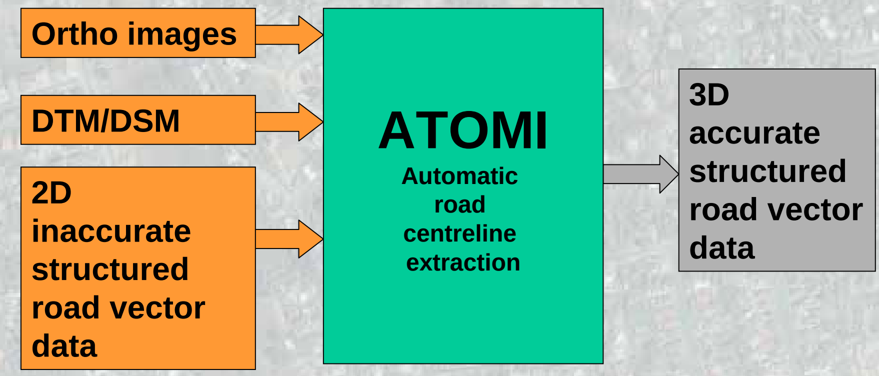
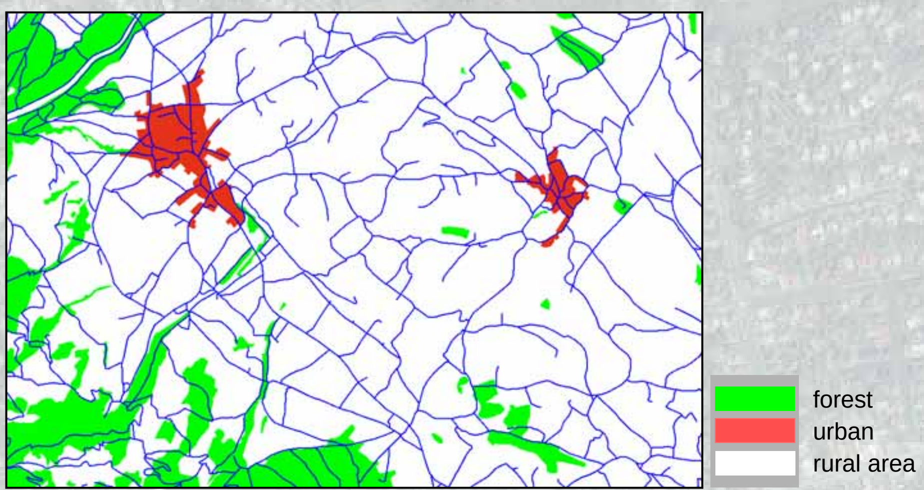
ATOMI input and output data

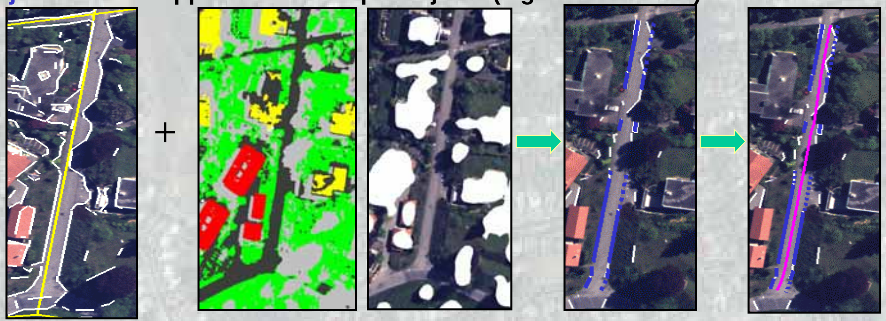


Classification of roads according to landcover

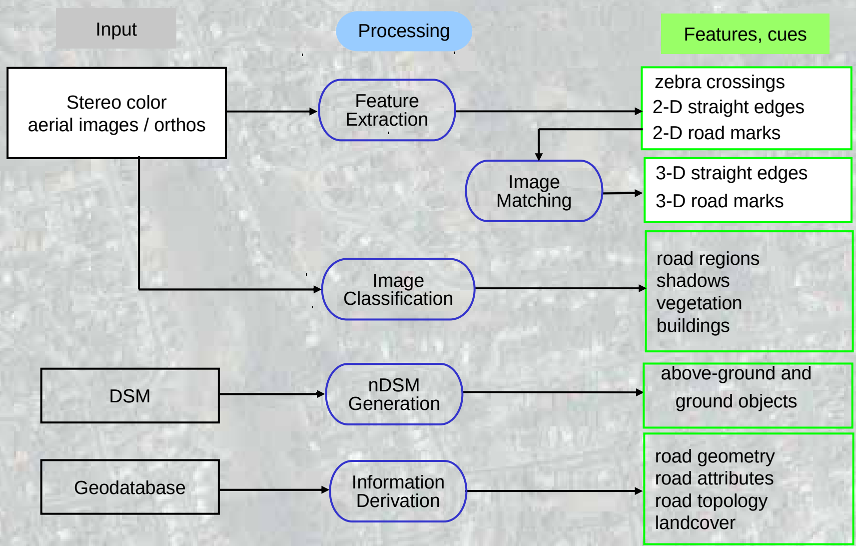


General Strategy

- Use of existing knowledge, rules and models
- Use and fusion of multiple cues about road existence
- Creation of redundancy through multiple cues to account for errors
- Early transition to object space, use of 2D and 3D interactions to bridge gaps and missing road parts
- Object-oriented approach in multiple objects (e.g. road classes)



Features, Cues and Algorithms



How ATOMI road extraction works

a. **Straight edge extraction**

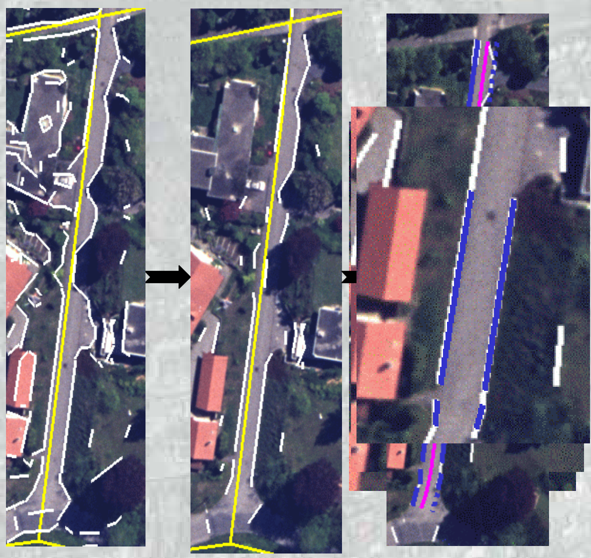
b. **Removal of irrelevant edges**

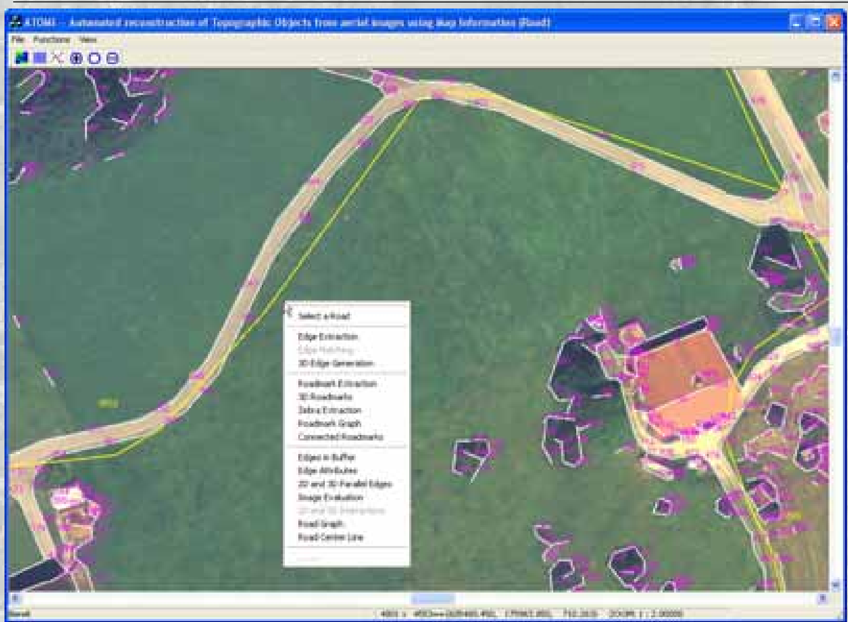
c. **Detection of Parallel Road Sides**

d. **Evaluation of Missing Road Sides**

e. **Bridging Gaps**

f. **Linking Road Sides to Extract Roads**





ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Test site in Switzerland

<u>Geneva 7km²</u>
Aerial Film 50cm **(summer '98)**
IKONOS PSM 100cm **(May '01)**
Quickbird PSM 70cm **(July '03)**
Manually measured reference data from 50cm orthophotos

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Results from Geneva (yellow VECTOR25, black result)

Quality evaluation of the results of Geneva

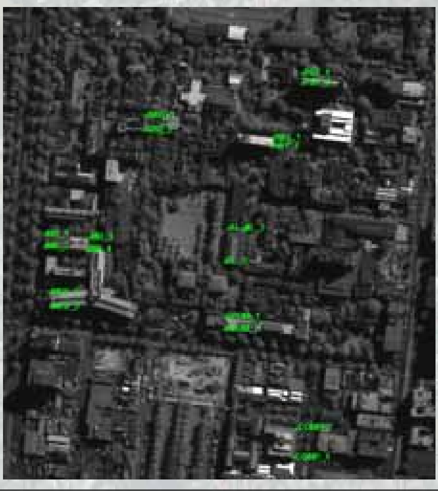
Quality measures		Aerial 50cm	IKONOS-PSM 100cm	Quickbird-PSM 70cm
Completeness		90.89%	54.22%	72.68%
Correctness		95.36%	81.22%	89.58%
Length of reference (km)		50.72	50.72	50.72
Length of extraction (km)		48.35	33.87	42.16
RMS error (m)	x	0.62	0.93	0.81
	y	0.56	0.82	0.75
Mean error (m)	x	0.07	-0.73	-0.44
	y	-0.05	0.34	0.50
Process time (s)		1510	992	924

Results from Geneva

- The system achieved good results with the 50cm aerial film imagery with 90% of rural roads extracted.
- The performance (mainly the completeness) of the satellite data was inferior to aerial imagery, especially the 1m IKONOS imagery
- In the satellite data, higher class (wider) roads were usually extracted, while most lower class (narrower) roads were not. This is because of ATOMI's algorithm requirement of min. 3 pixels road widths was not fulfilled.
- The smaller GSD of Quickbird made more roads visible and the road surface and road edges were clearer. But compared to aerial film the completeness was lower.
- With smaller GSD, correctness and accuracy do not deteriorate much, but completeness yes.

Building Extraction, Ikonos, Melbourne

Roof corners



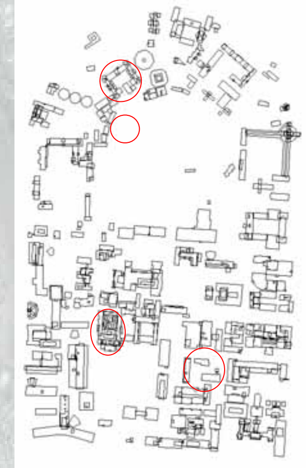
- **19 roof corners measured by GPS**
- **Measured in mono and stereo in all three images of Melbourne**

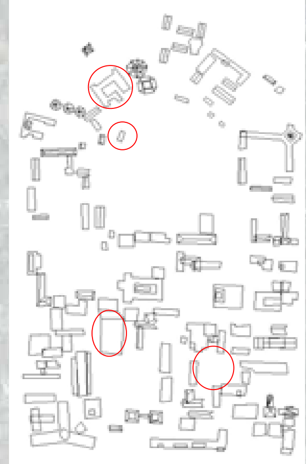
Results from stereo images and 6 GCPs (RMSE):

RPCs: XY = 0.7m
Z = 0.9m

Building Extraction

Aerial Photography (1:15,000) **_Ikonos_ 1m Pan Stereo**

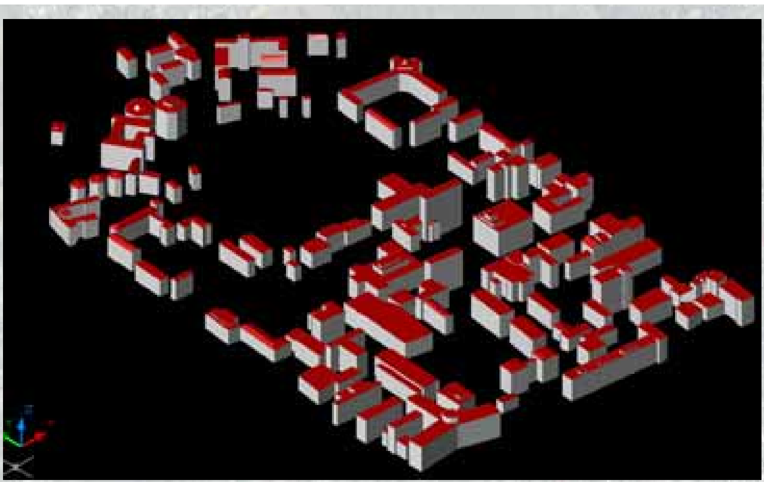




- **Omission of 15 % of buildings (small & large)**

Building Extraction

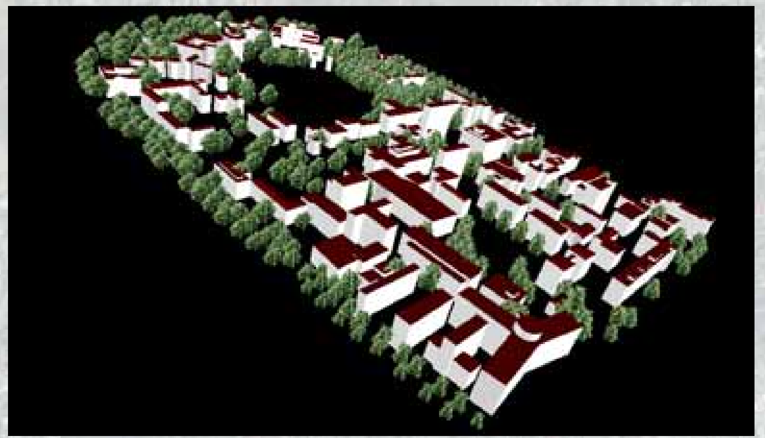
3D Model of University of Melbourne Campus from _Ikonos_ 1m PAN Stereo



Produced with CyberCity Modeler

Building Extraction

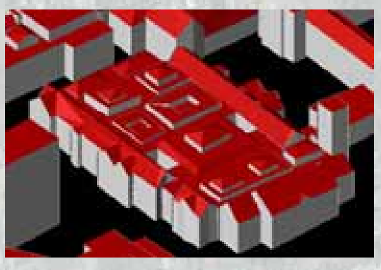
3D Model of University of Melbourne Campus from *Ikonos* 1m PAN Stereo

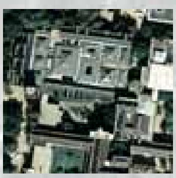


Produced with CyberCity Modeler

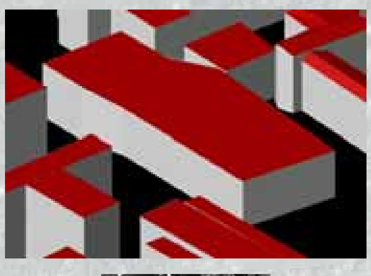
Building Extraction

Aerial Photography (1:15,000)





Ikonos 1m Stereo Imagery



Building Extraction

Aerial Photography (1:15,000)

Ikonos Stereo

Ikonos Nadir Pan-Sharp.

Conducive to building feature measurement

Building Extraction

Aerial Photography (1:15,000)

Ikonos Stereo

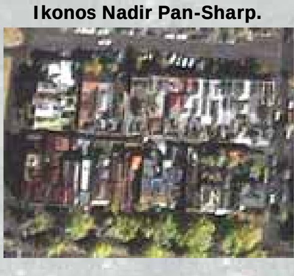
Ikonos Nadir Pan-Sharp.

Ikonos stereo of questionable value to building feature measurement in this case

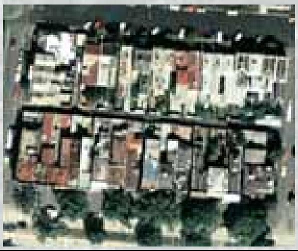
Building Extraction

Ikonos Stereo

Ikonos Nadir Pan-Sharp.



Aerial Photography (1:15,000)



Ikonos stereo of questionable value to building feature measurement in this case

High-Resolution **Sat**ellite Imagery **P**recision **P**rocessing Software **SAT-PP** (ETHZ)

Main Features of SAT-PP:

High-Resolution Satellite Imagery (HRSI): ≤ 5 m Geometrical Resolution

Joint Sensor Model for

IKONOS, QuickBird, SPOT, ALOS/RPISM and etc.

Specially Designed Image Matching Procedure for Linear Array Imagery

*Software **SAT-PP**:* New Processing Methods / Products for HRSI

Input

Imagery with Supplementary Data

+ IKONOS
+ QuickBird
+ SPOT ……

GCPs

SAT-PP

+ Image Orientation
+ Image Matching
+ Feature Collection
+ 3D City Modeling
+ Image Pan-Sharpening
+ DTM & Ortho-Image Generation

…….

Products

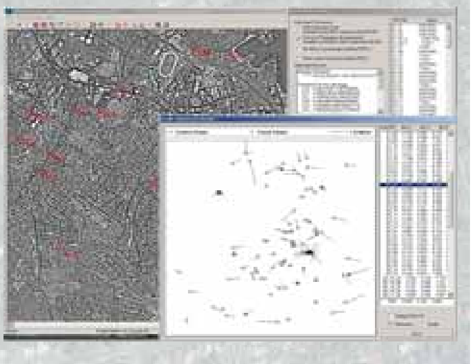
+ DSM / DTM
+ Ortho-Images
+ Pan-Sharpened Images
+ 3D Vector Data
+ Digital Image Maps
+ 3D City Models

…….

Main Features of SAT-PP:

- **Project and Data Management**
  + Multi-sensor HRSI data support, including IKONOS, QuickBird, SPOT and ALOS/PRISM
  + Image enhancement with an edge-preserving adaptive smoothing filter

- **Image Orientation**
  + Manual and semi-automated GCP / tie point measurement in multi-image environment
  + Both rigorous sensor models and generalized sensor models such as rational function models (RFM), affine projection model and projective direct linear transformation model (DLT)
  + On-line quality control and error analysis with interaction of graphics elements



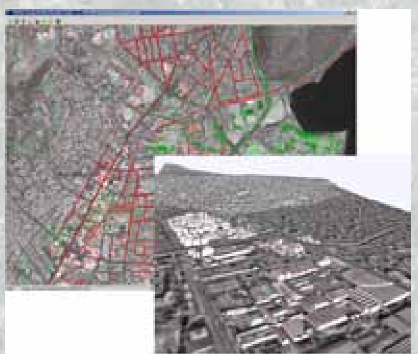
- **Quasi-Epipolar Resampling for Stereoscopic Feature Collection and Automated DSM / DTM Generation**

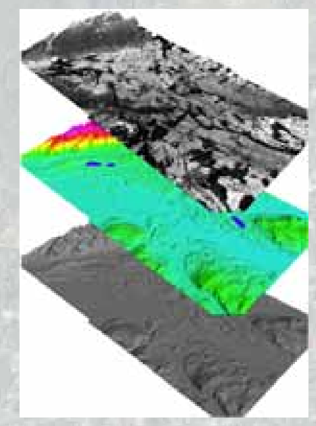
- **Automated DTM / DSM Generation**
  + A hybrid image matching procedure, which exploits the characteristics of linear array imagery and its image geometry, is used to produce dense, precise, and reliable results for DSM / DTM generation

Main Features of SAT-PP:

- **Orthorectification Image Generation**

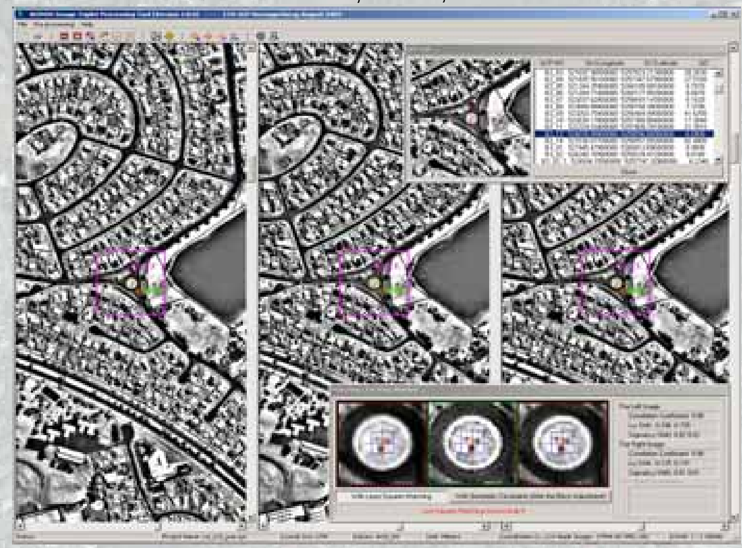
- **Image Pan sharpening**
  + Fully automated sub-pixel image registration between multi-spectral and panchromatic imagery
  + Enhancement of the visual information of multispectral imagery by fusing it with the detailed spatial information of panchromatic imagery





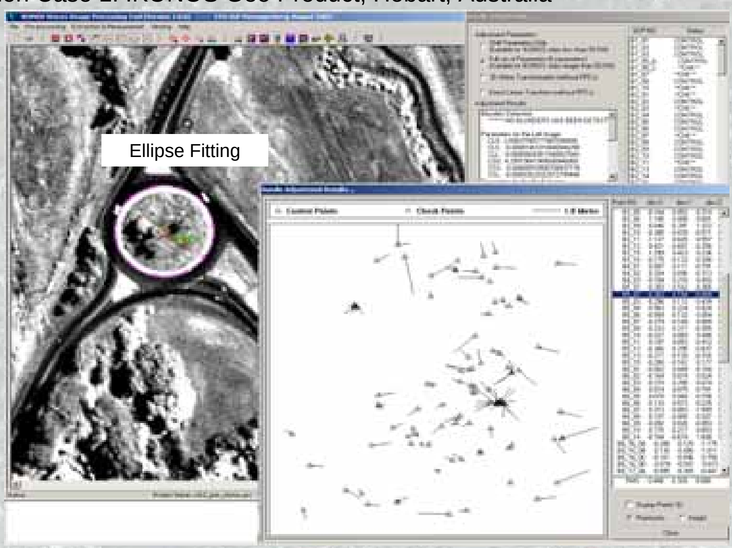
- **Feature Collection and Semi-Automated 3D City Modelling**
  + Works in stereoscopic and multi-image monoscopic mode
  + Features can be collected manually or semi-automatically
  + Mono-plotting with existing terrain data
  + Works with semi-automatic 3D city modeling software CyberCity Modeler™

Application Case 1: IKONOS Geo Product; Hobart, Australia



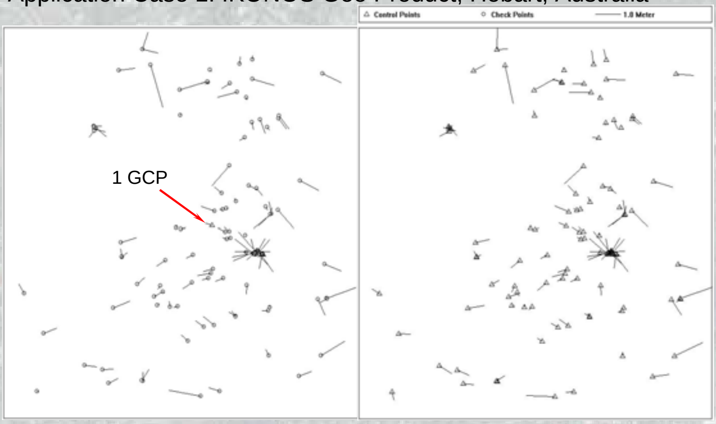
Semi-Automated GCP Measurement

Application Case 1: IKONOS Geo Product; Hobart, Australia



GCP Measurement & Triangulation

Application Case 1: IKONOS Geo Product; Hobart, Australia



Error Vectors of the Triangulation Procedure (with RPCs);

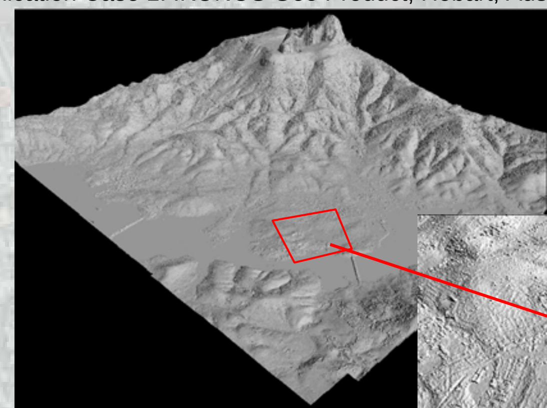
Left: with 1 GCP only;

Right: with all 124 GCPs

Orientation Results of IKONOS Triplet

Method	Number of GCPs (CPs)	RMS in East (m)	RMS in North (m)	RMS in Height (m)
DLT without RPCs	8 + 116	0.54	0.75	1.08
	124 + 0	0.36	0.52	0.73
With RPCs	1 + 123	0.49	0.35	1.04
	4 + 120	0.48	0.36	0.86
	124 + 0	0.45	0.35	0.84

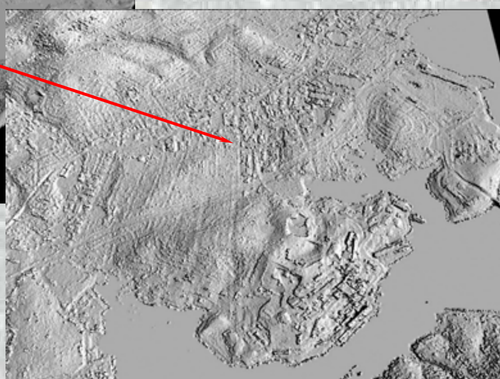
Application Case 1: IKONOS Geo Product; Hobart, Australia



3D Visualization of 5 m Grid DSM

Automated Extracted DSM by Image Matching

Feature Points + Line Features

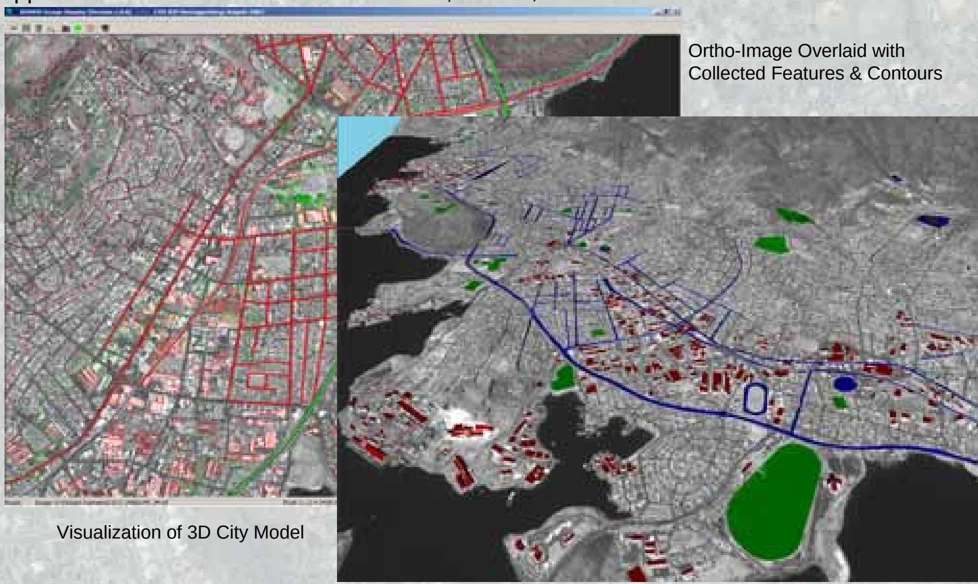


DSM Accuracy Test Results:

(Checked by more than 100 Feature (GPS) Points)

RMS: 0.9 m

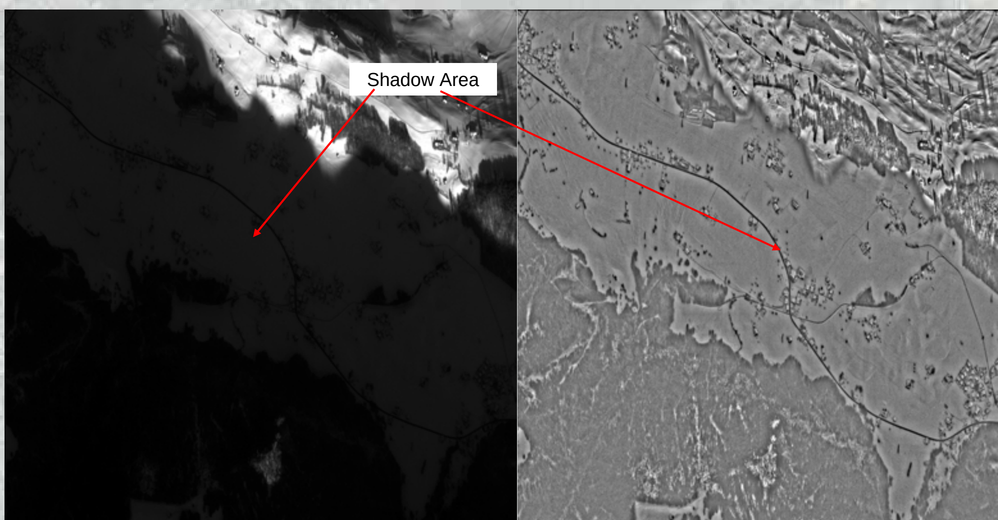
Application Case 1: IKONOS Geo Product; Hobart, Australia



Ortho-Image Overlaid with Collected Features & Contours

Visualization of 3D City Model

Application Case 2: IKONOS Geo Product; Thun, Switzerland



Original IKONOS Image

Enhanced IKONOS Image

E. Baltsavias – ISPRS Tutorial, AfricaGIS 2005, Tshwane (Pretoria)

Application Case 2: IKONOS Geo Product; Thun, Switzerland

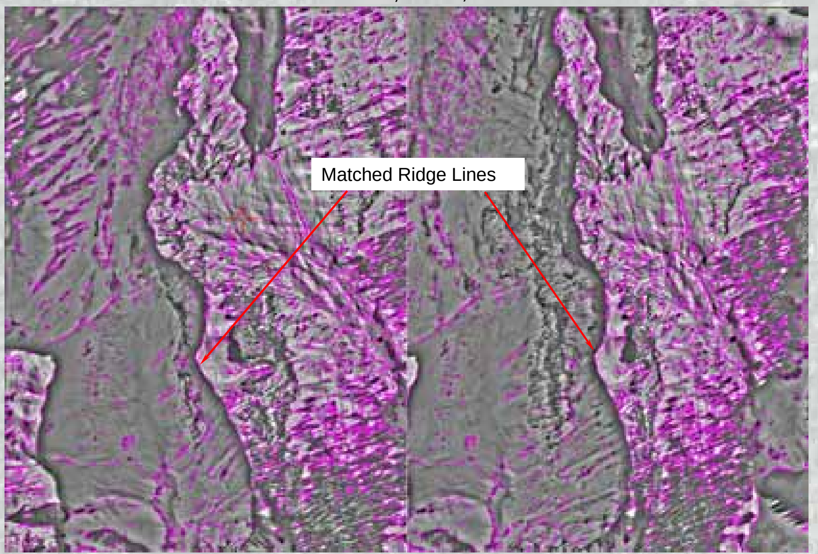
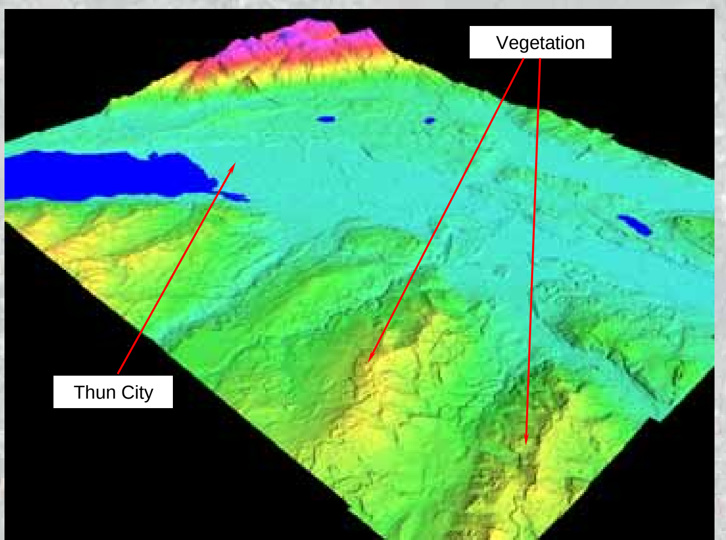


Image Overlaid with Matched Line Features

Application Case 2: IKONOS Geo Product; Thun, Switzerland



5 m Grid DSM Generated from 5 IKONOS Images

Image Orientation Accuracy:

RMS-X: 0.48 m

RMS-Y: 0.82 m

RMS-Z: 0.79 m

DSM Accuracy Test Results:

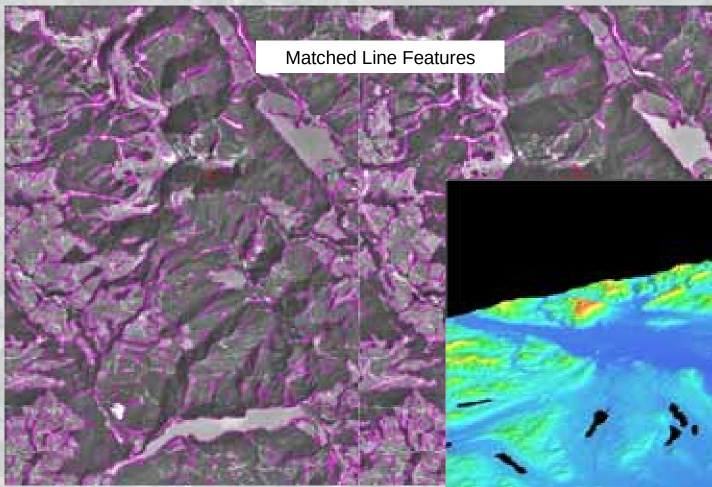
(With 2 m Reference DSM generated from LIDAR)

Whole Area: RMS: 4.8 m

City Area: RMS: 2.9 m

Open Area: RMS: 1.3 m

Application Case 3: SPOT5-HRS Imagery; CNES-ISPRS Study Team



SPOT5 Scene Bavaria

5 m Along-, 10 m Cross-Track

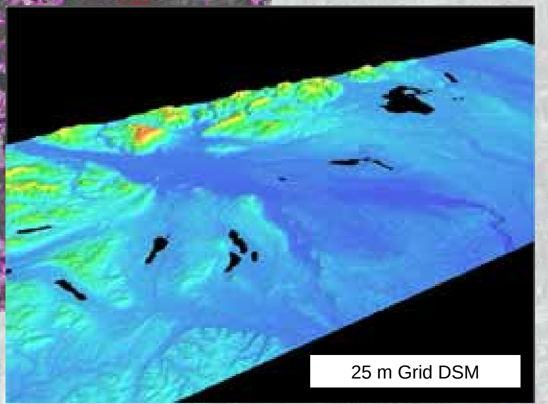
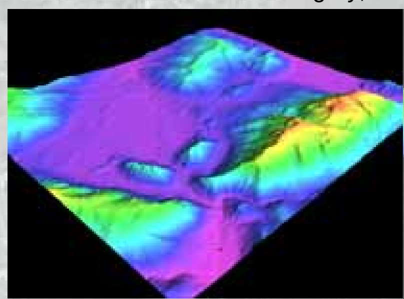


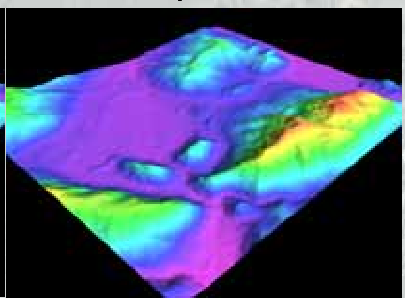
Image Orientation Results: (43 GCPs)

RMS-X: 6.48 m; RMS-Y: 3.28 m; RMS-Z: 1.85 m

Application Case 1: SPOT5-HRS Imagery; CNES-ISPRS Study Team



Reference DSM



DSM from matching

DSM Accuracy Test Report

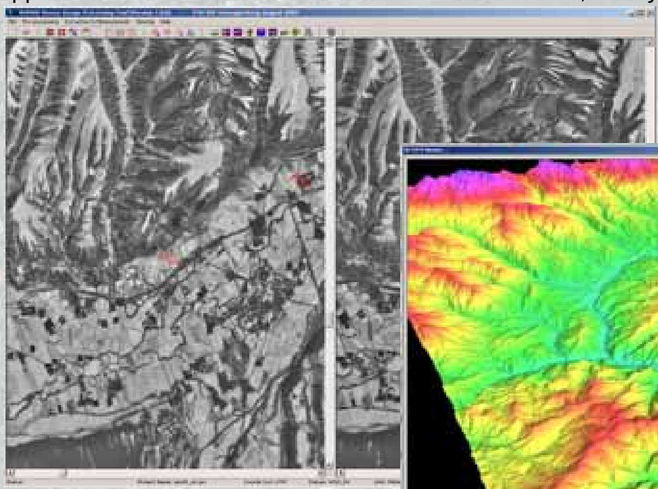
DEM Name	Terrain Characteristic	No. of Points		Maximum Difference	Minimum Difference	Average (meters)	RMS (meters)
		Matched	Reference				
DLR-DEM-01	Smooth, weakly inclined	35448	1000000	25.1	-32.9	-2.6	5.7
DLR-DEM-02	Smooth, weakly inclined	32932	1000000	29.1	-37.1	-1.2	5.0
DLR-DEM-03	Smooth, weakly inclined	33450	1000000	20.7	-17.2	-0.5	3.2
DLR-DEM-04	Smooth, weakly inclined	32067	1000000	13.6	-23.1	-2.5	4.7
DLR-DEM-05-1	Rough, strongly inclined	10327	21200	19.2	-33.5	-5.8	8.3
DLR-DEM-05-2	Rolling, strongly inclined	71795	139200	136.8	-89.3	-4.3	9.5
DLR-DEM-06	Rough, weakly inclined	130558	600000	26.8	-27.1	1.5	4.0

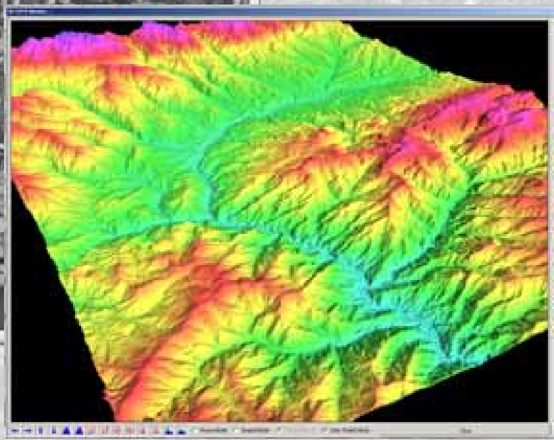
Application Case 4: SPOT5 Across-Track 2.5 m Stereo; Bamiyan, Afghanistan

Image Orientation Accuracy:

RMS-X: 1.2 m; RMS-Y: 2.1 m

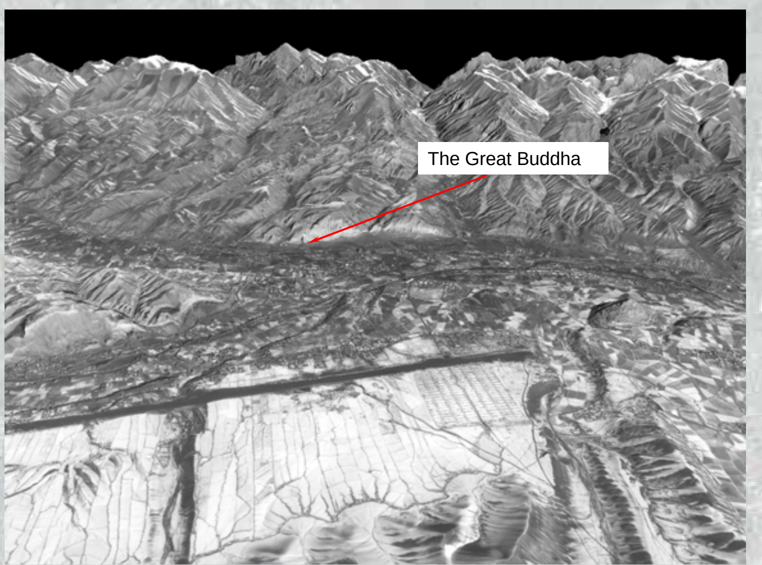
RMS-Z: 1.8 m





Visualization of 20 m DTM

Application Case 4: SPOT5 Across-Track 2.5 m Stereo; Bamiyan, Afghanistan



3D Visualization of the Bamiyan Area

(SPOT DSM overlaid with 1 m IKONOS Image)

Application Case 5: QuickBird 0.7 m Stereo 1B Product; Yokohama, Japan

ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Application Case 5: QuickBird 0.7 m Stereo 1B Product; Yokohama, Japan

3D Visualization of Textured DSM (overlaid with 2.8 m Multispectral Image)

E. Baltsavias – ISPRS Tutorial, AfricaGIS 2005, Tshwane (Pretoria)

Application Case 5: QuickBird 0.7 m Stereo 1B Product; Yokohama, Japan

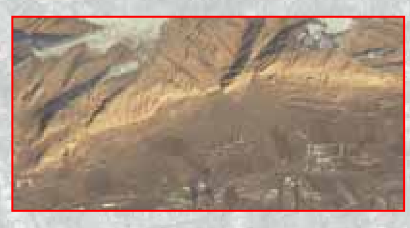
Image Pan-Sharpening: Enhance the visual information of multispectral imagery by fusing it with detailed spatial information in panchromatic imagery

0.7 m Panchromatic Image | 2.8 m Multispectral Image | 0.7 m Pan-Sharpened Image

Application example of High Resolution Satellite Images

3D modeling and visualization of cultural heritage sites

from high-resolution satellite imagery



Motivation

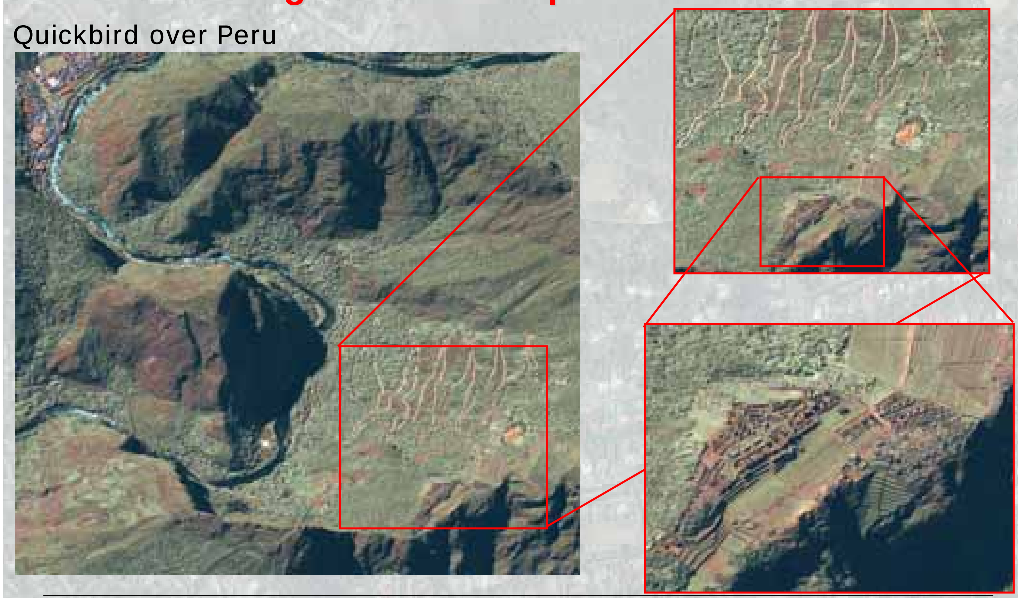
- Modeling of large cultural heritage areas can be required for monitoring, visualization, documentation or cartographic mapping
- C.H. areas are often located in areas not easily accessible or in problematic countries
- (High-resolution) satellite imagery offer a great alternative to standard aerial photo for mapping purposes

Cultural Heritage sites from space

Ikonos over Mexico

Cultural Heritage sites from space

Quickbird over Peru



High-Resolution satellite data

- Almost instant availability
- Large area coverage
- Increasing resolution
- Different products (PAN, multispectral, stereo, ...)
- High costs

Scene orientation (strict sensor model vs. RPCs)

↓

DTM/DSM generation

↓

Visualization

Satellite data and UNESCO

UNESCO has recently started the OPEN INITIATIVE, a partnership with different space agencies to support and assist in the monitoring and documentation of World Heritage sites, natural hazards and for the sustainable development using satellite data

=> great interest (not only in the scientific community) towards mapping from satellite data

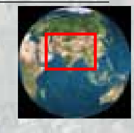
Different sensors available with resolution less than 5 m (QuickBird, IKONOS, SPOT-5/HRG, IRS-1C/1D, ...)

Satellite data used for documentation and visualization of the C.H. area of Bamiyan, Afghanistan

The Bamiyan project

1. DTM generation from high-resolution satellite images
2. Generation of tourist / geographic information system
3. 3D Modeling of the Great Buddha of Bamiyan
   [Gruen et al., 2002, 2003]
4. 3D modeling of the 2 empty niches
   [Gruen et al., 2004]
5. Mapping and visualization of frescos
   [Remondino et al., 2004]

Cultural heritage site of Bamiyan



- Included in UNESCO World Heritage List (2003)

  [http://whc.unesco.org]

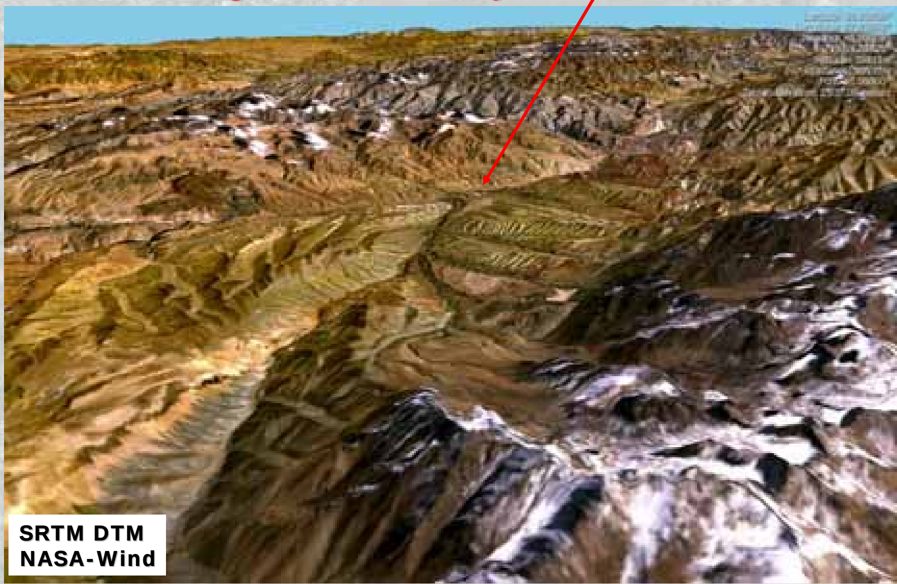
- ca 200 km N-W of Kabul
- ca 2500 m altitude
- Valley in the middle of silk road
- One of the major Buddhist areas
- 3 larger Buddha statues
- Nowadays 8 protected areas

E. Baltsavias – ISPRS Tutorial, AfricaGIS 2005, Tshwane (Pretoria)

Cultural heritage site of Bamiyan

E. Baltsavias – ISPRS Tutorial, AfricaGIS 2005, Tshwane (Pretoria)

Cultural heritage site of Bamiyan

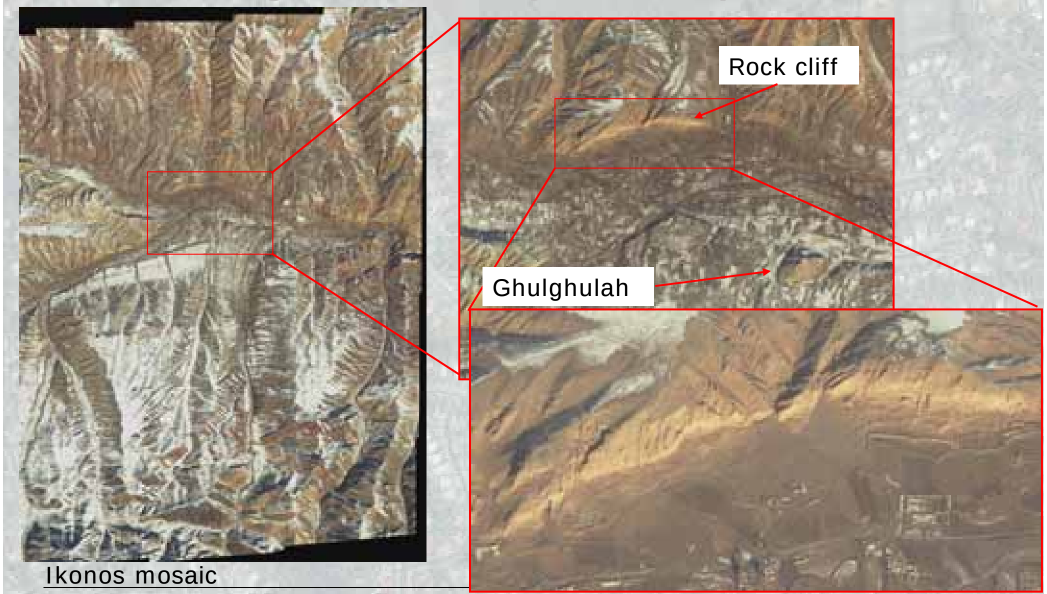


SRTM DTM
NASA-Wind

Cultural heritage site of Bamiyan

SRTM DTM
EarthGoogle

Cultural heritage site of Bamiyan from space



Ikonos mosaic

1. DTM from satellite images

1. **SPOT 5** - HRG stereo pair
   - for DTM generation
   - 2.5 m ground resolution
   - 60x60 km coverage

2. **IKONOS** Geo image mosaic
   - only for texture mapping
   - 1m ground resolution
   - ca 12x18 km coverage

7 GCP measured with GPS available
(□ master station, ○ rover station)

DTM Generation with SAT-PP Software (ETHZ)

High-Resolution **Sat**ellite Imagery **P**recision **P**rocessing
[*Zhang and Gruen, 2004*]

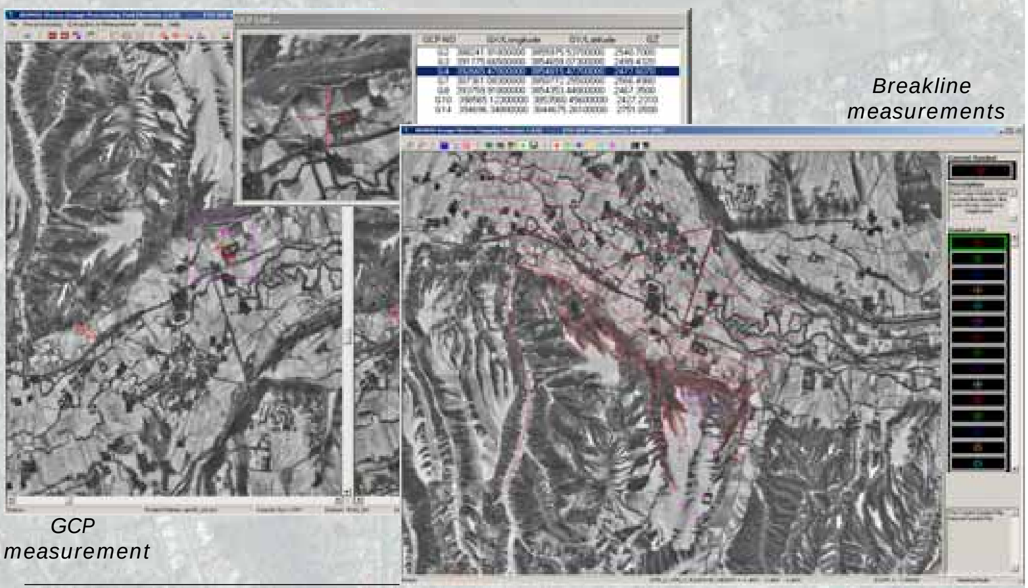
1. SPOT 5 - HRG stereo pair (B/W)
   - orientation with RPCs
   - DTM 20 m raster grid

2. IKONOS Geo image mosaic (color)
   - orientation with RPCs
   - DTM 5 m raster grid

Source	RMSE East (m)	RMSE North (m)	RMSE Height (m)
IKONOS	0.56	0.48	-
SPOT Image Pair	1.22	2.01	1.50

E. Baltsavias – ISPRS Tutorial, AfricaGIS 2005, Tshwane (Pretoria)

DTM Generation with SAT-PP Software



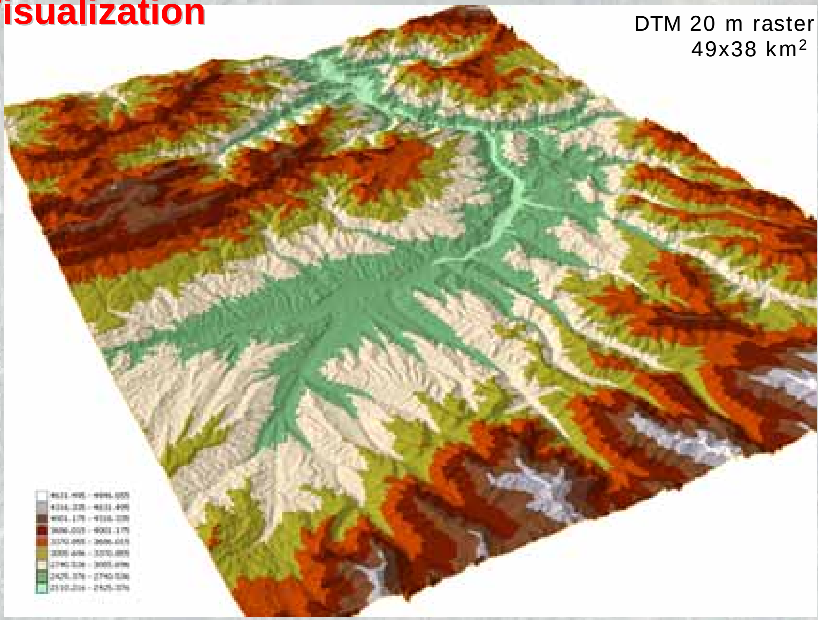
Breakline measurements

GCP measurement

E. Baltsavias – ISPRS Tutorial, AfricaGIS 2005, Tshwane (Pretoria)

DTM Visualization

DTM 20 m raster grid
49x38 km²



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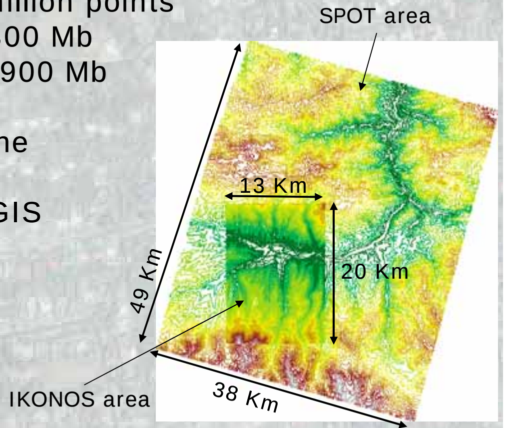
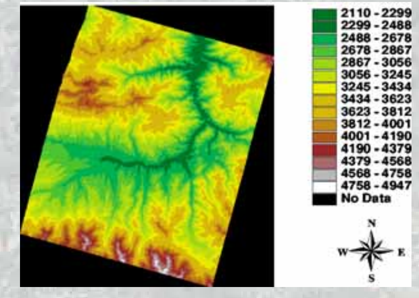
DTM data visualization / animation

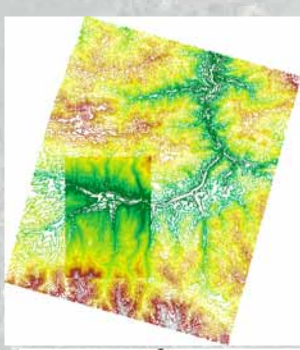
- 20 m grid = 4.6 million points
  B/W SPOT texture = ca. 435 MB
- 5 m grid (interpolated) = ca 12 million points
  B/W IKONOS texture = ca. 300 Mb
  Color IKONOS texture = ca. 900 Mb
- 3D views with ARCGIS - ARC Scene
- Flight-over with ERDAS - Virtual GIS

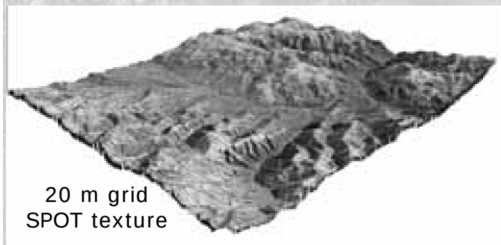


E. Baltsavias – ISPRS Tutorial, AfricaGIS 2005, Tshwane (Pretoria)

DTM Visualization

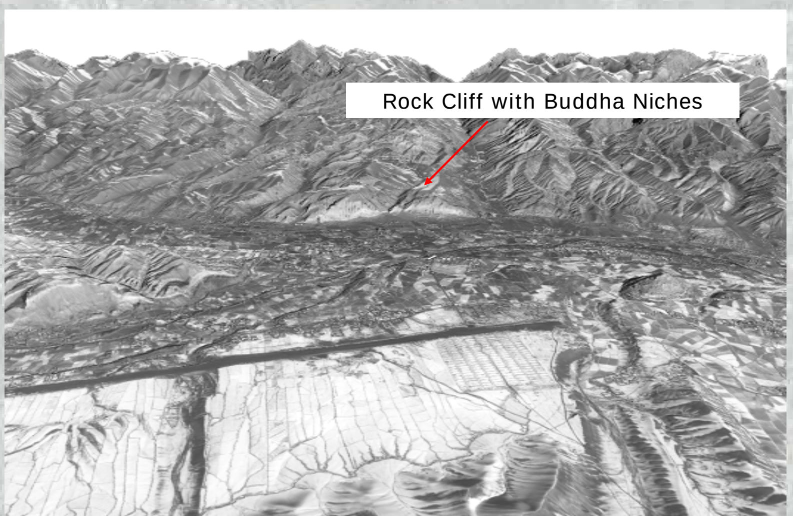




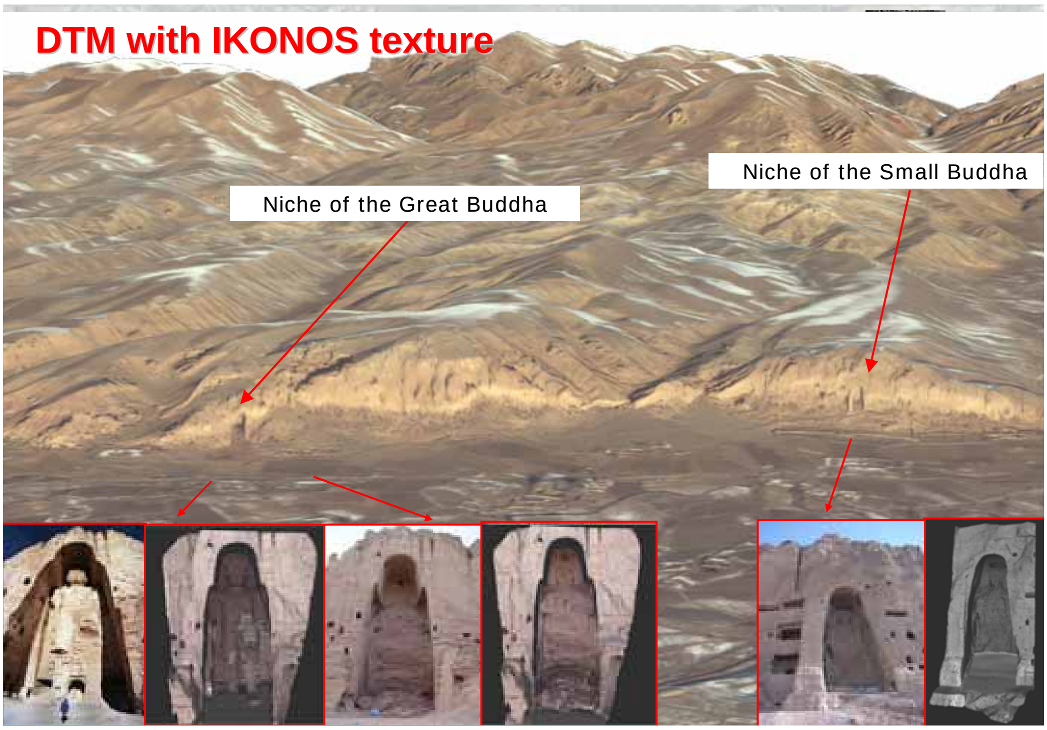


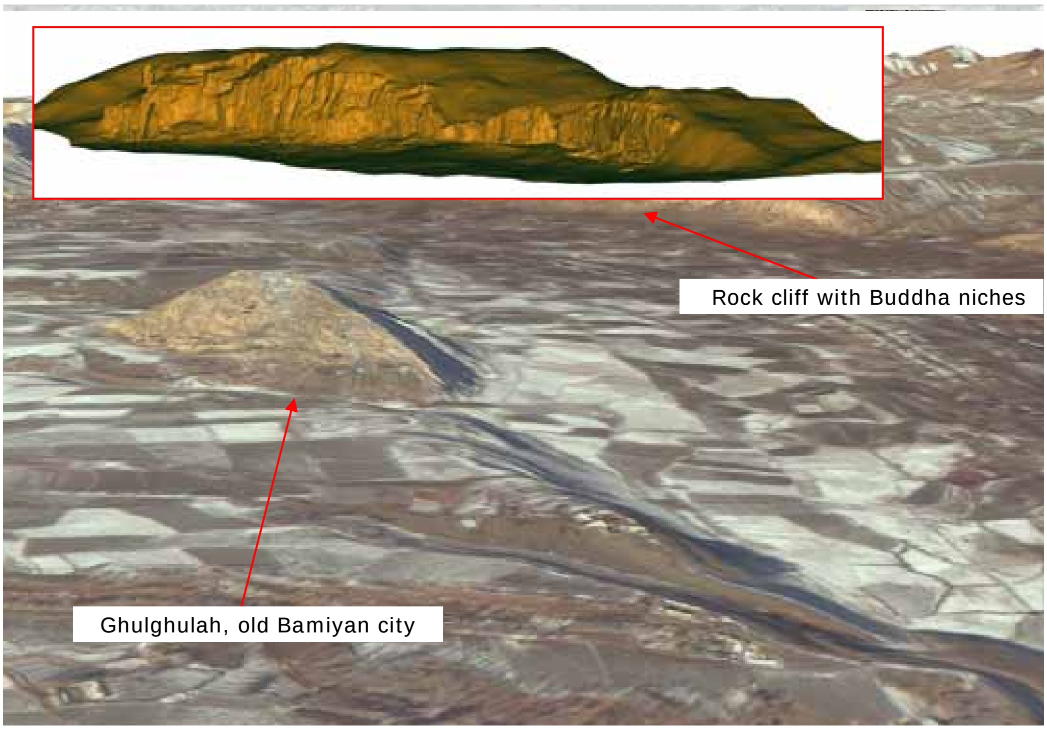
E. Baltsavias – ISPRS Tutorial, AfricaGIS 2005, Tshwane (Pretoria)

DTM with SPOT texture

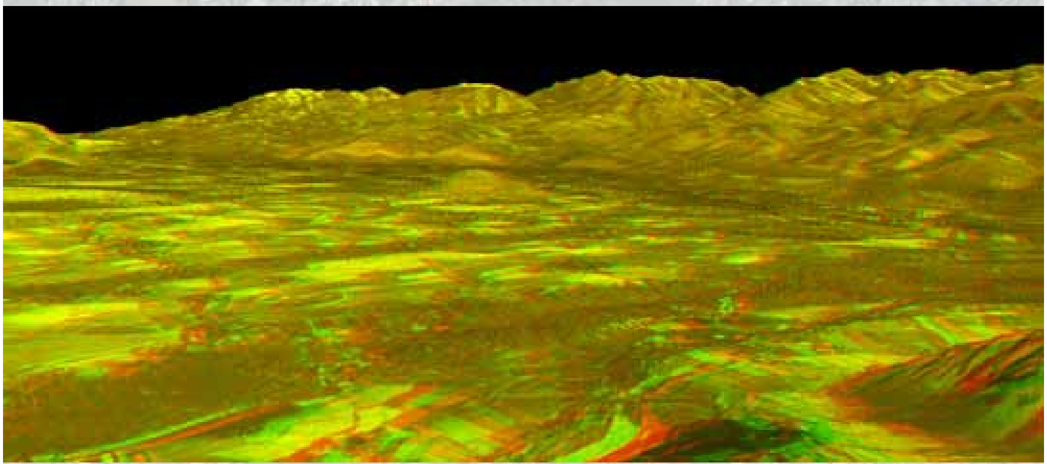


E. Baltsavias – ISPRS Tutorial, AfricaGIS 2005, Tshwane (Pretoria)

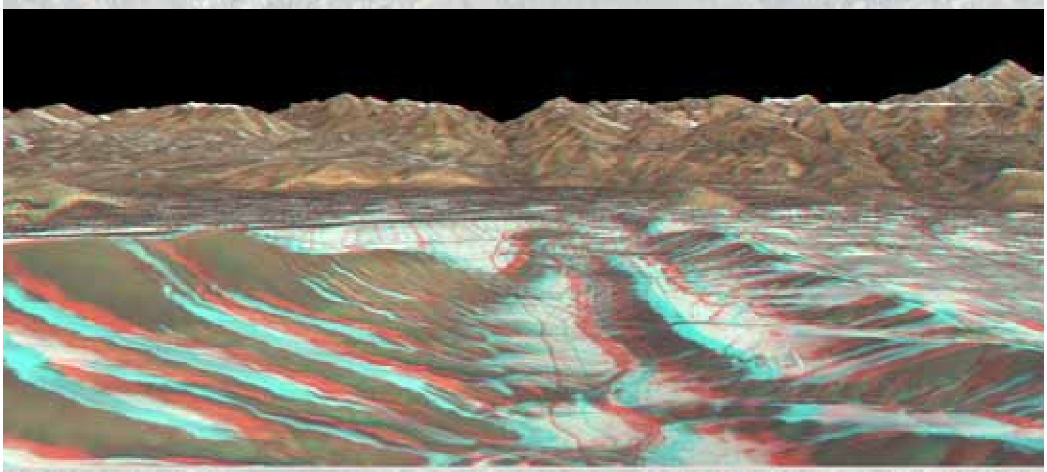

DTM with IKONOS texture
Niche of the Great Buddha
Niche of the Small Buddha


Rock cliff with Buddha niches
Ghulghulah, old Bamiyan city

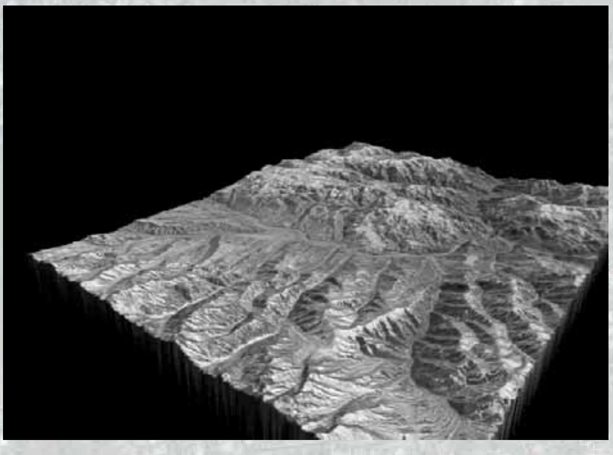
DTM - Anaglyph view



DTM - Anaglyph view

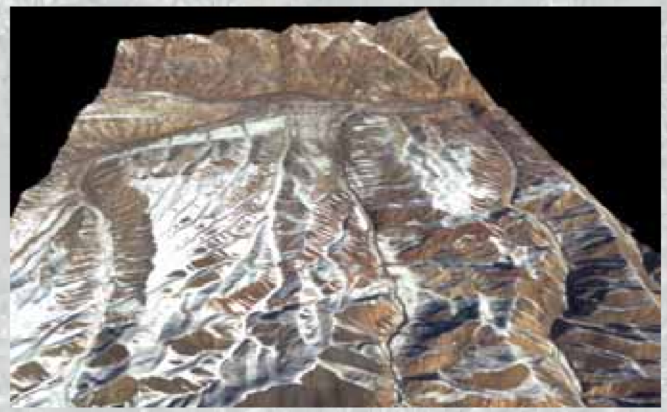


DTM data visualization/animation



Video - DTM with SPOT texture

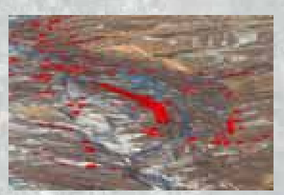
DTM data visualization/animation

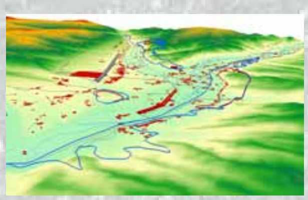


Video - DTM with IKONOS texture

2. Geographic / Tourist Information System

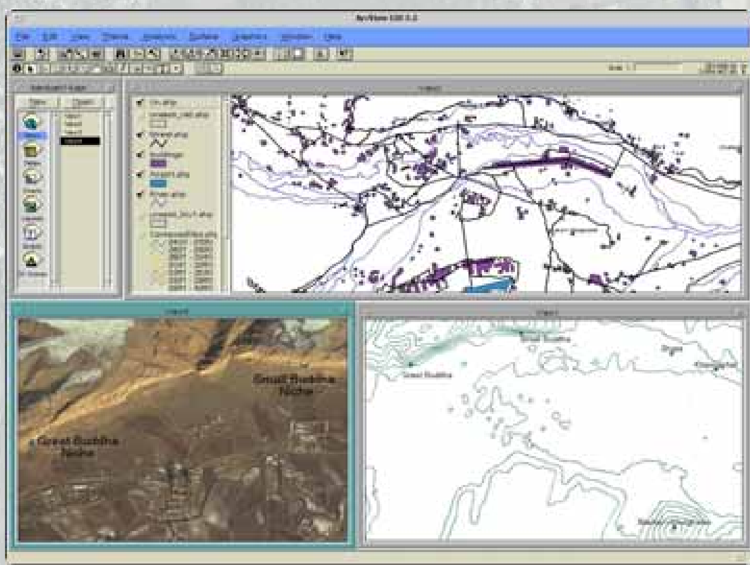
- Generation of new maps:
  contours, slopes, hydrology, settlements, ...
- Generation of documentation information system
- Manual extraction of features / layers from ortho-images
- ARC VIEW and ARC Scene





GIS data in ARCVIEW

Identification of UNESCO protected areas

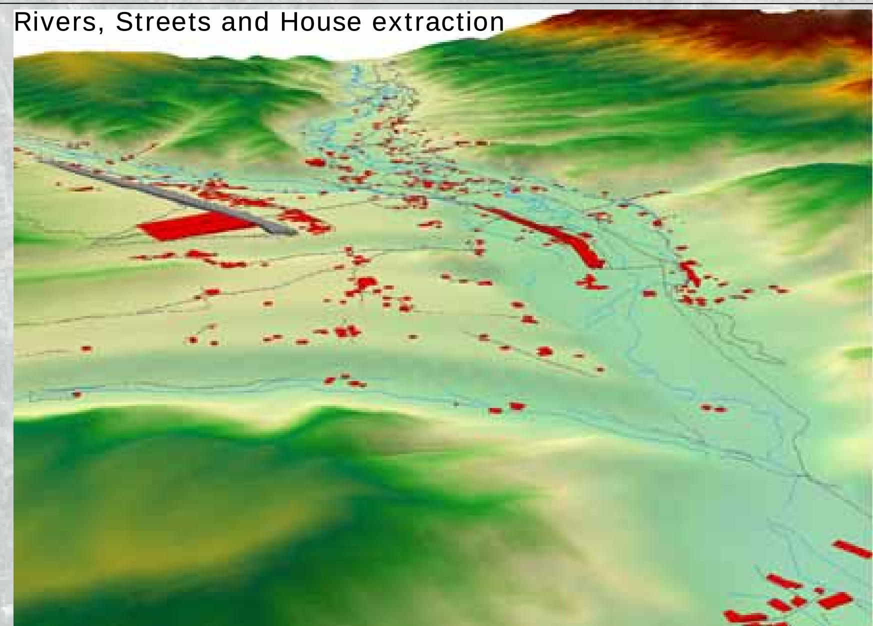


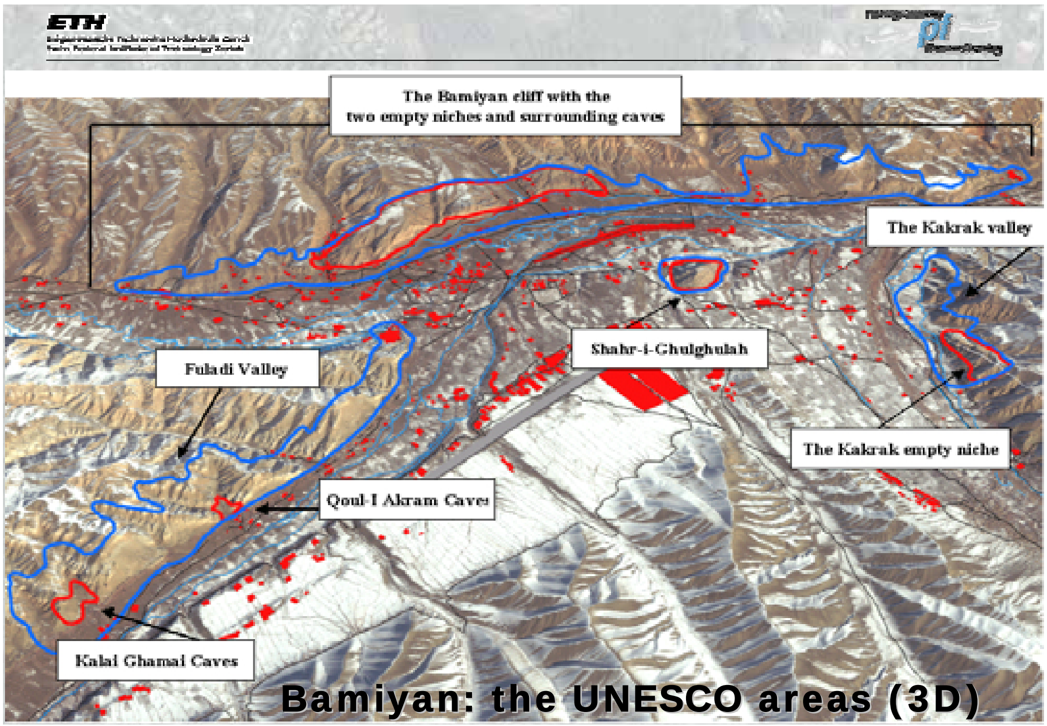
Difficult to handle data in 3D

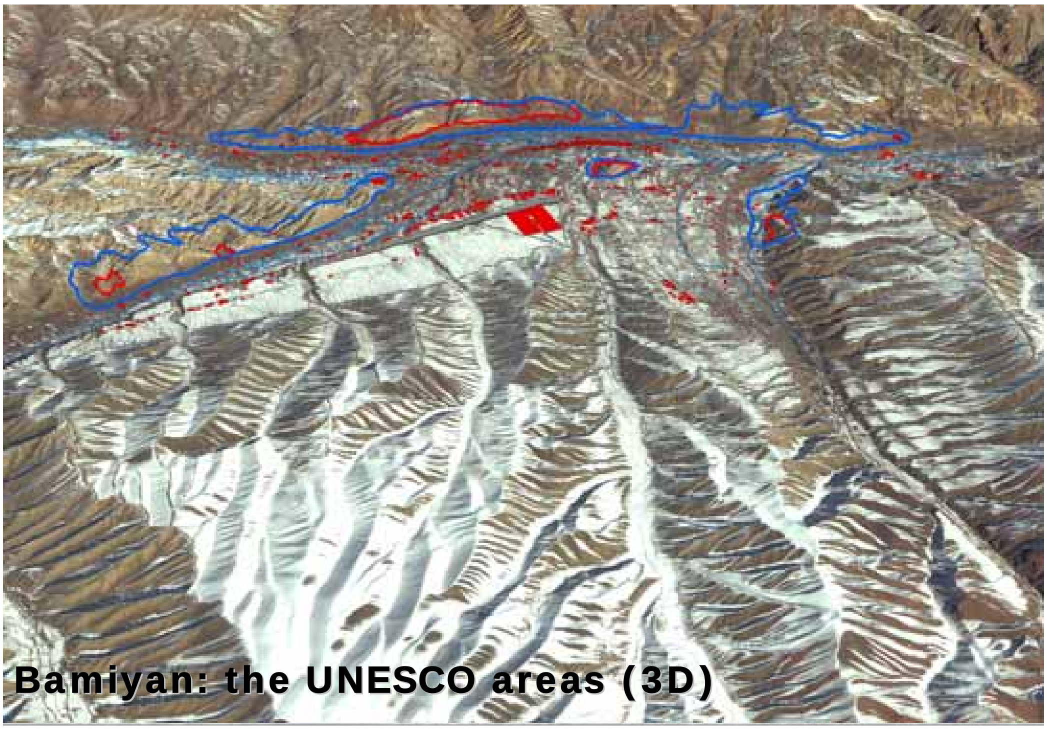
GIS data in ARCScene

- Easy to handle data in 3D
- Extrude 2D features vectors into 3D objects
- Flight-over
- 3D Analysis

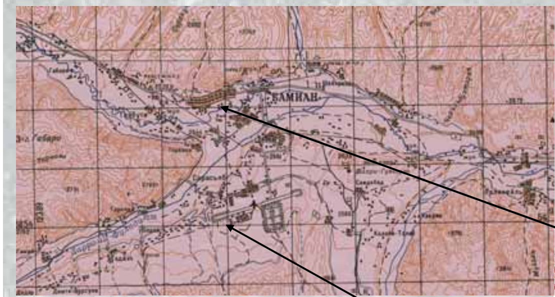
Rivers, Streets and House extraction




ETH
The Bamiyan cliff with the
two empty niches and surrounding caves
The Kakrak valley
Shahr-i-Ghulghulah
Fuladi Valley
The Kakrak empty niche
Qoul-I Akram Caves
Kalai Ghamai Caves
Bamiyan: the UNESCO areas (3D)

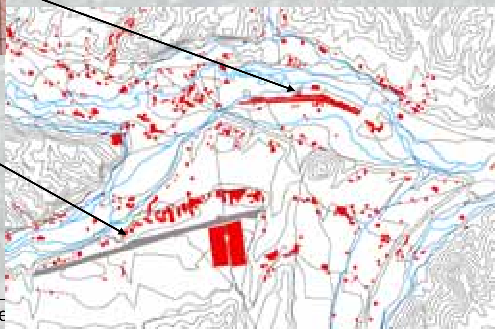

Bamiyan: the UNESCO areas (3D)

Bamiyan: new cartography



Russian Map (1970's)

New cartography (2003)



Summary of Bamiyan project

• Modeling of the whole cultural heritage area of Bamiyan for documentation and visualization purposes

• Different types of images (satellite, metric, tourist) for landscape modeling and 'lost objects' computer reconstruction

• Satellite data as only possibility for the landscape mapping and for the generation of new / updated cartography

• Potentiality of satellite imagery for documentation & visualization of C.H. areas

Some conclusions on use of HR for base geodata extraction

- Very high geometric potential
- GCPs very crucial, with smaller GSD requirements for GCP quality rise; GCPs with GPS preferable over use of GCPs from orthoimages and maps.
- Accuracy for well-defined points

  planimetry: down to 0.3 m (ca. 1/3 of GSD)

  height: down to 0.5 m (ca. 1/2 of GSD)
- DSM generation (no manual editing, best case)

  - maximum point density up to ca. 2-3m

  - accuracy (along track): 1-4 m depending on terrain slope and land cover. For open terrain 1 m or even less feasible.

  - certain loss of details due to area matching and pixel size

Some conclusions

- Interior orientation errors become important for high accuracy applications, need for in-flight calibration
- Orthoimages with submeter accuracy can be produced even with suboptimal DSMs / DTMs and GCPs. Accuracy can reach 0.5 GSD
- Extraction of objects (buildings, roads) limited by resolution. A 0.5 m GSD would be desirable for rather complete extraction of such objects.
- Accuracy of object extraction (manual or automatic) can be less than 1 GSD

Some conclusions

- Increased number of HR satellites expected next period, with more spectral channels and smaller GSD

BUT

- Will prices fall (espec. for stereo)?
- Will image availability improve?
- Will marketing and licencing policies improve?
- Will area covered by each image increase?

Greatest hopes with state-supported systems (e.g. ALOS) and low-cost large-area images, and small low-cost HR satellites.