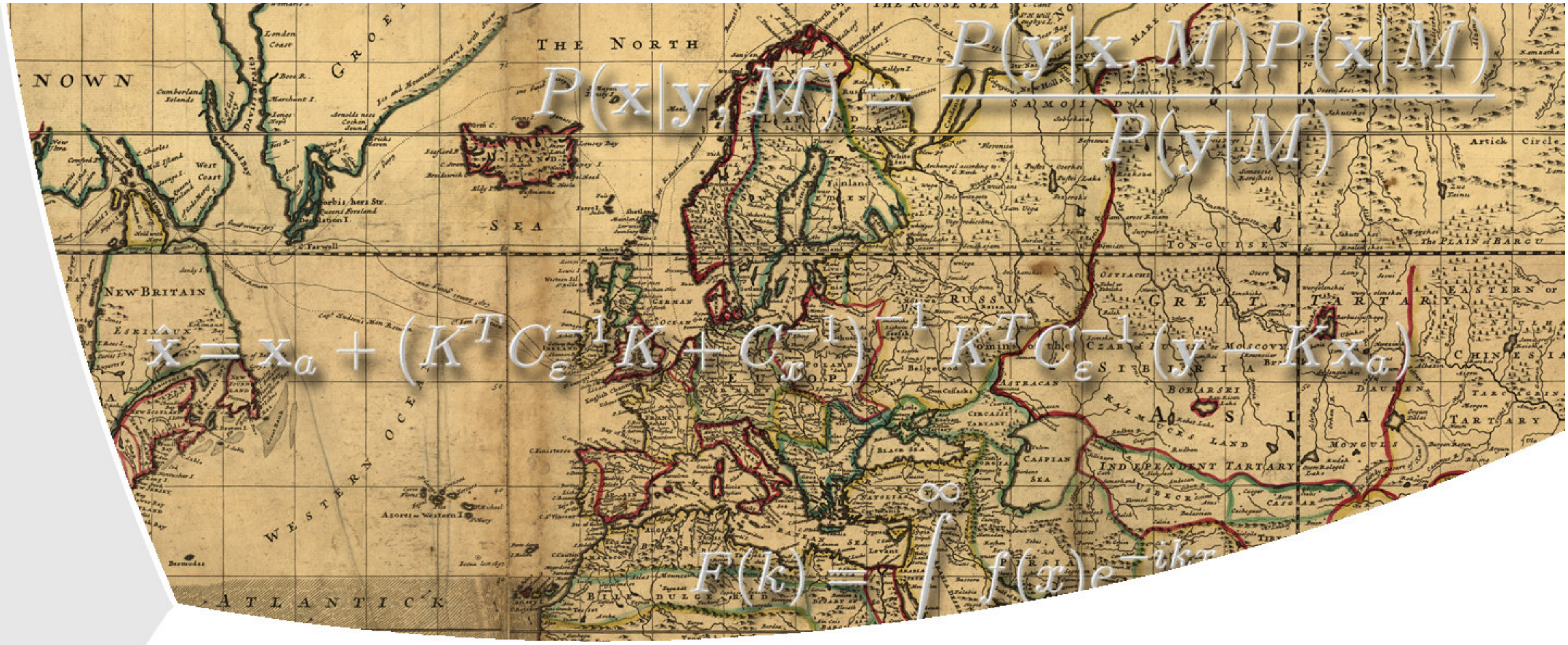

Orthorectification (IMAGE2006) and 3D-Imaging with Optical Satellite Data

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CONABIO-DLR Workshop,
Mexico City
April 23rd 2008

Outline

- Image2006: Orthorectification of 4000 satellite images in Europe
  - Principle and Requirements
  - Processing chain and methodology
  - Results and Experiences
  - Processing infrastructure

- 3D-Imaging from along-track stereo images with optical satellite data
  - Principle and Examples (MOMS-2P, SPOT)
  - Results from high resolution sensors:
    - ALOS-PRISM
    - Cartosat-1
    - Ikonos

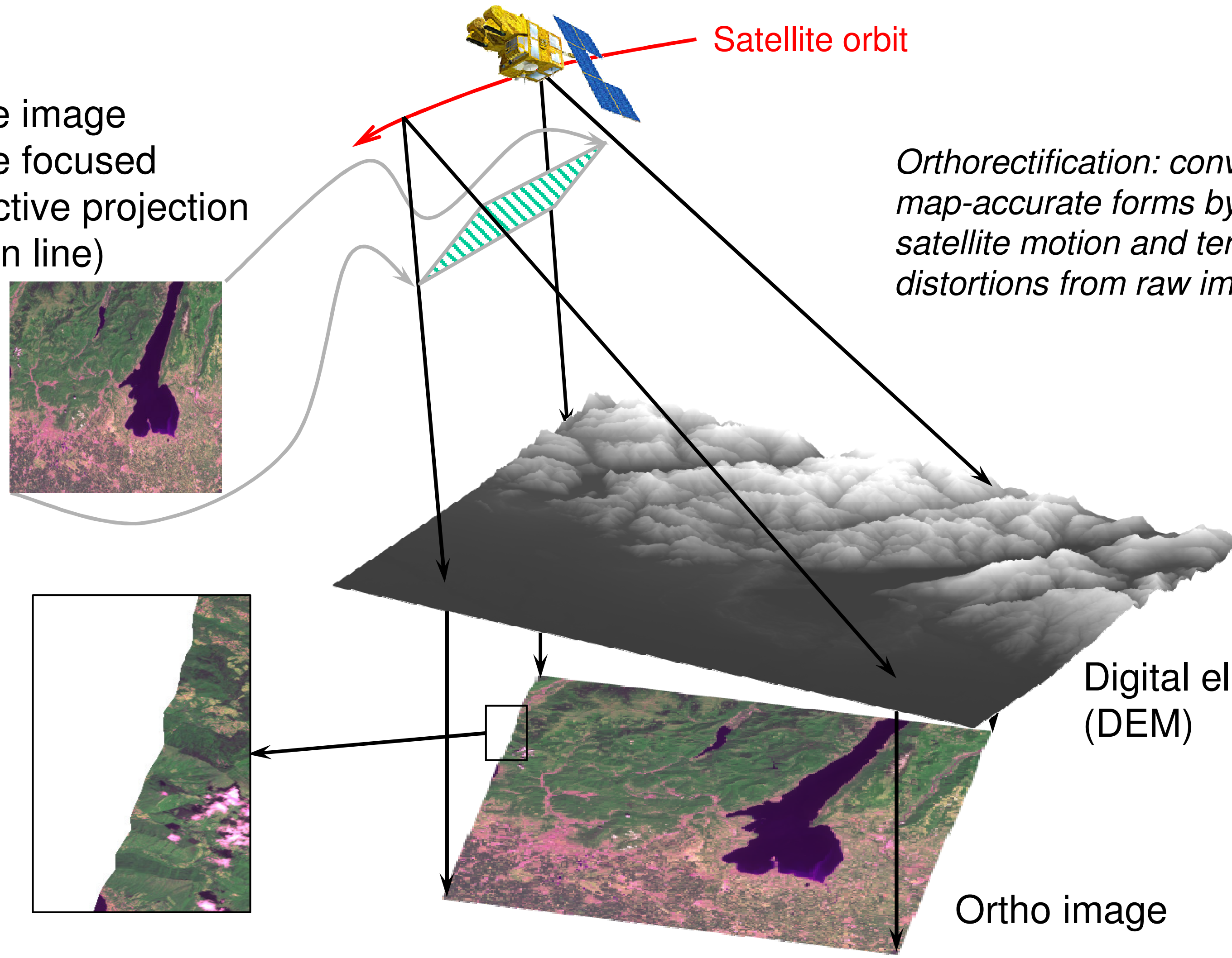
Background IMAGE 2006

- The GMES (Global Monitoring for Environment and Security) Fast Track Land monitoring Service (FTLS) will provide on a regular basis
  - European Satellite Image Mosaic (MOSAIC2006)
  - land cover changes (CLC2006, CORINE)
  - land cover map (CLC2006, CORINE)
  - high resolution forest layer
  - built-up areas including soil sealing.

- Within the GMES FTLS 2006-2008 a new dataset of orthorectified satellite images had to be produced covering the EU27 and neighbouring countries (total 38 countries, ~4000 images, ~6 Mio km²), referred to as IMAGE2006.
- Two coverages of Europe (spring and summer), European projection and special coordinate system for each country

From satellite raw image to orthorectified product

Satellite image (oblique focused perspective projection per scan line)



Orthorectification: convert imagery into map-accurate forms by removing sensor, satellite motion and terrain - related distortions from raw imagery

Satellite images to be orthorectified

Satellite / Sensor	Wavelength [nm] *green, red, NIR, SWIR*	GSD [m] @ nadir	Area [km²]	Product
IRS-P6 LISS III	520-590 620-680 770-860 1550-1700	23.5	142x141	Path oriented, system corrected scenes OrthoKit (GeoTiff, RPC, Super Structure BSQ)
SPOT 4 HRVIR	500-590 610-680 780-890 1580-1750	20	60x60	DIMAP L1A
SPOT 5 HRG	495-605 617-687 780-893 1545-1750	10	60x60	DIMAP [illegible]

up to 30° off-nadir view ⇨ $\Delta s = 0.58\ \Delta h$

Reference DEM

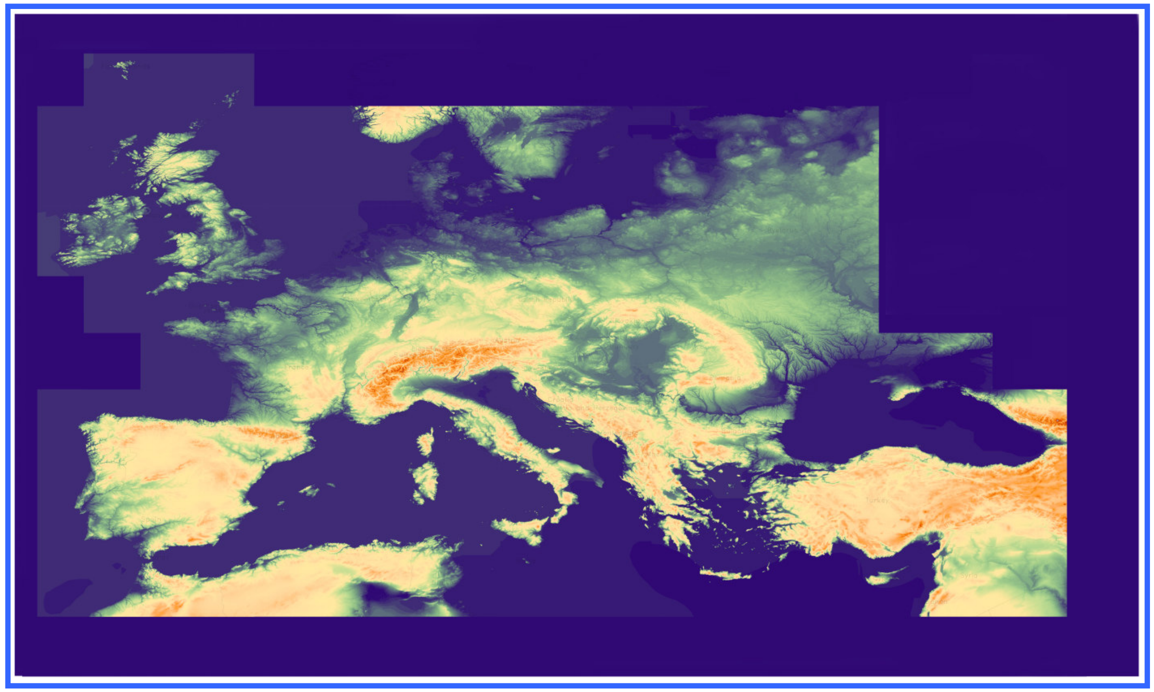
European DEM (<60° latitude north)
is derived from the data sets

- SRTM-C v2
- SRTM-X
- MONAPRO (parts in Alps)
- GLOBE (parts in east Turkey)

within a fusion process
using quality layers => best-of-DEM
(parts manually edited)

Height accuracy (1σ)
~6m (flat areas)
~30m (mountainous areas)

Switzerland: from maps 1:25000
1.5-10m accuracy; 25m resolution



Projection: Geographic (WGS84)
Height: Ellipsoid (WGS84)
Resolution: 1 arcsec

countries above 60° latitude are sub-contracted
to the Swedish company METRIA

Reference image data

- **Image2000 mosaic data ***
  covering 25 countries and derived from panchromatic ETM+ data

  Projection: Geographic WGS84
  Resolution: 0.000115° (~12m)

  official accuracy
  $RMSE_x$: 9-15 m
  $RMSE_y$: 7-18 m

- **USGS ETM+ Land Cover Data**
  covering all other countries

  Projection: UTM WGS84
  Resolution: 14.5 m

  official accuracy (global)
  $RMSE_{x,y}$: ~50 m

- **Swisstopo: SPOT 5 scenes**
  for Switzerland
  2004-2005 (10m resolution)

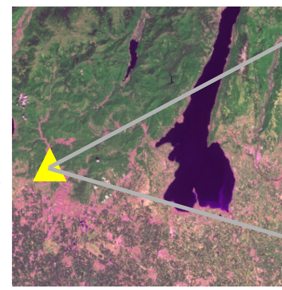
* © European Communities, Source: JRC Image2000, based on Landsat 7 ETM+ © ESA, distributed by Eurimage; ortho-correction EU15 Metria, ortho-correction other countries GISAT, mosaic production GISAT

Geometric accuracy of RMSE < 20m

- Provided metadata for geometric correction are not accurate enough to achieve this requirement (deviation on ground about 30m for SPOT5 and up to 500m for IRS-P6 and SPOT4)

- Therefore: Ground Control Points (GCPs) have to be used for improvement of geometric accuracy

  GCPs are points in image with known 3D object coordinates
  - by manual in situ GPS measurement
  - extraction from maps
  - extraction from reference images and DEM



Original Image

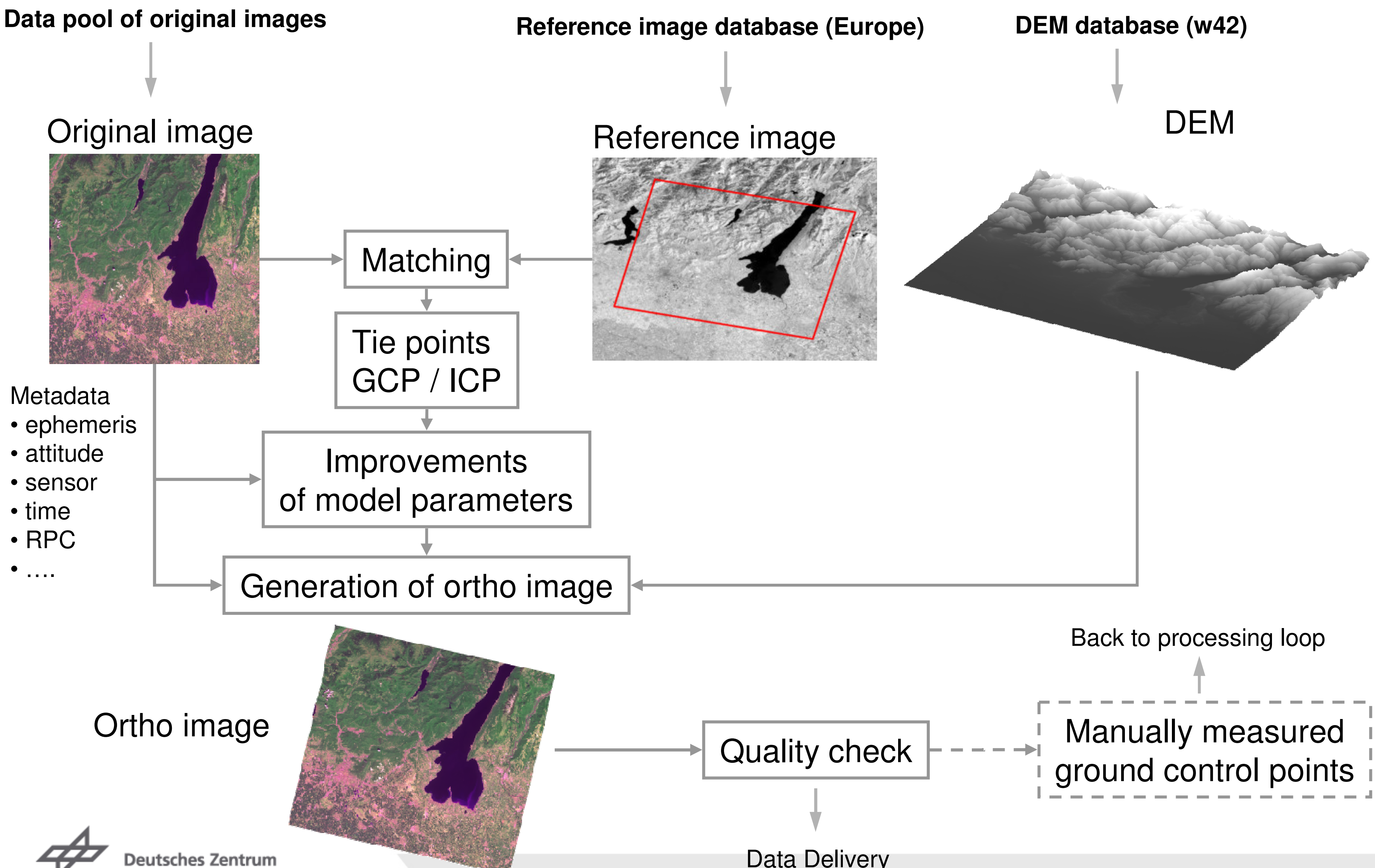
GCP
11.333456E
47.821445N
630m

Image
line 4242.6
Column 101.2

- Apply image matching techniques for automatic extraction of highly accurate and sufficient GCPs from the reference image data

  (up to 0.1 pixel matching accuracy, about 450 high quality points for 1000 km² found)

Overview of automatic processing chain

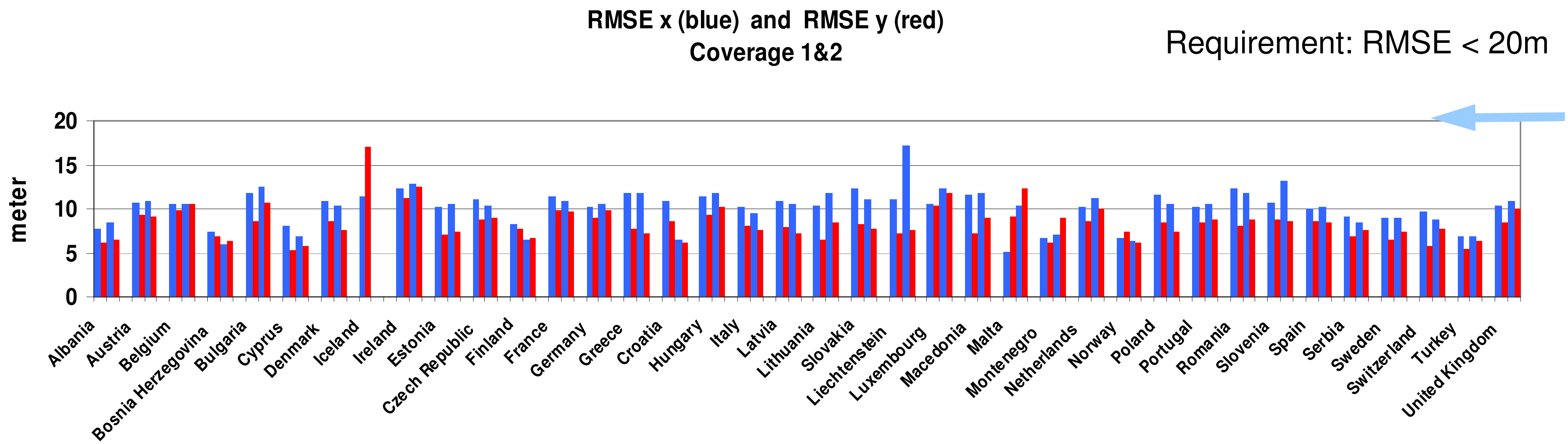


Methodologies (Key Technologies)

- Direct Georeferencing (DG) for SPOT4 HRVIR and Spot 5 HRG
- Rational Polynomial Functions (RPF) for IRS-P6 LISS III

Overall Geometric Accuracy

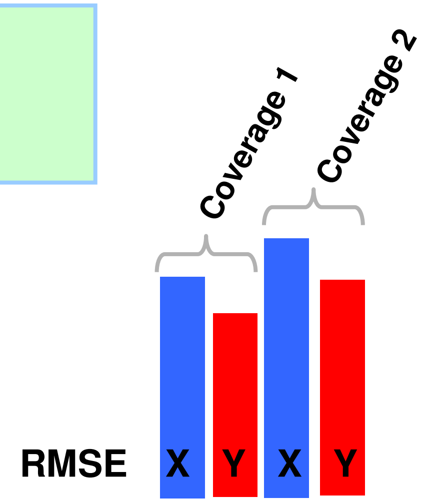
Requirement: RMSE < 20m



Overall (~4000 scenes) mean accuracy w.r.t. reference data set:
$RMSE_{x/y}$ ~ 10 m (CE64 ~14m)
~0.5 pixel size of resampled images

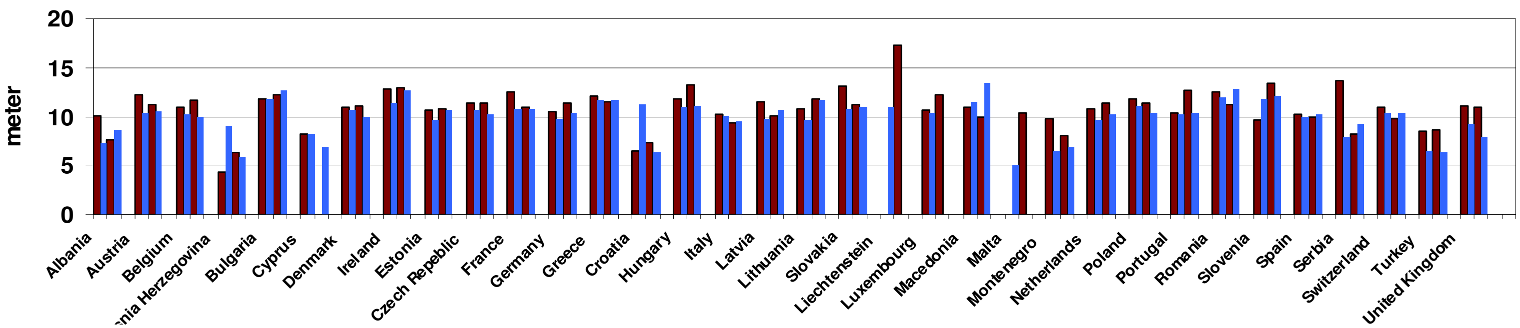
Mean number of ICPs per scene for accuracy assessment:

IRS-P6: 5496 points / scene
SPOT 4/5: 1360 points / scene
Residual plots available

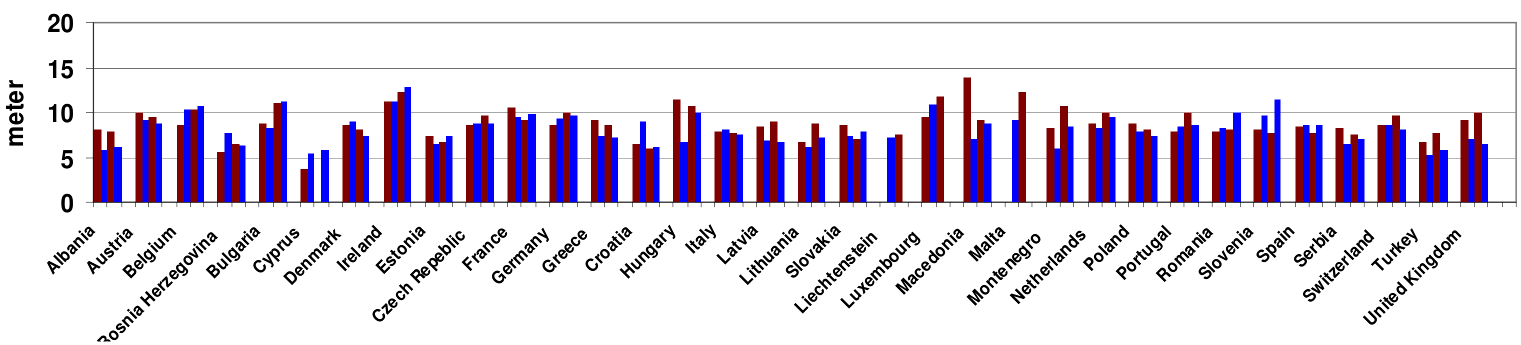


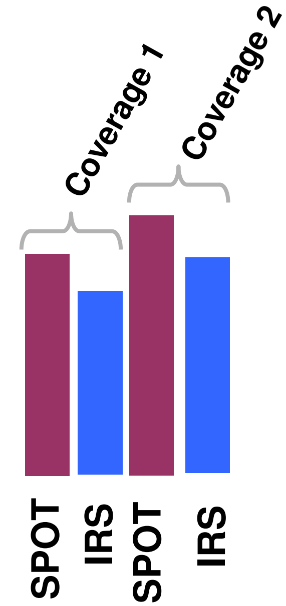
Comparison SPOT 4/5 and IRS-P6

Comparison SPOT / IRS-P6 RMSE x Coverage 1&2



Comparison SPOT / IRS-P6 RMSE y Coverage 1&2



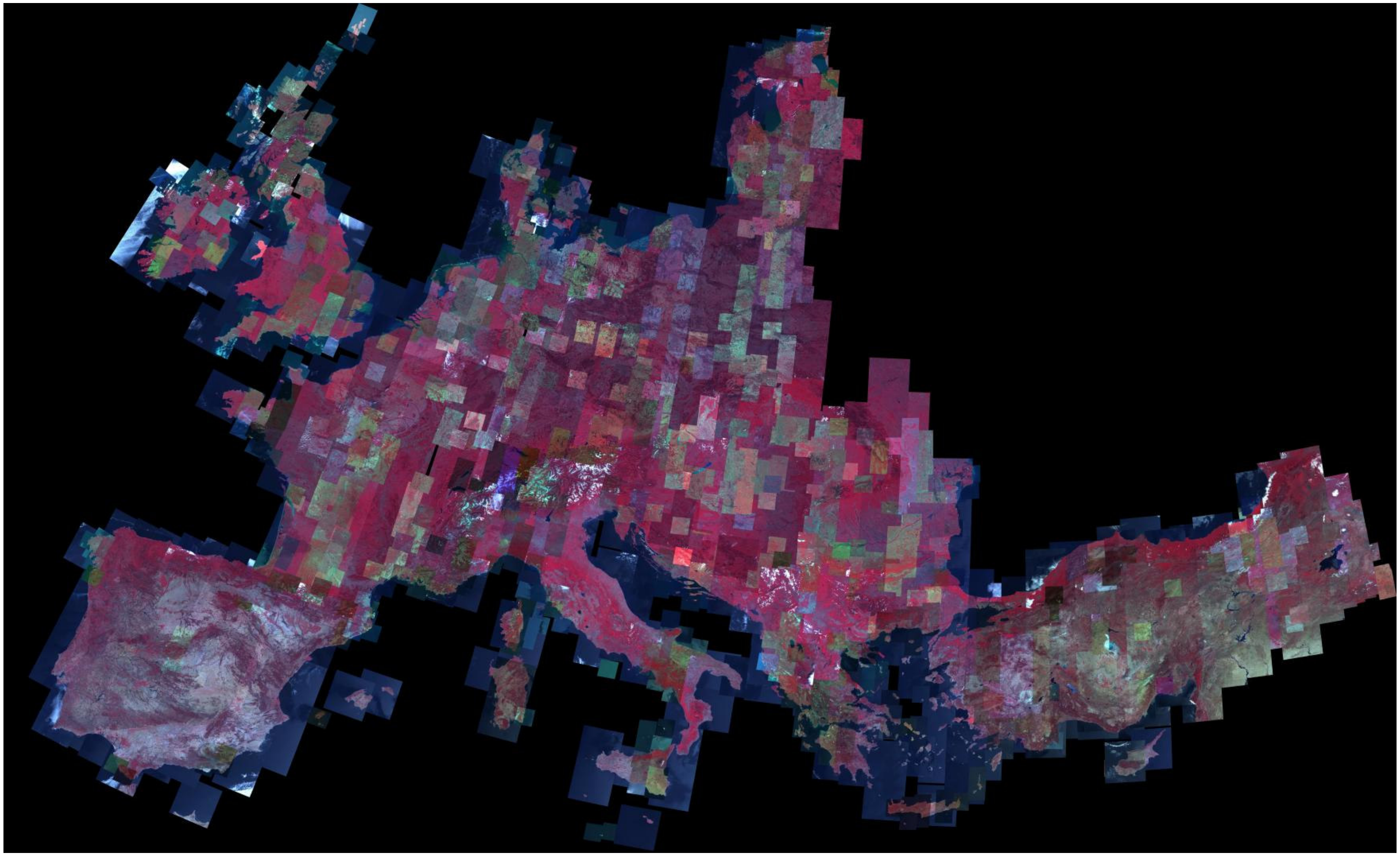


	$RMSE_x$ [m]	$RMSE_y$ [m]
SPOT	10.4	8.6
IRS-P6	9.7	8.0

…consider oblique view for SPOT => DEM error

about same orthorectification accuracy for both sensors

European Mosaic – First Coverage (April-June)



European Projection: LAEA-ETRS89; Resolution: 25m; ~1500 scenes SPOT&IRS

Quality Assessment

Correctness: QC includes checking if the

- automatically detected GCPs are distributed equally over the scene
- residual plots derived from the ICPs show no systematic behaviour
- RMS errors fulfil the requirement to be better than 20m in each direction
- orthorectified image fits with the overlaid (re-projected) reference image
- orthorectified image fits with overlaid neighbour scenes

Completeness: QC includes checking if the

- image mosaic shows no gaps
- data set for a country is complete (country border polygons)

Others include the

- visual inspection of radiometric quality and cloud coverage of the images
- visual inspection of used DEM tiles (gaps, artefacts) and used reference tiles (cloud coverage, radiometric quality, artefacts, geometric errors)

Automatic processing chain – some experiences

- Metadata quality (measurements) of SPOT 4/5 and IRS P6 LISS III used for orthorectification is excellent.
- Good candidates for image matching (in order to extract GCPs and ICPs) are arid areas (Spain, Turkey,…) or mountainous areas with time constant sharp ridges.

- The time gap of 5-6 years between images and reference data can cause problems because matching strongly depends on image similarity.
- Geometric errors in reference images cannot be handled with RPC or DG methods rigorously *(see next slides)*

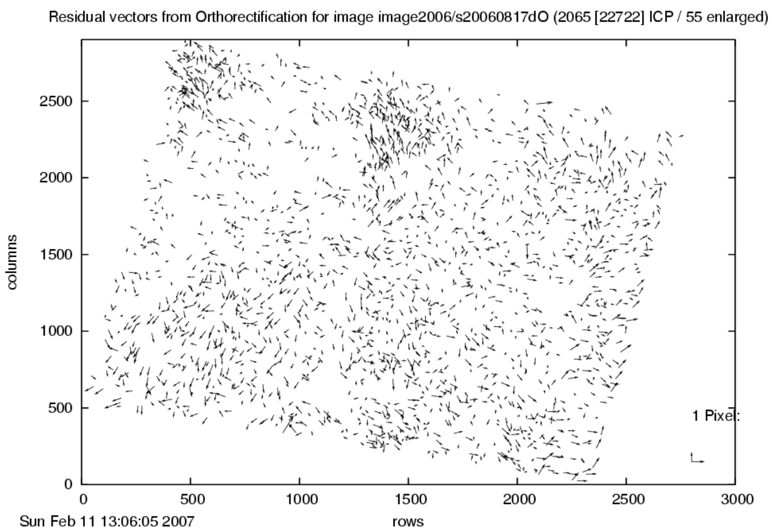
Errors in Reference Dataset (1)

Errors in Reference Dataset (2)

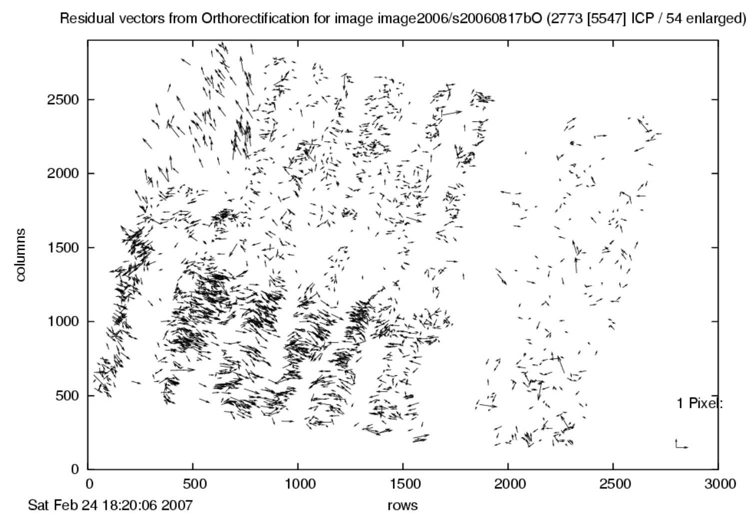
IMAGE2000 and USGS land cover datasets are considered as absolute reference, which contain systematic and local geometric distortions.

⇒ Models (DG and RPC) are not designed to handle *unrealistic* errors rigorously

Good distribution of ICPs;
no systematic behaviour



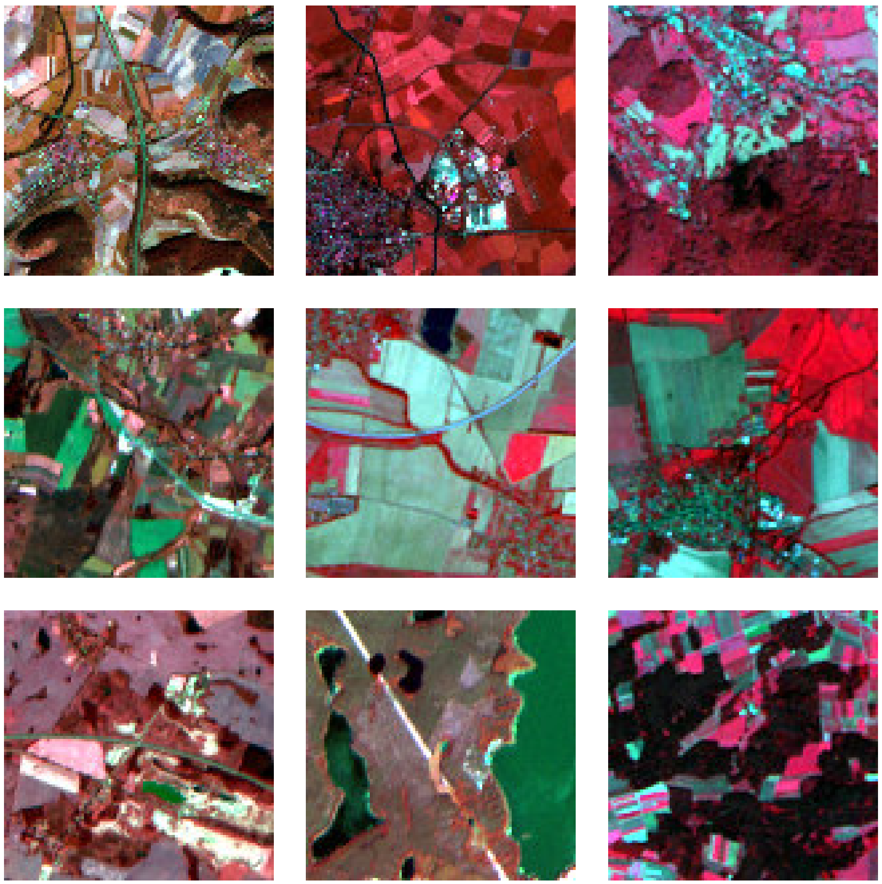
Probably wrong mosaicking of reference scenes or DEM error



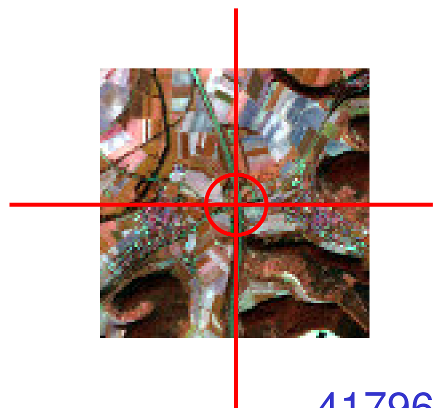
Residual plots: Deviations in pixel (enlarged) of ICPs from the reference image versus image coordinates of orthorectified scene after correction with GCPs

It can be assumed that an increased absolute geometric accuracy is achieved for IMAGE2006 products (has to be verified using GCP's of superior quality)

European GCP Chip Database

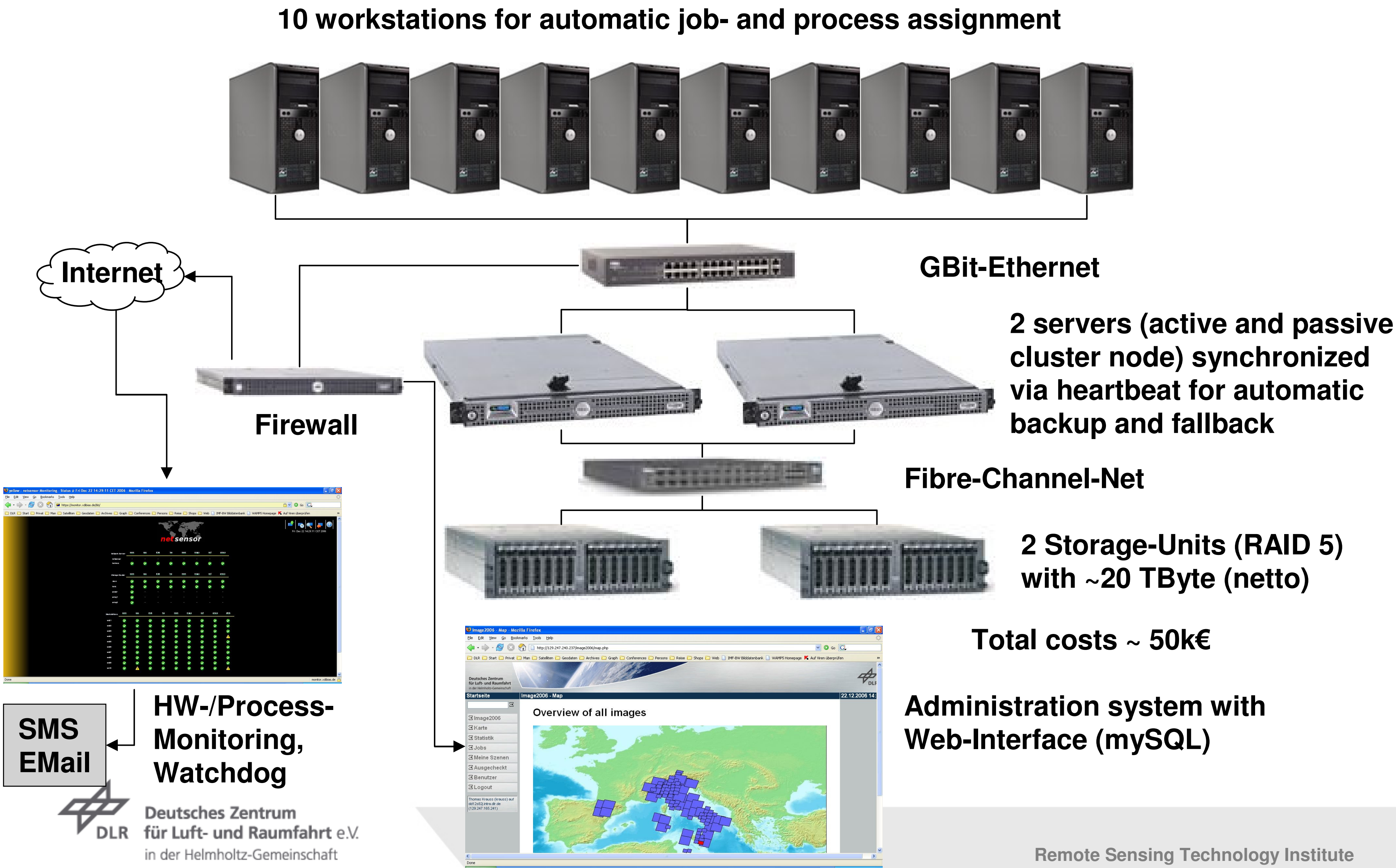


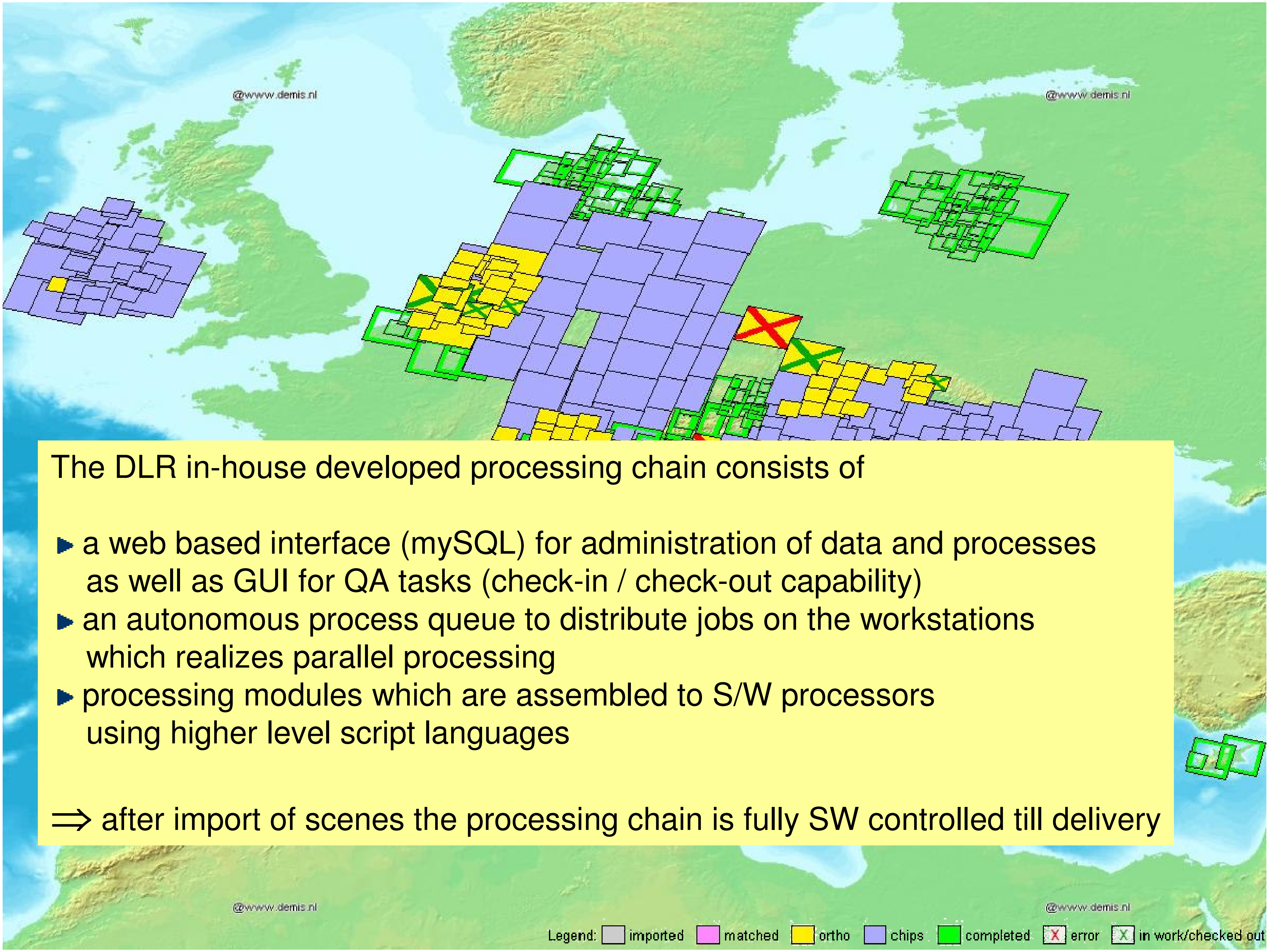
GCP chip naming convention:
<Easting>_<Northing>_<EllipsoidHeight>.png
Example: 4179645_2766680_385.png
Projection: LAEA-ETRS89
Resolution: 25 m
Chip size: 101 x 101 pixel
Channels: Green, Red, NIR
Origin: Image2006 data set of first coverage and interpolated "best of" DEM
Accuracy: ~10m w.r.t. reference data *(as Image2006)*
Density: ~5 GCP chips @ 1000 km²
Total amount of GCP image chips EU38: 61053
Extraction: manually from ICPs/GCPs



4179645_2766680_385.png

Overview IT-Infrastructure





The DLR in-house developed processing chain consists of

- a web based interface (mySQL) for administration of data and processes as well as GUI for QA tasks (check-in / check-out capability)
- an autonomous process queue to distribute jobs on the workstations which realizes parallel processing
- processing modules which are assembled to S/W processors using higher level script languages

$\Rightarrow$ after import of scenes the processing chain is fully SW controlled till delivery

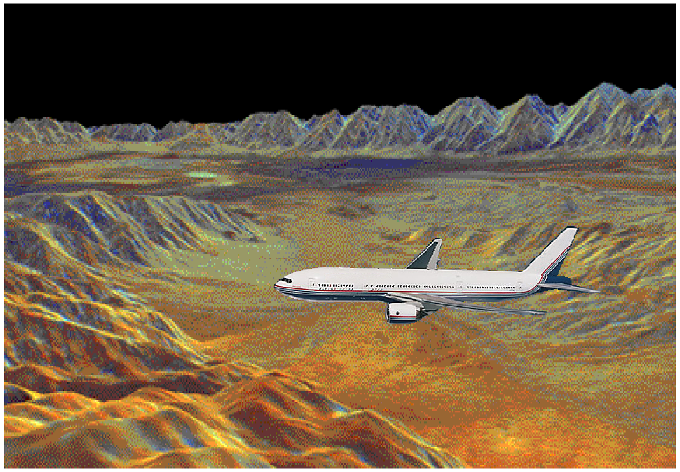
Data throughput for one workstation in hours

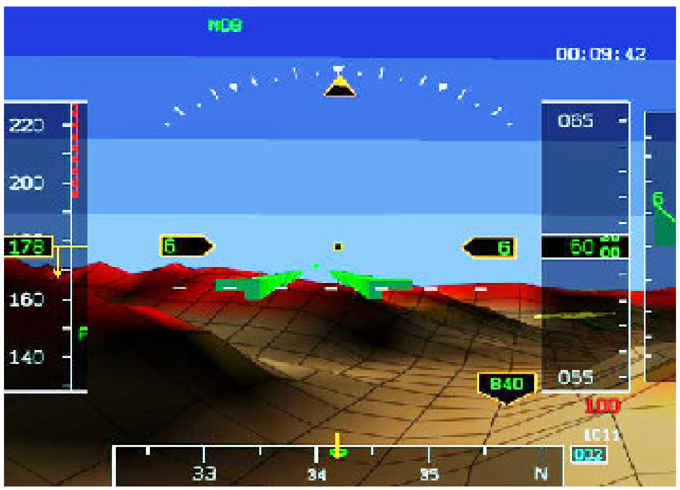
Sub-task	IRS-P6	SPOT 4/5
Transcription, DEM & Reference tile generation, coarse rectification	0.2	0.1
Matching, GCP/ICP generation	2.2	0.3
Geocoding (National and European product) plus parameter estimation and re-projection of reference image towards European projection for QS	1.5	0.5
Quality control (manual/visual)	~1.5	~1.0

The maximum throughput of the whole processing system
(10 desktop workstations, 5 operators) including manual Quality Control is therefore
for one ***IRS-P6*** scene about ***0.5 h***
for one ***SPOT*** scene about ***0.2 h***.

About 3% of the images have to be processed manually
(additional GCP measurements) in cases the product does not pass
the internal quality control.

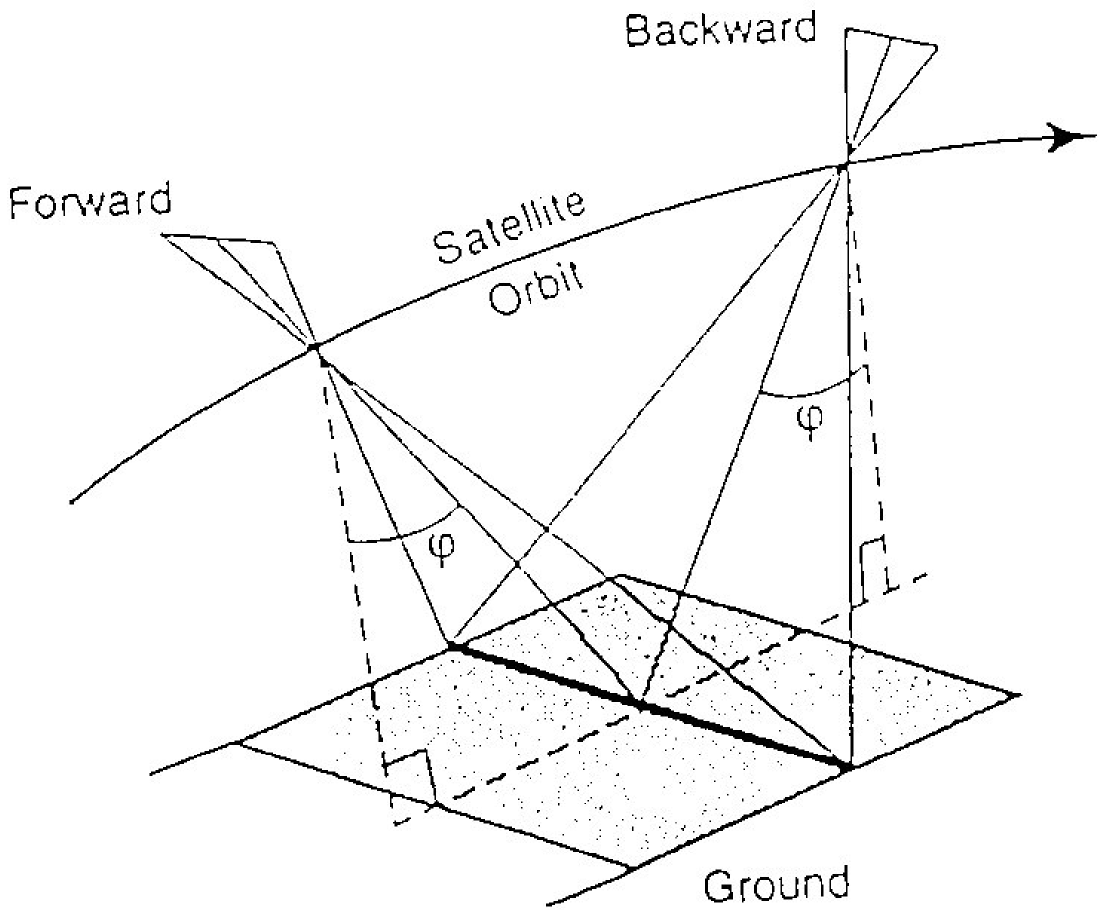
Need for Digital Elevation Modells





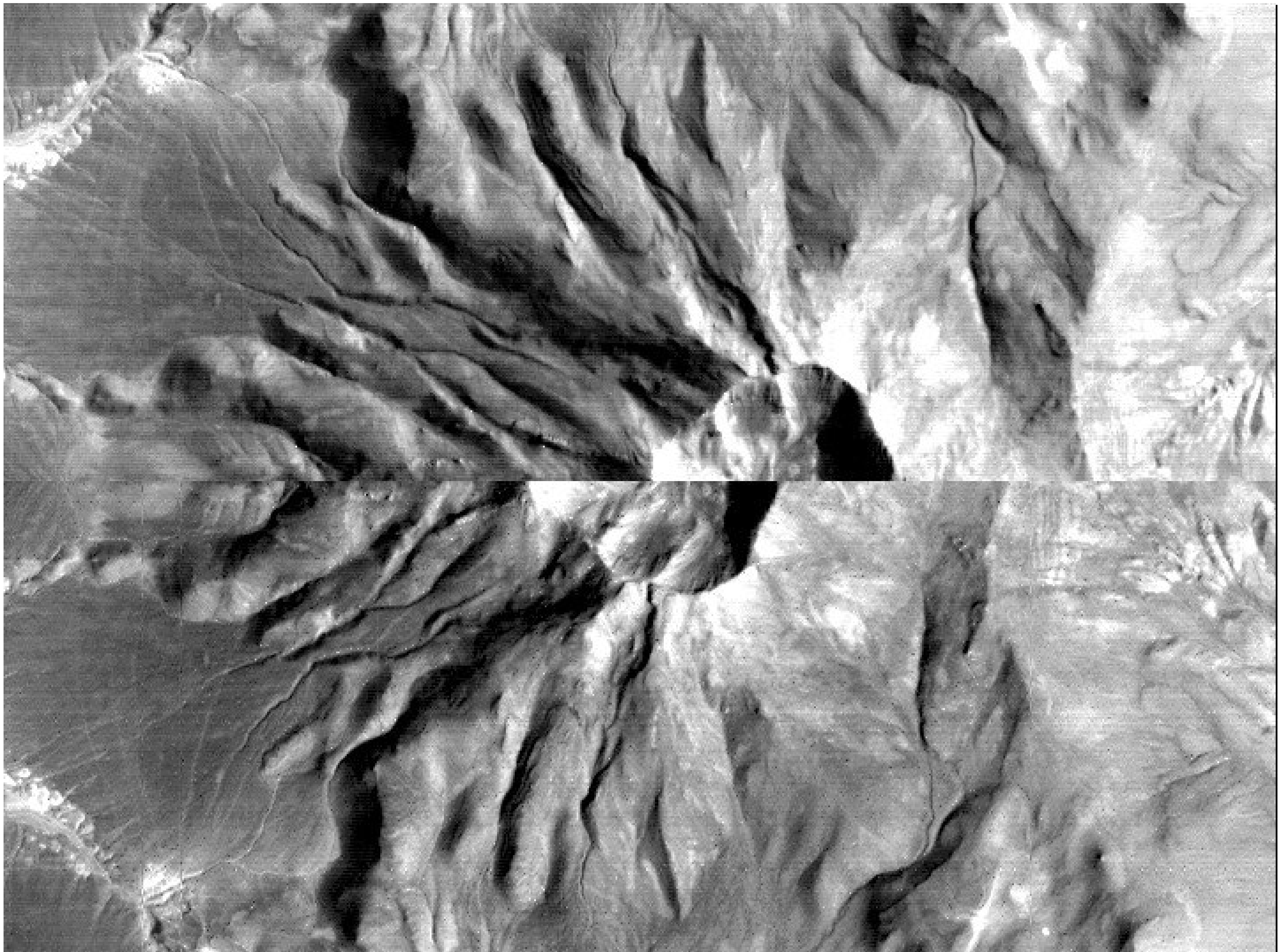
- **Geoscience**
  - Cartography
  - Ecology (Erosion, Glaciers)
  - Geology
  - Meteorology
- **Civil Engineering**
  - Infrastructure planning
  - Disaster management
- **Navigation**
  - Flight security, Virtual Cockpit
  - Navigation
- **Telekommunikation**
  - Mobile Communication
  - Radio, TV

Along Track Stereo Data Acquisition from Space



φ: Stereoangle

Parallaxes in Stereo-Images

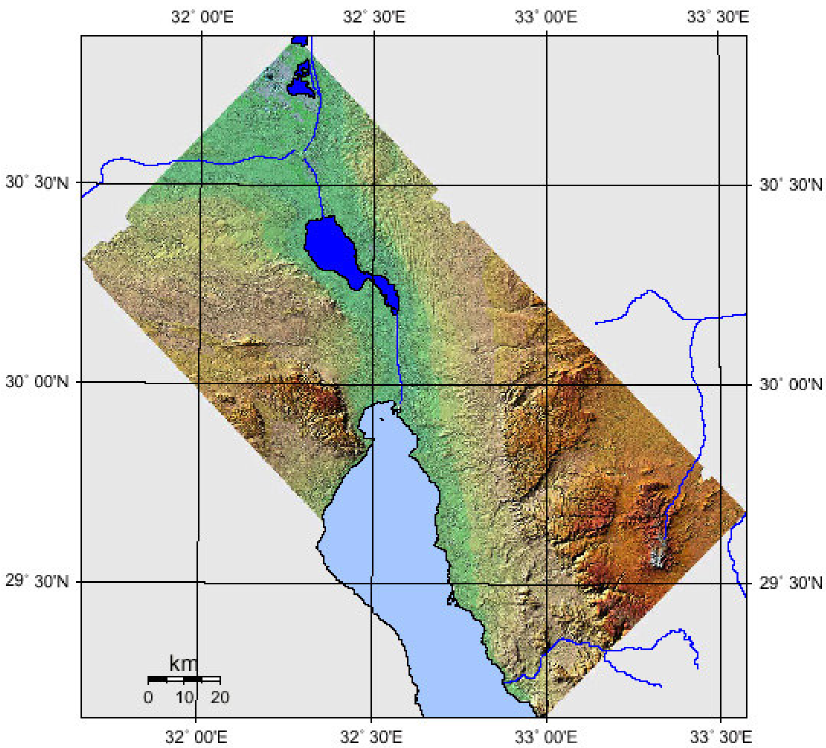


MOMS
Looking
forward

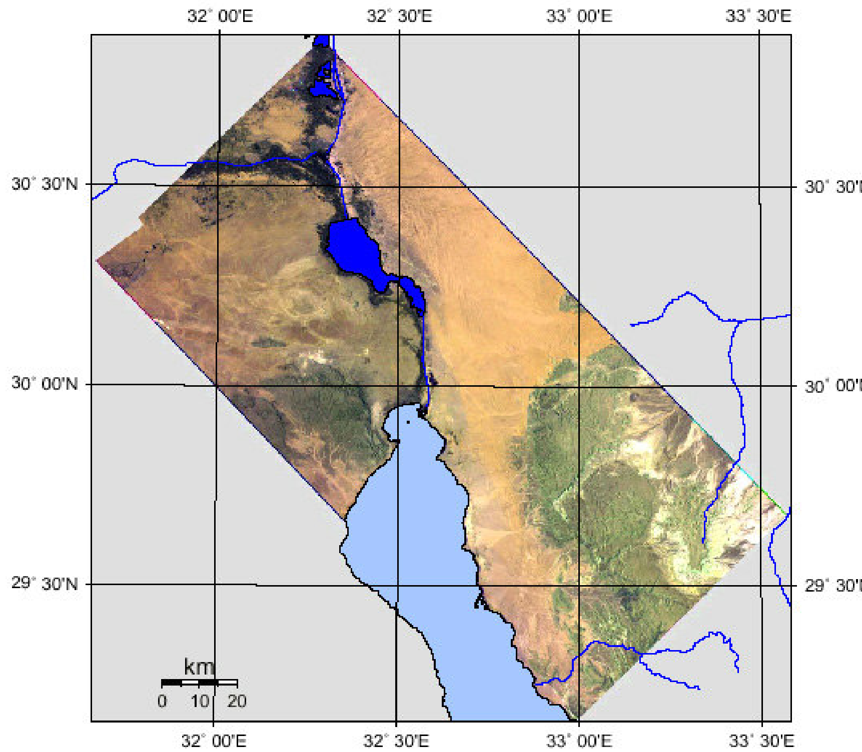
MOMS
Looking
backward

MOMS Stereo-Products

Suez Channel, Egypt (+H500)



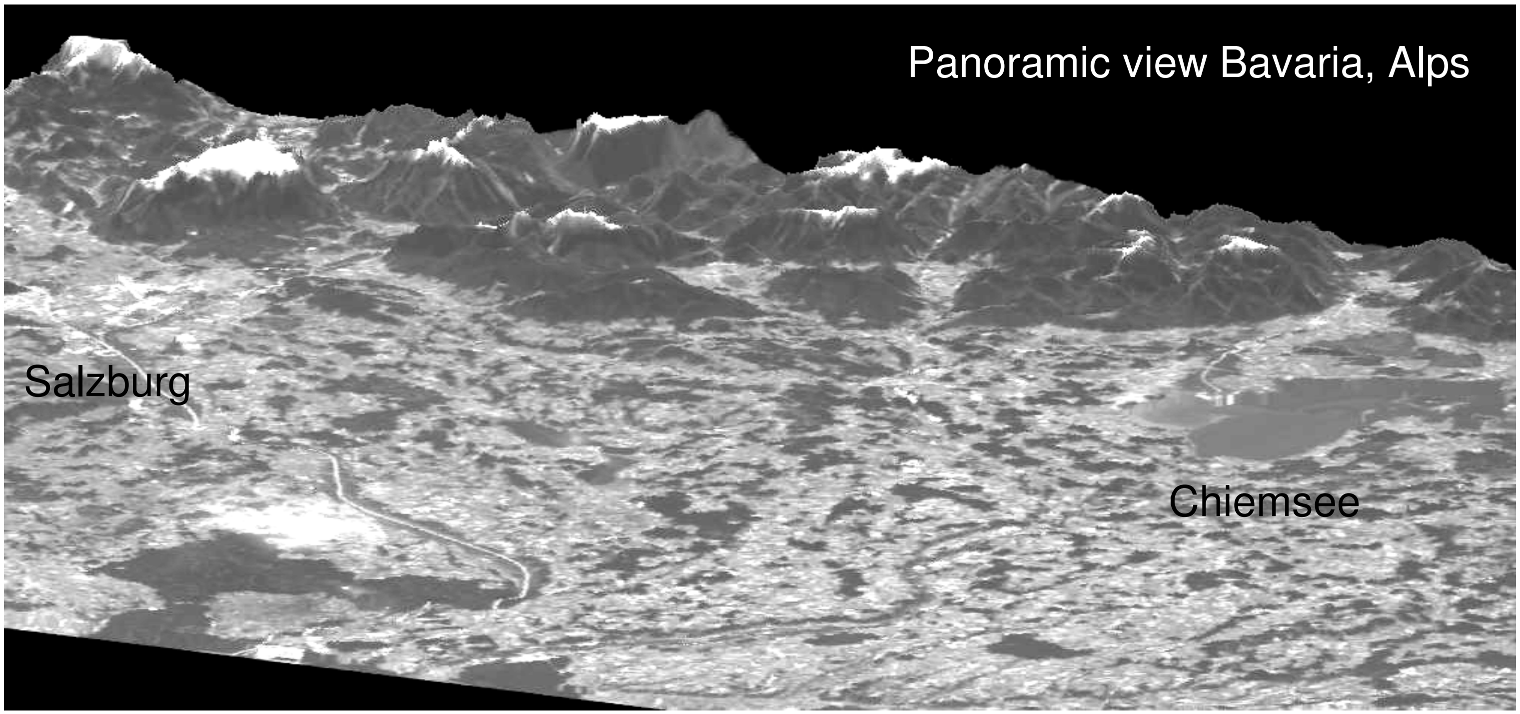
DEM (Height Accuracy 10 Meter)



Orthoimage 15m x 15m Pixelsize

3D-Processing:
Digital Surface Model (DSM) from SPOT data

Resolution 5 m in along-track

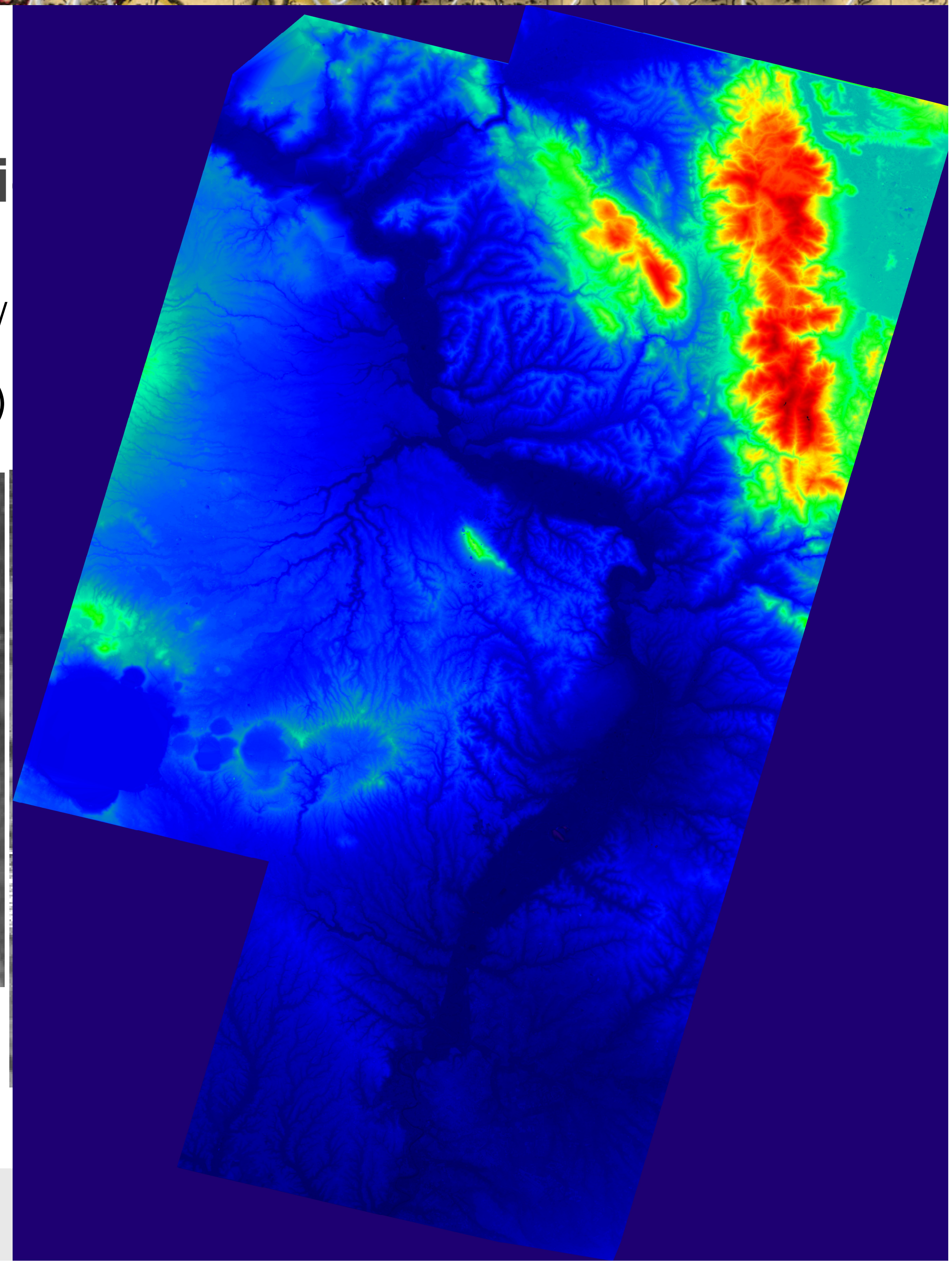


Absolute accuracies using 3 GCP / Scene (direct referencing):

$\sigma_X = 6$ m; $\sigma_Y = 5$ m; $\sigma_Z = 4$ m

3D-Processing:
DSM from new generati

- ALOS/PRISM (2.5 m / 2.5 m /
- CARTOSAT-1 (2,5 m / 2.1 m)



3D-Processing:
DSM from new generation stereo data

- ALOS/PRISM, CARTOSAT-1: DSM comparison to reference DSM (airborne)

Catalunya	Number of DSM points	3D shift			σ_z
		Δx	Δy	Δz	
Cartosat-1	6.79 million	0.4	-1.1	-0.5	2.4
ALOS-PRISM (compressed)	5.98 million	-0.6	-0.9	-0.6	2.3

Cartosat-1 DSM Processor
Overview

- Products:
  - DSM on 10 m grid.
  - Orthoimage, resolution 2.5 m.
- Mostly automatic processing
  - Automatic GCP using reference images (Landsat ETM+, SRTM).
  - Final quality inspection/editing step required.
- Processor based on XDibias, DLR software

Stereo Matching → RPC correction against reference images → DSM creation → DSM editing

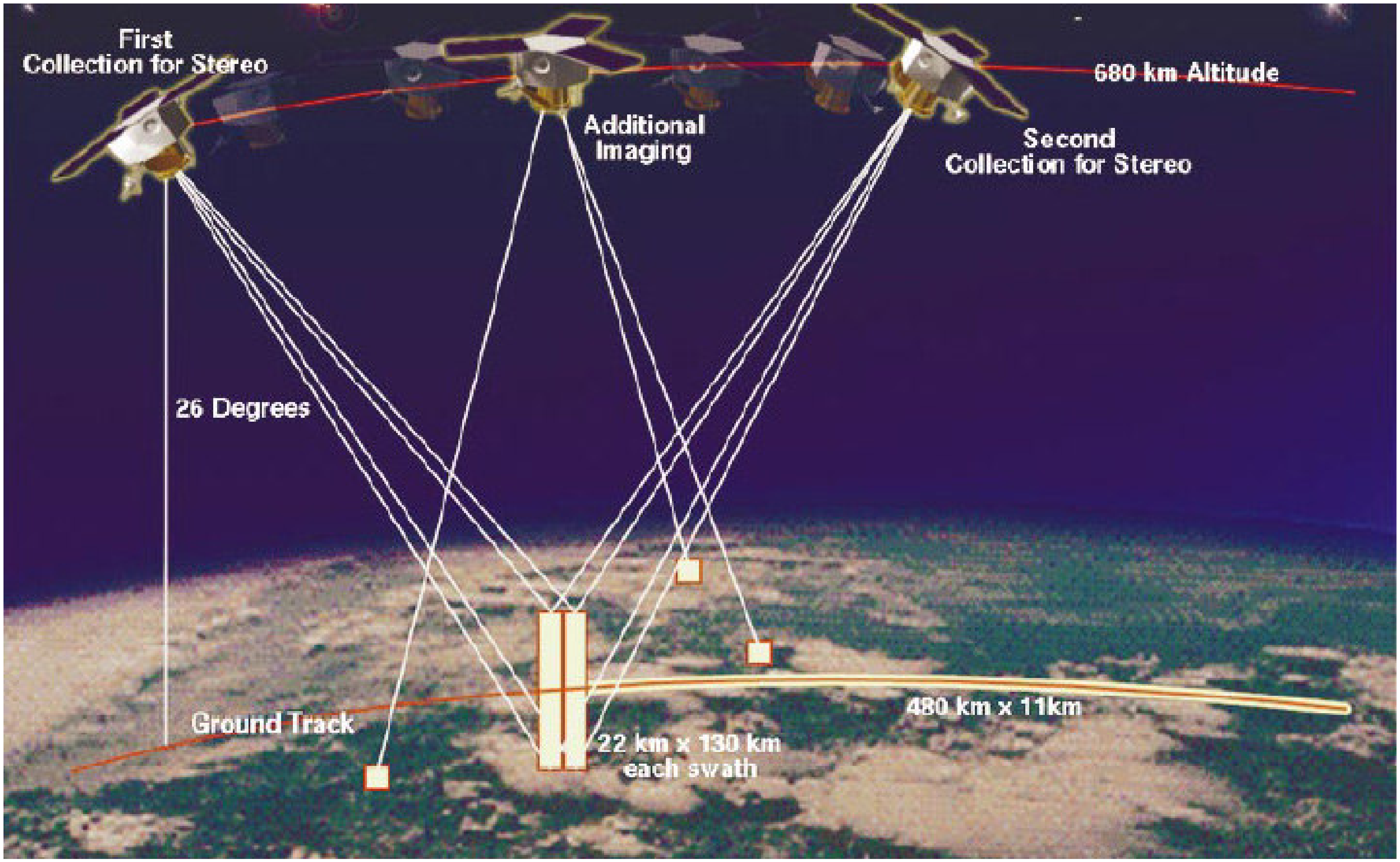
Cartosat P5 DSM processor
Results (Rome)

DEM Accuracy: Height: ~ 3m (1 σ)
x,y: ~ 5m (limited by GCP accuracy)

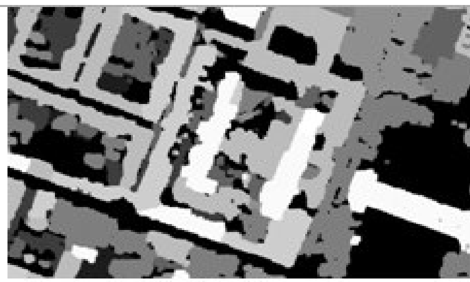
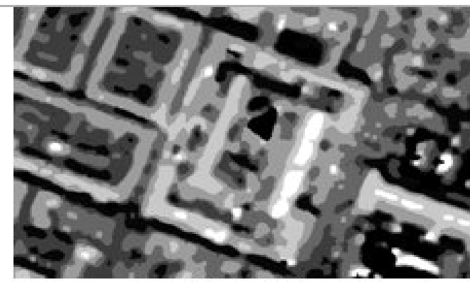
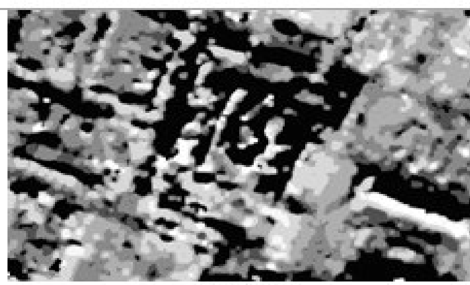
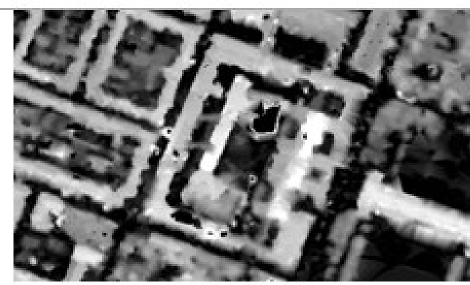
Cartoset P5 DSM processor
Results (Rome)

3D view of using Cartosat DEM and IRS image

IKONOS Stereo Imaging

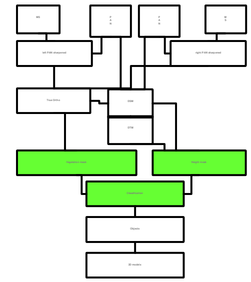


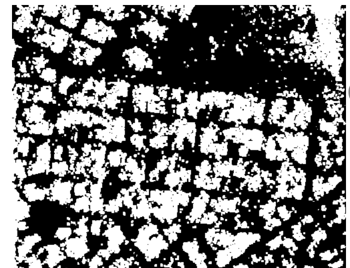
Methodologies for DSM generation

 Ground-Truth	 DLW
 GraphCut	 SGM-BT
 SGM-MI	 Standard

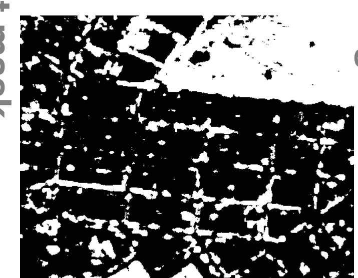
Simple classification

- Two binary masks
  - “Height mask”: Binary mask showing high Objects (difference of DSM – DSM larger than threshold of typical 4 m)
  - “Vegetation mask”: NDVI of true ortho image larger than threshold
- = 4 Classes
  - low+no vegetation: Roads, …
  - high+no vegetation: Buildings, …
  - low+vegetation: Meadows, ...
  - high+vegetation: Trees, ...

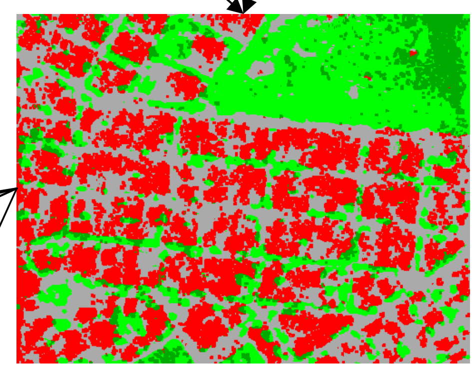




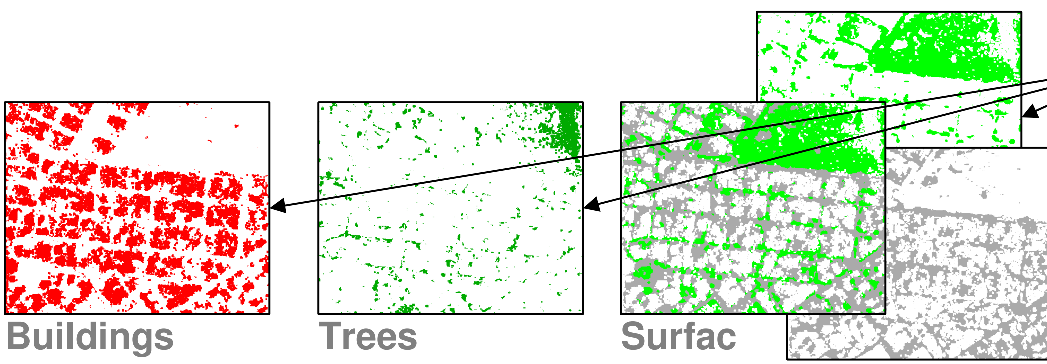
Height mask



Vegetation mask



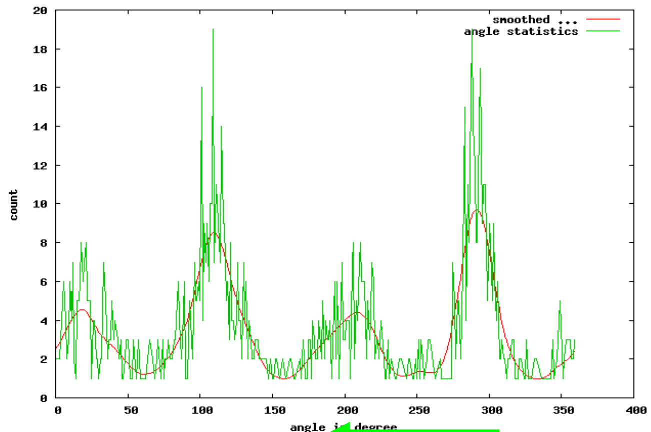
Classification



Buildings Trees Surfac e

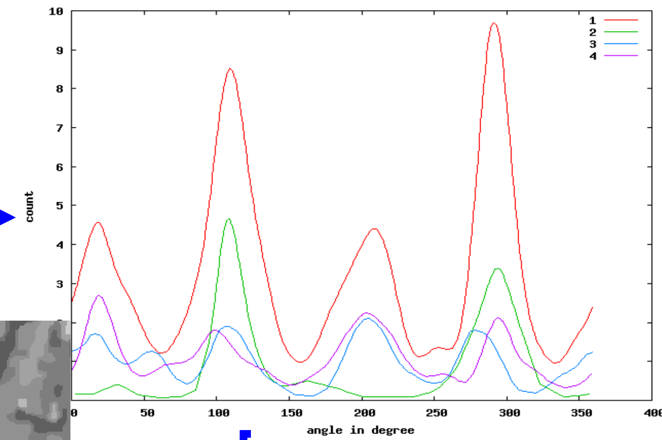
(all images: Athens, 500 m × 400 m)

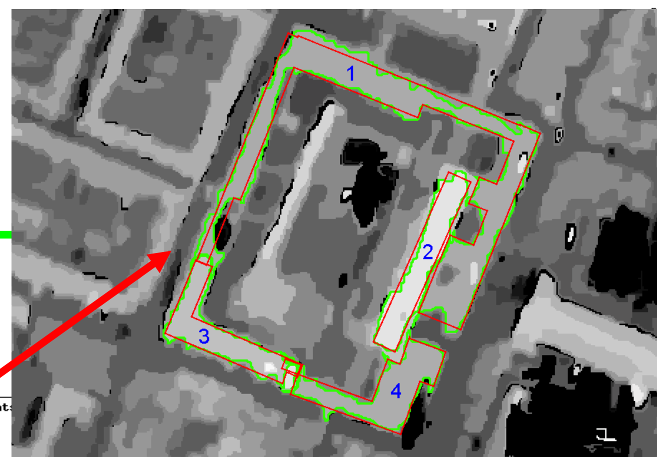
Extraktion of rectangular Buildings



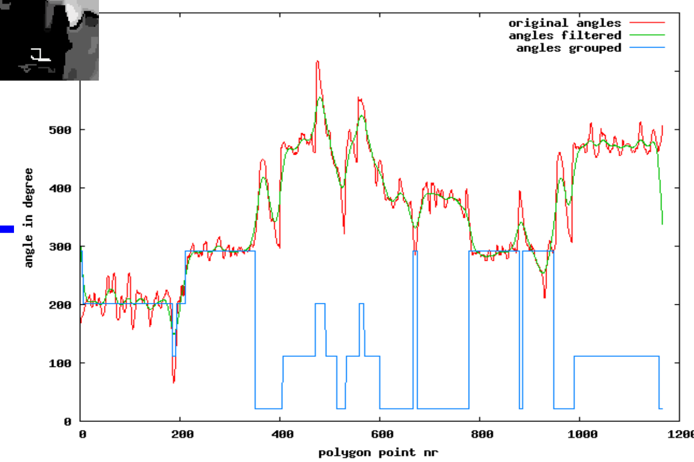
1: Build statistics on directions of border pixels of "high+no vegetation" objects (green)

2: Smooth angular distribution

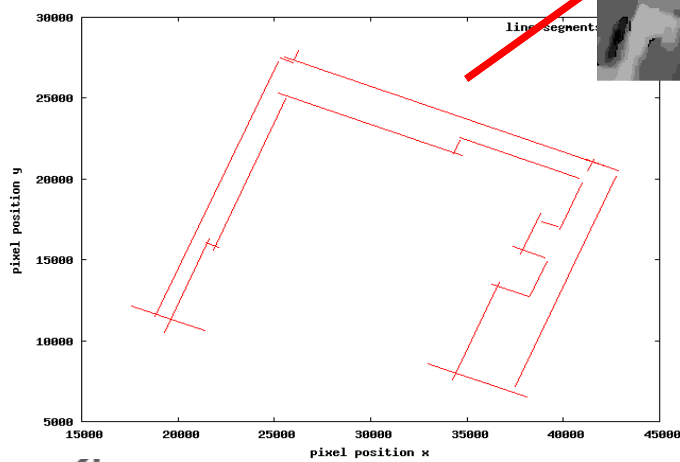


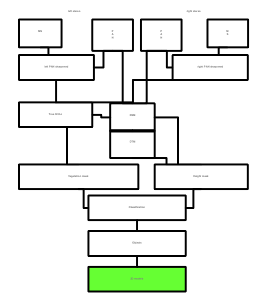


3: Group line segments for (4) main directions



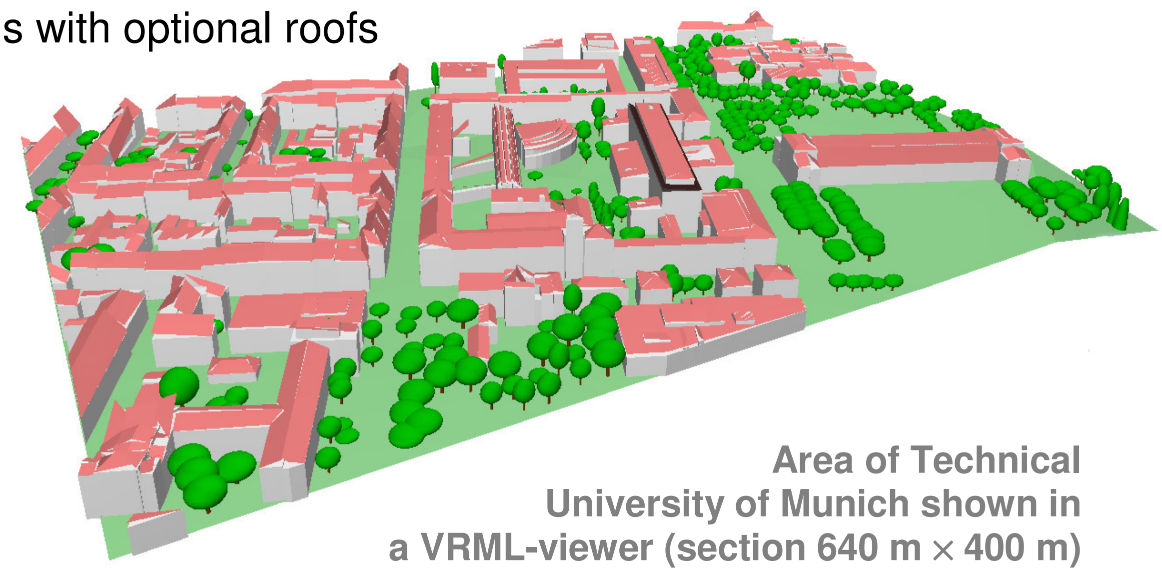
4: Intersect consecutive line segments to closed polygon





Export 3D objekts in suitable file format

- Models:
  - Ground: textured height-field
  - Trees: Ellipsoids on cylinders
  - Buildings: Polygons with optional roofs
- Optional texturing using projection of 3D model back to ortho image



Area of Technical University of Munich shown in a VRML-viewer (section 640 m $\times$ 400 m)

IKONOS-2 true ortho image (Munich, Königsplatz)

Original image

and

True ortho image

Conclusions

- Image2006: Orthorectification of 4000 satellite images in Europe
  - Automatic orthorectification is possible with accuracy of ½ pixel size w.r.t. reference, only 3% manual interaction
  - Processing chain developed and operational
  - Improvements through better DSM, better reference image

- 3D-Imaging from along-track stereo images with optical satellite data
  - DSM accuracies with about 3 meter RMSE in z direction for 2.5 m data
  - Operational chain for DSM generation is in preparation, operational in summer 2008
  - For VHR data (IKONOS, QuickBird) new methods necessary, rough city models are achieved

Thank you for your attention