

The HRS-SAP initiative: A scientific assessment of the High Resolution Stereoscopic instrument on board of SPOT 5 by ISPRS investigators.

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ABSTRACT:

SPOT 5 has been commissioned after performed its launch in May 2002 and the geometric calibrations and assessments show the good quality of the images. Few months after this launch CNES proposed to ISPRS a joint initiative for assessing the new HRS (High Resolution Stereoscopic) instrument and especially the quality and accuracy of DEM which could be derived from HRS stereo pairs. This proposal was agreed and the announcement of the program (HRS-SAP) and its organization (HRS Study Team) was made during the ISPRS Commission I Symposium in Denver (November 2002).

The HRS-SAP is organized within a HRS Study Team with a Secretariat, Principal Investigators and Co-Investigators. Nine test areas have been selected with associated PI's. In addition 16 more Co-Investigators have been accepted and they have received HRS images and Reference Data. Final results should have been achieved by end 2003 but up to April 2004 only half of the reports have been received. Nevertheless on the Bavarian test site all 7 investigators have produced results, confirming the high quality of the HRS instrument, especially on open areas where a height standard deviation of about 5 m is the rule. More detailed results and synthesis are still expected to be presented during this Istanbul Congress.

RÉSUMÉ:

La recette en vol de SPOT 5 a été prononcée après le lancement du satellite en mai 2002, confirmant la bonne qualité géométrique des images. Quelques mois après ce lancement le CNES a proposé à la SIPT de mettre en place une initiative pour évaluer la précision et la qualité du nouvel instrument HRS (Haute Résolution Stéréoscopique) qui est destiné à produire des MNS (Modèles Numériques de Surface) Cette proposition a été acceptée et l'annonce du programme HRS-SAP (Programme Scientifique d'Evaluation d'HRS) ainsi que de son organisation (Equipe d'Etude HRS) a été faite lors du Symposium de la Commission I de la SIPT à Denver en novembre 2002.

Le programme HRS-SAP est organisé autour d'une équipe d'étude comprenant un Secrétariat, des investigateurs principaux (PIs) et des co-investigateurs (CoIs). Neuf zones test ont été retenues avec un investigateur principal pour chacune d'elle. Seize autres co-investigateurs ont été acceptés. Les données HRS, accompagnées de données de référence (MNT, points de contrôle, ..) ont été livrées par Spot Image en juillet 2003. Les résultats finaux auraient dus être fournis pour fin 2003 mais en avril 2004 seule la moitié des rapports ont été remis. Cependant sur l'un des sites, en Bavière, les 7 investigateurs ont tous fourni des résultats, confirmant la bonne qualité de l'instrument HRS, en particulier en région de plaine où un écart-type en Z de l'ordre de 5 m est généralement observé. Des résultats plus détaillés et synthétiques sont espérés lors des présentations à ce Congrès d'Istanbul.

ZUSAMMENFASSUNG:

Spot 5 ist im Mai 2002 gestartet worden; während der anschließenden Testphase mit geometrischer Kalibration und Funktionsprüfung der Kamera konnte die erwartete hohe Qualität der Bilddaten bestätigt werden. Einige Monate nach dem Start bot CNES der ISPRS an, in einer gemeinsamen Initiative die neue HRS (High Resolution Stereoscopic) Kamera und die aus ihren Stereoaufnahmen gewonnenen DEMs im Hinblick auf die erreichbare Genauigkeit zu untersuchen. Dieser Vorschlag wurde von ISPRS angenommen und als HRS-Scientific Assessment Programm (HRS-SAP) auf dem Denver Symposium der Commission I im November 2002 bekannt gegeben.

Für die Durchführung wurde ein HRS-Study Team gebildet. Dieses Team besteht aus einem koordinierenden Sekretariat und den Principal- and Co-Investigators. Insgesamt sind neun Testgebiete mit zugehörigen PIs ausgewählt worden; weiterhin wurden Vorschläge von 16 Co-PIs akzeptiert. Alle Beteiligten haben HRS-Aufnahmen und Gelände Referenzdaten erhalten. Ergebnisberichte sollten bis Ende 2003 geliefert werden, jedoch wurde bis April 2004 nur die Hälfte der erwarteten Berichte eingereicht. Für das Testgebiet "Bavaria" haben alle 7 Investigators Ergebnisse geliefert, die die hohe Qualität der HRS Aufnahmen bestätigen; insbesondere wurde im offenen Gelände eine Standardabweichung in der Höhe von 5m erreicht. Weitere ausführlichere Ergebnisse werden auf dem Istanbul Kongress präsentiert werden.

1. INTRODUCTION

The HRS Scientific Assessment Program is a new initiative for CNES and its partners in the SPOT program. It is the first time that an international user community (ISPRS) is formally associated to the scientific assessment of the "system" quality of a satellite, in this case SPOT 5 and especially its new instrument HRS (High Resolution Stereoscopic)

The results of this program, to be presented during the next ISPRS Congress in Istanbul, July 2004, should help CNES to improve its future Earth Observation systems (such as Pléiades: Baudoin 2004) and all users to better know and trust the accuracy and quality of the HRS instrument and of the derived DEM.

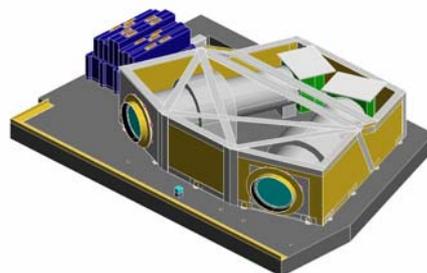


Fig 2: HRS instrument

2. SPOT 5

SPOT 5 is the latest satellite of the SPOT family, launched during the night of the 3rd to the 4th of May 2002 from the European Spaceport in Kourou (French Guyana) with one of the last Ariane 4 to be used. (Flight V151 with AR42P)

This satellite (Fig 1) ensures data continuity with the previous satellites but provides also enhanced images (at 2.5 m resolution with its two HRG instruments) and new stereoscopic capabilities with the HRS instrument. A fourth imaging sensor, Vegetation 2 (recurrent model of Vegetation 1 on SPOT 4) gives a wide-swath (2500 km) daily coverage. A star tracker is used to get better attitude measurements and therefore better image location.

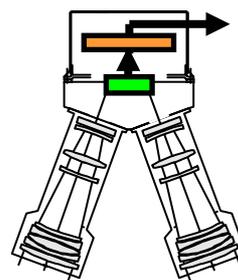


Fig 3: HRS optics and detection unit

A continuous strip of 600 km length can be covered stereoscopically with 10 m ground resolution across track and with 5m ground sampling distance along track (parallax lines). (Fig. 5)

High Resolution Geometry Instrument

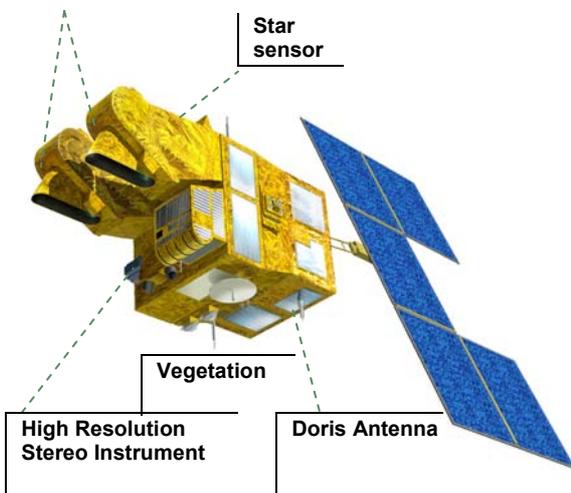


Fig 1: Spot 5 satellite and payloads

3. HRS CHARACTERISTICS

The High Resolution Stereoscopic instrument (HRS) has already been described (Fratter, 2001; Bernard, 2001, Gleyzes, 2003) Figures of the instrument (Fig.2), of its optics (Fig.3) and its main technical characteristics (Table 4) are presented below. With two telescopes HRS acquires nearly simultaneous stereo pairs (at 90-second interval) of 120-km swath, along the track of the satellite, with a B/H ratio of about 0.8.

HRS characteristics	
Mass	90 kg
Power	128 W
Size	1.0 x 1.3 x 0.4 m ³
Panchromatic band	0.48-0.70 μm
Ground sampling distance	10 m cross-track, 5 m along track
Field of view/swath width	+/- 4° 120 km
Focal length	0.580 m
Detectors per line	12,000
Detector size	6.5 μm
Integration time/ line	0.752 ms
Fore/aft viewing angle	+/- 20°
Signal / Noise Ratio	> 120
MTF	> 0.25

Table 4: HRS characteristics

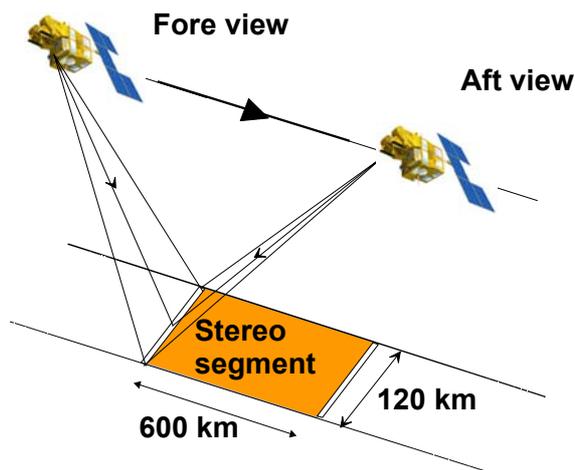


Fig. 5 Stereo acquisition

4. HRS PARTNERS

One particularity of this instrument is its programmatic framework. In January 1999 CNES, Spot Image and Matra Marconi Space (MMS which is now Astrium) signed an Agreement about the development of this instrument in which Spot Image is funding 54% of the cost of the instrument. This private investment on an instrument was quite new in the Spot program, previously paid by French, Swedish and Belgian public funds only (excepted the SPOT 5 ground segment paid by Spot Image). In April 2002 another Agreement was signed between CNES, the French Ministry of Defense and Spot Image about the use and exploitation of the HRS instrument, split between French Defense and civilian / commercial market. Spot Image and IGN (Institut Géographique National, the French Mapping Agency) have also defined together a new 3D Database, named Reference3D, mainly extracted from HRS data. (Airault, 2003; Bernard, 2004)

These agreements are reflecting the fact that the main HRS objective is to produce DEM on (very) large areas to satisfy dual (military and civilian) use. Therefore no original image data will be offered on the market.

5. HRS ASSESSMENT

After a two-month in-flight commissioning phase, the use of the satellite was given in the hands of its commercial operator, Spot Image, on the 12th of July 2003.

All on-board equipments have been checked and declared operational. About twenty well-equipped test areas all over the world have been used for either radiometric or geometric calibration. (Breton, 2002)

For the HRS payload the two telescopes, HRS1 and HRS2, were calibrated with a remaining error of less than 0.05 pixel (Bouillon 2003). HRS absolute location accuracy, decreased from an initial 63 m RMS value right after the commissioning phase (July 2002), down to about 20 m RMS (Bouillon, 2004). This result is even increased (16-m @ 90%) using spatiotriangulation (bundle block adjustment on a large area) (Airault, 2003)

First assessments of DEM accuracy derived from HRS give good results, even better than expected: in flat or low-relief landscape the altimetric accuracy is better than 5m RMS,

with more than 95% good correlation. (Rudowski, 2003; Nonin, 2003; Valorge, 2003).

It can be noticed that this HRS assessment has been performed on very large areas (about 600 km by 200 km over the Alps) and with high quality reference data (DEM derived from aerial photogrammetry on Manosque area, one of the HRS-SAP test site)

6. BACKGROUND OF THE HRS-SAP

As mentioned in the introduction the HRS-SAP is a new initiative. Its originality is due to new status and capabilities of the HRS instrument.

Previously, for SPOT 1 to SPOT 4, and this is also true for the main payload of SPOT 5 (the two HRG instruments) all images (at several geometrical processing levels) are available to any user, through the Spot Image distribution network.

This is not usually the case for the HRS instrument which images are archived and processed to produce and market Digital Elevation Models, as said previously.

Nevertheless, many scientific users asked to get HRS images not only for deriving HRS DEMs, but also for other photogrammetric purposes or for thematic evaluations.

It has been recognized that, beyond the operational use of HRS, for which stereo pairs are intermediate products, some selected scientific and/or assessment projects could be given the permission to use original HRS images. The Earth Science and Applications unit at CNES then proposed to set up an international team in association with ISPRS especially for the photogrammetric assessment of the HRS instrument. For other scientific projects, other solutions, on a case by case basis, are also possible.

CNES reached an agreement with ISPRS for promoting and organizing such assessment in July 2002, agreeing that the announcement of this common initiative should be done during the Commission I Symposium, in Denver in November 2002.

Manfred Schroeder, as Chairman of WG I-2 of ISPRS (Sensor calibration and testing), agreed to represent ISPRS and co-chair this "HRS Study Team". The initiative was announced during the Denver Symposium and also published on the ISPRS website and E-mailed to about 200 potential participants.

7. THE HRS STUDY TEAM

The HRS Study Team is organized as follows:

A Secretariat, composed of the authors of this paper, is in charge of the management of the Program. It is co-chaired by Alain Baudoin for CNES and Manfred Schroeder for ISPRS. The other members are representing CNES (Christophe Valorge) in charge of image quality, Spot Image (Marc Bernard) in charge of HRS production and delivery and IGN (Véronique Rudowski) in charge of Reference Data assessment and of result synthesis.

The Principal Investigators (PI's) are responsible for providing reference data on selected test areas. This Reference Data should be more accurate than the expected HRS accuracy (5m) and include a precise DEM (derived from photogrammetry or laser with 1-2 m Z accuracy) and/or Ground Control Points (with X-Y-Z accuracy better than 1m).

Co-Investigators (as well as PI's) should use HRS stereo pairs and Reference Data to produce DEM (with one or several

methods) and to evaluate them in terms of quality and accuracy, and when possible to compare (or combine) them with other sources (ex HRG, SRTM, laser...).

8. THE PI SELECTION

After the publication of the HRS-SAP initiative 34 proposals were received from all parts of the world. A Selection Team was organized on March 19, 2003 in Toulouse, with the HRS Secretariat and the ISPRS Secretary General. Each proposal was quoted according to several criteria. Due to the very short schedule only areas where HRS data was already available were accepted. Then the expected quality of



Fig 6 HRS stereo pair on test site 5 (Aix-en-Provence area, France)

Then nine sites were confirmed : three in France: Manosque, Aix-en-Provence (Fig. 6) and Montmirail; three in Europe, outside France: Chiemsee (Bavaria - Germany), Liege (Belgium), Barcelona (Catalonia- Spain); and three in other parts of the World: Merowe (Sudan -Africa), Melbourne (Australia) and Rasht (Iran). Unfortunately, no site could be selected in America. The selected sites are well diversified in terms of climate, relief or landscape and it is hoped that future results could be representative of most situations in the world.

9. CO-I SELECTION

Few days after the pre-selection of the PI's in March 2003 a call for participation as Co-I was published by ISPRS. Then 19 new proposals have been received by the end of May 2003.

The selection was made using email exchanges between the Selection Team, asking when necessary more information to the candidates. For this selection the main criterion was the scientific and technical professional capacity (in DEM production) of the proposed team.

After this selection, made on June 14, 2003, 15 Co-Investigators have been agreed and all of them signed the requested Co-I Agreement. A 16th Co-Investigator has been selected in November 2003, after having formalized his proposal during the ISPRS Workshop in Hanover. As some CoI's were already PI's and some have been selected on two test sites the total number of experiments is 29.

the proposed Reference Data and also the experience and scientific references of the candidates were also quoted.

From the 34 proposals 11 have been selected. The candidates were informed of this selection. When pre selected they have been asked to formally agree the HRS SAP rules and to send the proposed Reference Data for checking.

Among those pre-selected PI's most of them have agreed and signed the PI Agreement, and sent their Reference data to the Secretariat. Unfortunately an interesting site on Gujarat-India, proposed by Dr. Ramesh P. Singh (Department of Civil Engineering, Indian Institute of Technology, India) could not be confirmed, as the Reference DEM has been found not accurate enough. Another site in the Alps was also cancelled due to the fact that the pre-selected PI, (Etienne Berthier, GDR STRAINSAR, France) could not accept the proposed HRS images due to too large snow coverage.

10. DATA DELIVERY

In order to avoid unnecessary data duplication all HRS images and Reference Data (Table 7) were produced and sent at the same time, by mid July 2003, by Spot Image.

Test site	HRS stereo pairs	Reference Data
1 Montmirail	1	DEMs 1m
2 Merowe	1	DEM 1m, GCPs
3 Liege	1	DEM 1m, 74 GCPs
4 Melbourne	1	DEM 1m, 33 GCPs
5 Aix-en-P.	1	DEMs 0.5-1m
7 Rasht	1	DEM 1.6m, GCPs
8 Barcelona	2 (+2 HRG)	DEMs 1.1 m Orthoimages
9 Bavaria	2	DEMs 0.5-2m, 82 GCPs
10 Manosque	2	DEMs 0.5-1 m

Table 7 Data provided to the investigators

It can be noted that on the Barcelona test site two HRS stereo pairs have been provided, and also two HRG images, at 2.5m resolution, giving the opportunity to test tri-stereo.

11. INVESTIGATORS

For each test site the number of investigators is between two and seven:

- 2 for Merowe (Sudan), Liege (Belgium), Melbourne (Australia), Aix-en-Provence;

- 3 for Manosque (France), Montmirail (France) and Rasht (Iran);
- 5 for Barcelona (Spain);
- 7 for Chiemsee (Germany)

Here is the list of Principal Investigators (PIs) and Co Investigators (CoIs) selected for each test site. For other investigators working with these PIs and CoIs please refer to other papers presented in HRS sessions of this Congress listed at the end of this paper.

TS 1: Montmirail (France)

PI: Sylvain Airault (Institut Géographique National, France)
 CoI-1: Ramanathan Nandakumar (Satellite Photogrammetry & Digital Cartography Division, Space Applications Centre, ISRO, India)
 CoI-2: Yun Zhang (Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada)

TS 2: Merowe (Sudan)

PI: Rolf Becker (MAPS Geosystems, UAE)
 CoI-1: Isabelle Couloigner (Department of Geomatics Engineering, Faculty of Engineering, University of Calgary, Canada)

TS 3: Liège (Belgium)

PI: Yves Cornet (Geomatics Unit, Department of Geography, University of Liège, Belgium)
 CoI-1: Isabelle Couloigner (Department of Geomatics Engineering, Faculty of Engineering, University of Calgary, Canada)
 CoI-2: Michel Roux (Département TSI, ENST, France)

TS 4: Melbourne (Australia)

PI: Clive Fraser (Department of Geomatics, University of Melbourne, Australia)
 CoI-1: Ramanathan Nandakumar (Satellite Photogrammetry & Digital Cartography Division, Space Applications Centre, ISRO, India)

TS 5: Aix-en-Provence (France)

PI: Ian Dowman (Department of Geomatic Engineering, University College London, UK)
 CoI-1: Michel Roux (Département TSI, ENST, France)

TS 7: Rasht (Iran)

PI: Farhad Kianifar (National Cartographic Center of Iran)
 CoI-1: Yun Zhang (Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada)
 CoI-2: Mikhail Fomtchenko (Sovinformsputnik, Russia)

TS 8: Barcelona (Spain)

PI: Wolfgang Kornus (Institut Cartogràfic de Catalunya, Spain)
 CoI-1: Ian Dowman (Department of Geomatic Engineering, University College London, UK)
 CoI-2: Peter Reinartz (DLR, Germany)
 CoI-3: Urbano Fra Paleo (Department of Geography and Spatial Planning, University of Extremadura, Spain)
 CoI-4: Hannes Raggam (Joanneum Research, Institute of Digital Image Processing, Austria)

TS 9: Bavaria (Germany)

PI: Peter Reinartz (DLR, Germany)
 CoI-1: Daniela Poli (Institute of Geodesy and Photogrammetry, Swiss Federal Institute of Technology, ETH Zurich, Switzerland)

CoI-2: Karsten Jacobsen (Institute of Photogrammetry and GeoInformation, University of Hannover, Germany)
 CoI-3: Jorge Torres (Division de Física Aplicada, CICESE, Mexico)
 CoI-4: Romuald Kaczynski (Institute of Geodesy and Cartography, Poland)
 CoI-5: Alexander Suchkov (Geoinformation Agency – Innoter, Russia)
 CoI-6: Konstantin Eremeev (Geo-Nadir, Russia)

TS 10: Manosque (France)

PI: Véronique Rudowski (Institut Géographique National, France)
 CoI-1: Maria Tsakiri-Strati (Department of Cadastre, Photogrammetry & Cartography, Aristotle University of Thessaloniki AUTH, Greece)

It can be noted that there is no TS 6, as this pre-selected test area on Gujarat in India has not been confirmed, as for TS 11 on Mont-Blanc in France.

12. EXPERIMENTS ARE STILL IN PROGRESS

According to the initial schedule all results should have been completed and sent to the HRS-SAP Secretariat by 31 December 2003 in order to leave some time for analysis and synthesis. Only few results were available by this date and the deadline has been postponed until 29 February 2004.

Up to now (15 April 2004) only 13 reports and DEM have been provided, some of them presented as preliminary reports, to be completed.

Therefore it is difficult to give in this paper, as expected, an overview of the results. Most of the investigators should present their results during dedicated sessions (3 Technical Sessions and 1 Poster Session) at the ISPRS Congress and then more results should be available.

Nevertheless it can be noticed that one test site has been particularly appreciated and studied: this is the Bavarian area (TS 9) on which all 7 investigators have provided reports and DEMs. Comparison of these results will be presented by Véronique Rudowski in this Congress (Rudowski, 2004)

It can be noticed that, as different orientation methods, matching processes and quality assessments have been used, comparisons should be done carefully.

Several orientation models have been used, with more or less unknown parameters. Daniela Poli has found that the use of Rational Polynomial Coefficients could lead to slightly better results than using only a Rigorous Sensor Model (Poli, 2004)

Different matching processes, with or without epipolar resampling have been used. Jorge Torres (Torres, 2004), as among others, has used a pyramidal (multi-resolution) approach.

Peter Reinartz has made an interesting comparison of results with and without using Ground Control Points. Without any GCP, using only ancillary data an absolute mean height accuracy of 5 to 9 meters could be achieved with a standard deviation of 2 to 4 meters on matched points and of 4 to 7 meters for interpolated DEM. With only few GCPs the absolute accuracy can be improved to 1-3m. (Reinartz, 2004)

Karsten Jacobsen (Jacobsen, 2004), as Peter Reinartz, has compared DEM accuracies on open areas and forest areas. The use of a specific software to take into account forest/urban areas can improve the overall accuracy.

As expected, most of investigators have identified worse results in mountainous areas and Karsten Jacobsen has evaluated the slope effect: he proposes that height accuracy could be given by a linear formula:

$\sigma H = a + b \cdot p$ where a and b are accuracy parameters and p the terrain slope ($\tan(\alpha)$)

$a = 3.5$ m to 5 m and $b = 1.6$ m to 23.2 m (depending of the landscape)

13. CONCLUSION

The HRS SAP program has already confirmed the high quality of the HRS instrument on board of Spot 5. Unfortunately it is too early to give a complete overview of the program as only half of the expected results have been delivered at this stage (mid-April 2004). Nevertheless, the DEM/DSM accuracy derived from HRS has been assessed around 5 m (relative) / 10 - 15 m (absolute).

Current results show that even without GCPs good results could be obtained from HRS, due to the quality of the ancillary data. As expected better results are obtained on flat areas, without forest or urban features. This has been identified and measured on the Bavarian test site.

There is still more work to do, comparing results according to other types of landscape (if results on Africa, Asia, Australia are provided), other orientation or matching methods. This should lead to interesting exchanges between investigators (most of them have worked alone up to now)

With the authorization of the investigators data and results of this HRS-SAP initiative should be available on the ISPRS web site after this Congress.

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