# REFERENCE3D LOCATION PERFORMANCE REVIEW AND PROSPECTS

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**ABSTRACT**

This paper presents work on modelling and technical qualification of HRS by the French space agency CNES and the French mapping agency IGN. The results of this work show that existing topographic maps are no longer needed to produce extremely accurate digital elevation models (DEMs) and orthoimages, and that the ambitious pre-launch specifications set by users for Reference3D (16 metres for 90% of points) can be met using data from the HRS instrument on SPOT 5, provided the many parameters involved are monitored continuously. Such monitoring is essential if we are to dispense with ground control points (GCPs), the scarcity of which has so far been a significant handicap precluding wider dissemination and use of satellite data in many application areas.

## 1. INTRODUCTION

Spot Image and France's Institut Géographique National (IGN) began working together in August 2002 to produce a 3D database containing DEMs and orthoimages, called Reference3D, compiled using data from the High Resolution Stereoscopic instrument (HRS) on SPOT 5. HRS acquires stereopair images simultaneously at a resolution of 5 metres by 10 metres, with a base-to-height ratio (B/H) of 0.8.

### 1.1 Reference3D location performance specifications

Reference3D specifications were based on requirements expressed by users prior to the launch of SPOT 5:

- circular planimetric accuracy: < 16 metres for 90% of points
- elevation accuracy: < 10 metres for 90% of points
- maximum number of ground control points: none

This paper aims to present work undertaken to optimize Reference3D's location performance and to check compliance with specifications.

### 1.2 Reference3D production process

The DEM production process basically involves three steps:

- Registration of each stereopair to be processed
- Generation of a DEM by automatic correlation of each stereopair
- Overall calculation of absolute site geometry by block triangulation; this step has a major bearing on Reference3D's location performance

### 1.3 Sources of error affecting location performance

The chief sources of error governing Reference3D location accuracy are:

- Focal plane calibration
- Thermoelastic effects related to latitude
- Determination of satellite attitude
- Time-related effects (seasonal variations, ageing)
- DEM extraction
- HRS instrument stability

## 2. ERROR MODELLING

### 2.1 Interior orientation of the HRS instrument

The focal planes of the HRS instrument were calibrated with accuracy better than 0.03 pixels rms from high-resolution aerial photos and from a very accurate digital surface model (< 1 metre) (Gachet, 2003).

### 2.2 Determining attitudes and microvibrations

Attitudes are determined using a gyro-stellar unit optimized during the in-orbit commissioning phase. The residual location error is lower than 8 metres rms (the impact of very-high-frequency microvibrations is negligible).

### 2.3 Orbital thermoelastic effects

**Initial absolute location performance**

Drift along the satellite track is approximately 1 metre per degree latitude (Figure 1).

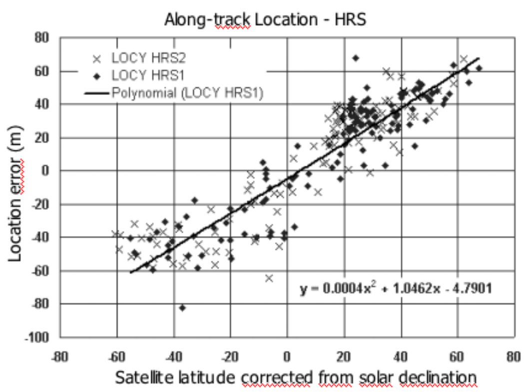


Figure 1. Initial HRS along-track location error (measured from 162 HRS stereopairs)

Errors observed in the cross-track direction are of the same order of magnitude and are due to thermoelastic distortion of the HRS instrument and/or of the support structure. These errors are modelled using the satellite latitude corrected for solar declination (Bouillon, 2003).

### 2.4 Seasonal residuals

Once the model has assimilated the above corrections, monitoring of location performance with respect to the viewing date shows that we can further reduce measurement dispersion, by applying an additional correction model that uses the exact calendar day. The amplitude of this phenomenon is of the order of 10 metres.

### 2.5 Temporal stability and ageing of HRS instrument

We do not yet have enough data for detailed analysis. Measurements made so far have shown that the impact of these parameters is small.

## 3. RESULTS

### 3.1 Evaluation protocol

To check all parameters related to geometric image quality, we use a set of 20 test sites around the globe, each with 100 points with known *xyz* or *z* values. For each site, we evaluated performance by comparing results obtained using block triangulation, with and without GCPs. Location errors are measured in scene corners, whose three-dimensional coordinates are estimated by matching the same corner in the "foreground" scene and the "background" scene.

For each test described below, results are presented in three ways:

- A graph showing, for each scene corner, the spatial distribution of planimetric location errors. The magenta circle represents the 16-metre/90% specification.
- A graph showing, for each scene corner, the error measured in the $z$ direction ($x$ axis) and the residual parallax ($y$ axis). The residual parallax has a strong bearing on DEM processing, since we assume that the one-dimensional matching process yields an accurate estimate of residual parallax.
- A table of statistics.

### 3.1 Raw location performance

The first estimate measures "raw" location performance, that is, the level of accuracy achieved directly from positional and attitude measurements acquired on board the satellite, without correcting for its orbital position and without comparing points in the two images. The planimetric accuracy for 90% of points is around 60 metres, and the elevation accuracy around 15 metres.

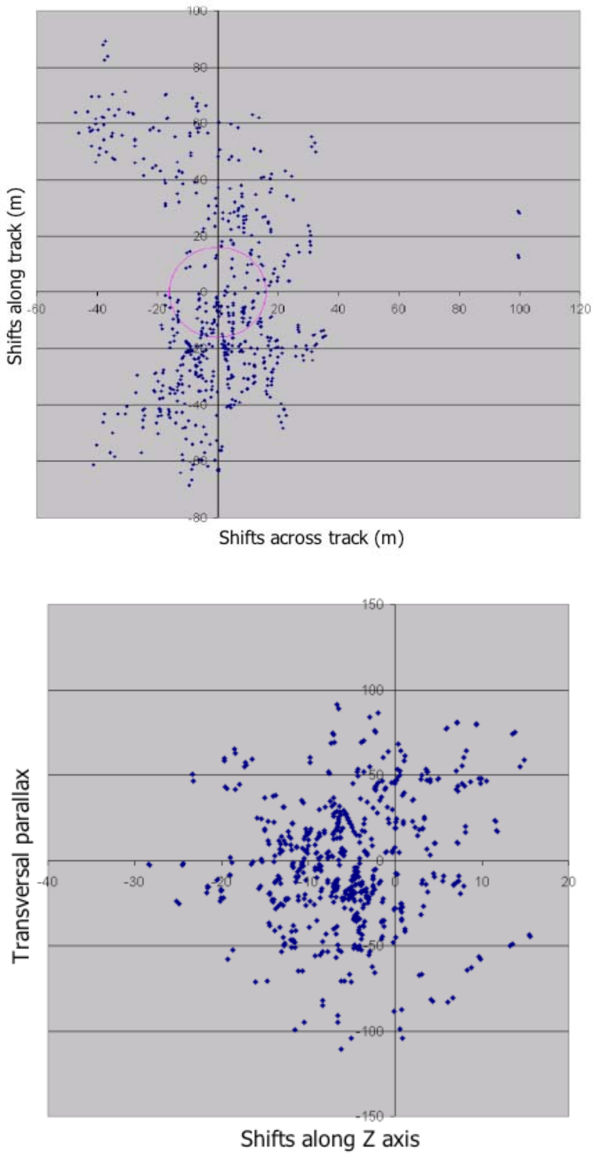


Figure 2. Raw planimetric and elevation location accuracy

| | Cross track | Along track | z |
|---|---|---|---|
| **Mean** | -0.7 m | -3.7 m | -5.6 m |
| **Standard deviation** | 18.7 m | 34.3 m | 7.4 m |
| **90% threshold** | 62.4 m | | 14.5 m |

Table 3. Raw location performance

### 3.3 Modelling of thermoelastic effects related to orbital position

Correcting for thermoelastic effects related to the satellite's orbital position significantly improves location performance, yielding a planimetric accuracy of 27 metres and an elevation accuracy of 12 metres for 90% of points.

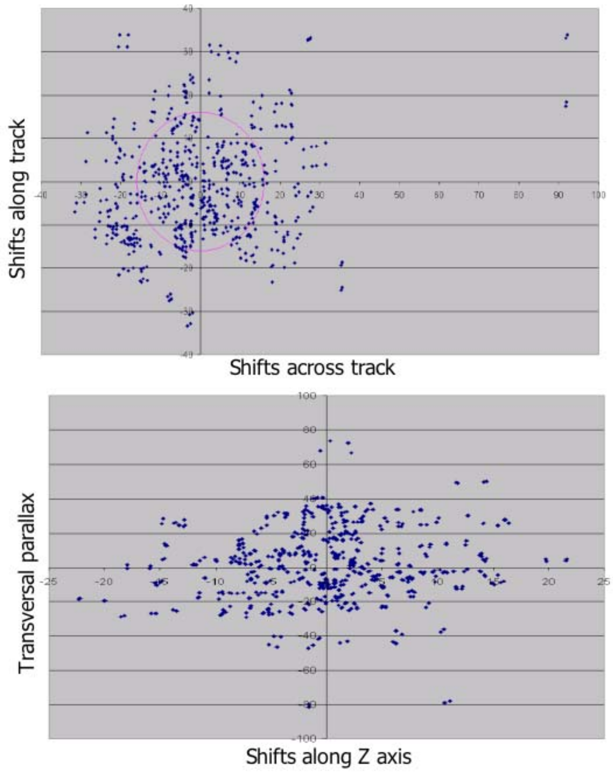


Figure 4. Planimetric and elevation location accuracy after correction for orbital position

| | Cross track | Along track | Z |
|---|---|---|---|
| **Mean** | -0.1 m | -1.3 m | -0.1 m |
| **Standard deviation** | 15.5 m | 12.4 m | 7.4 m |
| **90% threshold** | 27.4 m | | 12.8 m |

Table 5. Location performance after applying a correction model factoring in orbital position

### 3.4 Block triangulation

Block triangulation proves most beneficial, increasing planimetric accuracy to 12 metres and elevation accuracy to 4 metres for 90% of points. Planimetric location errors are clustered according to the test sites. Elevation displacements virtually cancel out residual parallax.

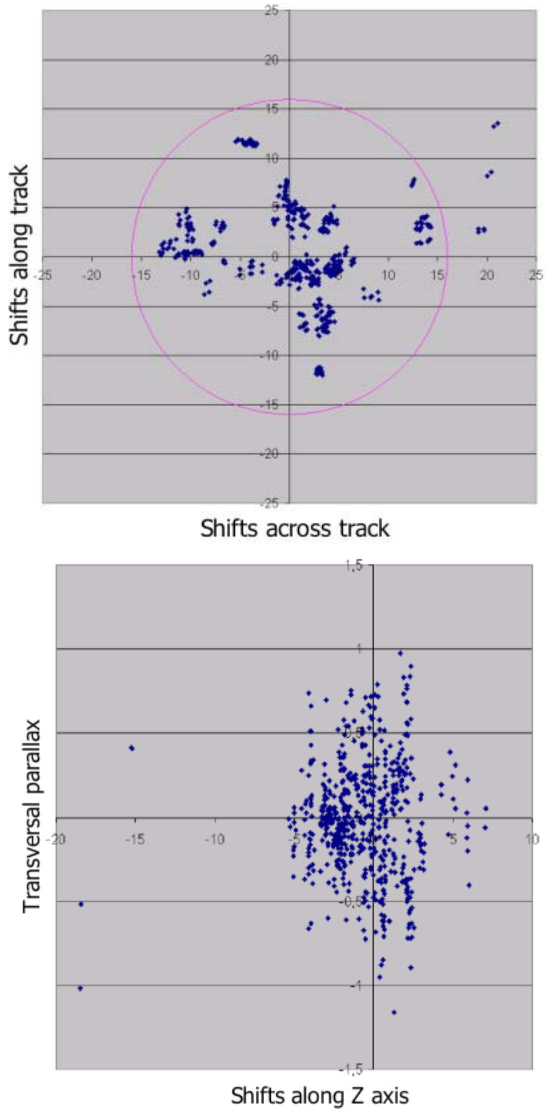


Figure 6. Planimetric and elevation location accuracy after block triangulation

| | Cross track | Along track | *z* |
|---|---|---|---|
| **Mean** | 0.5 m | 0.5 m | -0.7 m |
| **Standard deviation** | 6.4 m | 5.2 m | 2.6 m |
| **90% threshold** | 12.3 m | | 4.0 m |

Table 7. Location performance after block triangulation

### 3.5 Impact of *z* control points on measurement of performance

Factoring the elevation of known points into the block triangulation process significantly improves elevation to 1.2 metres for 90% of points.

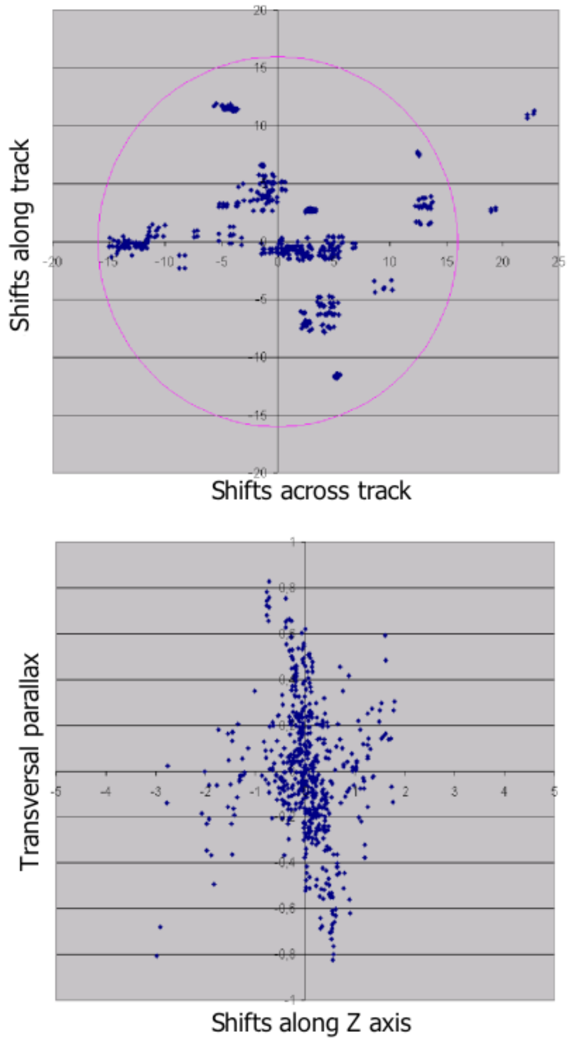


Figure 8. Planimetric and elevation location accuracy with *z* control points

| | Cross track | Along track | *z* |
|---|---|---|---|
| **Mean** | -0.3 m | 0.5 m | 0.0 m |
| **Standard deviation** | 7.2 m | 5.1 m | 0.7 m |
| **90% threshold** | 13.4 m | | 1.2 m |

Table 9. Location performance after block triangulation with *Z* control points

Obtaining elevation control points should prove feasible, since coastlines offer an infinite number of potential points at zero elevation. Moreover, such points will very often be located within Reference3D survey areas.

## 4. PARAMETER MONITORING

In the light of these results, we decided to monitor some of the parameters described above:

- The focal plane and magnifications will be re-evaluated to check their stability one year after satellite launch
- Other errors—relative yaw, inter-HRS rigidity, thermoelastic distortion, seasonal effects—are monitored regularly through quarterly reviews of 20 test sites.

## 5. REFERENCE3D PRODUCT QUALITY CONTROL

Three kinds of checks are carried out on the production process to maintain quality of location performance: quality control of block triangulation, quality control of DEM elevation consistency, and quality control of orthoimage planimetric consistency.

### 5.1 Quality control of block triangulation within a survey area

Tie points between HRS data strips are currently entered manually, following a rigorous procedure. If GPS points are available, they are used as check points (never as ground control points) to provide extra validation of block triangulation.

Once points have been entered and checked, an expert verifies modelling residuals and their geographic distribution, filters out any tie points thought incorrect, asks for new points to be entered if necessary, and then validates the result.

### 5.2 Quality control of elevation consistency in DEMs of a survey area

Differences between DEMs after resampling at 120 metres are calculated to detect any bias or tilt. Constant or tilt differences smaller than 3 metres are compensated for before merging individual DEMs to generate the DEM of the area. If the bias or tilt difference between two elementary DEMs is greater than 3 metres, the block triangulation step is rerun (tie points are rechecked, any bad points are deleted, and new tie points are entered if necessary).

### 5.3 Quality control of planimetric consistency in orthoimages of a survey area

Seam lines are overlaid on the mosaicked orthoimages, and any location errors of linear features—rivers, roads, embankments, tracks, railway lines, etc.—are measured. If location errors greater than the 5-metre local consistency specification are found, a full audit is performed, working backwards through each step in the process.

## 6. OPEN ISSUES - PROSPECTS

### 6.1 Rigidity of the HRS instrument

For all of the results described in this paper, we have assumed that the HRS instrument is rigid, in other words, that the relative orientation of the instrument's forward and aft viewing directions within the spacecraft reference frame is stable over time.

Introducing unknowns with respect to distortions into the block triangulation calculation generates centred elevation differences, of the order of one metre. We need to explain what causes this phenomenon, and model it.

### 6.2 Seasonal effects or ageing?

Since we only have measurements covering one year of observations, it is difficult to conclude for the time being whether seasonal effects or ageing effects are at work. We will be keeping a close check on this issue in the coming months, and if necessary we will introduce a time-related parameter to factor ageing into the model.

### 6.3 Error propagation

Analysing how errors propagate within a triangulation block is difficult. A block covering an area similar to a typical Reference3D survey area is currently being examined in France. Existing maps are of sufficient quality to continuously evaluate geometry using a large number of check points, to monitor seasonal effects and to improve understanding of propagation of residual errors.

## 7. CONCLUSION

The work presented in this paper confirms that the ambitious specifications defined by users for Reference3D prior to satellite launch can be met, provided the many parameters involved are monitored continuously. Such monitoring is essential if we are to dispense with GCPs, the scarcity of which has so far been a significant handicap precluding wider dissemination and use of satellite data in many application areas.

## 8. REFERENCES


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