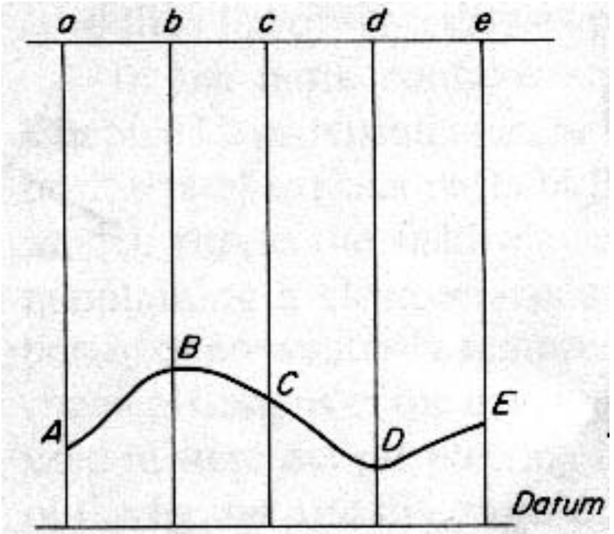
High spatial resolution satellite images: some special notes on orthoimage generation

(**Note**: orthoimage was treated in a BSc course by Prof. K. Schindler; if somebody has not taken this course we can provide the course slides (in German) and explanations)

Orthogonal vs. perspective projection

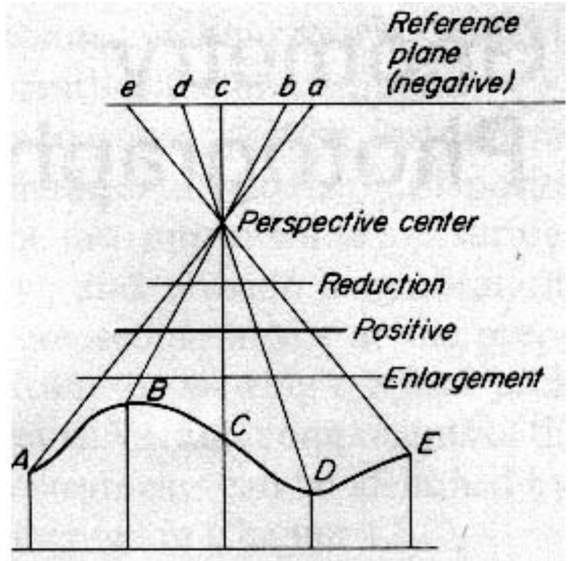


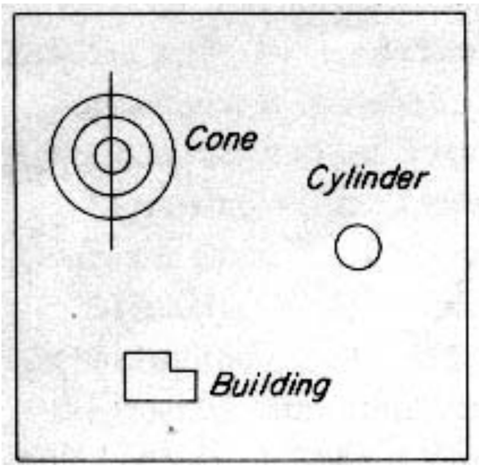
Orthogonal Projection

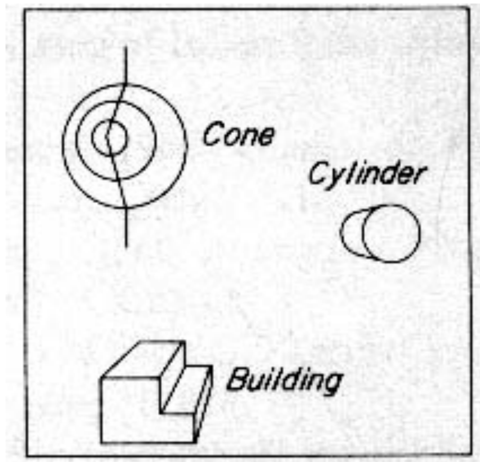
- Uniform scale
- No relief displacement

Perspective Projection

- Non-uniform scale
- Relief displacement







Idealised objects in orthographic and perspective projection

Orthorectification principle

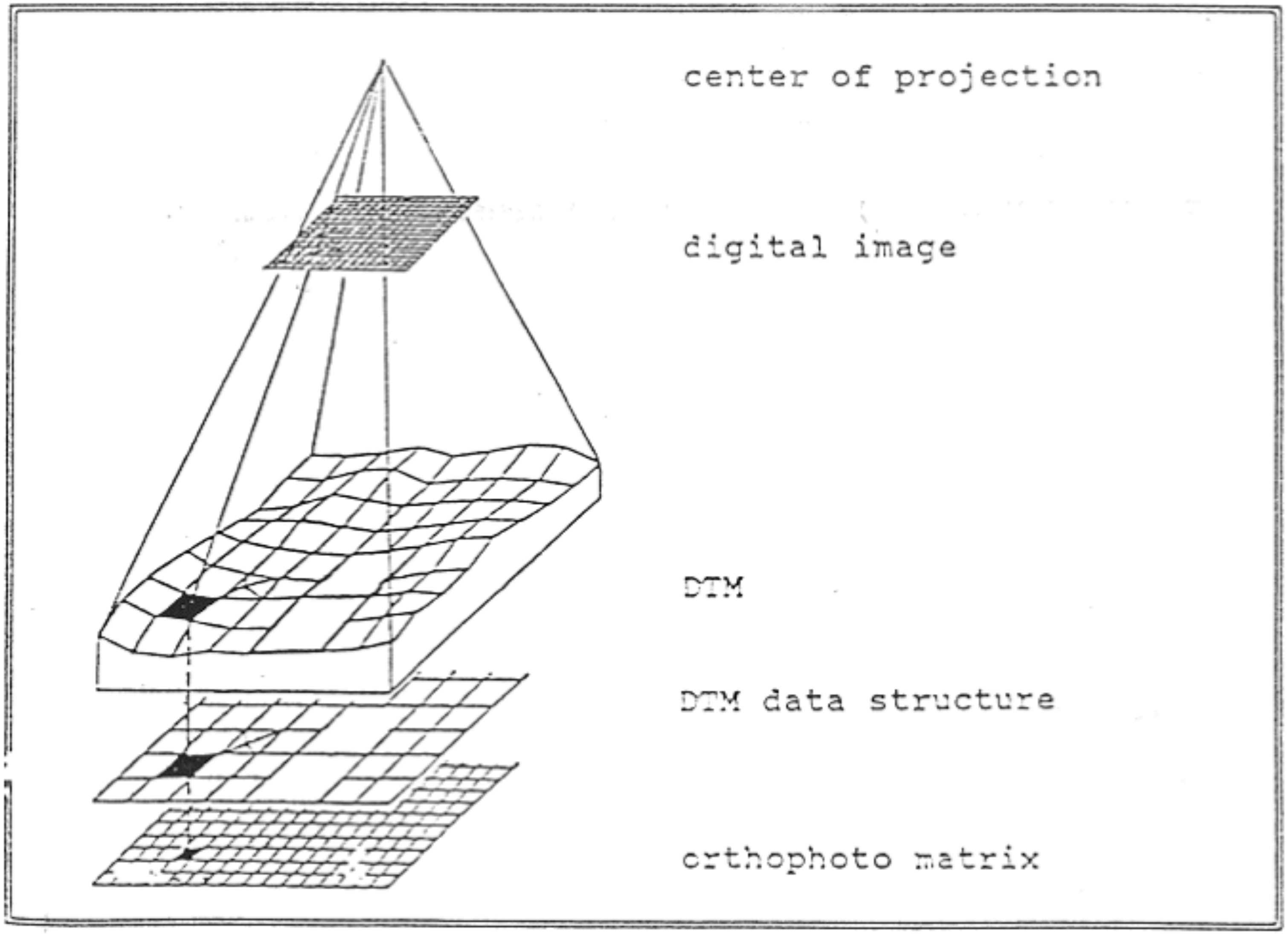


Figure 1

Raw image and orthoimage example

Geometrically RAW Image

Orthoimage

Raw image vs. orthorectified image

Aerial image:

Overlapping of image and vector data <u>is not</u> consistent / correct.

<u>Not possible</u> to measure correctly distances, due to perspective effects.

Orthoimage:

Correct overlap between image and vector data.

Measured distances, areas and positions are like on a map.

Orthorectification

- main error source is DSM / DTM
- note also the difference between using DTM or DSM (vertical walls, long straight edges)
- Theoretically, only a DSM should be used to avoid planimetric displacement of objects not in DTM (objects above the ground)

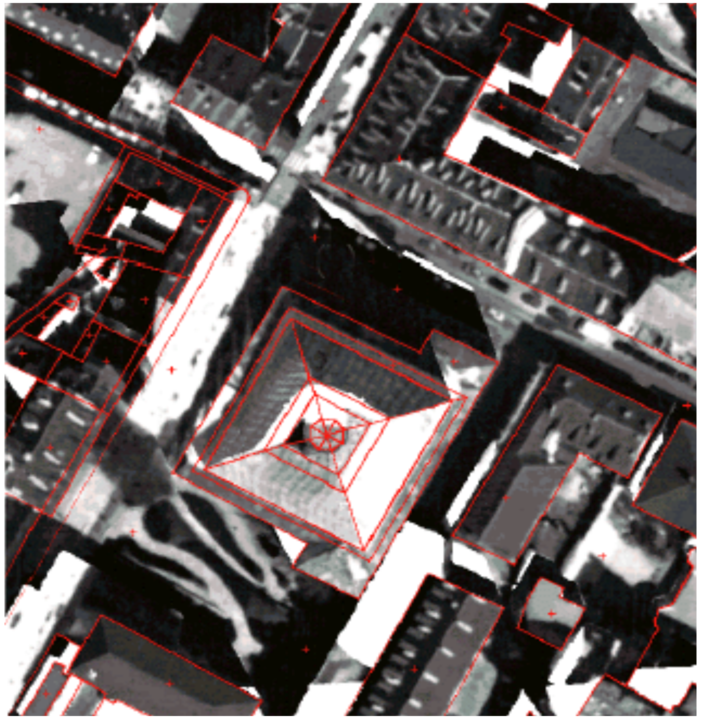
Orthoimage generated with DTM

Orthoimage generated with (wrong) DSM (note DSM errors in long straight edges at roofs)

True ortho (defined as = generated with DSM, no occluded areas -> use multiple images to generate orthoimage)

Orthoimage - Border area
Only the ground parts correct

True Orthoimage



True Orthoimage - Overlay with vectors for quality control

Important characteristics of high resolution sensors regarding orthoimages

- Very narrow across-track Field of View (FOV)

- about 0.9 deg for Ikonos, usually 1-2 degrees for high spatial resolution satellite sensors. Why? Because focal length too big (to achieve high spatial resolution) compared to sensor width (across flying path = swath width = mostly linear sensor physical width). E.g. for Ikonos, sensor length = 0.166m, focal length = 10 m!

- compared to much larger FOV for aerial but also satellite sensors of less spatial resolution (aerial FOV is e.g. 30-90 degs, lower spatial resolution satellite sensors' FOV from e.g. 5 to more degs)

An important point for orthoimage generation!

- The major error source is height errors in the DEM used for orthoimage generation.
- The larger the DEM error, the larger the planimetric accuracy orthoimage error.
- ALSO: for a nadir (vertical image ray), a DEM error causes no orthoimage planimetric error, but the further away from the nadir an image ray is, the larger the error -> THUS
- The larger the FOV -> the larger the distance of image borders from the nadir -> the larger the planimetric error

Important characteristics of high resolution sensors regarding orthoimages

Prefer high sensor viewing angle elevation (angle between sensor viewing direction and locally flat plane, e.g. 90 deg sensor elevation = nadir viewing angle. Sometimes called as the opposite angle, i.e. off-nadir angle). This is mentioned in the sensor metada that you receive with the image BUT you should check it before ordering an image for ortho generation. A high sensor viewing angle elevation results in:

- less occlusions

- AND most importantly smaller influence of DEM errors on planimetric orthoimage accuracy, for the same reasons as for the small FOV (see also the table at the end of these overheads)

E.g. check before ordering for www.digitalglobe.com images (the currently largest high spatial-res satellite private company (USA)). Check, how easy it is (a torture in my opinion) to find and browse their archive! And after finding an image, e.g. over Zurich, check the metadata, incl. sensor elevation, a quicklook (to check image quality, clouds etc.) and more.

Orthoimage generation (IKONOS, Quickbird) in Geneva

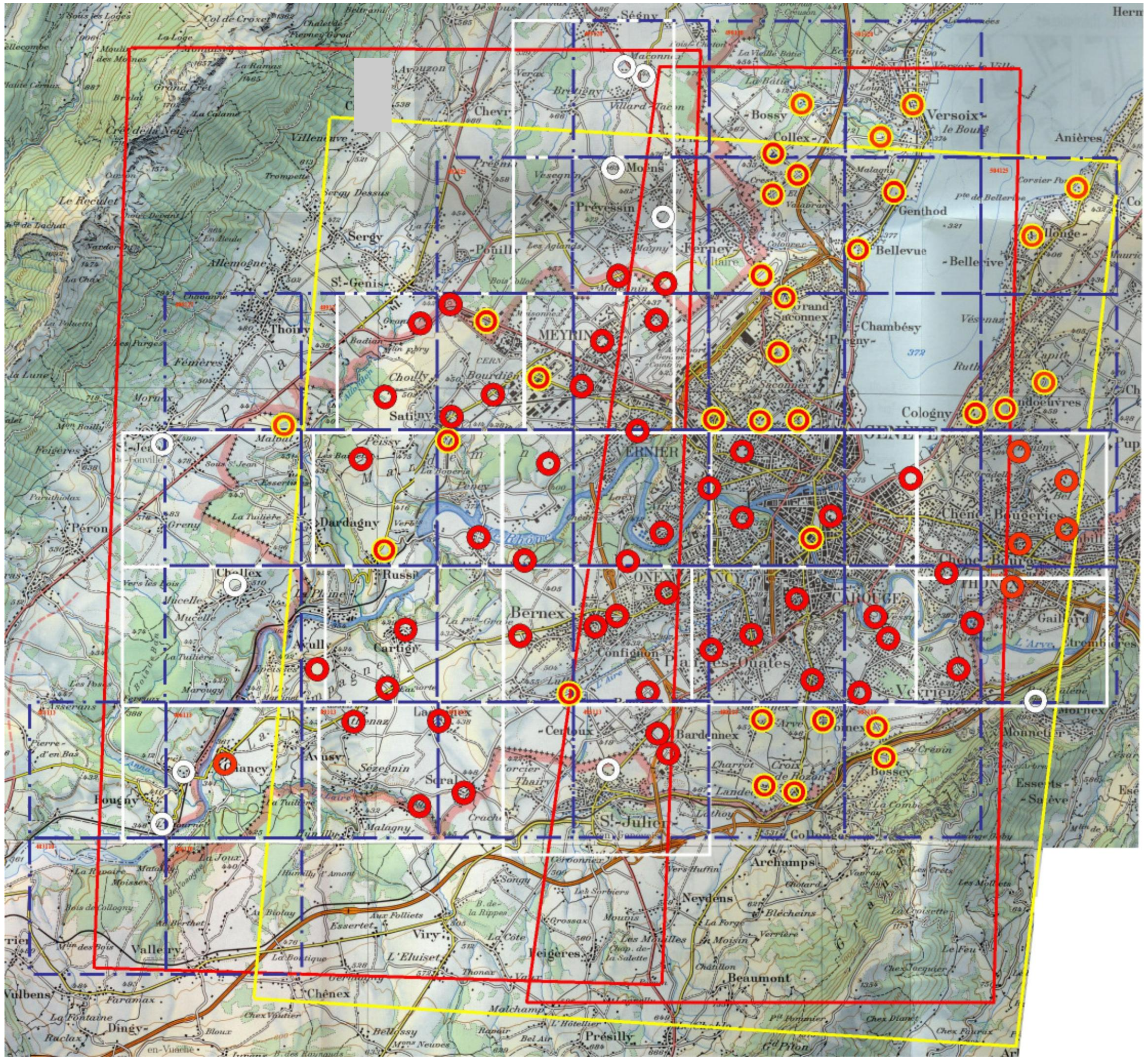
Input data

Images:
2 IKONOS images (IKONOS-West / IKONOS-East) (1m GSD)
1 QUICKBIRD image (0.7m GSD)

Orthoimages (used for acquisition of Ground Control Points (GCPs)):
1. OP-DIAE: Orthoimages of Canton Geneva (25 cm pixel size, 0.5 m planimetric RMSE)
2. Swissimage: Orthoimages of Switzerland from Swisstopo (50 cm pixel size, 1m planimetric RMSE)

DTMs:
1. DTM-AV of Canton Geneva (from airborne laser scanning): 1 m grid spacing, 0.5 m height RMSE
2. DHM25 of Swisstopo (from digitised contours): 25 m grid spacing, 1.5-2 m height RMSE

Orthoimage generation (IKONOS, Quickbird) in Geneva

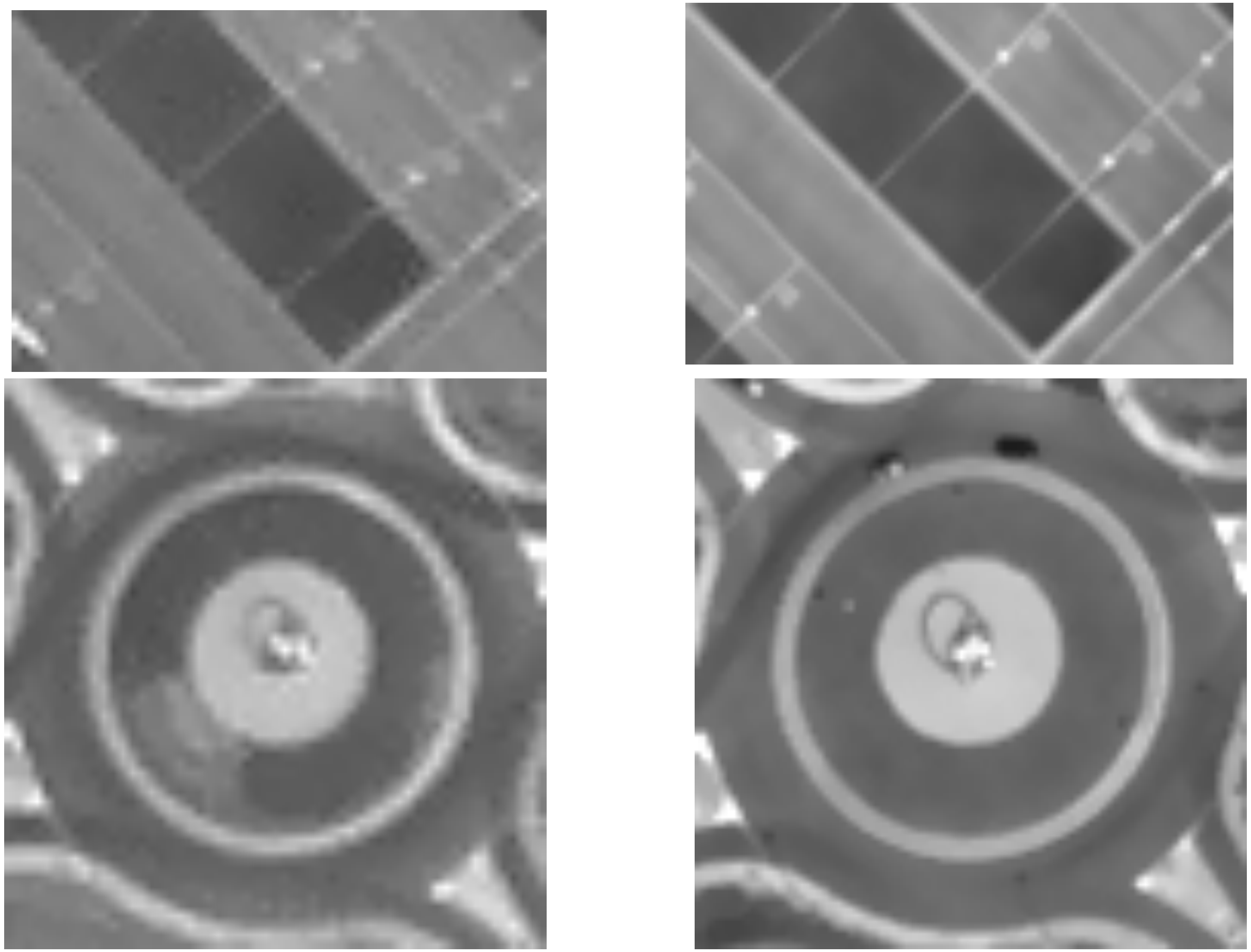


Distribution of GCPs (different colors show different input sources).
Two red outlines are the Ikonos images, the yellow one the Quickbird image.

Orthoimage generation (IKONOS, Quickbird) in Geneva

Pansharpened orthoimages: Left Ikonos (1 m orthopixel size), right Quickbird (0.7m orthopixel size).

Orthoimage generation (IKONOS, Quickbird) in Geneva



Definition of lines and circles. Left Ikonos, right Quickbird.

Note the large visual difference although pixel size is 1m and 0.7m respectively.

Orthoimage generation (IKONOS, Quickbird) in Geneva

Planimetric accuracy of panchromatic orthoimages with GCPs from OP-DIAE

(CPs = check points)

Image	Number of GCPs/CPs	X RMS (m)	Y RMS (m)	X mean with sign (m)	Y mean with sign (m)
Ikonos West	10/23	0.55	0.63	0.25	-0.49
Ikonos East	10/33	0.47	0.76	0.10	-0.59
Quickbird	10/53	0.56	0.60	-0.08	-0.38

Quickbird is not more accurate than Ikonos although GSD was 0.7m and 1m respectively.

Planimetric accuracy could be even higher with well defined GCPs measured with GPS.

In Y mean (bias) large due to coordinate system differences (Geneva and CH national systems differ).

Orthoimage generation (IKONOS, Quickbird) in Geneva

Planimetric accuracy of panchromatic orthoimages with GCPs from OP-DIAE and Swissimage

Image	Number of GCPs/CPs	X RMS (m)	Y RMS (m)	X mean with sign (m)	Y mean with sign (m)
Ikonos West	10/58	0.91	0.72	-0.07	-0.30
Ikonos East	10/57	0.67	0.75	0.00	-0.33
Quickbird	10/93	0.66	0.77	-0.06	-0.11

Submeter accuracy even with GCPs from not so accurate Swissimage orthos.

In-depth investigations of parameters influencing the accuracy of orthoimages from high resolution satellites

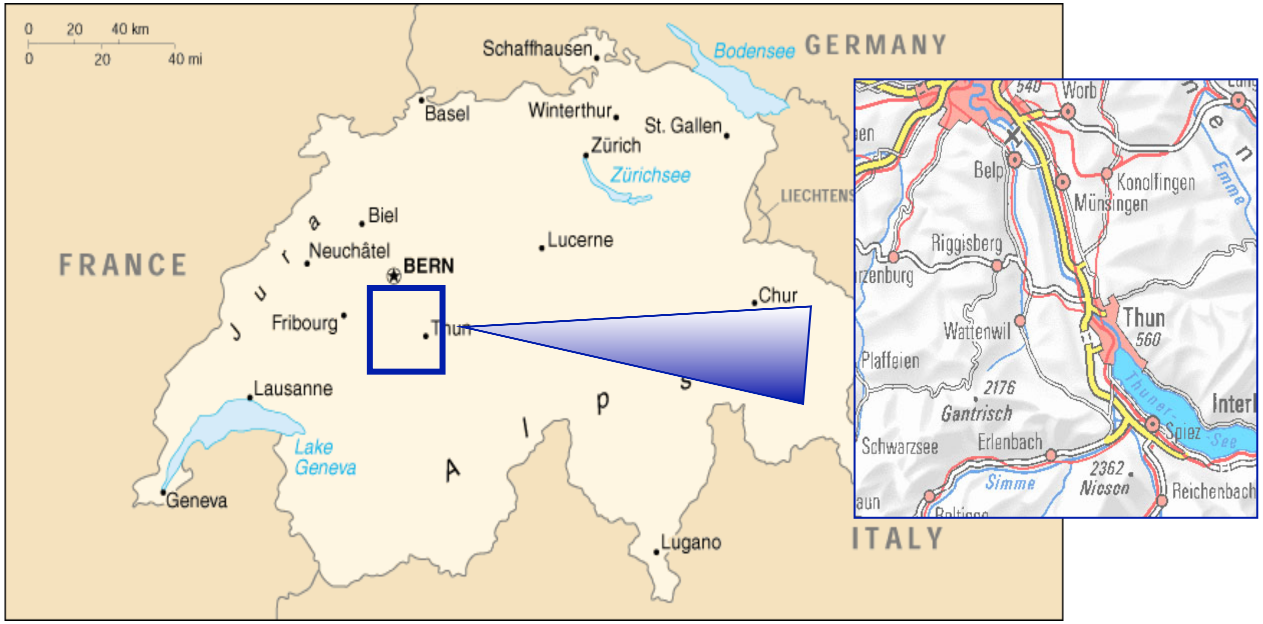
AIMS

The aim of this work was the analysis of orthoimage accuracy produced from IKONOS images using different type of input data in Switzerland. More specifically, we were interested to see the influence on the orthoimage planimetric accuracy of

- different sources for the measurement of GCPs from (a) Swissimage orthoimages and (b) measured with GPS (same quality and accuracy as you used for sensor orientation),
- different elevation models (4 different ones with different resolution and accuracy), and
- different sensor elevation (63^o and 83^o).

Specifications of the data

The test area, Thun, lies in the central part of Switzerland 40 km southern of the capital of Switzerland, Bern. In this region, we established a testfield with a coverage of 30 by 30 sqkm. Note: the area covered by the Lidar DTM-AV is smaller, thus also the number of CPs is smaller.



Resolution and accuracy of used input data (orthoimages and DTMs)

	Swissimage orthoimages	DTM-AV	DHM25	Rimini
Produced by	Swiss Federal Office of Topography (Swisstopo)			
Reference frame	LV03	LV03	LV03	LV03
Used elevation model for orthoimage generation	DHM25			
Orthopixel size / DTM grid spacing [m]	0.50	2.0	25.0	250
Orthoimage planimetric accuracy [m]	1.0			
DTM height accuracy [m]		0.5/ vegetation : 1.5	Flat-hilly-Jura: 1.5 Voralps: 2 Alps: 5 - 8	average deviation to DHM25 is about 17

The matching elevation model listed in the table below was created by the IGP software SAT-PP (see overhead 60 of overheads on automated DSM generation) which is a very good matching method. The grid spacing was 5m and the accuracy about 3m.

Orthoimage accuracy in the Thun test area (in bold the best RMSE for each elevation model)

Orthoimage version			Number of CPs	Mean		RMSE		Max Absolute	
Elevation model	Type of GCP	Sensor elevation		X (m)	Y (m)	X (m)	Y (m)	X (m)	Y (m)
Rimini	GPS	63	20	0.0	-0.9	1.2	8.0	3.0	22.4
Rimini	ORTHO	63	20	0.1	-0.9	1.7	8.8	5.7	22.9
Rimini	**GPS**	**83**	**21**	**0.4**	**-1.2**	**1.0**	**2.0**	**2.3**	**3.6**
Rimini	ORTHO	83	21	0.3	-0.7	1.2	2.0	3.5	4.5
DHM25	GPS	63	20	0.1	-0.4	1.0	3.6	3.7	9.6
DHM25	ORTHO	63	20	-0.1	-0.3	1.0	3.7	2.4	10.2
DHM25	GPS	83	17	0.2	-0.9	0.9	1.3	2.2	3.2
DHM25	**ORTHO**	**83**	**19**	**0.1**	**-0.8**	**0.8**	**1.2**	**1.9**	**2.6**
Matching	GPS	63	20	0.2	-0.5	1.1	1.2	3.2	3.5
Matching	ORTHO	63	20	0.1	-0.4	1.3	1.1	4.0	2.9
Matching	**GPS**	**83**	**17**	**0.2**	**-0.7**	**0.7**	**1.0**	**1.7**	**1.9**
Matching	ORTHO	83	19	0.1	-0.4	0.7	1.0	1.9	2.3
LIDAR	GPS	63	12	-0.4	-0.2	1.0	1.0	2.6	2.0
LIDAR	ORTHO	63	11	-0.6	0.3	1.2	1.2	2.9	2.8
LIDAR	**GPS**	**83**	**11**	**0.3**	**-0.9**	**0.8**	**1.2**	**2.4**	**2.1**
LIDAR	ORTHO	83	10	-0.3	0.4	1.1	1.0	3.2	2.4

Conclusions - Orthoimage generation

- Due to narrow FOV of high spatial resolution optical sensors, height errors influence planimetric accuracy of orthoimages much less.
- Height errors also have less influence, the higher the sensor elevation is (most critical factor together with DSM quality for orthoimage accuracy). Accuracy of georeferencing (and quality of used GCPs), as long as they are generally within a quality range (e.g. 1 GSD), play less role. Since GCP acquisition is costly and time consuming, the selection of GCP acquisition method should be made based on the accuracy of the available DTM/DSM and the sensor elevation.
- High accuracy DTM/DSM provide more similar accuracy in X and Y, quite independently of the sensor azimuth and elevation. As the DTM/DSM accuracy deteriorates, a higher sensor elevation is needed and the height errors are distributed in X and Y differently, depending on sensor azimuth.
- Orthoimage should have approx. the same ground pixel size as the GSD of the raw image. The DSM grid spacing is usually 5-10 times the orthoimage GSD (the smaller, the better).
- Geometric accuracy of orthoimages under good conditions: 0.5-1 GSD. Orthoimages with 1-GSD accuracy can be produced even with suboptimal DSMs / DTMs and GCPs (if sensor elevation high).
- Although geometric accuracy can compete with the accuracy of aerial orthoimages, the spatial resolution and interpretability of objects is generally worse (due to the GSD and image quality).