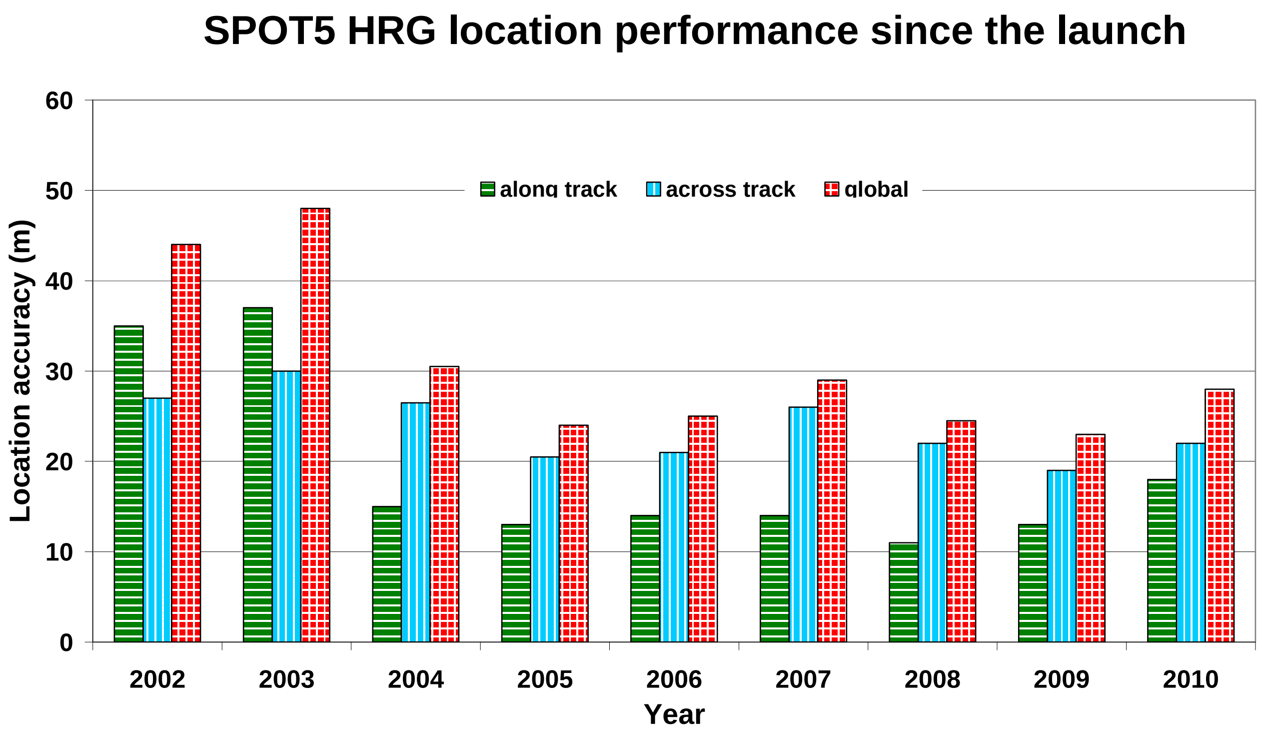
5.1.3 SPOT5 HRG location accuracy

5.1.3.1 Geometrical particular event in 2010

We don't notice any particular geometrical event since the last HRG geometrical calibration in 2008.

5.1.3.2 Evolution of SPOT5 HRG location accuracy since the launch

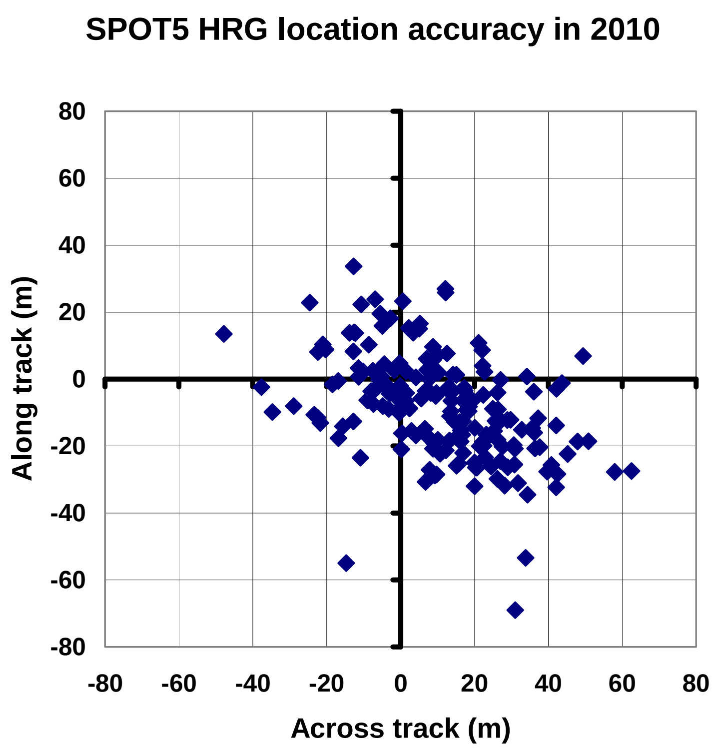
The following graph shows the evolution of SPOT5 HRG location accuracy since the launch in 2002.



The graph clearly shows an improvement of the results between 2003 and 2004. This improvement is due to a modification which has been brought onboard SPOT5 on the fourth of September 2003, as explained in paragraph A1.3. Therefore, we distinguish two periods : before September 2003 (results in annex) and after September 2003 (results in the following paragraphs).
We can observe that the results are very stable since 2004, even if we notice a slight evolution in 2010 (see below). It must be noticed that these results take into account the modification of the ground parameters (PSTS) processed in 2008 through a new alignment biases calibration, in order to have this high level of quality. This calibration is explained in the document referenced : S5-NT-76-10168-CN, "Note technique de livraison de PSTS géométriques HRG, Novembre 2008".

5.1.3.3 Results estimated between September 2009 and August 2010

SPOT5 HRG location accuracy is assessed on an annual basis for every exploitation review.
The following graph shows the distribution of the measures estimated on images acquired between September 2009 and August 2010. One point corresponds to the location accuracy of one image.



The following table shows the detailed statistical results estimated on images acquired between September 2009 and August 2010.

	SPOT5 HRG 2010		
	183 images - 09/2009 to 08/2010		
meters	**across track**	**along track**	**global**
Mean	**11**	**-9**	
Std	**19**	**15**	
RMS	**22**	**18**	**28**
Max for 90 %			**43**

We can observe that the performance is better along track than across track (standard deviation is higher for across track) : HRG across track location accuracy is mainly due to the steering mirror behavior.

We also observe both on the graph and in the table a residual bias for the across track and along track location performance. This leads to a slight evolution of performance since 2009. Il this evolution is confirmed in 2011, it will be necessary to perform a new alignment biases calibration in order to maintain a high level of performance (see Annex A2.1 for more details). However this performance remains very good and is fully compliant with specification, and even much better.

5.1.4 SPOT5 HRS location accuracy

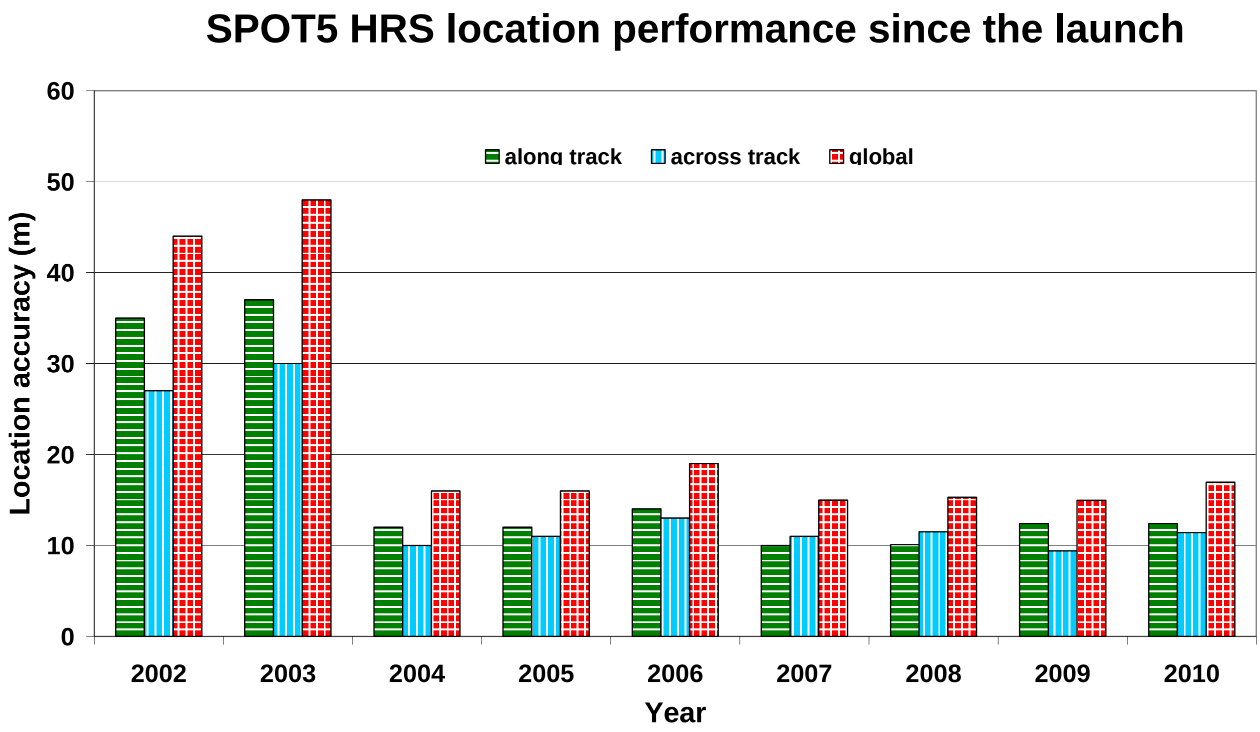
5.1.4.1 Geometrical particular event in 2010

Since 2009, we had noticed an evolution of the HRS location performance results, due to a significant evolution of the residual roll bias. Consequently, it was decided in 2010 to process a new alignment biases calibration in order to correct this phenomena. We can notice that this evolution is not new : such a phenomena, modeled by a slope, has been observed since the launch and was already corrected in 2007 through a bias (see DR1).
This new evolution in 2009-2010, modeled by a slope, was corrected through a roll bias of +16 microrad. A pitch bias of -5 microrad was also corrected. A new group of ground parameters (PSTS) was processed, valid since 01/06/2008. This calibration is explained in the document DR2.
It must be noticed that thanks to this new calibration, we have observed a gain of 30% on the HRS location performance in 2010.

All the results presented in the following paragraphs take into account this new geometrical calibration.

5.1.4.2 Evolution of SPOT5 HRS location accuracy since the launch

The following graph shows the evolution of SPOT5 HRS location accuracy since the launch in 2002.

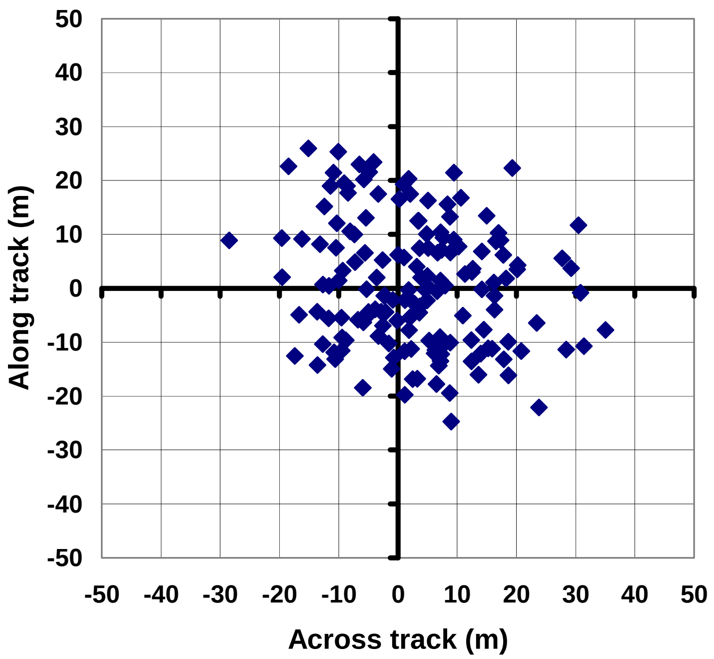


The graph clearly shows an improvement of the results since September 2003. This improvement is due to a modification which has been brought onboard SPOT5 on the fourth of September 2003, as explained in paragraph 5.1.1. The results before September 2003 are presented in annex A1 and those after September 2003 in the following paragraphs.
We can observe that the results are stable since 2004. It must be noticed that these results take into account the modification of the ground parameters (PSTS) processed in 2007 and in 2010 through a new alignment biases calibration (see above), in order to keep this high level of quality.

5.1.4.3 Results estimated between September 2009 and August 2010

SPOT5 HRS location accuracy is assessed on an annual basis for every exploitation review.
The following graph shows the distribution of the measures estimated on images acquired between September 2009 and August 2010. One point corresponds to the location accuracy of one image.

SPOT5 HRS location accuracy in 2010



The following table shows the detailed statistical results estimated on images acquired between September 2009 and August 2010.

	SPOT5 HRS 2010		
	144 images - 09/2009 to 08/2010		
meters	**across track**	**along track**	**global**
Mean	**3**	**0**	
Std	**12**	**11**	
RMS	**12**	**11**	**17**
Max for 90 %			**24**

The performance is very good and is fully compliant with specification, and even much better.

5.1.5 Synthesis

A summary of the global location accuracy for every SPOT satellite is given in the following table. These results have been estimated on images acquired between September 2009 and August 2010 for SPOT4 and SPOT5. For SPOT1, the results have been estimated on images acquired in 2001 and 2002. For SPOT2, the results have been estimated on images acquired at the end of 2008.

	SPOT5		**SPOT4**	**SPOT2**	**SPOT1**
	HRG	**HRS**	**HRVIR**	**HRV**	**HRV**
Nb images	183	144	66	16	62
Global RMS	**28 m**	**17 m**	**471 m**	**510 m**	**628 m**
Specification (RMS)	65 m	50 m	1500m	1500m	1500m

Location accuracy summary

These results are fully compliant with specifications, and even much better.

5.2 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 δd = |d-d'| in meters ⇔ **measure precision in meters** ;
- for **distances over 5 km** : rms of δd/d in percent ⇔ **measure precision in percent.**

		Length Distortion	
		d<5km δd (meters rms)	**d>5km** δd/d (% rms)
SPOT5	HRG	**3.9 m.**	**0.078 %**
	HRS	**2.7 m.**	**0.054 %**
SPOT4	HRVIR	**4.5 m.**	**0.090 %**
SPOT3	HRV	**4.6 m.**	**0.093 %**
SPOT2	HRV	**3.6 m.**	**0.073 %**
SPOT1	HRV	**5.7 m.**	**0.114 %**

These results are fully compliant with specifications (for example for SPOT5, the specification is 5m for distances under 5 km and 10^{-3}, that is to say 0.1 %, for distances over 5 km).

5.3 Multi-spectral registration

Definition :
The multispectral registration performance is the accuracy 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.

Specifications : there are given in the following table.

Results :
This performance was measured during commissioning phase for each satellite and every year for SPOT2 (until 2008), SPOT4 and SPOT5. We did not observe any evolution compared to previous years. Consequently, only latest figures, measured in 2008 for SPOT2 and in 2010 for SPOT4 and SPOT5, are given in the following table. We can notice that SPOT5 performance is given after ground registration.

			Specification	XS registration (XS pixel)	
		Resolutio n	With/Without SWIR	With SWIR	Without SWIR
SPOT5 (2009)	HRG1	10 m	0.4 / 0.2	**0.16 pix RMS**	**0.12 pix RMS**
SPOT5 (2009)	HRG2	10 m	0.4 / 0.2	**0.20 pix RMS**	**0.12 pix RMS**
SPOT4 (2009)	HRVIR1	10 m	0.3 / 0.3	**0.33 pix RMS**	**0.30 pix RMS**
SPOT4 (2009)	HRVIR2	10 m	0.3 / 0.3	**0.39 pix RMS**	**0.34 pix RMS**
SPOT3 (1993)	HRV1/2	20 m.	0.6	***No SWIR***	**0.38 pix RMS**
SPOT2 (2008)	HRV1	20 m.	0.6	***No SWIR***	**0.39 pix RMS**
SPOT2 (2008)	HRV2	20 m.	0.6	***No SWIR***	**0.39 pix RMS**
SPOT1 (1988)	HRV1/2	20 m.	0.6	***No SWIR***	**0.21 pix RMS**

These results are fully compliant with specifications (except for SPOT4, which performance was accepted during development phase).

5.4 Elevation performance

Definition :

The elevation performance represents the typical performance obtained while producing DEM with SPOT images. It usually depends on the lateral stereoscopy configuration (B/H ratio), on the time elapsed between the two acquisitions of the stereoscopic pair (for exhaustivity) and on the terrain's slopes.

Specifications :

The specification of elevation performance for SPOT5 HRG (2.5m/5m) is 5 m RMS.
The specification of elevation performance for SPOT5 HRS is 5 m RMS.
The specification of elevation performance for SPOT1, SPOT2 and SPOT4 is 10 m RMS.

Results :

The following table gives the typical performance for all instruments as measured during theirs commissioning phases.

Are considered here:

- For HRV, HRVIR and HRG: a stereoscopic pair with a B/H ratio close to 0.5, an elapsed time lower than 4 months between the 2 images of the pair and medium terrain relief.
- For HRS, a near simultaneous stereoscopic pair with a B/H ratio 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.**

These results are fully compliant with specifications.
These performance are also noticed by DEM data producers (Spot Image, etc).

6 CONCLUSION

The main performances have been successfully carried out in 2010.

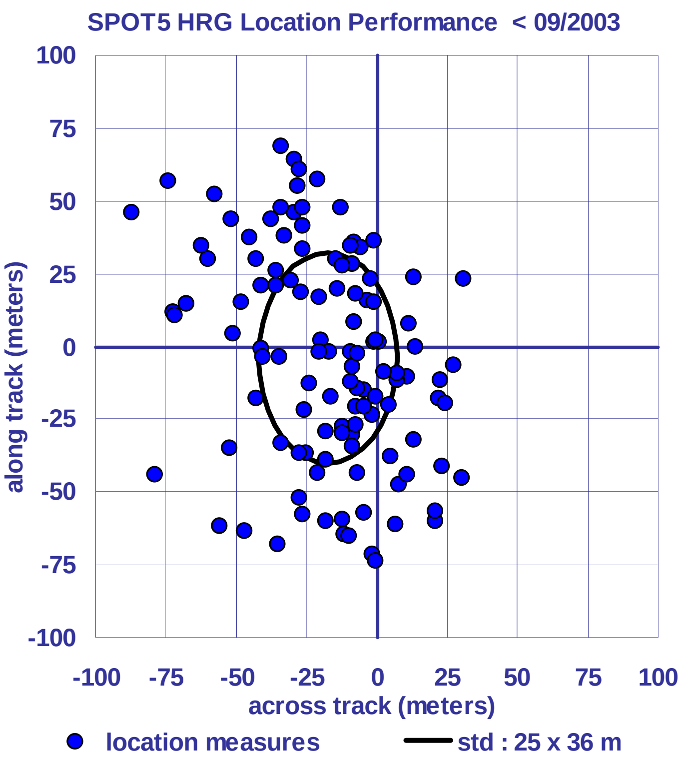
Concerning the radiometric image quality, the evolution for the absolute calibration coefficient is stable for all the instruments. There is no specification for this coefficient, which is representative of the lost of sensitivity of the detectors. The Signal to Noise ratio results are compliant with the specifications for all the satellites. It can be out of specifications for SPOT4 (SWIR channels), due to a strong degradation of the SWIR detectors (radiations sensibility). The MTF values for SPOT 5 HM channels are decreasing slightly but are better than the specified values.

Concerning the geometrical image quality, the analysis shows a good stability of the results. Particularly, location accuracy remains fully compliant and even much better than specification. The new geometrical HRS calibration processed in 2010 has allowed to maintain a very high level for HRS location performance.

Annex 1 : SPOT5 location accuracy before September 2003

A1.1 - SPOT5 HRG location accuracy before September 2003

The following graph shows the distribution of the measures estimated on HRG images acquired before September 2003. One point corresponds to the location accuracy of one image.



The following table shows the detailed statistical results estimated on HRG images acquired before September 2003.

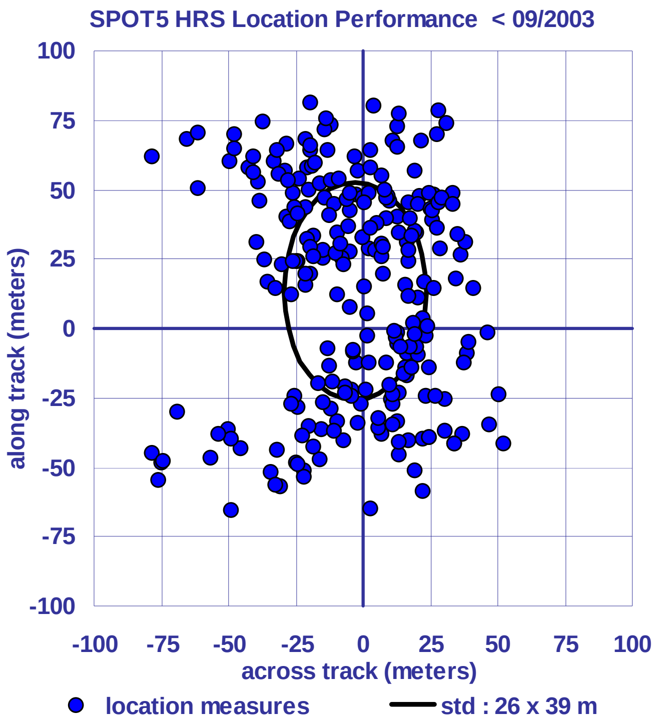
meters	SPOT5 HRG < 09/2003 116 images - 09/2002 to 09/2003		
	⊥ track	// track	global
Mean	-17	-4	18
Std	25	36	44
Rms	30	36	**47**
Max / 90 %	51	60	79

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 was impacted by a bad initialisation of the on board star tracker's relativist compensation process.
The average location performance, is not close to 0, especially along track, because location is optimised for latitudes around 20°N.

A1.2 - SPOT5 HRS location accuracy before September 2003

The following graph shows the distribution of the measures estimated on HRS images acquired before September 2003. One point corresponds to the location accuracy of one image.



The following table shows the detailed statistical results estimated on HRS images acquired before September 2003.

	SPOT5 HRS < 09/2003		
	246 images - 09/2002 to 09/2003		
meters	⊥ 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 was impacted by a bad initialisation of the on board star tracker relativist compensation process.
For HRS, the average location performance is close to 0 because it is world-wide optimised.

A1.3 SPOT5 enhanced location model for images before September 2003

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.

Before September 2003, SPOT5 location performances was impacted by a bad initialisation of the on board star tracker's relativist compensation process. This problem caused 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.

<u>Attitude polynomial correction model :</u>

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 :

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

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

Corrected latitude estimation :

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

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

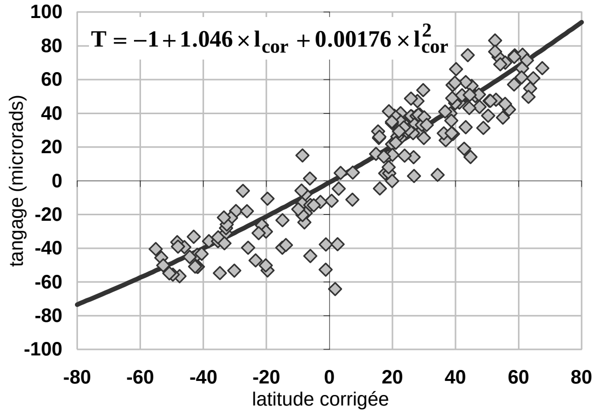
Correction model coefficients :

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

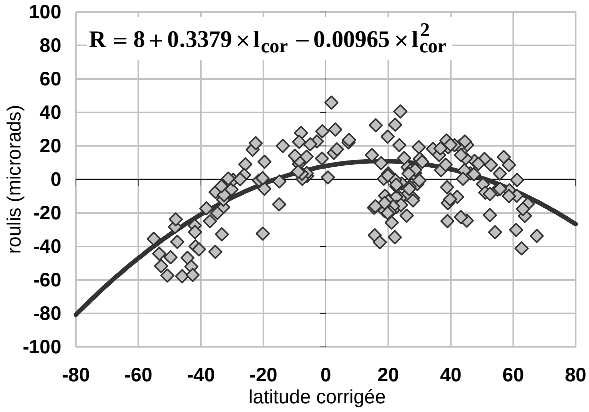
Latcor²	-0.00965	0.00176	0.00755

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 latcor² line provides coefficients R2, P2 and Y2

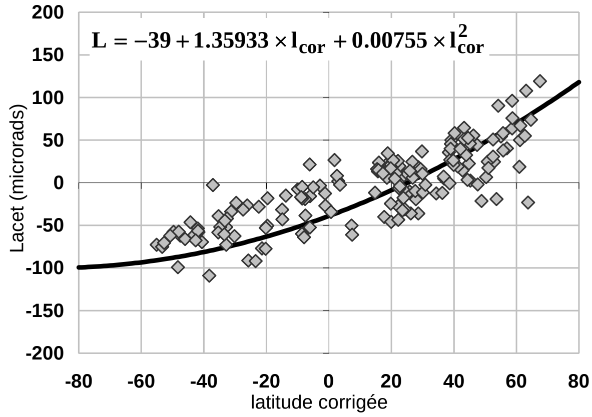
Attitude correction model tunning on HRS measures :



Pitch



Roll



Yaw

Comments :

These model doe's 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.

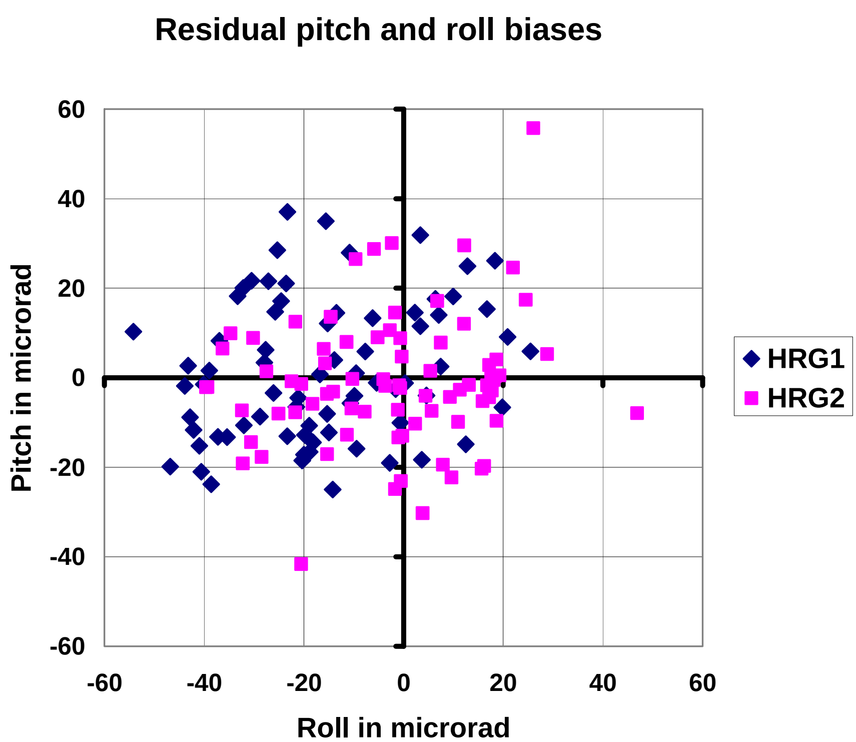
Annex A2 – SPOT5 Residual alignment biases analysis

The analysis of the residual alignment biases allows to understand the evolution of location accuracy relatively to different parameters such as time or latitude, and allows to know if a new alignment biases calibration is necessary.

A2.1 SPOT5 HRG residual alignment biases analysis

We present here only the main phenomena observed on HRG location performance since September 2003, after taking into account the geometrical calibration processed in November 2008.

The following graph and tables show the residual pitch and roll biases for both HRG, measured on images acquired between September 2009 and August 2010. We can observe a residual bias especially in roll, which explains the evolution of the location performance observed in 2010.



	HRG1 (106 scenes)	
microrad	Pitch	Roll
Mean	-10,4	-12,7
Std	13,3	21,7

	HRG2 (74 scènes)	
microrad	Pitch	Roll
Mean	1,5	-9,3
Std	15,5	18,4

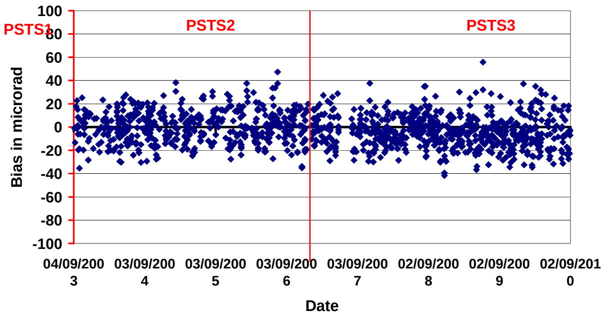
	HRG (180 scènes)	
microrad	Pitch	Roll
Mean	-5,5	-11,3
Std	15,4	20,5

The two following graphs show the evolution of the residual HRG biases in pitch and roll relatively to the date since September 2003. We can clearly observe two types of evolutions for roll bias :

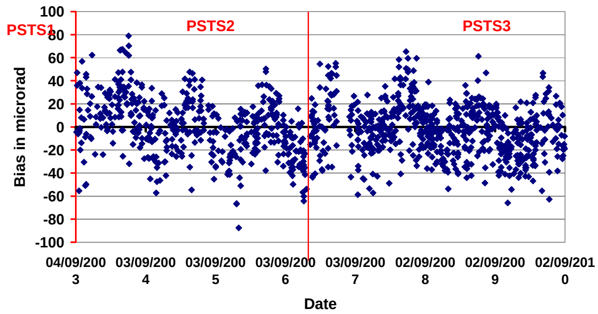
- a sinusoidal seasonal evolution, attributed to thermo-elastic effects,
- a slight slope, attributed to an ageing process, between September 2003 and December 2006, which is corrected on the beginning of the second period, in 2007-2008, thanks to the new group of PSTS n°3 (correction through a bias) but which may be seen again since

2009. If this phenomena is confirmed in 2011, it will be necessary to correct it through a new group of PSTS.

Residual HRG pitch bias

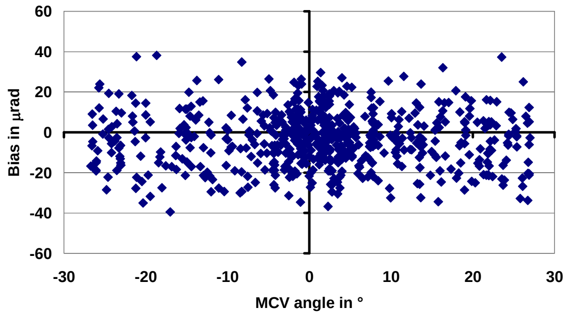


Residual HRG roll bias

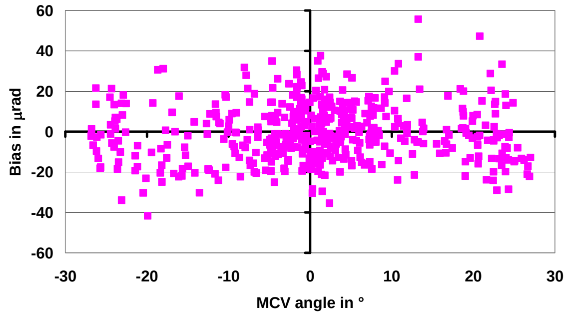


The following graphs show the evolution of the residual pitch and roll biases relatively to the steering mirror (MCV) viewing angle. All the measures since September 2003 were considered. We can observe that the MCV laws are perfectly corrected, thanks to the calibration processed in November 2008.

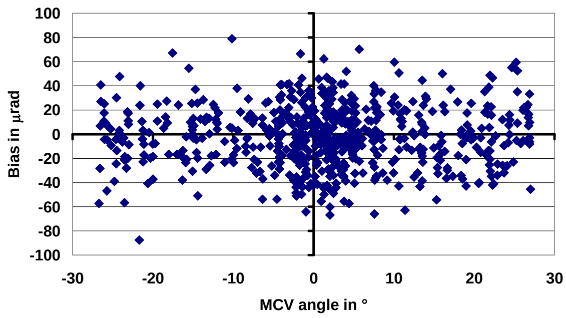
Residual HRG1 pitch bias



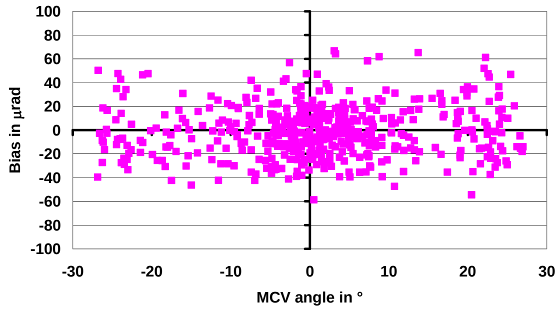
Residual HRG2 pitch bias



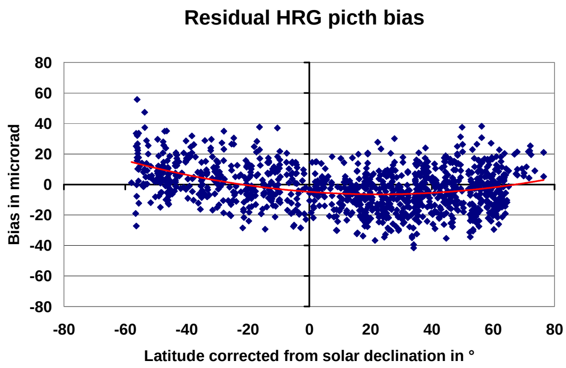
Residual HRG1 roll bias

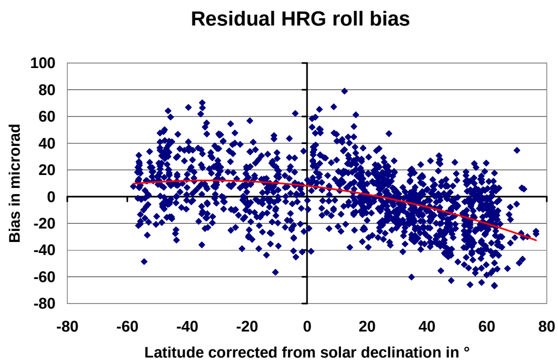


Residual HRG2 roll bias



The two following graphs show the evolution of the residual HRG biases in pitch and roll relatively to the latitude corrected from solar declination. We can observe evolutions for both roll and pitch biases, attributed to thermo-elastic effects. It must be noticed that these evolutions cannot be taken into account through a new HRG geometrical calibration (because only biases can be corrected).

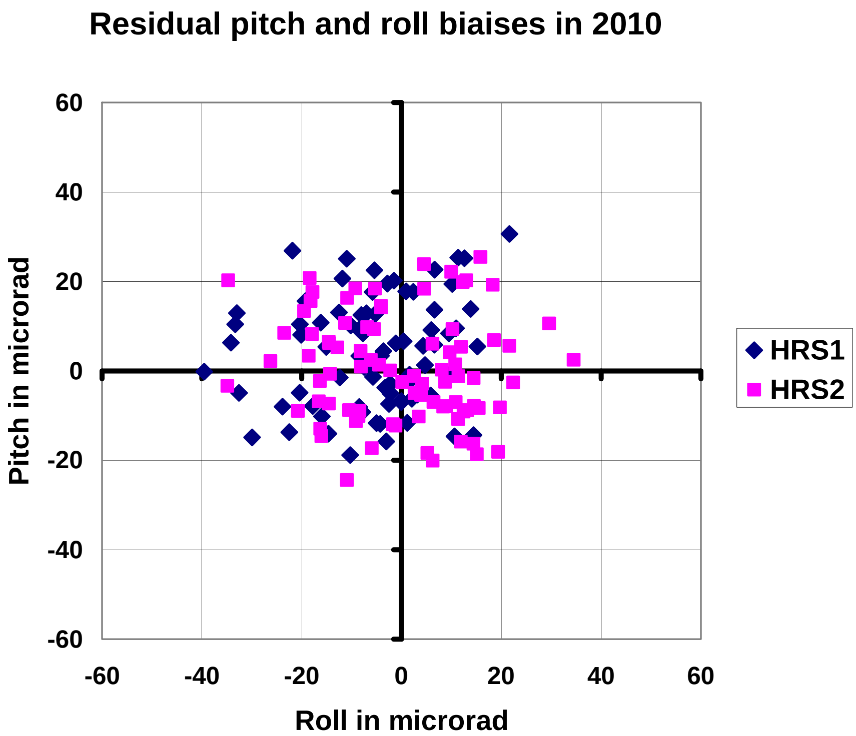




A2.2 SPOT5 HRS residual alignment biases analysis

We present here only the main evolutions observed on HRS images since September 2003.

The following graph and tables show the results obtained on HRS1 and HRS2. These results were measured on images acquired between September 2009 and August 2010, taking into account the new geometrical calibration processed in 2010. We can observe that HRS alignment biases are perfectly corrected.

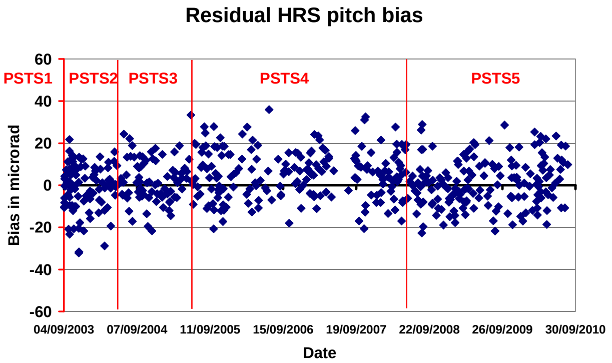


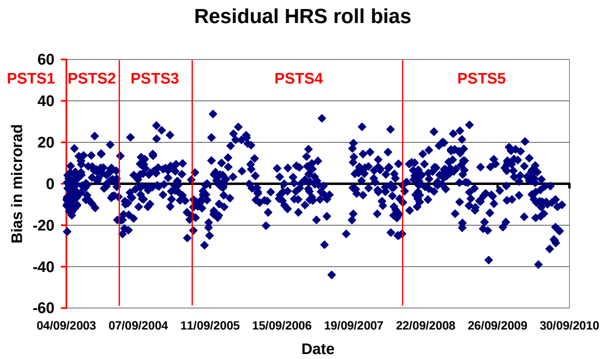
	HRS1 (75 images)	
microrad	Pitch	Roll
Mean	4	-6
Std	12	13

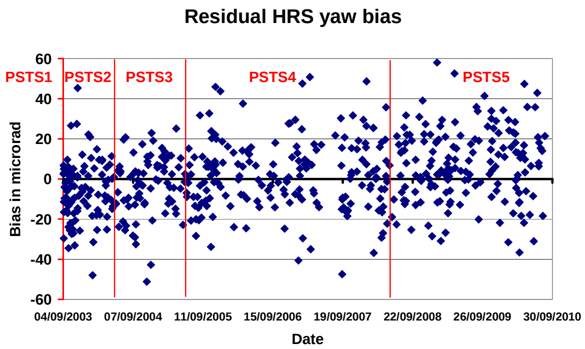
	HRS2 (75 images)	
microrad	Pitch	Roll
Mean	1	0
Std	12	15

	HRS (150 images)	
microrad	Pitch	Roll
Mean	2	-3
Std	12	14

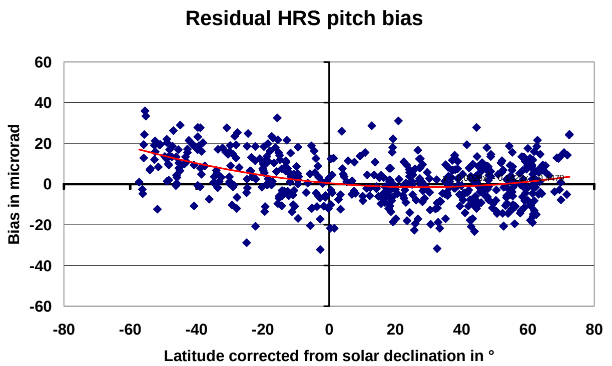
The two following graphs show the evolution of the residual HRS biases in pitch and roll relatively to the date since September 2003.
We can observe that the various alignment biases calibration, thus the various groups of ground parameters (PSTS), have allowed to maintain a very high level of performance since September 2003.
We also observe a sinusoidal seasonal evolution, attributed to thermo-elastic effects but it cannot be taken into account by a new calibration (because only biases can be corrected).

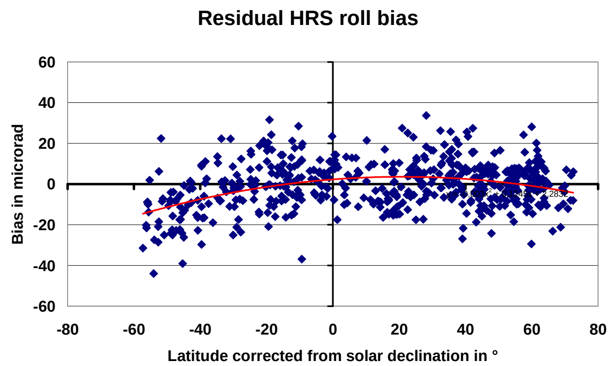






The two following graphs show the evolution of the residual HRS biases in pitch and roll relatively to the latitude corrected from solar declination. We can observe very slight evolutions for both roll and pitch biases, attributed to thermo-elastic effects. It must be noticed that these evolutions cannot be taken into account through a new HRS geometrical calibration (because only biases can be corrected).





Annex A3 – Estimation of the SPOT 2/4/5 location accuracy without ULS and/or DORIS data

The location accuracy is always measured in nominal mode:
- SPOT 5: with ULS and DORIS data.
- SPOT 2/4: with DORIS data.

The ULS and DORIS flag statut are given to final users through the auxiliary data file, on:
- Fields "STAR_TRACKER_USED" and "DORIS_USED" for DIMAP Spot Scene format.
- Ephemeris/Attitudes Record of the Header file, bytes 921 to 922 for CEOS SPOT Scene format.

DORIS system events are also reported by the International DORIS Service (IDS) at the following web page: http://ids.cls.fr/html/doris/events.php3

We can give an estimation of this performance without ULS and DORIS data, thanks to our knowledge of :
- location accuracy of SPOT4 images (there is no ULS on SPOT4),
- estimation of MADRAS data used when DORIS is out of order.

For SPOT 5 (HRG and HRS):
- When DORIS is out of order but ULS OK, location accuracy is estimated to about 250 meters RMS.
- When ULS is out of order, location accuracy is estimated to about 350 meters RMS (like SPOT4's one).

For SPOT 2/4:
- When DORIS is out of order, location accuracy is estimated to about 500 meters RMS.