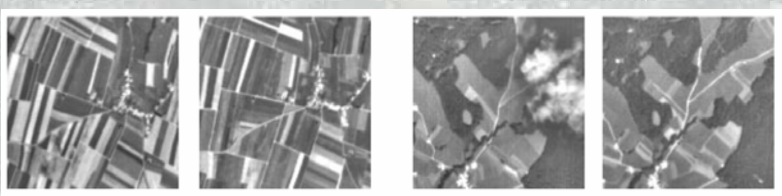
DSM Generation

- Almost all HR sensors are stereo capable. Some can produce even triplettes within the same strip (facilitating multi-image matching).
- Mostly SPOT (1-5) used for stereo and Ikonos (in spite of high potential of Ikonos for accurate DSM generation, it has been used relatively little)
- High costs of stereo images, initially sold only to governments.
- Almost all HR satellites can acquire stereo images quasi-simultaneously (called wrongly along-track stereo), thus facilitating automatic DSM/DTM generation with image matching, reducing the temporal image differences.



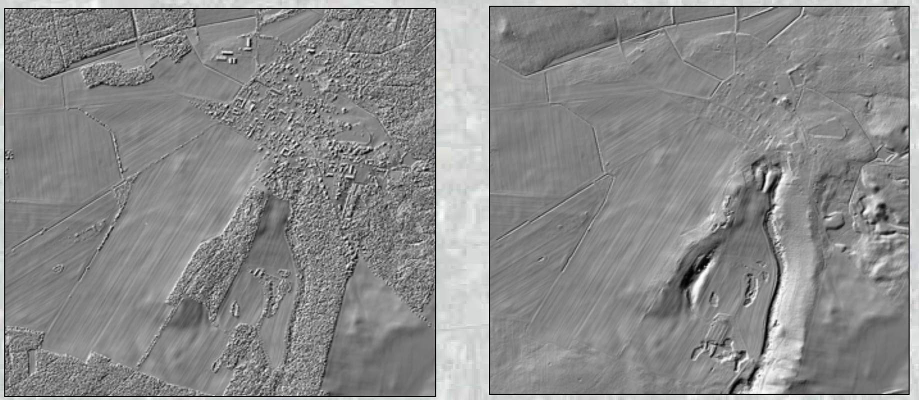
SPOT-1 stereo images taken from different orbits with one month difference

Automatic DSM Generation

- Manual, automatic, semi-automatic measurement modes. Last includes pre- and/or post-editing and is the preferable way.
- Full automation is very difficult.
- For agile satellites, matching methods function better when occluded areas coincide as much as possible with shadow areas, e.g. when the orbit is to the East of the area imaged.
- With automatic mode only DSM can be measured, with the others both DSM and DTM. Reduction of DSM to DTM can rarely be performed fully automatically (e.g. in flat areas with scarce buildings and vegetation).

•Digital Surface (DSM) vs Digital Terrain Model (DTM)

Here DSM reduced probably semi-automatically (Lohr, 2001).
Here airborne laser data, where DSM AND DTM generation easier, when laser registers more than one echo per pulse.



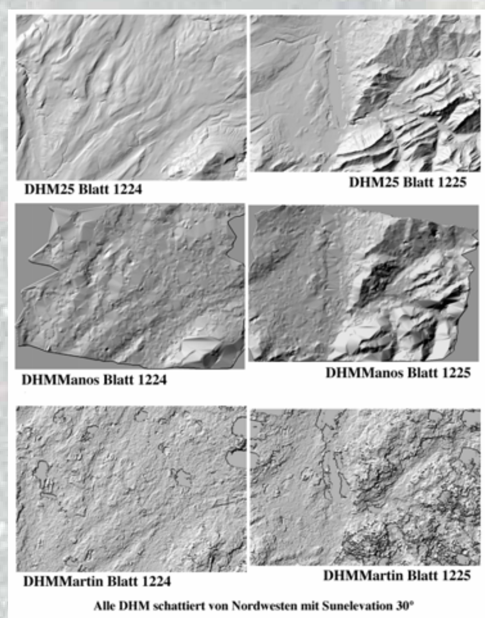
Automatic DSM Generation

- Rules of thumb (for matching):
  - DSM / DTM spacing: at min. 2-3 GSD
  - Image measurement accuracy (good case): 0.5 to 1.5 pixels
  - Height accuracy: depends mainly on Base / Height ratio but also quality of sensor model and GCP quality; can be in the best case < 1 pixel, average values 1-2 pixels, except difficult areas (dense urban, vegetation).

Automatic DSM Generation

- Matching modules exist in various commercial RS and photogrammetric systems. Methods used are often based on cross-correlation, and match at a regular object or image grid.
- Much better methods exist in research labs. The example from 1991 on the next page, shows for two 1:25,000 scale map sheets, the Swiss national DTM (DHM25) derived from digitising contour lines, fully automated DSM results from SPOT-1 with ETHZ algorithms, and the same using the commercial system PCI. The two SPOT images had large radiometric differences.
- For good quality the breaklines must be well modeled which can be achieved better by using edge-based matching, in combination with other matching methods that provide denser results (see ETHZ method of Zhang Li below).

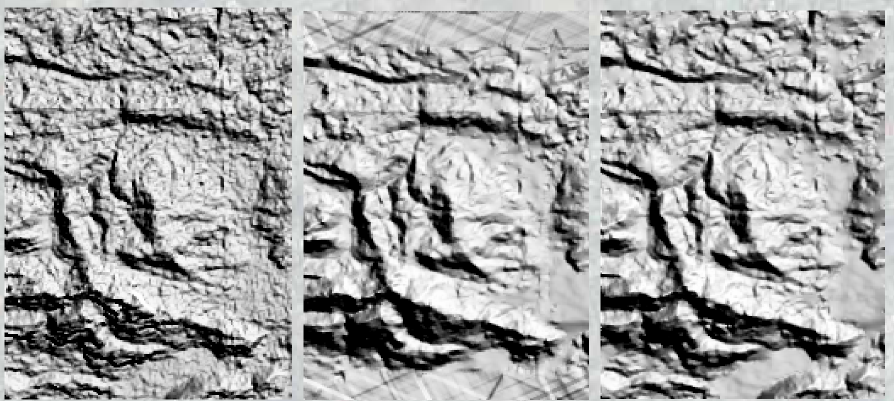
Automatic DSM Generation



Alle DHM schattiert von Nordwesten mit Sunelevation 30°

Automatic DSM Generation

- Matching results, espec. with commercial systems, can vary a lot depending on the selection of the matching parameters (which have sometimes an unclear definition or at least effect).
- 3 automatically generated DSMs with DPW770, SocetSet. Left and right ATE, middle Adaptive ATE (effect of different matching strategies and matching parameters is clear)



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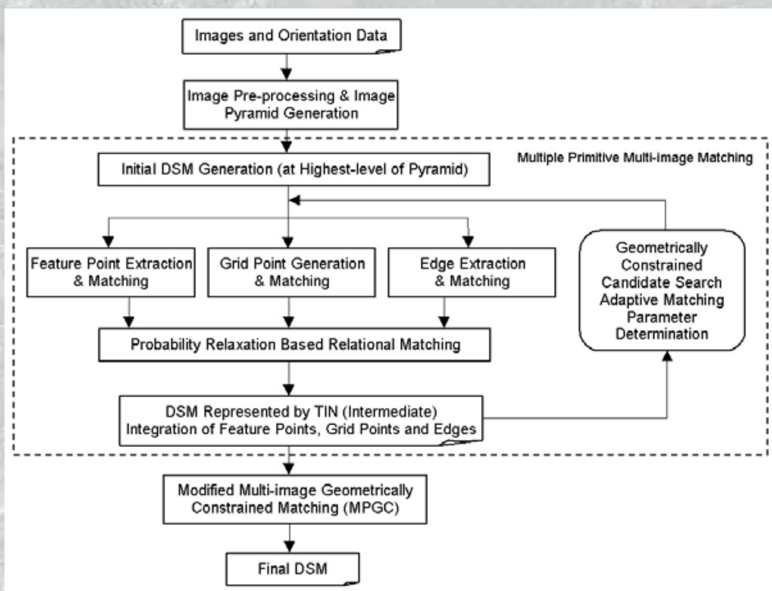
Automatic DSM Generation (one of the methods developed at ETHZ by Zhang Li)



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Automatic DSM Generation

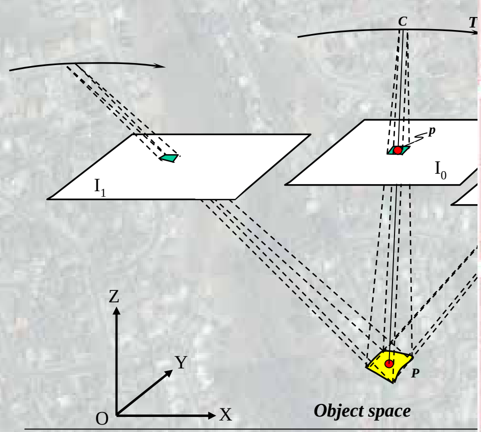
- Multiple image matching
  - + Matching guided from object space
  - + Simultaneously multiple images (>= 2) with Geometrically Constrained Cross-Correlation
- Matching with multiple primitives - points + edges
- Self-tuning matching parameters
- High matching redundancy
- Efficient surface modeling
  - + TIN (from a constrained Delauney triangulation method)
- Coarse-to-fine hierarchical strategy

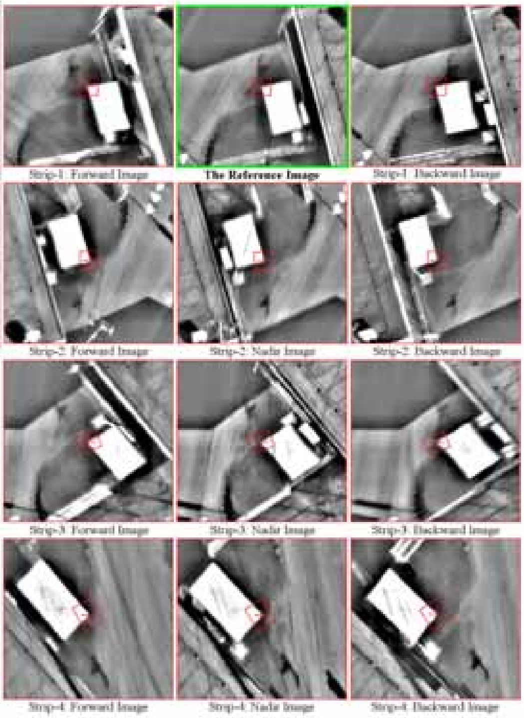
Multiple Image Matching

Geometrically Constrained Cross-Co

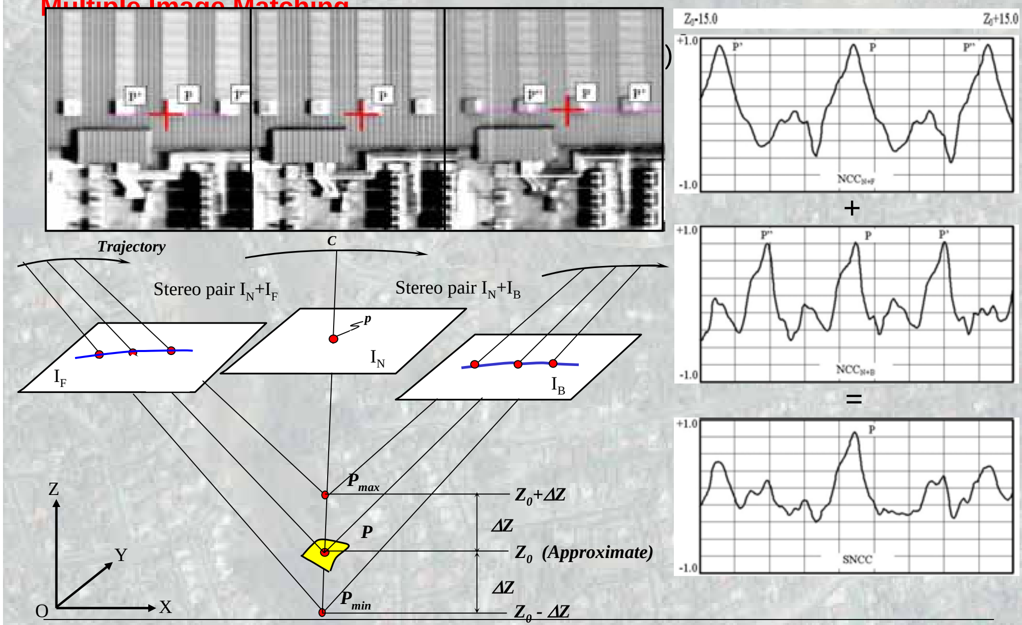
+ Extension of traditional cross-correlation met

Step 1: Correlation window warping

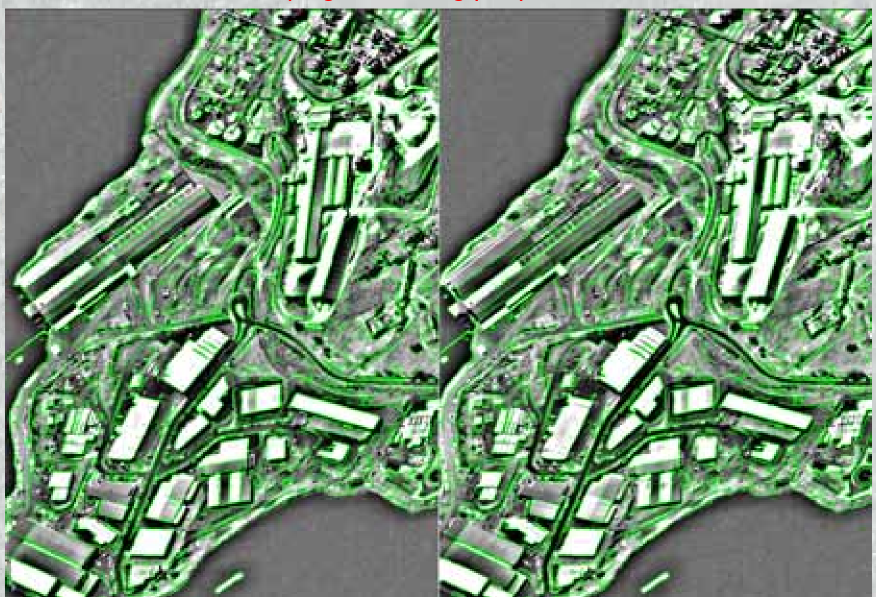




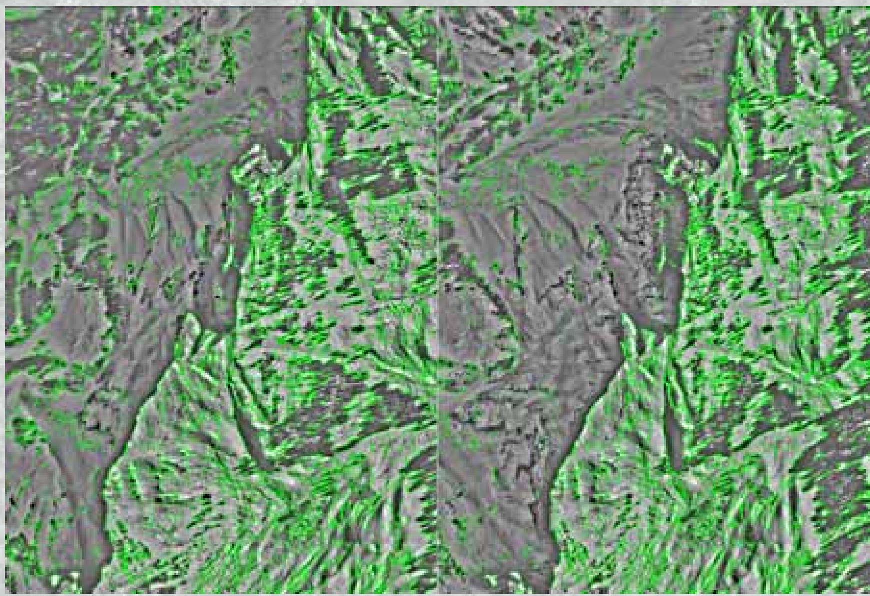
Multiple Image Matching



Automatic DSM Generation (edge matching part)



Automatic DSM Generation (edge matching part)



Automatic DSM Generation (IKONOS, Thun, Switzerland)

Study area: Thun, Switzerland

+ Area: 17 × 20 Km^2

+ Height Range: 1600 m

IKONOS Geo Product (O, N below mean with old, new sensor calibration/interior orientation)

Dataset	Image No.	Acquisition Date	Generation date	Sensor-Azimuth	Sensor-Elevation
T_DEC_O	135251_000	2003-12-25	2004-01-19	180.39°	62.95°
	135251_100	2003-12-25	2004-01-19	72.21°	82.15°
	135254_000	2003-12-25	2004-01-19	128.17°	82.62°
T_DEC_N	163001_000	2003-12-25	2005-03-02	180.39°	62.95°
	163001_100	2003-12-25	2005-03-02	72.21°	82.15°
	163003_000	2003-12-25	2005-03-02	128.17°	82.62°
T_OCT	157928_000	2003-10-12	2004-02-11	10.74°	77.85°
	157928_100	2003-10-12	2004-02-11	4.69°	85.26°
	157928_200	2003-10-12	2004-02-11	197.09°	71.95°

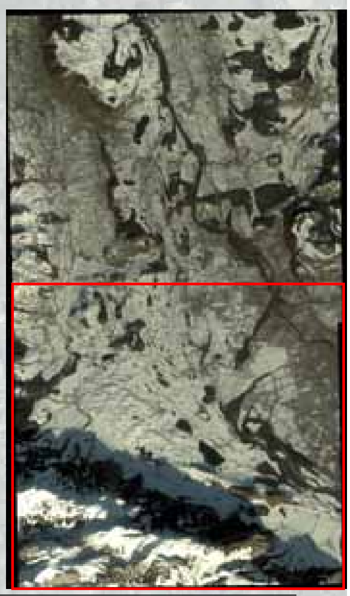
Reference

+ 2m spacing LIDAR DSM as reference

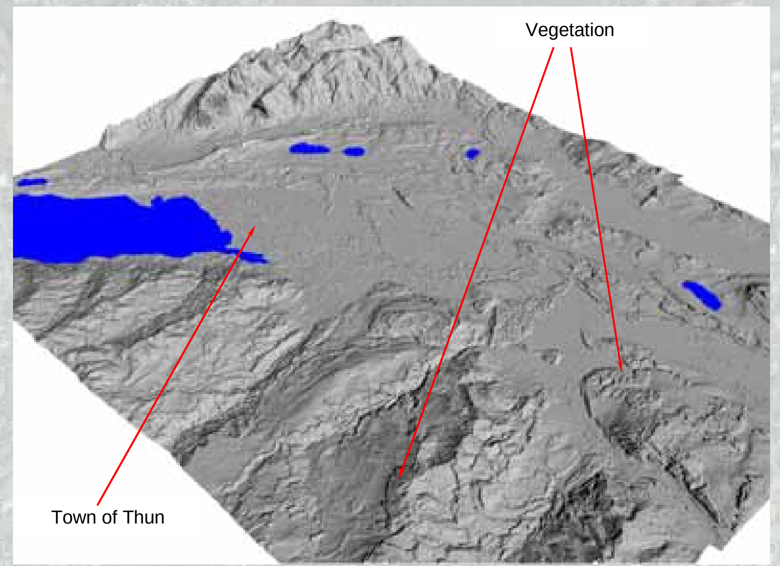
accuracy: 0.5 m (1σ) for open areas;

1.5 m for vegetation areas

+ 50 GPS GCPs (only 39 used)

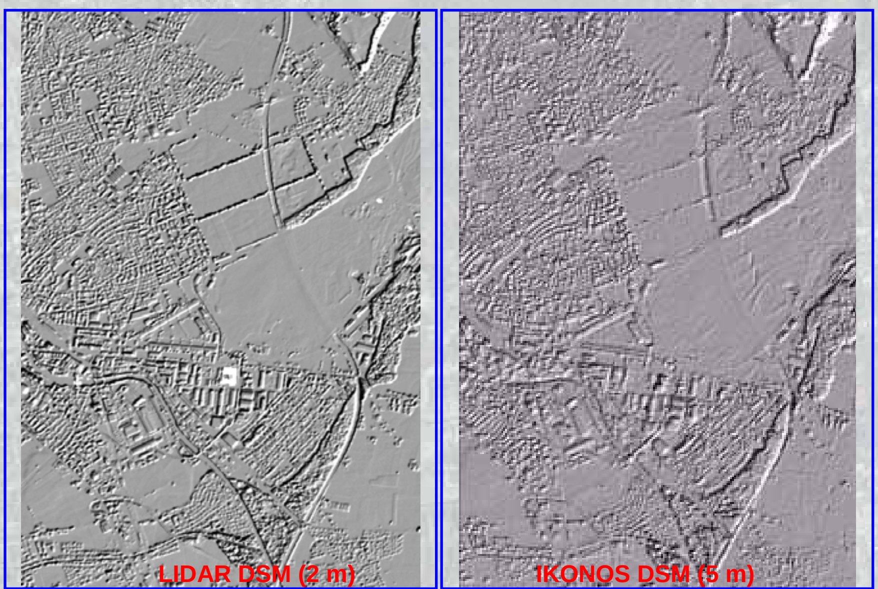


Performance Evaluation: IKONOS, Thun, Switzerland

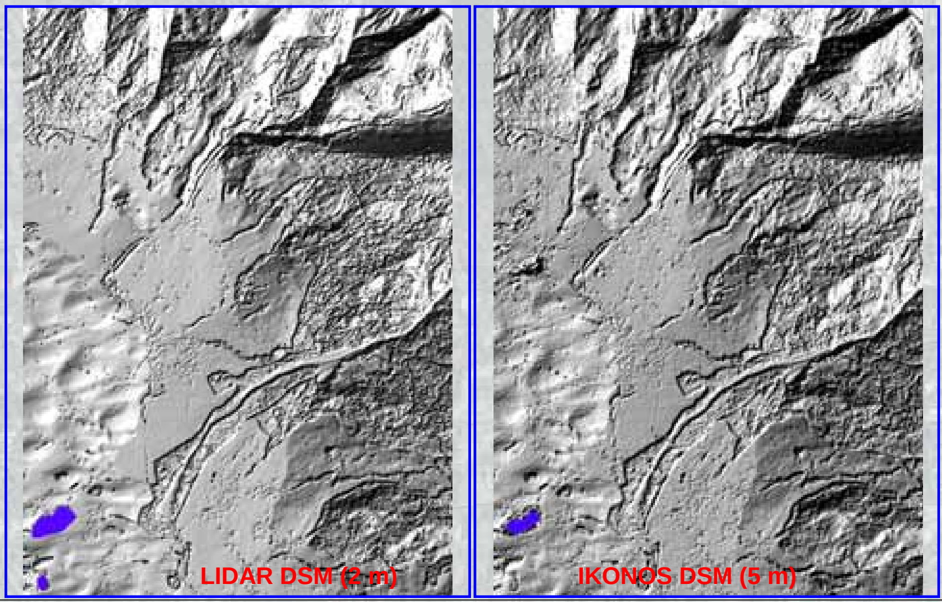


Raster DSM (5 m spacing) generated from IKONOS images (T_DEC_N)

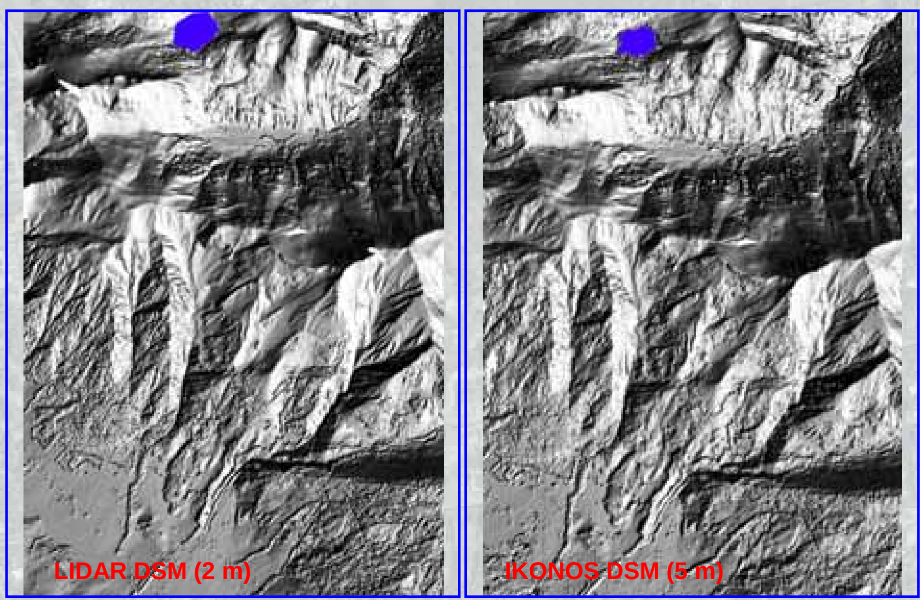
Performance Evaluation: IKONOS, Thun, Switzerland



Performance Evaluation: IKONOS, Thun, Switzerland



Performance Evaluation: IKONOS, Thun, Switzerland



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Performance Evaluation: IKONOS, Thun, Switzerland

Lidar DSM - matching (in m) for the triplet **T_DEC_O**

Terrain type	No. of compared points	RMSE	Average	RMSE (95)	Average (95)
B1	7,037,578	**1.27**	0.82	0.93	0.89
B2	7,993,875	**1.84**	0.92	1.04	0.92
B3	9,763,257	**2.11**	0.80	1.20	0.80
C	2,794,389	**3.34**	0.30	2.36	0.30
V	8,689,642	**8.16**	1.68	-	-
W1	28,854,764	**4.93**	1.13	4.24	1.14
W2	18,022,149	**2.74**	0.70	1.45	0.69

B1 – Bare ground; B2 – Bare ground (including mountainous area); B3 – Bare ground (including mountainous and shadow areas)

C – City area only

V – Vegetation area only

W1 – Whole area; W2 – Whole area without vegetation areas.

RMSE (95) and Average (95) are RMS and average after excluding the 5% largest differences

Performance Evaluation: IKONOS, Thun, Switzerland

Lidar DSM - matching (in m) for the triplet **T_DEC_N**

Terrain type	No. of compared points	RMSE	Average	RMSE (95)	Average (95)
B1	7,037,578	**1.15**	0.31	0.73	0.37
B2	7,993,875	**1.90**	0.34	0.93	0.35
B3	9,763,257	**2.14**	0.29	1.19	0.30
C	2,794,389	**3.38**	0.55	2.41	0.55
V	8,689,642	**8.05**	1.58	-	-
W1	28,854,764	**4.90**	0.50	4.23	0.50
W2	18,022,149	**2.54**	0.35	1.41	0.34

Performance Evaluation: IKONOS, Thun, Switzerland

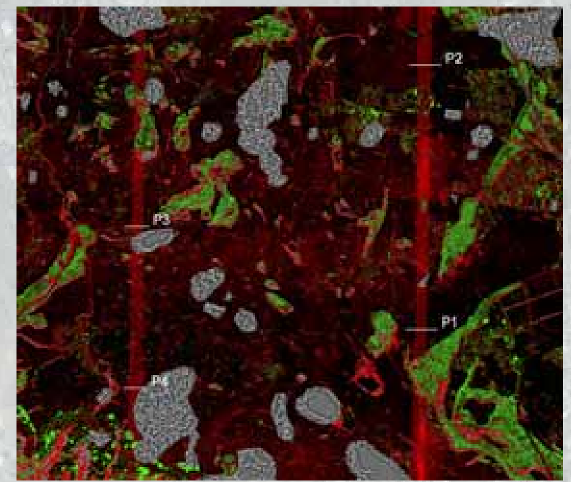
Terrain type	RMSE T_DEC_N	RMSE T_DEC_O	Average T_DEC_N	Average T_DEC_O
B1	1.15	1.27	**0.31**	**0.82**
B2	1.90	1.84	**0.34**	**0.92**
B3	2.14	2.11	**0.29**	**0.80**
C	3.38	3.34	0.55	0.30
V	8.05	8.16	1.58	1.68
W1	4.90	4.93	0.50	1.13
W2	2.54	2.74	0.35	0.70

Performance Evaluation: IKONOS, Thun, Switzerland

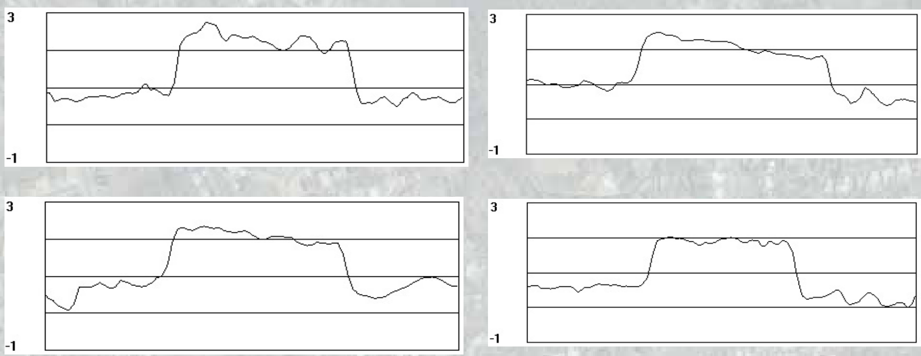
Lidar DSM - matching (in m) for the triplet **T_OCT**

Terrain type	No. of compared points	RMSE	Average	RMSE (95)	Average (95)
B1	7,037,578	**1.41**	0.22	0.95	0.21
B2	7,993,875	**1.77**	0.29	1.09	0.29
B3	9,763,257	**1.75**	0.29	1.07	0.29
C	2,794,389	**2.83**	-0.25	2.08	-0.25
V	8,689,642	**6.61**	-1.97	-	-
W1	28,854,764	**4.25**	-0.40	2.96	-0.39
W2	18,022,149	**2.05**	0.16	1.32	0.16

DSM generation results (Ikonos triplet, Thun, Dec_O)

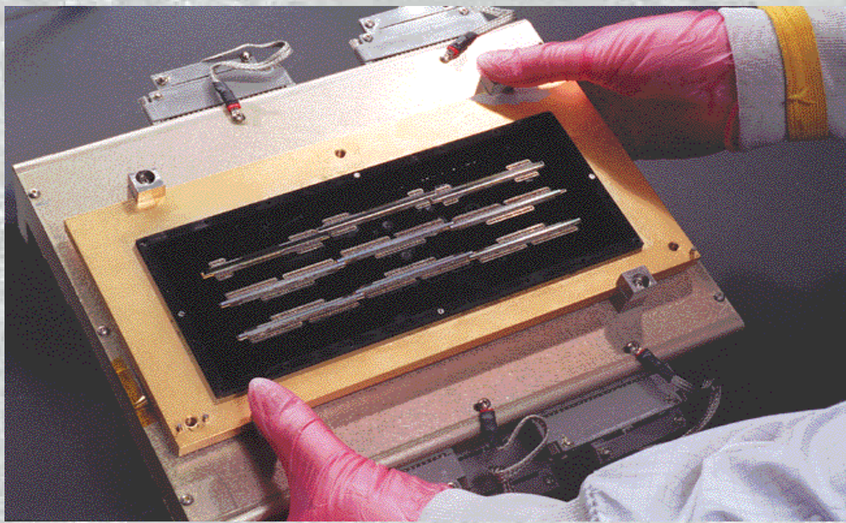


DSM generation results (Ikonos triplet, Thun)

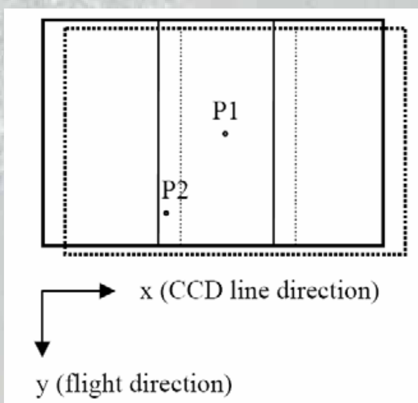


• **Height jump of 1.3-1.5 m corresponds to 0.7-0.8 pixel y-parallax error**

Ikonos focal plane (shift of middle partial PAN CCD caused jump)



Ikonos interior orientation error



The cause of vertical stripes with larger height error due to inaccurate interior orientation modelling. E.g. a possible shift of the middle CCD relative to the other two will cause the same pixel coordinate error for point P1, but not for point P2, introducing thus a y-parallax (and height) error.

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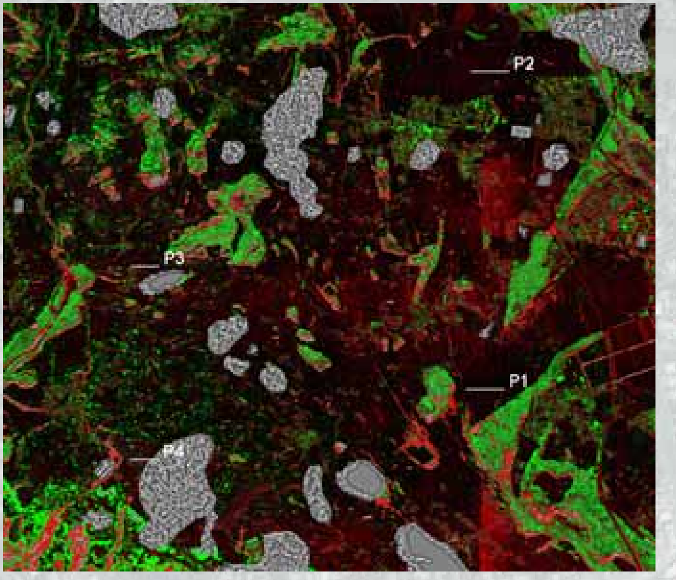
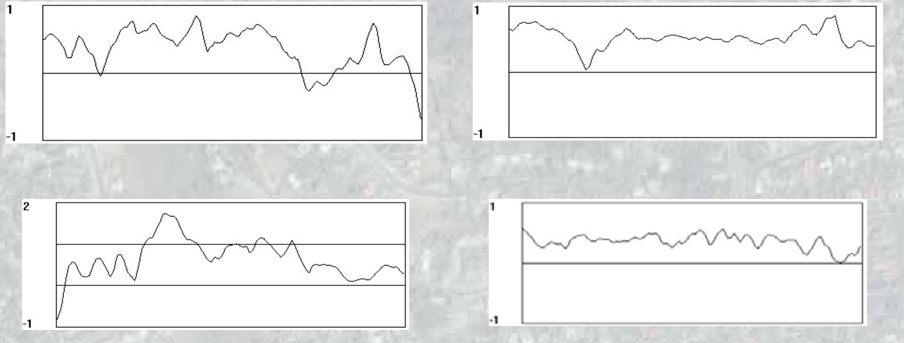
DSM generation results (Ikonos triplet, Thun, Dec_N)

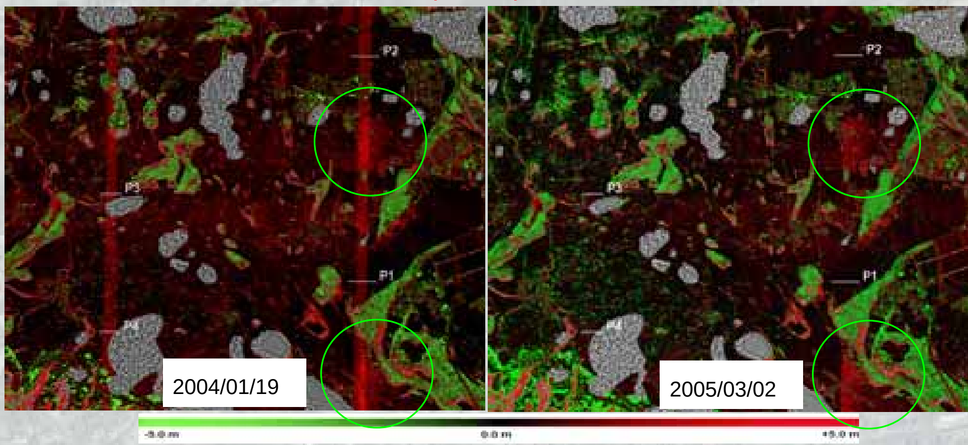


ETH Eidgenössische Technische Hochschule Zürich / Swiss Federal Institute of Technology Zurich

DSM generation results (Ikonos triplet, Thun)



Performance Evaluation: IKONOS, Thun, Switzerland



- Possibility for in-flight calibration of interior orientation errors with good reference DSM and accurate DSM measurement from Ikonos
- Detection of systematic Lidar DSM errors (see marked circles)

Performance Evaluation: SPOT5-HRS, Bavaria, Germany

Study area: Bavaria, Germany

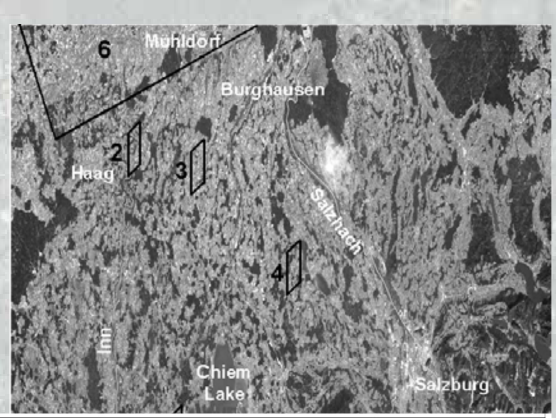
+ Area: 120 × 60 Km²
+ Height range: ca. 1600 m

SPOT HRS stereo pair

+ Acquisition time: 1st October, 2002
+ 5m / 10m GSD along-/cross-track

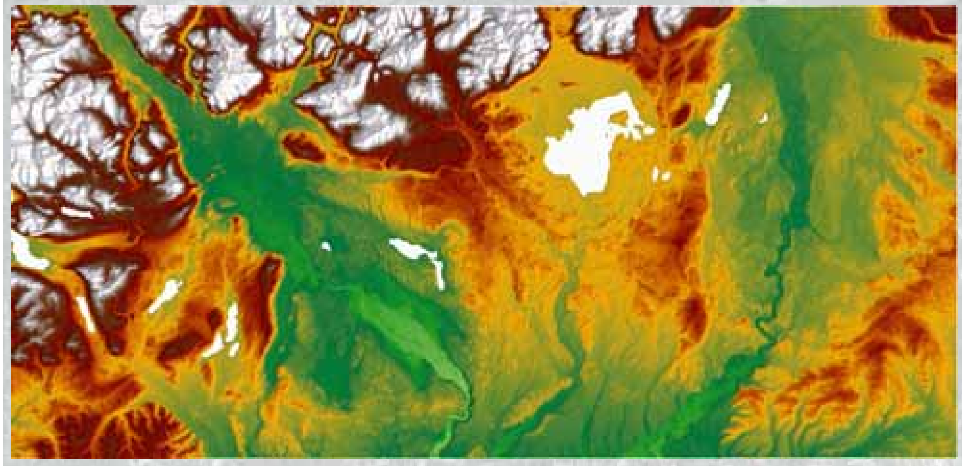
Reference data:

+ 81 GPS GCPs (only 41 used)
+ 6 reference DTMs



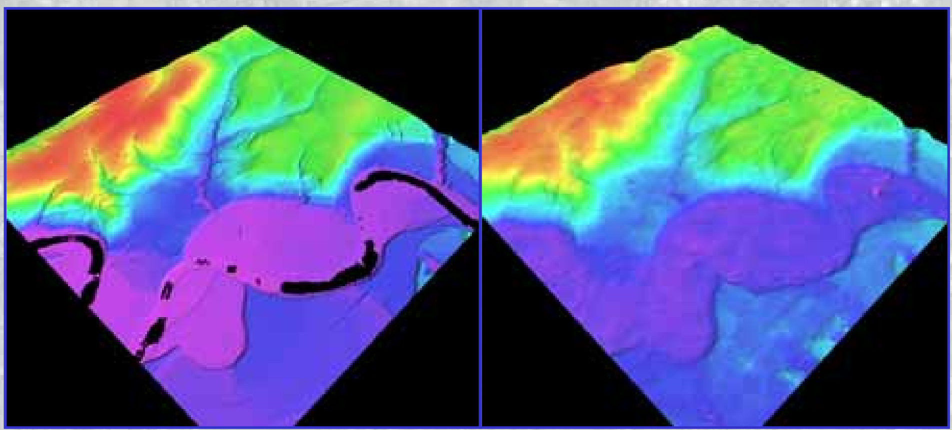
DTM Name	Location	DTM Spacing (m)	Source	DTM Size	Height Accuracy (m)
DTM-1	Prien	5 × 5	Laser Scanner	5km × 5km	0.5
DTM-2	Gars	5 × 5	Laser Scanner	5km × 5km	0.5
DTM-3	Peterskirchen	5 × 5	Laser Scanner	5km × 5km	0.5
DTM-4	Taching	5 × 5	Laser Scanner	5km × 5km	0.5
DTM-5-1	Inzell-North	25 × 25	Laser Scanner	10km × 1.3km	0.5
DTM-5-2	Inzell-Sourth	25 × 25	Contour lines	10km × 7.7km	5.0
DTM-6	Vilsbiburg	50 × 50	Photogrammetry	50km × 30km	2.0

Performance Evaluation: SPOT5-HRS, Bavaria, Germany



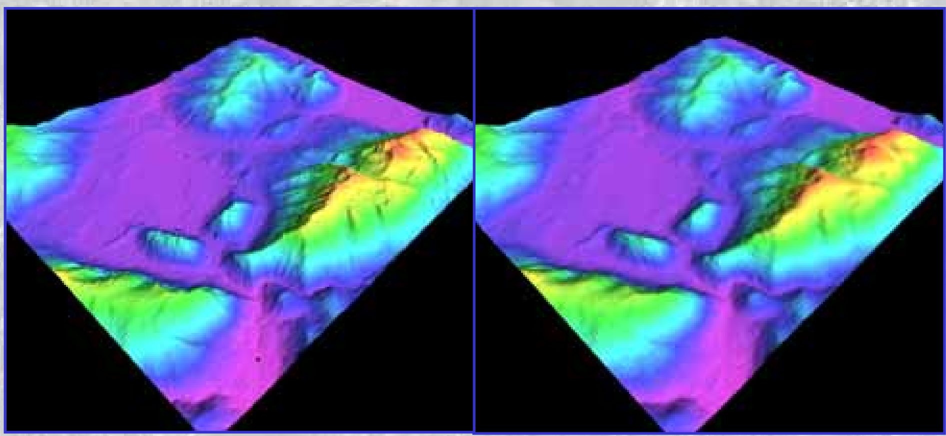
Raster DSM (25 m Spacing,120 × 60 km^2)

Performance Evaluation: SPOT5-HRS, Bavaria, Germany



Reference DSM (5 m) SPOT5 DSM (25 m)

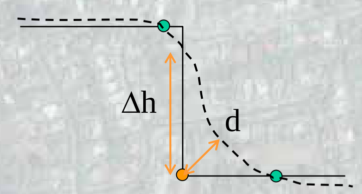
Performance Evaluation: SPOT5-HRS, Bavaria, Germany



Reference DSM (25 m) SPOT5 DSM (25 m)

Accuracy analysis

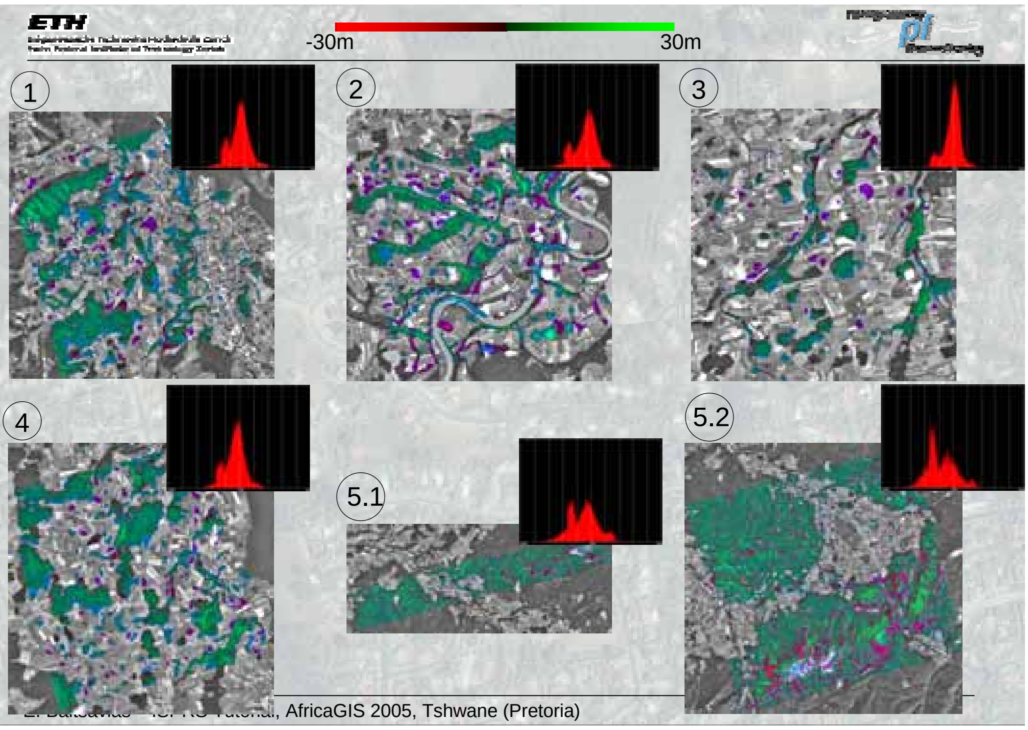
- Quantitative comparison to reference DEMs
- Two comparisons:
  - **Terrain height (2.5D)**: difference between the heights of reference DEMs and the heights interpolated from generated DSMs
  - **Euclidean distance (3D)**: normal distance between the surfaces (Geomatic Studio v4.1 by Raindrop)
- Limit of terrain height comparison: even if the measurement is correct (●), the surface modeling error may cause large height differences (example: step profile)



Accuracy analysis

- Terrain height (2.5D)
  - Original results

	Number of points		RPC model			
	IGP DEM	Reference DEM	Max Diff.	Min Diff.	Mean	RMSE
1	35448	1000000	25.1	-32.9	-2.6	5.7
2	32932	1000000	29.1	-37.1	-1.2	5.0
3	33450	1000000	20.7	-17.2	-0.5	3.2
4	32067	1000000	13.6	-23.1	-2.5	4.7
5-1	10327	21200	19.2	-33.5	-5.8	8.3
5-2	71795	139200	136.8	-89.3	-4.3	9.5
6	130558	600000	26.8	-27.1	1.5	4.0

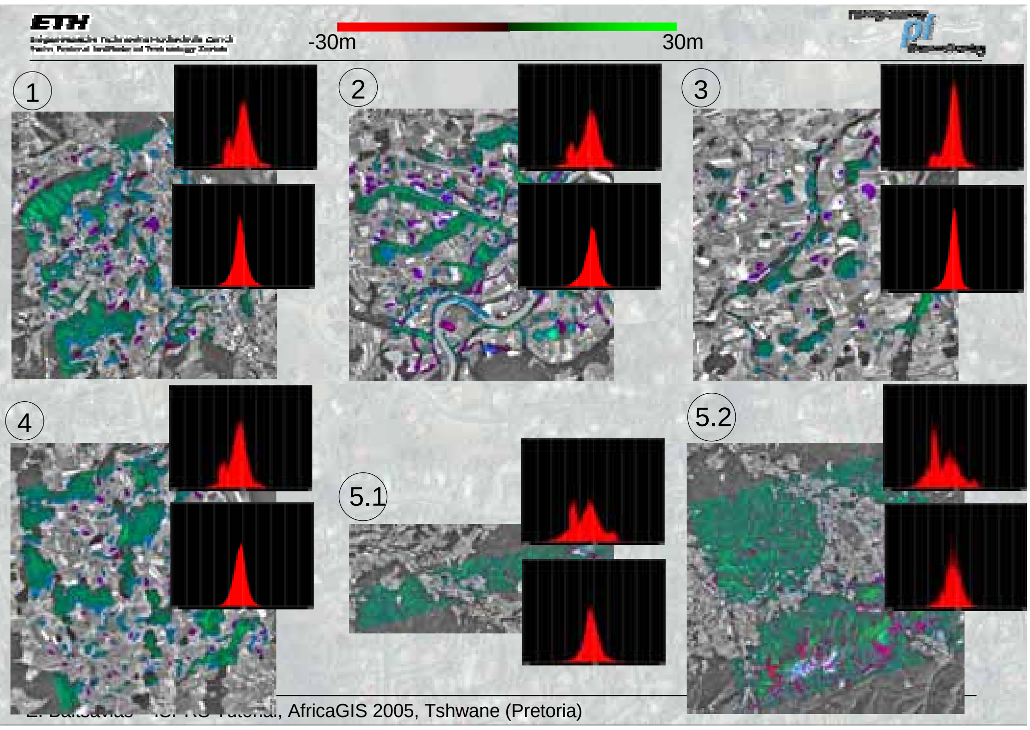


, AfricaGIS 2005, Tshwane (Pretoria)

Accuracy analysis

- Terrain height (2.5D)
  - Removal of areas covered by trees

	RPC model			
	Max Diff.	Min Diff.	Mean	RMSE
1	15.4	-23.7	-1.7	4.6
2	29.1	-31.7	0.2	3.6
3	20.7	-13.6	0.1	2.9
4	10.5	-18.4	-1.2	3.2
5-1	19.1	-13.3	-1.7	4.9
5-2	49.8	-66.8	-1.3	6.7
6	26.8	-25.9	2.1	4.4



, AfricaGIS 2005, Tshwane (Pretoria)

Accuracy analysis

- Normal distance (3D)

	RPC model			
	Max distance	Average distance	Standard deviation	RMSE
1	18.7	2.2	1.7	2.8
2	37.5	2.7	2.0	3.4
3	21.4	2.7	1.8	3.2
4	20.0	2.2	1.6	2.7
5-1	26.3	6.4	4.4	7.8
5-2	70.1	6.0	5.0	7.8

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Swiss Federal Institute of Technology Zurich

Orthoimage Generation (partly old Kratky sensor model used)

Methods:

- **Kratky's Polynomial Mapping Functions (PMFs)**
- **Relief corrected affine transformation**

Reference plane -> reference plane of DTM

3 GCP's are needed but 4-6 are suggested

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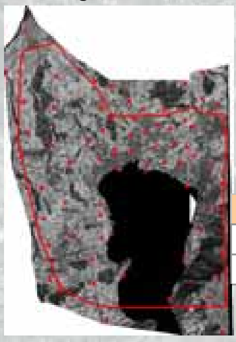
Orthoimage Generation

Zug



Test results

Sens elev. (deg)	85.7
DTM spacing / accur (m)	5 / 0.4
GCP accuracy (m)	1.5-2
GCP definition	Medium to good
Elevation range (m)	400-990

Version	GCPs / CPs	RMS/X	RMS/Y	Max. abs X	Max. abs Y
1	27 / 41	1.5	1.6	3.8	3.2
2	27 / 69	2.5	2	11.3	6.5

Method: Kratky's PFMs

Extrapolation occurs when check points are defined outside the perimeter of the GCPs (version 2)

Orthoimage Generation

Luzern

Test results

Sens elev. (deg)	67.7
DTM spacing / accur (m)	25 / 2.5 lowland, 10 Alps
GCP accuracy (m)	0.5 – 3
GCP definition	Very poor to good
Elevation range (m)	400-2100

Method: Affine transformation

GCPs/CPs	RMS/X	RMS/Y	Max. abs X	Max. abs Y
0 /66	134.2	30.6	501.5	118.1
6 / 65	2.6	2.2	9.9	5.9
6/14	0.6	0.6	1	1.1

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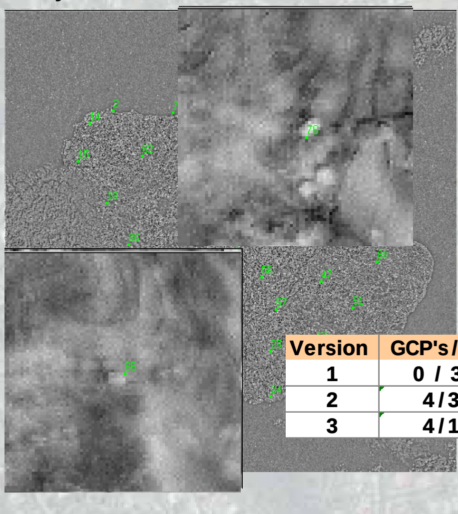
Orthoimage Generation

Nisyros



Test results

Sens elev. (deg)	73.5
DTM spacing/accur (m)	2 / 3.3
GCP accuracy (m)	ca. 0.5
GCP definition	Poor to good
Elevation range (m)	0-700

Method: Affine transformation

Version	GCP's/CPs	RMS/X	RMS/Y	Max. abs X	Max. abs Y
1	0 / 38	106.1	75.5	153.1	122.8
2	4/34	1.7	1	4.4	2.3
3	4/15	0.9	0.6	1.5	1.4

Orthoimage generation (IKONOS, Quickbird) in Geneva

Input data

2 IKONOS Geo images (IKONOS-West / IKONOS-East)
1 Basic QUICKBIRD Image

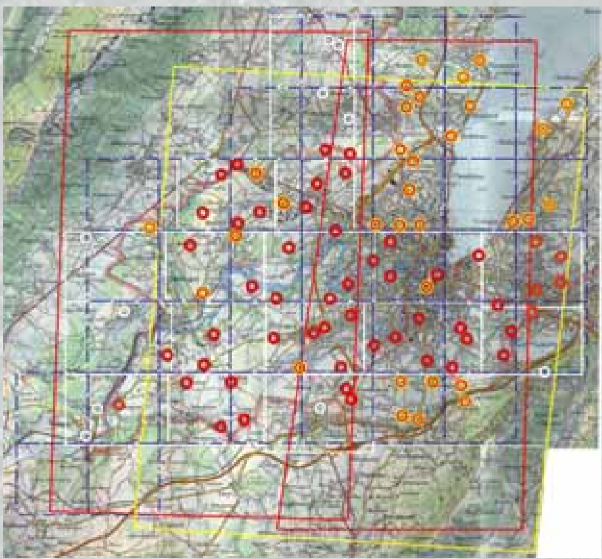
Orthoimages (for acquisition of GCPs):
OP-DIAE: Digital Orthos of Canton Geneva (25 cm pixel size, 0.5 m planimetric RMS)
Swissimage: Digital Orthos of Switzerland of Swisstopo (50 cm pixel size, 1m planimetric RMS)

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

Measurement of GCPs with ellipse fit and line intersection.

Image orientation with various sensor models. RPCs with subsequent affine transformation used for orthoimage generation.

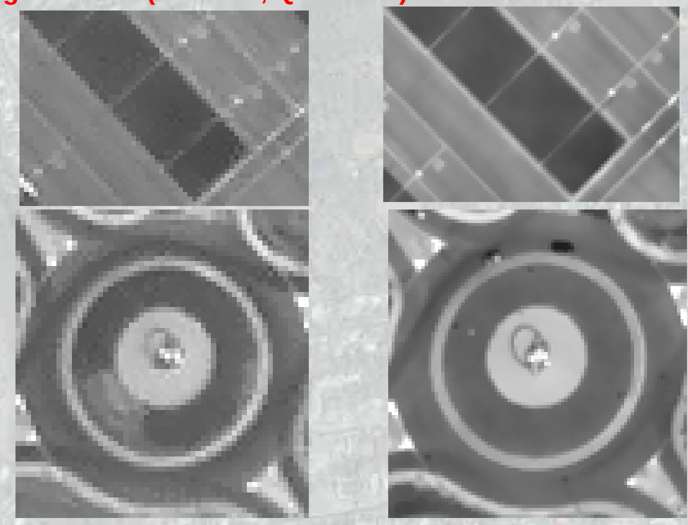
Orthoimage generation (IKONOS, Quickbird) in Geneva



Orthoimage generation (IKONOS, Quickbird) in Geneva

Pansharpened orthoimages. Left Ikonos, right Quickbird.

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 orthos 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 can be even higher with well defined GCPs measured with GPS.

In Y mean (bias) large due to coordinate system differences.

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Orthoimage generation (IKONOS, Quickbird) in Geneva

Planimetric accuracy of panchromatic orthos 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.

Road Extraction – Project ATOMI

- **A**utomated Reconstruction of **T**opographic **O**bjects from Aerial Images using **M**ap **I**nformation.
- It's a co-operation between swisstopo (Swiss Federal Office of Topography) and ETH Zurich, financed by swisstopo.
- ATOMI uses edge detection and existing knowledge and cues about road existence to detect road centrelines from orthophotos.
- ATOMI is used to remove cartographic generalisation and fit the geometry of roads to the real world to an accuracy of better than 1m in x, y and z
- ATOMI keeps the topology and attributes of the input vector map data set (VECTOR25)
- The result is a new accurate 3D road centreline data set without gaps, containing the topology and attributes of the input data as well as new weighted mean road width attributes

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