SPOT IMAGE

Reference3D Product Description

Version 6.1 - May 2011

This edition supersedes previous versions

Acronyms

ANDORRE	Atelier Numérique D'Ortho Rectification
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CC	Confidence (or Correlation) Coefficient
CNES	Centre National d'Études Spatiales
DIMAP	Digital Image MAP (encapsulation format supporting data display with an Internet browser)
DTED	Digital Terrain Elevation Data
DXF	Drawing eXchange Format (AutoCAD)
GeoView	IGN image processing software
HRG	High Resolution Geometric (SPOT 5 sensor)
HRS	High Resolution Stereoscopic (SPOT 5 sensor)
IGN	Institut Géographique National (France's survey and mapping agency)
JPEG, JPG	Joint Photographic Expert Group
Mb, Tb	Megabytes, Terabytes
DTM **DEM**	Digital Terrain Model Digital Elevation Model
CE90	Circular Error (90% confidence level)
LE90	Linear Error (90% confidence level)
SD	Serveur de Déspatialisation (Spot Image's data acquisition & processing server)
STANAG	STANdardisation AGreement (OTAN)
SRTM	Shuttle Radar Topographic Mission
SVG	Scalable Vector Graphics
TIFF - GeoTIFF	Tag Image File Format – GeoTIFF is the geocoded version of TIFF
Tile	1° longitude by 1° latitude geocell
XML	eXtensible Markup Language – Format of certain files in DIMAP

Contents

1 Introduction

This document describes the specifications and format for the Reference3D database, which chiefly comprises SPOT 5 HRS data covering pre-defined regions of interest. This database is planned to cover at least 80 million square kilometres (end 2014).

Reference3D is co-produced by Spot Image and IGN, France's national survey and mapping agency.

Reference3D comprises three registerable layers of data:

- a DTED level 2 DEM
- an HRS orthoimage with a resolution of near five metres
- a full layer of quality and traceability data, including 2 performance maps

These three layers are encapsulated within a DIMAP profile for display using an Internet browser.

Reference3D is designed for a broad range of applications:

- the DEM layer provides a ready-to-use solution for thematic applications
- the orthoimage layer can be used to generate vector databases or interpreted for map updating at scales around 1 :50 000 to 1:100 000
- Reference3D is a sophisticated product that supports low-cost production of highly accurate application-specific DEMs
- Reference3D can be used as an accurate source for producing orthoimages 100% automatically, whatever the image source: for example, the ANDORRE NG system currently allows Spot Image and every SPOT terminal owner to automatically produce SPOT orthoimages.

2 Product features

2.1 Reference3D contents

Reference3D comprises three layers of information:

- a DTED level 2 DEM
- an HRS orthoimage
- a set of quality and traceability information, including 2 performance maps

2.1.1 Data structure

Reference3D stores data as tiles of one square degree (about 100 km x 100 km) covering the Earth's landmasses and aligned along parallels and meridians. HRS DEMs and orthoimages are expressed in geographic coordinates. DEMs have a post spacing of one arc second (about 30 metres at the equator) and orthoimages a post spacing of one-sixth of an arc second (about 5 metres). The longitude spacing increases with latitude above 50 degrees, in accordance with the DTED level 2 standard.

2.1.2 Coverage

The HRS instrument cannot guarantee complete coverage of some zones due to weather conditions, and also correlation limits due to the landscape. Gaps in DEMs therefore will be filled locally by interpolation or with other source data (mainly SRTM DEM where available).

Unless specified, the standard ratio of HRS data within one Reference3D tile is 90% or more.

2.1.3 Quality layer

The quality layer provides:

- general information about each tile, DEM and orthoimage layer
- statistical data derived during the block triangulation process
- references of source image or DEM data, including footprints in polygon form
- binary masks containing georeferenced data for DEM quality control
- horizontal and vertical performance maps

2.1.4 Product format

Reference3D products are in DIMAP format. Each product is a set of XML files referencing the DEM and orthoimage layers, as well as the metadata.

The advantage of DIMAP is that it allows users to read Reference3D data with off-the-shelf software. For example, they can read the DTED level 2 DEM and the GeoTIFF orthoimage with any software supporting these formats.

2.1.5 Tile naming

The identifier of each Reference3D one-degree-square tile is built from the geographic coordinates of its South-West corner using a **<N/S>XX<E/W>YYY** model, where XX is the corner latitude and YYY the corner longitude in degrees.

2.2 Data acquisition

The SPOT 5 satellite's HRS instrument acquires stereopairs for Reference3D. The satellite tasking schedule is revised periodically to include new programming requests.

2.3 Production process

2.3.1 Block triangulation of HRS data strips

This phase determines Reference3D horizontal location accuracy.

- A mean orbit is calculated from the forward and aft data strips
- The orbit attitude angles are filtered from possible false values (ex: proton hits in Stellar Sensors)
- HRS stereopairs and eventual HRG images (where Tri-stereo is needed) are grouped into massive triangulation blocks (including thousands of strips)
- Intra-strip tie points are massively and automatically selected in HRS and HRG images
- Controlled ground control points (Various sources, VLBI, GPS, High resolution image stacks, etc…) are identified and measured on overlaying images
- Various altitude control points (Shoreline points, IceSat measures points in flat areas) are inserted in the modelling
- Each block model is computed and the residuals controlled
- Samples of DEM and ortho-images can be computed for block adjustment validation
- A block adjustment localisation accuracy map is computed with an algorithm using the block structure, the GCP distribution and the validation measurements

2.3.2 Generation of DEMs per HRS data strip

DEMs are extracted from each HRS stereopair by automatic correlation.

- Processing of DEMs (automatized "DEM factory")
- Computing of confidence coefficients (CCs), during or after DEM processing

2.3.3 Assembly into survey areas (various size, depending on production scheduling)

- Bias correction of strip DEMs (correction of possible small DEM tilts, possible when using old acquisitions)
- Automatic merging of DEMs and CCs of adjoining data strips. An automatic void filling, with SRTM or a smoothed GDEM, depending on area, is computed at the same time (all voids are filled if exogenous DEM data is available). Two versions of this merging, with different parameters, are computed.
- Manual merging of both merged version (different solution, depending on area and landscapes)
- Computing of sub-sampled orthoimages (on the final merged DEM)
- Semi-automatic Mosaïc of HRS images and automatic radiometric equalisation
- Generation of dxf and svg assembly files
- Delineation of water and clouds bodies along tiles edges
- DEMs and CCs divided into 1° x 1° tiles
- Assembly quality control (Control of the lack of DEM bias, of the global quality of the merged DEM, of the amount of DEM patches, of the coherence with patches masks, of the

coverage and adequation of the orthoimages, of the radiometric equalisation, and of the intermediate metadatas coherence)

2.3.4 Processing of large water bodies in each tile

This step is run for seas and oceans and for any water body or swamp area (above a minimum extent) where the DEM is of bad quality.

- If HRG or HRVIR images, with MIR channel, are available, the sea mask and the lake mask can be (semi-)automatically computed
- If not, water bodies are manually digitized on HRS orthoimages (using the help of various water databases and of other images if available for water identification)
- Flattening of DEM to constant elevation, calculated automatically (0m on sea and oceans)
- Water bodies quality control (quality of the digitization, size, computed altitude and fitting with adjacent tiles)

2.3.5 DEM quality control and artifact reduction for each tile

- Manual patching complement (in areas where automatic patching has failed). SRTM or GDEM, or in some seldom cases smothered HRS are used for the patches, depending on areas.
- Interpolation of small artefacts (artificial peaks in flat areas, voids in mountainous areas wherever exogenous DEM isn't available, shoreline bubbles, patched rivers where exogenous DEM is of bad quality, raising of negative Z areas near coastlines, etc…). The digitization of these areas to be interpolated is a manual process.
- Interactive generation of the control mask MQu (digitization of areas where the HRS DEM or the eventual patch is of doubtful quality, and where no better data is available for an artefact correction). This process is an expert interpretation, using all available data, landforms logic and special visualization tools.

2.3.6 Orthoimage production

- Calculation of final orthoimage mosaic (using final DEM and previously calculated mosaic lines and equalization formulas)
- Orthoimage divided into tiles
- Full quality check
- Generation of the remaining clouds mask MCl

2.3.7 Global quality control

- Independent controllers check all intermediary data produced at this stage (DEM, orthoimage mosaic, quality layers and metadata's). If any default is found, the corresponding production step is replayed.
- A control report is issued

2.3.8 Packaging

- Generation of DEM performance map (automatic process using ICESAT as control points for HRS DEM flat areas, ICESAT points combined with statistics of differences with SRTM in non-void sloppy areas, and producer specification for exogenous DEM on patches)
- Generation of orthoimage mosaic performance map (automatic process combining the block adjustment localisation accuracy map, the DEM performance map, the orthoimage mosaic lines and the raw image incidence)

- Visual control of the performance maps
- Generation of final Reference3D product in DIMAP format
- Automated format and content checking

3 Reference3D specifications

3.1 DEM layer

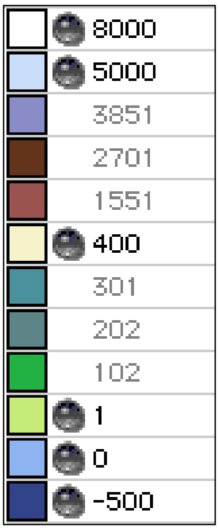
3.1.1 Data format and encoding

The DEM layer of Reference3D is compliant with the DTED level 2 standard.

The DEM contains elevation values in metres, encoded as 16-bit signed integers with the most significant bit first.

The –32767 value in the DTED format that indicates a null value is not used. Instead, the most likely value is given with a reliability indicator in the quality masks.

For the symbolisation of quicklook and thumbnail files, the following radiometric scale is used :



Radiometric values are interpolated between 2 altitude levels.

3.1.2 Datum

DEM values are given in geographic coordinates with respect to WGS84.
The vertical datum is EGM 96.

3.1.3 DEM post spacing – Number of nodes per tile

The DEM post spacing is in accordance with the DTED level 2 standard, as shown in the table below:

Tile latitude	Latitude post spacing	Longitude post spacing	Nodes
0° to 50° North or South	1 arc second	1 arc second	3601 * 3601
50° to 70° North or South	1 arc second	2 arc seconds	3601 * 1801
70° to 75° North or South	1 arc second	3 arc seconds	3601 * 1201
75° to 80° North or South	1 arc second	4 arc seconds	3601 * 901
80° to 90° North or South	1 arc second	6 arc seconds	3601 * 601

To conform to the DTED standard, there is an overlap of one post between neighbouring DEM tiles. Also, grid nodes are ordered South to North in data records of constant longitude. Successive records are arranged West to East.

3.1.4 DEM geometric accuracy specifications

The DEM accuracy specifications below apply to DEMs generated from HRS imagery and not to DEMs derived from external sources.

- **Absolute elevation accuracy specification**

  linear error with respect to EGM96 (confidence level 90%)
  flat or rolling terrain (slope ≤ 20 %).. **10 m**
  hilly terrain (20 % < slope ≤ 40 %)... **18 m**
  mountainous terrain (slope > 40 %)... **30 m**

- **Absolute horizontal accuracy specification**

  circular error with respect to WGS84 (confidence level 90%)............. **10 m***
  * 16mCE for some geocells before 2008 (see Performance Map)

NB : from users' assessments and feedbacks, effective accuracy is very commonly better than specification.

3.1.5 Landform characteristics

Landform characteristics supplement geometric accuracy specifications, in particular for local features in a DEM. Special attention is paid to the following features, which must be visible in the DEM:

✓ **Critical landforms other than islands** (confidence level 96%)
  - features larger than 200 m by 100 m
  - and an elevation difference with the surrounding terrain greater than 30 m

✓ **Islands** (confidence level 99%)
  - islands larger than 200 m by 100 m
  - and an elevation difference with the surrounding water greater than 15 m

  OR
  - islands larger than 300 m by 300 m

✓ **Watersheds and drains** (confidence level 96%)
  - Drains wider than 150 m

✓ **Cliffs** (confidence level 99%)
  - longer than 200 m
  - higher than 30 m with a local slope greater than 80%

✓ **Artefacts**
  - artefacts larger than 300 m by 200 m
  - and an elevation error greater than 40 m

  must cover less than 1% of the 1° x 1° square

✓ **Water bodies**

Elevation is manually flattened over important water bodies:

- seas and oceans (elevation is set to 0m),
- water bodies more than 1800m x 1800m or 3 km^2 wide, and reservoir lakes more than 0.8km^2 wide, or any water body or swamp area of any size if underlaying DEM is of bad quality.

3.1.6 Tile uniformity and continuity

No elevation discontinuities exhibiting a bias greater than 2 m are accepted within a Reference3D tile.

3.2 Orthoimage layer

HRS images—as well as SPOT 5 / HRG images, wherever used—are orthorectified using the Reference3D DEM.

3.2.1 Format and datum

The orthoimage comes in GeoTIFF 8-bit format.

Values are given in geographic coordinates with respect to WGS84.

3.2.2 Orthoimage post spacing – Number of nodes per tile

The orthoimage post spacing is one-sixth of the DEM spacing, that is, about five metres at the equator. The longitude post spacing increases with latitude as shown in the table below:

Tile latitude	Latitude post spacing	Longitude post spacing	Nodes
0° to 50° North or South	1/6 arc second	1/6 arc second	21606 * 21606
50° to 70° North or South	1/6 arc second	1/3 arc second	21606 * 10806
70° to 75° North or South	1/6 arc second	1/2 arc second	21606 * 7206
75° to 80° North or South	1/6 arc second	2/3 arc second	21606 * 5406
80° to 90° North or South	1/6 arc second	1 arc second	21606 * 3606

The orthoimage footprint registers exactly with the DEM. Orthoimages of two adjoining tiles usually have an overlap of six pixels (see paragraph 5.3 below).

3.2.3 Orthoimage performance specifications

- **Absolute horizontal accuracy**

circular error with respect to WGS84 (confidence level 90%)….. ………… **10 m***
* 16mCE90 for some geocells before 2008 (see Performance Map)

- **Residual cloud cover**: 10% or less

3.3 Quality layers

3.3.1 Source data footprint and type

Reference3D contains the references and ground footprints of source data, in polygon form in DXF and SVG formats.

3.3.2 Performance maps

Reference3D can be provided with Performance Maps. Performance maps are 8-bit indexed colors GeoTIFF files containing geographic coordinates, with the same post spacing as the DEM. They provide evaluations of horizontal and vertical performances as computed by the producer himself.

✓ **DEM Altitude Accuracy Map (MGD)**

In this map, all pixel value corresponds to an altitude accuracy in meter; i.e. pixel altitude value error is less than the map pixel value (LE90: linear error at 90% confidence level).

A different process is used to compute the performance value for 3 slope classes:

- slope lesser than 20%
- slope between 20% and 40%
- slope bigger than 40%

For slope lesser than 20%, global tile statistics (bias and standard deviation) are computed against available ICESat points, and the max difference at 90% is extracted. All pixels from this class are given this value (even on DEM patches).
For the 2 steeper slope classes, the standard deviation derived from the ICESat measurement is multiplied by a scale factor computed from the standard deviations of the differences with an exogenous DEM on the different slope classes. The max difference at 90% is then computed with using these scale factors. For these 2 other slope classes, patched areas are given the value of the used exogenous DEM specifications.

Water areas are given a uniform performance of 5m.

Example of Altitude Accuracy Map (MGD):

✓ **Orthoimage location accuracy Map (MGO)**

In this map, all pixel value corresponds to a location accuracy class (CE90: circular error at 90% confidence level). The correspondences between the pixel values (color indexes) and the location accuracy are given in the following table:

Index	*Horizontal location accuracy (absolute , CE90)*
10	0 to 3 m
11	3 to 6 m
20	6 to 10 m
21	10 to 15 m

30	15 to 30 m
40	30 to 50 m
41	50 to 75 m
50	75 to 100 m
51	100 to 150 m
52	150 to 200 m
53	200 to 300 m
60	Accuracy unknown

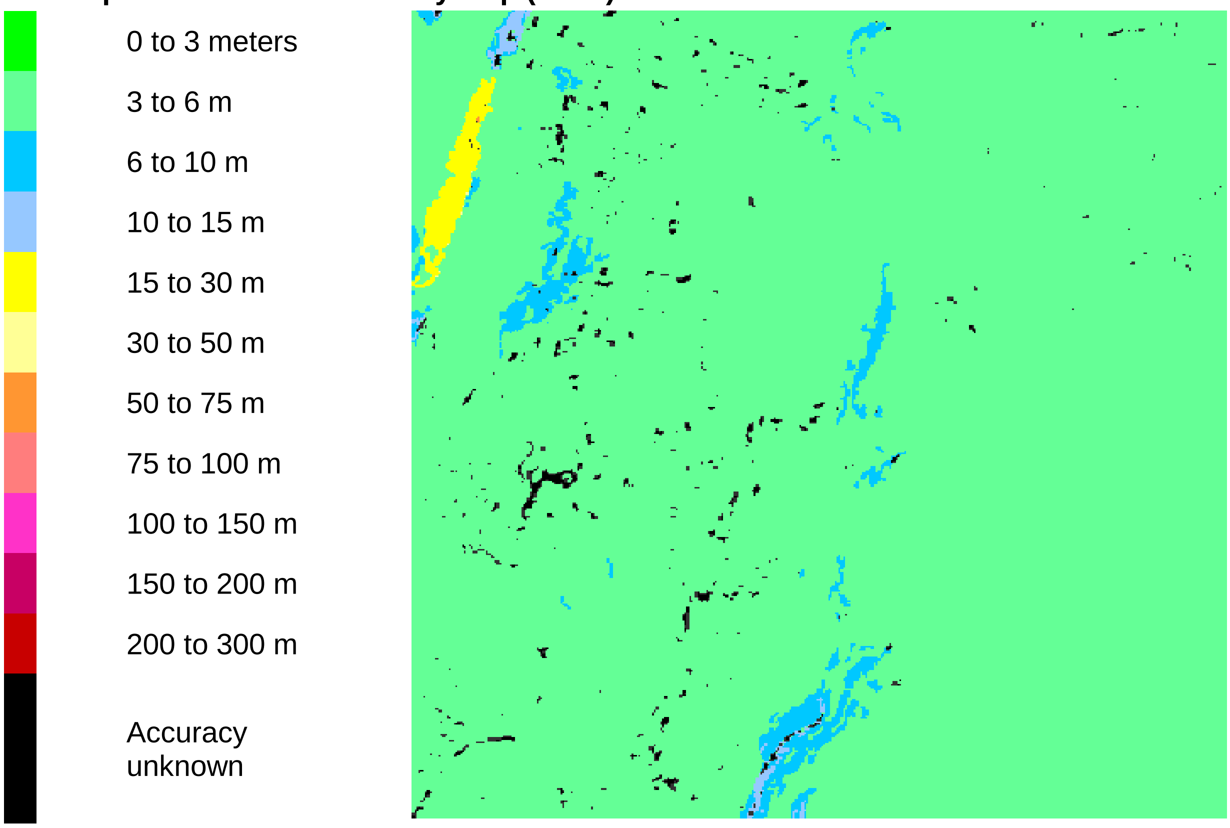
This map is computed by combining the block adjustment accuracy map (in meters) and the altitude accuracy map.

The computing formula uses 3 parameters:
- The MGD value (from the altitude accuracy map)
- The block adjustment performance value for the pixel (in meters) : ΔD
- The incidence angle of each image included in the orthoimage mosaic: i.

$$MGO = \sqrt{[\Delta D^2 + MGD^2 \times \tan(i)^2]}$$

(*NB: Users reports show that the accuracy estimations are often very conservative*)

Example of Location Accuracy Map (MGO):



3.3.3 Quality control masks

Ref3D masks are 1-bit GeoTIFF files, with the same post spacing as the DEM. They all refer to the DEM, except the MCI (cloud/snow) which describes the orthoimage.

✓ **Water mask (MWa)**

Contains flat maritime or inland water bodies where the DEM was flattened to a constant elevation. MWa is produced by manual or semi-automatic delineation from an orthoimage underlay. The water mask is not significant in zones that are zero-rated in the MCl mask (cloudy areas).

0: sea or water body where the DEM was flattened
1: no flattening of the DEM

- ✓ **DEM merge mask (MMe)**

Contains areas derived from a single DEM. MMe is generated through an automated process.

0: single HRS source or no HRS
1: at least two merged HRS sources

- ✓ **Correlation mask (MCo)**

Generated by a 50% thresholding of CCs.

0: confidence coefficient less than 50%
1: confidence coefficient greater than or equal to 50%

- ✓ **Cloud/snow mask (MCl)**

Describes the cloud covered areas which remain in the Reference3D orthoimage. It is delineated manually using the orthoimage and the DEM. MCl only contains “problematic” areas regarding DEM extraction.

0: cloud
1: no cloud

- ✓ **Exogenous mask (MEx)**

Indicates areas computed using external data. Semi-automatic.

0: exogenous data
1: no exogenous data

- ✓ **Regulation mask (MRe)**

Contains those artefacts that were interpolated and corrected either during the matching process or within the interactive DEM editing phase. Automatically computed through the following formula :

MRe = MCo - MWa - MEx

0: artefacts detected and corrected
1: no artefacts

- ✓ **Visual control mask (MQu)**

Generated by a visual examination of the final DEM. This mask identifies areas in the DEM deemed by the operator not to meet specifications.

0: data do not meet Reference3D specifications
1: data meet Reference3D specifications

- ✓ **Validated area mask (MVa)**

Contains all areas deemed not completely satisfactory in the initial stages of production before the interactive correction phase (the “worst case” Mask). MVa is generated automatically by merging several other masks:

MVa = MQu + MRe + MCl + MEx

3.3.4 Metadata

- ✓ **HRS data strip**

The following metadata are provided for each HRS data strip used to produce a tile:

SPOT5SEGMENTS5S1S0210150732178	
DESCRIPTION	SEGMENT HRS1 S
DATE	2002-10-15
TIME	07:32:32
INSTRUMENT	HRS1
MODE	B_W
INCIDENCE_ANGLE	-22.957857 (DEG)
VIEWING_ANGLE	0.000000 (DEG)
SUN_AZIMUTH	154.089591 (DEG)
SUN_ELEVATION	39.245105 (DEG)

✓ **Block triangulation**

Tie points:

number of points
mean/average of horizontal residuals (in 10-m pixels)
standard deviation of horizontal residuals (in 10-m pixels)

Z points:

number of points used
mean of vertical residuals (in metres)
standard deviation of vertical residuals (in metres)

✓ **Mosaic seams in orthoimages**

Value of planimetric discontinuities (in metres)

✓ **DEM**

number of rows/columns
coordinates of 4 corners
post spacing

✓ **Orthoimage**

number of rows/columns
coordinates of 4 corners
post spacing

✓ **DEM derived from HRS data strips merged to produce tile**

mean of elevation differences in overlap areas
standard deviation of elevation differences in overlap areas

✓ **Exogenous data**

Source
Rotation/translation

✓ **General information**

Geodetic reference system
Producer reference

4 Quality checks during the production steps

✓ **Block triangulation**

Careful checkings are performed on:

- horizontal residuals on Tie Points,
- elevation residuals on Z points,
- horizontal residuals on Control Points (if any) and Check Points (if any)

✓ **Production**

Checks are performed on:

- elevation biases between adjacent HRS DEMs
- matching of DEMs and water masks across adjacent geocells
- delineation and flattening of water bodies in the DEM
- artefact removal in the DEM
- final DEM quality: content (for generation of MQu mask), seams, elevation value statistics
- final orthoimage quality: content, mosaic seams
- format (certification report)
- viewing of DEM, orthoimage and metadata layers in Internet browser

✓ **Reference3D product checks**

A person outside the production team checks:

- Z min / Z max consistency (against available map or atlas)
- MQu / DEM consistency
- MWa / DEM consistency
- DEM / MMe / MEx / svg / dxf consistency
- Orthoimage / MCl / MWa consistency
- orthoimage svg / dxf consistency
- connections between adjacent products : orthoimage, DEM, MCl, MEx and MWa masks
- format

✓ **Final checks on CD-ROM before delivery**

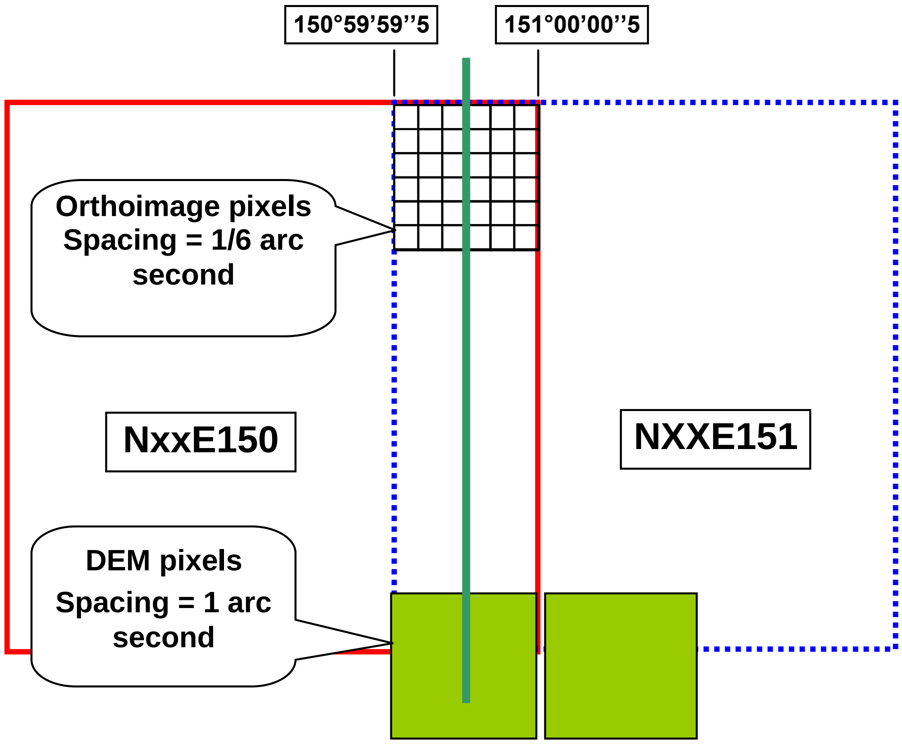
- formats
- visual check of DEM and orthoimage files (on a sample of tiles)
- calculation of relative percentages of 0/1 values in MQu and MVa masks (on a sample of tiles)

5 Reference3D product structure

5.1 File formats

File	Format
Tile metadata	XML
Source metadata	XML
DEM metadata	XML
Orthoimage metadata	XML
DEM	DTED 2
Orthoimage	8-bit uncompressed GeoTIFF
DEM quality masks	1-bit uncompressed GeoTIFF
DEM source image footprints	DXF (polygons)
Orthoimage source image footprints	DXF (polygons)
DEM and orthoimage quicklooks	JPEG
DEM and orthoimage thumbnails	JPEG
Quicklooks of DEM and orthoimage source image footprints	SVG

5.2 Tile overlap



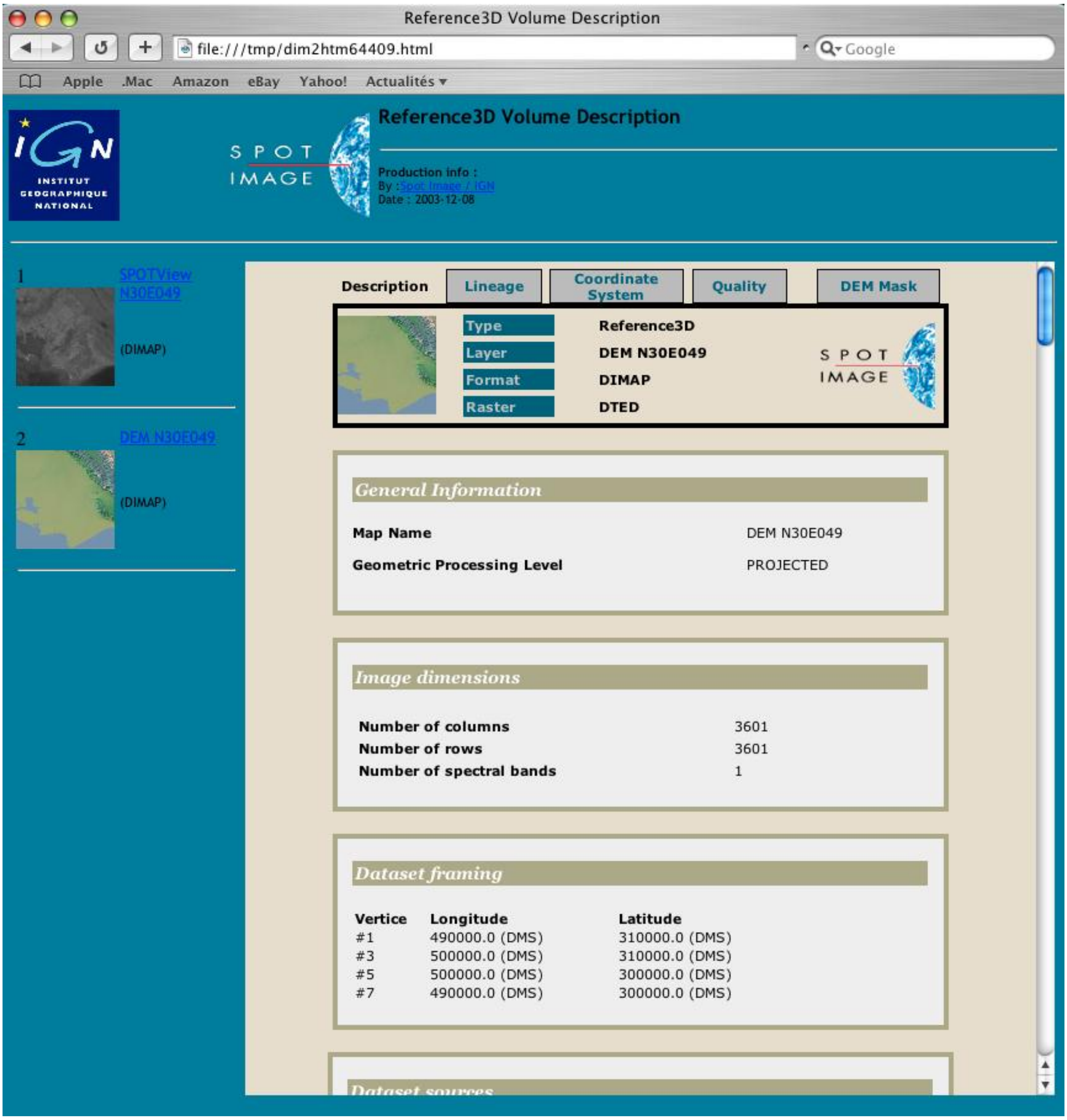
Longitude 151 degrees

Important : Orthoimage data overlapping the neighbouring tiles (three rows/columns along the four edges of the tile) are only given to ensure that the DEM and orthoimage register exactly. They are provided for information purposes only and Spot Image does not warrant their fitness for any particular use.

5.3 Style sheets

Every Reference3D product in DIMAP format comes with several XSL style sheets that allow its main features to be displayed with an Internet browser.

An example style sheet is shown below:



6 Reference3D file sizes

The appropriate maximum file sizes for each layer of a Reference3D tile can be estimated as shown below. The largest files will be those constituting tiles at latitudes below 50°. File sizes for all other tiles will decrease significantly as latitude increases.

- ✓ **DEM**
  3,600 x 3,600 pixels, two-byte encoded = **25 MB**
- ✓ **Orthoimage**
  21,606 x 21,606 pixels, one-byte encoded = **445 MB**
- ✓ **DEM quality control masks**
  3,601 x 3,601 pixels, one-bit encoded = 1.5 Mb per mask, i.e. about **12 MB** for all 8 masks
- ✓ **Performance Maps**
  3,601 x 3,601 pixels, 8-bit encoded = 12 Mb per mask, i.e. about **24 MB** for 2 masks
- ✓ **Other files**
  Remaining files take up about **3 MB**.

Giving a total of about 510 Mb per geocell.

In late 2014, when Reference3D covers an area of 80 million km² as planned (corresponding to approximately 11,000 tiles), the complete database will take up **5 to 6 TB**.