# AUTOMATIC PRODUCTION OF A EUROPEAN ORTHOIMAGE COVERAGE WITHIN THE GMES LAND FAST TRACK SERVICE USING SPOT 4/5 AND IRS-P6 LISS III DATA

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**ABSTRACT:**
Since the mid 1980s an European Land Cover dataset has been regularly produced for land cover changes, land cover map (CORINE), high resolution forest layer and built-up areas including soil sealing. Within the GMES (Global Monitoring for Environment and Security) Fast Track Land Service 2006-2008 a new dataset of orthorectified satellite images has to be produced covering the EU25 and neighbouring countries (total 38 countries). On behalf of ESA/ESRIN the DLR established an automatic processing chain to orthorectify about 3800 satellite images (two European coverages) within a time frame of 5 months including quality control and creation of a consistent GCP database.
High resolution satellite images from SPOT 4 (20m GSD), SPOT 5 (10m GSD) and IRS-P6 LISS III (23m GSD) serve as input to derive orthoimages in European Map Projection with 25m resolution and National Map Projection for each country with 20m resolution and with an overall accuracy better than 20m RMSE in each direction with respect to the European Land Cover dataset Image2000 (EU25) and USGS ETM+ Land Cover dataset (neighbouring countries). For SPOT4/5 the Line-of-Sight vector is derived from continues measurements of the state vectors and attitude parameters as well as the calibrated camera model provided by SpotImage. For IRS-P6 LISS III the RPCs (Rational Polynomial Coefficients) serve as input, which is provided by Euromap (Universal Sensor Model). Further input is the European wide digital elevation model (DEM) from SRTM-C band Version2 of NASA, improved by using inputs from MONAPRO and SRTM-X band DEM within a fusion process. In order to achieve the required accuracy of 20m RMSE ground control points (GCPs) are automatically extracted via image matching between the Image2000 / USGS Land Cover dataset and the new satellite scenes. From these GCPs corrections of the exterior orientation for SPOT4/5 and of the RPC for IRS-P6 LISS III (affine transformation) are derived.
The paper describes the background, the requirement specifications and the methodology of the automatic orthorectification chain as well as its limitations in problematic cases. Quality assessment is based on automatically extracted ICPs, from which mean RMSE values for each scene and whole countries are derived or from which residual plots are produced.
The paper also describes the H/W infrastructure established for this demanding task as well as the S/W environment, which is based on a mySQL database, to administrate the huge amount of data to organize the parallel processing.

## 1. INTRODUCTION

The general objectives of the GMES (Global Monitoring for Environment and Security) Land Fast Track Service (LFTS) 2006-2008 is to produce an updated version of the European Land Cover dataset, which has been produced since the mid of 1980s regularly. The outputs of the overall project are orthorectified satellite images for the reference year 2006 ± 1 year and a European mosaic based on these orthorectified scenes (referred to as IMAGE2006). On the basis of these orthorectified scenes each involved country contributes to the Corine Land Cover map (referred to as CLC2006) mainly used for land cover change purpose, mapping of built-up areas and generation of high resolution forest layers.
On behalf of ESA the DLR established an automatic processing chain to orthorectify about 3800 satellite images covering the European countries twice.
First the requirements for the IMAGE2006 project are described as stated by the costumer ESA. Second the different types of satellite images and used databases needed to perform the geocoding task are presented including their accuracy specifications. Third the description of the operational and automatic processing chain is given followed by the S/W and H/W infrastructure to handle the huge amount of data. The last chapter deals with the results of the processing and the discussion of problematic cases.
This paper describes the intermediate results of the ongoing IMAGE2006 project.

## 2. STATEMENT OF WORK

Within the IMAGE2006 project two full European coverages of the EEA (European Environment Agency) member countries namely Austria AT, Belgium BE, Bulgaria BU, Cyprus CY, Czech Republic CZ, Denmark DE, Estonia EE, Finland FI, France FR, Germany DE, Greece GR, Hungary HU, Iceland IS, Ireland IE, Italy IT, Latvia LV, Liechtenstein LI, Lithuania LT, Luxembourg LU, Malta MT, Netherlands NL, Norway NO, Poland PL, Portugal PT, Romania RO , Slovakia SK, Slovenia SI, Spain ES, Sweden SE, Switzerland CH, Turkey TR, United Kingdom GB as well as the western Balkan countries namely Albania AL, Bosnia-Herzegovina

BA, Croatia HR, Former Yugoslavian Republic of Macedonia MK and Serbia-Montenegro ME have to be processed.

The following tasks (as relevant for this paper) should be performed:

- Produce from high resolution images of SPOT4 HRVIR Level 1A, SPOT5 HRG Level 1A and IRS-P6 LISS III orthorectified images using a Digital Elevation Model (DEM) of accurate enough quality.
- Consider as absolute reference the IMAGE2000 panchromatic layers with the exception of those areas where IMAGE2000 shows larger errors in the geolocation accuracy. For countries not covered by IMAGE2000 the USGS ETM+ Land Cover dataset should be used.
- Generate in only one resampling step orthorectified products in European Projection LAEA ETRF89 (Lambert Azimuthal Equal Area) with 25m resolution and National Projection for the countries with 20m resolution using Cubic Convolution for the resampling.
- Produce orthoimages with an overall accuracy of 20m RMSE in each direction and perform internal quality control in order to generate quality layers.

Further tasks - the paper is not going into detail - concern the generation of a consistent European wide GCP chip database with more than 15 GCPs for an area of 3600 km² and the generation of a geolayer containing 2D object coordinates for each original pixel in European and National projection in order to offer the possibility for (fast) reprocessing.

The evaluation of images from countries above 60° latitude (Sweden, Finland, Norway, Iceland) has been subcontracted to the Swedish company Metria, because for these countries no DEM of sufficient accuracy was available at DLR.

## 3. DATA BASIS

For the automatic orthorectification process and the subsequent quality control the following data and databases are used.

**SPOT 4 HRVIR [1]**
Multipectral (Green: 500-590 nm; Red: 610-680 nm; NIR: 780-890 nm; SWIR: 1580-1750 nm) of level 1A from SPOT 4 HRVIR images with 20m GSD covering an area of 60x60 km² for each scene provided by SpotImage as DIMAP product [8].

**SPOT 5 HRG [1]**
Multipectral (Green: 495-605 nm; Red: 617-687 nm; NIR: 780-893 nm; SWIR: 1545-1750 nm) of level 1A SPOT 5 HRG with 10m GSD covering an area of 60x60 km² for each scene provided by SpotImage as DIMAP product [8].

**IRS P6 LISS III [2]**
Path oriented and system corrected multispectral (Green: 520-590 nm; Red: 620-680 nm; NIR: 770-860 nm; SWIR: 1550-1700 nm) IRS-P6 LISS III full scenes in UTM projection with 23.5m GSD covering an area of 142x141 km² for each scene provided by Euromap as OrthoKit product [9].

**Digital Elevation Model**
A European wide digital elevation model (DEM) derived from SRTM-C band Version 2 of NASA and improved by using inputs from MONAPRO and SRTM-X band DEM within a fusion process [7].

**Reference Data Sets**
For the countries, which took part in the IMAGE2000 project, the absolute references are the orthorectified panchromatic images derived from Landsat 7 Enhanced Thematic Mapper ETM+ imagery given in geographic projection with a resolution of 0.000115° and an accuracy of about 9-15m $RMSE_x$ and 7-18m $RMSE_y$ (except for Austria with 52m $RMSE_x$ and 27m $RMSE_y$). For all other countries the USGS ETM+ Land Cover dataset given in UTM projection with a resolution of 28.5m and a global accuracy of about 50m $RMSE_{xy}$ serves as absolute reference. Additionally the accuracy of both reference data has been investigated using ground control information from superior quality in the region of southern Baveria. Table 1 summarizes the quality assessment derived from 12 GCPs.

| | $RMSE_{x/y}$ [m] | $Mean_{x/y}$ [m] | $Sigma_{x/y}$ [m] |
|---|---|---|---|
| Image2000 | 15.6 / 13.2 | 2.9 / -6.2 | 15.4 / 11.7 |
| USGS | 30.6 / 21.2 | 28.9 / 17.6 | 10.1 / 11.8 |

**Table 1** Absolute geolocation accuracy of reference images derived from 12 GCPs of superior quality in southern Baveria

These results confirm the official accuracy specifications with slightly better values for the USGS land cover dataset in this region. A systematic error for the USGS land cover dataset can be obtained, but with similar standard deviations as for the IMAGE2000 dataset.

## 4. METHODOLIGY

Figure 1 illustrates the overall operational processing chain, which is fully automatic, except for the manual process of the internal quality control. The automatic processing steps are:

- **Transcription:** The transcription system reformats the original images to an internal image format and extracts from the metadata the information needed for further processing (internal level 1 product). For SPOT 4/5 images the ephemeris data (position and velocity) and the attitude measurements are interpolated for each image line based on synchronisation information. The interior orientation given by look direction angles is evaluated for each pixel in the scan line. For IRS-P6 images the Rational Polynomial Coefficients (RPCs) are extracted from the OrthoKit product, which contains human readable dumps of the Super Structure files.
- **DEM & Reference Tile Generation:** Using the provided coarse image corner coordinates congruent tiles from the DEM database and from the reference image database are extracted and mosaicked with a margin of about 2km due to the pointing knowledge of the sensor.
- **Coarse Orthorectification:** Also based on the four image corner coordinates a coarse rectification using simple affine transformation is performed. The coarse orthorectified images serve as input for an automatic image matching with the reference image tiles.

- **Automatic tie point generation by matching:** In order to automatically extract GCPs/ICPs (Ground Control Points / Independent Control Points) from the reference image a hierarchical intensity based matching is performed [10] [11]. The matching process uses a resolution pyramid to cope with large image differences between the reference and the coarse orthorectified image. Based on the Foerstner interest operator pattern windows are selected in one of the images and located with an accuracy of about one pixel in the other image via the maximum of the normalized correlation coefficients computed by sliding the pattern area all over the search area. The search areas in the matching partner image are determined by estimation of local affine transformations based on already available tie points in the neighborhood (normally from a coarser level of the image pyramid). The approximate tie point coordinates are then refined to sub-pixel accuracy by local least squares matching. The number of points found and their final (sub-pixel) accuracy achieved depend mainly on image similarity and decrease with time gaps between imaging. Only points with high correlation and quality figure are selected as tie points including cross checking by backward matching of all found points.
- **GCP/ICP Generation:** The tie points - or manual measured points - belonging to the reference image are supplemented to 3D object points by interpolated DEM values. Finally the set of tie points is divided into GCPs for an improvement of the orthorectification and ICPs for quality assessment. The selection of GCPs is based on the requirement of equally distributed points over the scene with high quality figure.
- **Parameter estimation:** Within the next processing step improved parameters for the orthorectification are estimated using GCP information. For SPOT 4/5, which utilizes the DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) system to achieve high accuracy orbit determination (position accuracy < 1m), attitude restitution remains the main task. For SPOT 4 especially the initial attitude values and for SPOT 5 the thermal affected misalignment between sensor and body coordinate frame are the major causes of pointing errors. For IRS-P6 LISS III a RPC correction via affine transformation is performed. Within the Least Squares Adjustment simple, iterative blunder detection is integrated, which eliminates step by step GCPs with a residual greater than 2 pixels starting with the bottom quality GCP.
- **Geocoding:** For SPOT 4/5 scenes the physical model of Direct Georeferencing (DG) [4] and for IRS-P6 scenes the rational polynomial camera model (RPC) [2] is applied to produce orthoimages with 25m resolution in European projection LAEA ETRS89 (Lambert Azimuthal Equal Area with European Terrestrial Reference System 1989 as geodetic datum) [3] and with 20m resolution in National map projection different for each country. For the resampling process bi-cubic spline interpolation (a-factor = 0.66) is applied to achieve best image quality for thematic interpretation.

**Quality control** can be separated into examination of correctness of the orthorectified images and completeness of the coverage and is partly based on the "Guidelines for Best Practice and Quality Checking of Ortho Imagery" [1].

The correctness check includes the following tasks:

- Checking for equal distributed GCPs over the scenes
- Checking of residual plots derived from the ICPs (residual vectors should not show systematic behaviour)
- Checking if RMS errors fulfil the requirement to be better than 20m in each direction
- Visual checking of orthorectified image overlaid with re-projected reference image.
- Visual checking of orthorectified image overlaid with neighbour scenes.
- Visual checking of radiometric quality and cloud coverage of the orthorectified images
- Visual checking of used DEM tiles (holes, artefacts) and used reference tiles (cloud coverage, radiometric quality, artefacts, geometric errors)

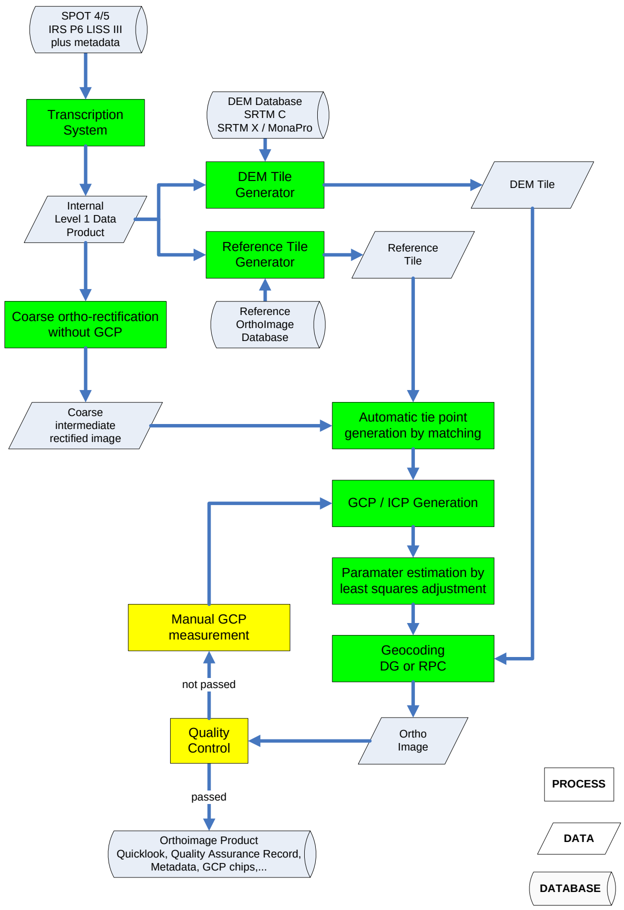


**Figure 1** Operational automatic processing chain for orthoimage production

The results of the quality check are summarized in a Quality Assurance Record (QAR) and stored in a database. In case the geolocation accuracy requirement is not fulfilled or inconsistencies are detected GCPs are measured manually and the scenes are "checked in" for re-processing.

For the completeness check image mosaics of whole countries are generated (images with broad cloud coverage are stacked to the background). Using country frontier polygons the image mosaic is proofed for a complete coverage of the country without any holes.

## 5. PROCESSING ENVIRONMENT

For the huge amount of scenes to be processed in a very short time interval the S/W and the H/W must be suitable for parallel processing with the capability of reliable data storage.

The H/W consists of a passive and active cluster node - file servers replicated and synchronized via heartbeat - with two dual core Intel 5050 processors each, which are connected to a direct attached storage (RAID 5) of 2.7 TByte via fibre channel. For parallel processing 10 workstations are attached to the file server via 1Gbit Ethernet. The Linux 64bit CentOS 4.4 x86 serves as operating system. A permanent external monitoring process watches the condition of system resources – namely network connectivity, RAID status, CPU, memory, fan, power, storage resources and system processes - and reports fail functions and storage overflows via SMS and e-mail.

The S/W front end consists of a web based interface for the administration of the image data and the different processing levels – namely imported, GCP/ICP generated, geocoded, quality controlled, completed, delivered - with a mySQL database in the background. The parallel processing is realized by an autonomous process queue distributing the jobs among the workstations. The different processing modules are assembled to S/W processors using higher level script languages. The whole processing chain is a DLR in-house development and therefore allows flexible reactions to fulfil (changing) requirements.

## 6. RESULTS

Till now approximately a complete European coverage has been processed. Table 3 shows the results broken down into the processed countries and different sensor systems. For SPOT4/5 and IRS-P6 orthorectified scenes an overall geometric accuracy with respect to the reference images of about 10m RMSE in each direction is reached, which corresponds to half a pixel size. The table also shows the mean number of ICPs per scene used for the accuracy assessment and the number of scenes per country and sensor system.

The number of automatically derived ICPs (and GCPs) strongly depends on the similarity of the images having a time gap of 5-6 years. Especially agriculture areas show greater changes over the years, which reduce dramatically the amount of tie points. In the case of Romania with heavy flooding between the years 2000 and 2006 for some affected scenes less tie points can be found. Good candidates for image matching are arid areas like in Spain or mountainous areas with time constant sharp ridges.

For scenes containing only land areas of small extend (like scenes with islands) the image matching sometimes fails due to the image pyramid up to level 32. At this high pyramid levels small land areas vanish. In these cases manual GCP measurements have to be performed.

As stated before IMAGE2000 and USGS land cover datasets should be considered as absolute reference. These datasets contain systematic and local geometric distortions. The models and the parameter estimations used for the orthorectification process (DG and RPC) are not designed to handle such unrealistic errors in a rigorous manner. For example figure 2 shows an ideal distribution of ICPs (and GCPs) over a SPOT scene with equally distributed residual vectors. In figure 3, which represents a mountainous area in Austria, larger deviations can be obtained in the bottom-left part. This results, for example, from the mosaicking of orthorectified reference images with insufficient geometric accuracy.

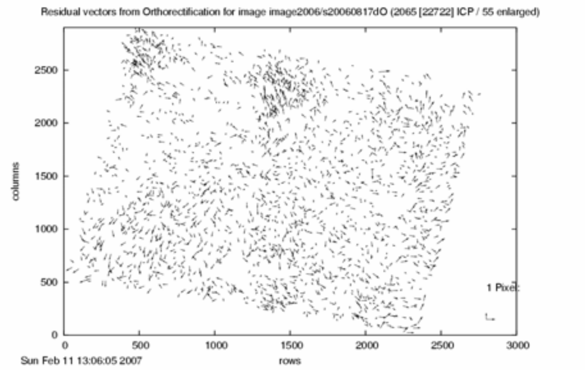


**Figure 2** Deviations in pixel - factor 55 enlarged - of automatically determined ICPs from the reference image versus image coordinates of the orthorectified scene (SPOT 4) after correction with GCPs ($RMSE_x$=12.4m, $RMSE_y$=8.0m)

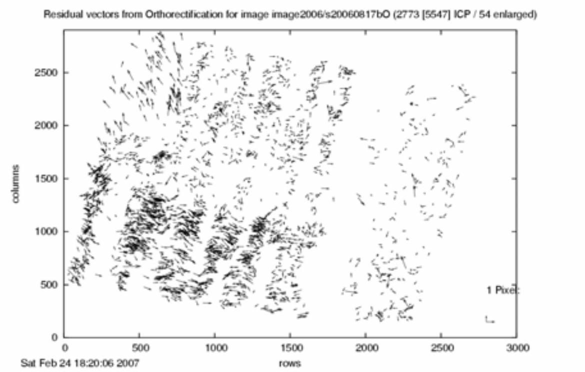


**Figure 3** Deviations in pixel - factor 54 enlarged - of automatically determined ICPs from the reference image versus image coordinates of the orthorectified scene (SPOT 4) after correction with GCPs ($RMSE_x$=12.6m, $RMSE_y$=12.3m)

A further experience made - or better: lesson learned - is the difficult task to produce orthoimages in the manifold National map projection systems. Especially the description of the geodetic datum with the different definition possibilities can lead to wrong processing results.

The demanding task to process about 3800 scenes in a very short time frame requires fast and parallel processing. Table 2 shows the processing times for the different subtasks:

| Sub-task | IRS-P6 | SPOT 4/5 |
|---|---|---|
| Transcription, DEM & Reference tile generation, coarse rectification | 0.1 | 0.1 |
| Matching, GCP/ICP generation | 2.2 | 0.3 |
| Geocoding (National and European product) plus parameter estimation and reprojection of reference image | 1.5 | 0.5 |
| Quality control (manual) | ~1.5 | ~1.0 |

**Table 2** Throughput values in hours for one workstation

The throughput of the system is for an IRS-P6 scene about 0.5h and for a SPOT scene about 0.2 h.

| Country | IRS-P6 LISS III | | | | SPOT 4 HRVIR & SPOT 5 HRG | | | |
|---|---|---|---|---|---|---|---|---|
| | RMSE x [m] | RMSE y [m] | ICPs / scene (~19600km²) | scenes | RMSE x [m] | RMSE y [m] | ICPs / scene (~3600km²) | scenes |
| Austria | 10.35 | 9.10 | 22235 | 12 | 12.16 | 9.98 | 3586 | 20 |
| Belgium | 10.25 | 10.37 | 5934 | 5 | 10.88 | 8.64 | 1476 | 9 |
| Bosnia and Herzegovina | 8.60 | 7.55 | 69 | 9 | 4.31 | 5.58 | 45 | 8 |
| Bulgaria | 11.76 | 8.33 | 10648 | 12 | 11.80 | 8.83 | 2956 | 35 |
| Cyprus | 8.14 | 5.52 | 91 | 2 | 8.17 | 3.76 | 37 | 1 |
| Denmark | 10.63 | 8.96 | 615 | 4 | 10.96 | 8.55 | 352 | 32 |
| Ireland | 11.34 | 11.16 | 2748 | 10 | 12.81 | 11.25 | 1501 | 29 |
| Estonia | 9.67 | 6.47 | 3080 | 7 | 10.61 | 7.44 | 1841 | 15 |
| Czech Republic | 11.03 | 9.28 | 7803 | 6 | 10.65 | 7.31 | 3900 | 9 |
| France | 11.28 | 9.71 | 10670 | 47 | 13.58 | 11.11 | 1516 | 136 |
| Germany | 9.83 | 8.99 | 9773 | 40 | 10.48 | 8.61 | 3814 | 97 |
| Greece | 11.21 | 7.32 | 11573 | 20 | 12.04 | 9.03 | 1473 | 71 |
| Croatia | 11.27 | 8.91 | 1406 | 10 | 6.45 | 6.46 | 126 | 12 |
| Hungary | 10.91 | 6.65 | 1497 | 5 | 11.72 | 11.42 | 280 | 35 |
| Italy | 10.14 | 8.11 | 9562 | 37 | 10.16 | 7.83 | 848 | 57 |
| Latvia | 9.77 | 6.85 | 3855 | 6 | 11.44 | 8.48 | 2181 | 20 |
| Lithuania | 9.69 | 6.10 | 3662 | 4 | 10.75 | 6.76 | 1241 | 26 |
| Slovakia | 10.75 | 7.34 | 4026 | 5 | 13.04 | 8.63 | 2545 | 17 |
| Liechtenstein | 10.98 | 7.14 | 19981 | 1 | | | | 0 |
| Luxembourg | 10.39 | 10.95 | 8158 | 1 | 10.60 | 9.42 | 2412 | 2 |
| Malta | 5.04 | 9.05 | 462 | 1 | | | | 0 |
| Montenegro | 6.43 | 6.05 | 4813 | 3 | 9.80 | 8.23 | 302 | 3 |
| Netherlands | 9.68 | 8.31 | 5423 | 5 | 10.78 | 8.84 | 1042 | 24 |
| Portugal | 10.19 | 8.47 | 10874 | 12 | 10.31 | 7.96 | 4054 | 4 |
| Romania | 11.89 | 8.29 | 1273 | 24 | 12.58 | 7.84 | 1134 | 44 |
| Slovenia | 11.86 | 9.67 | 23375 | 2 | 9.70 | 8.02 | 5667 | 9 |
| Spain | 9.99 | 8.56 | 34433 | 57 | 10.22 | 8.35 | 2719 | 43 |
| Serbia | 7.90 | 6.47 | 4019 | 8 | 13.67 | 8.28 | 276 | 33 |
| Switzerland | 10.37 | 8.59 | 14920 | 5 | 10.89 | 8.68 | 2482 | 17 |
| Turkey | 6.27 | 5.25 | 3781 | 86 | | | | 0 |
| | | | | | | | | |
| **Synopsis** | **9.9** | **8.1** | **8025** | **446** | **10.8** | **8.3** | **1844** | **808** |

**Table 3** Geometric accuracy of orthorectified scenes with respect to reference images from IMAGE2000 and USGS Land Cover dataset.

## 7. CONCLUSION

An operational and automatic processing chain to orthorectify satellite images from SPOT 4 HRVIR, SPOT 5 HRG and IRS-P6 LISS III covering European and neighbouring countries has been developed and successfully applied for the ongoing IMAGE2006 GMES Fast Track Land Service project.
Up to now about 1500 scenes are processed and an overall geometric accuracy of about 10m RMSE in each direction with respect to the IMAGE2000 and USGS Land Cover reference datasets is achieved, which corresponds to half a pixel size. The accuracy assessment is based on ~450 automatically extracted ICPs per 1000 km².
About 5% of the images have to be processed manually (additional GCP measurements) in cases the product does not pass the internal quality control.

## 8. REFERENCES


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