Economic Considerations for Photogrammetric Mapping

Paper
to the RACURS Conference 2008

Porec, Croatia

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by
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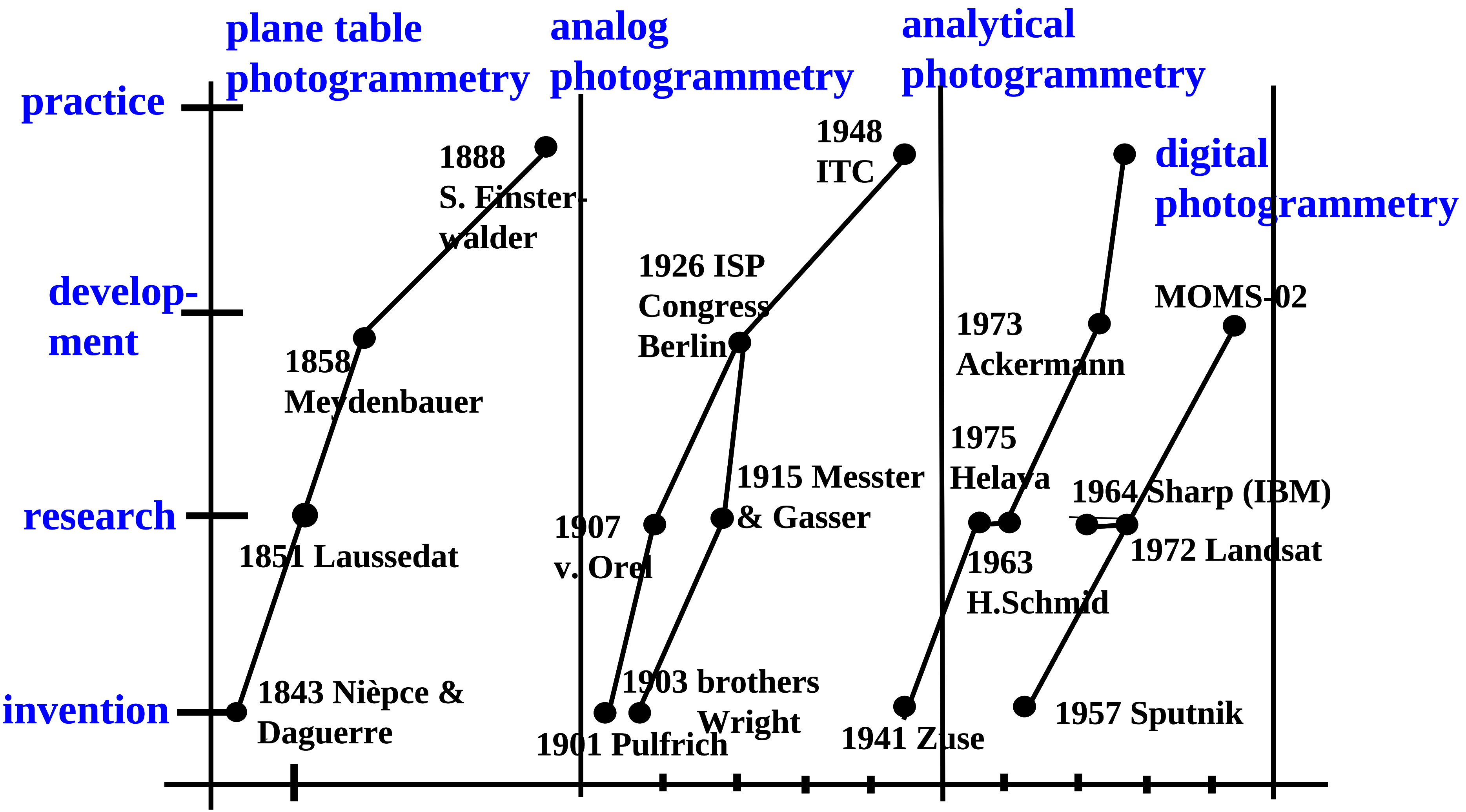
The four development phases of photogrammetry



1.1 Plane Table Photogrammetry

A. Methodology:• Derivation of Angles from Image Points

B. Users:• Surveyors

C. Auxiliary Disciplines:
- **Photography**
- **Descriptive Geometry**
- **Projective Geometry**
- **Perspective**

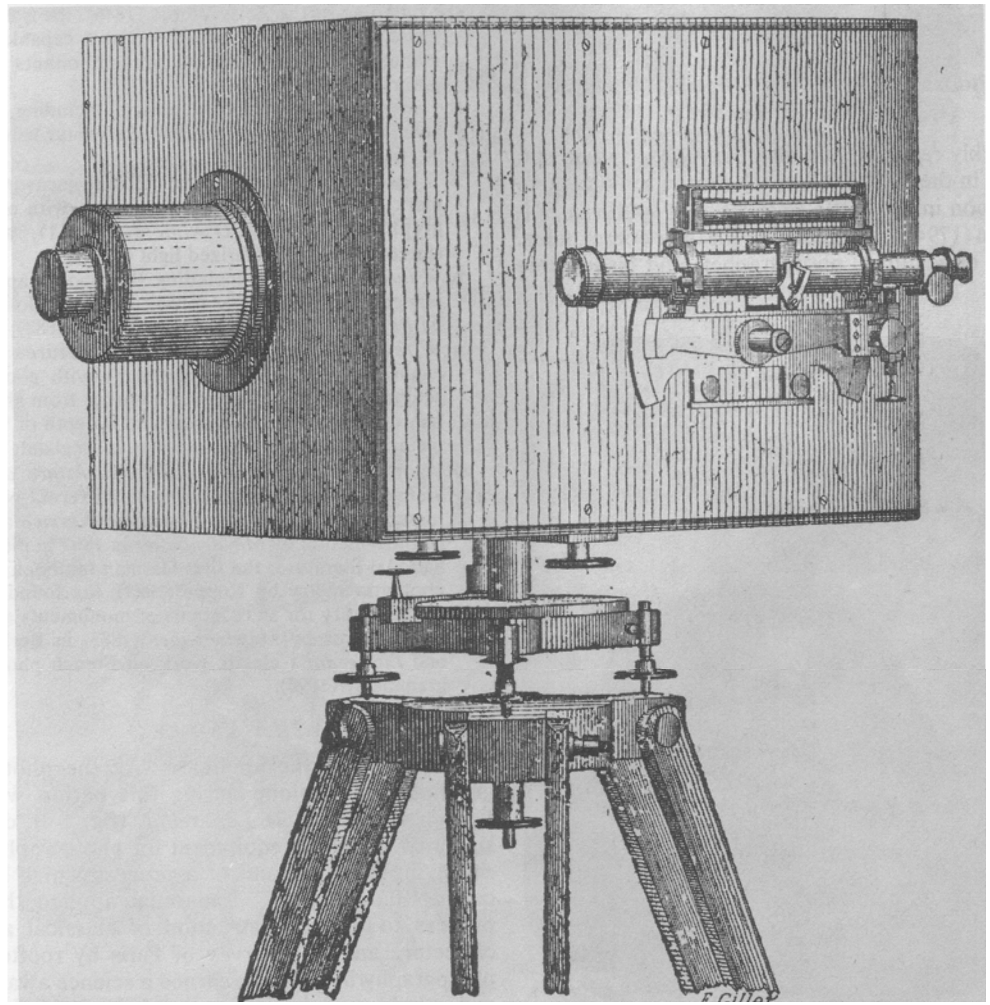
D. Origins:
- **Laussedat, Paris 1851**
- **Meydenbauer, Wetzlar 1858**

E. Practical Uses:
- **Seb. Finsterwalder**
  Vernagt Glacier, 1888

F. Application:
- **Limited to terrestrial surveys of inaccessible objects**
  (mountains, expeditions, glaciers, buildings)

Aimé Laussedat,
Colonel of French Army

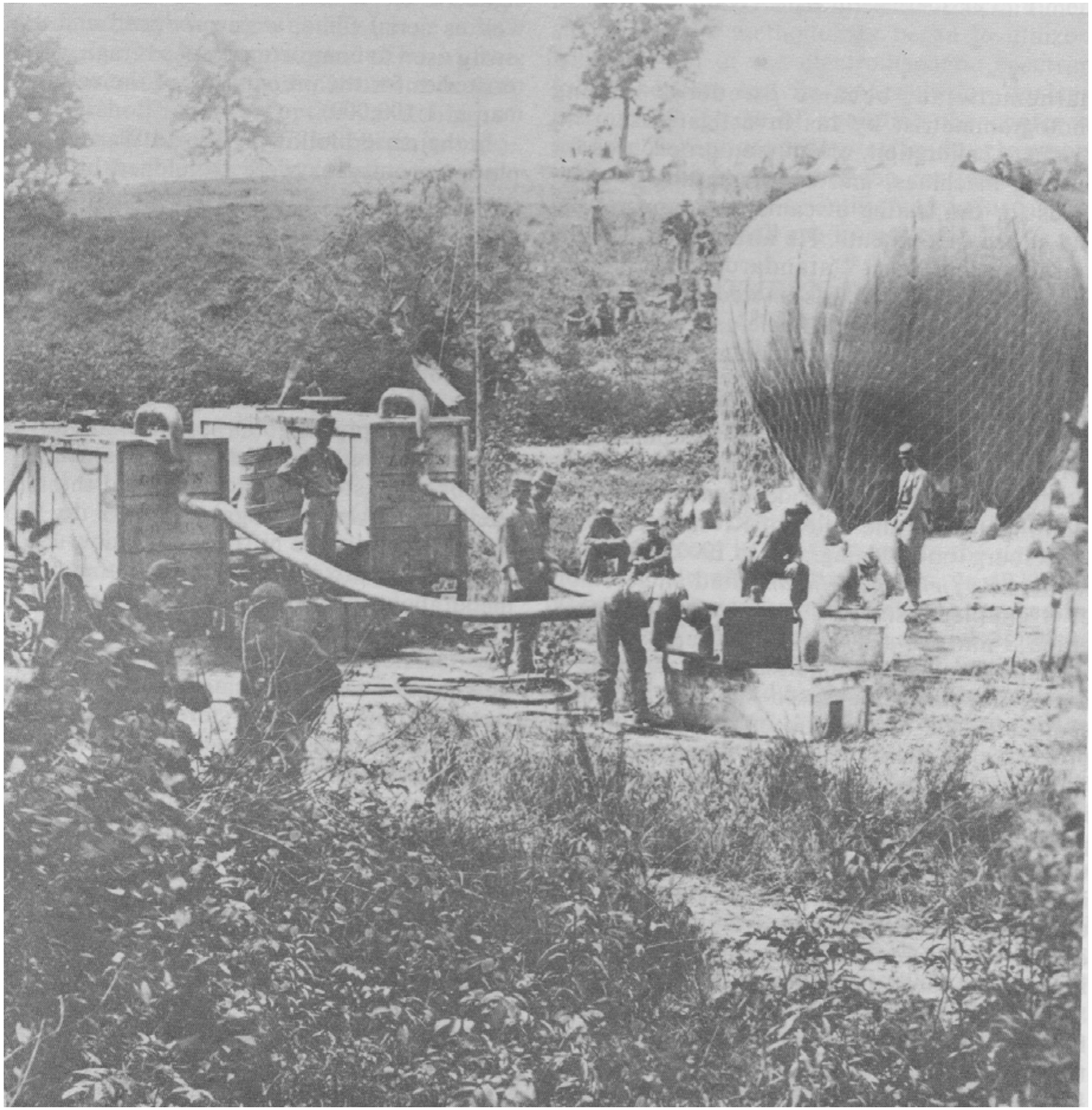
use of photography
for mapping from
the roofs of Paris



Balloon Photography

in the US Civil War

1862



Sebastian Finsterwalder

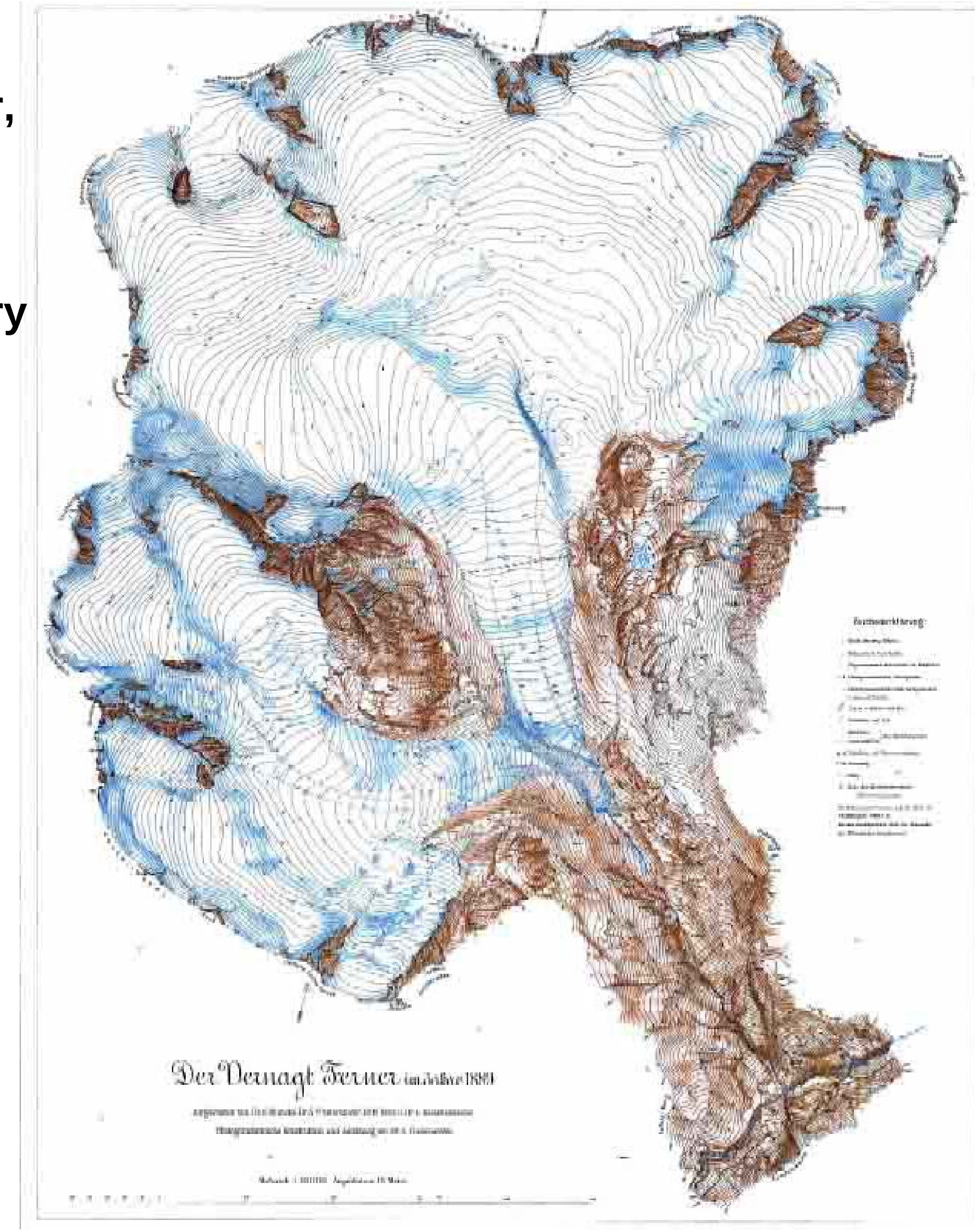
Professor of Mathematics

Technical University of Munich

1887-1888 Terrestrial Photogrammetric Survey of the Vernagt Glacier Austia

1899 -1902 Analytical Restitution of two Balloon Images (Gars am Inn)

Map of the Vernagt Glacier, Austria, compiled by terrestrial photogrammetry in 1889 by Sebastian Finsterwalder of Munich



1.2 Analog Photogrammetry

A. Methodology:Reconstruction of Stereomodels by optical or mechanical instruments

B. Users:Photogrammetrists

C. Auxiliary Disciplines: Optics, Mechanical Tooling Stereoscopy

D. Origins:Pulfrich Stereocomparator 1901
von Orel Autograph 1907
Gasser Plotter (Multiplex) 1915

E. Practical Uses:Stereoplotters by Leica (Wild), Zeiss etc. 1926

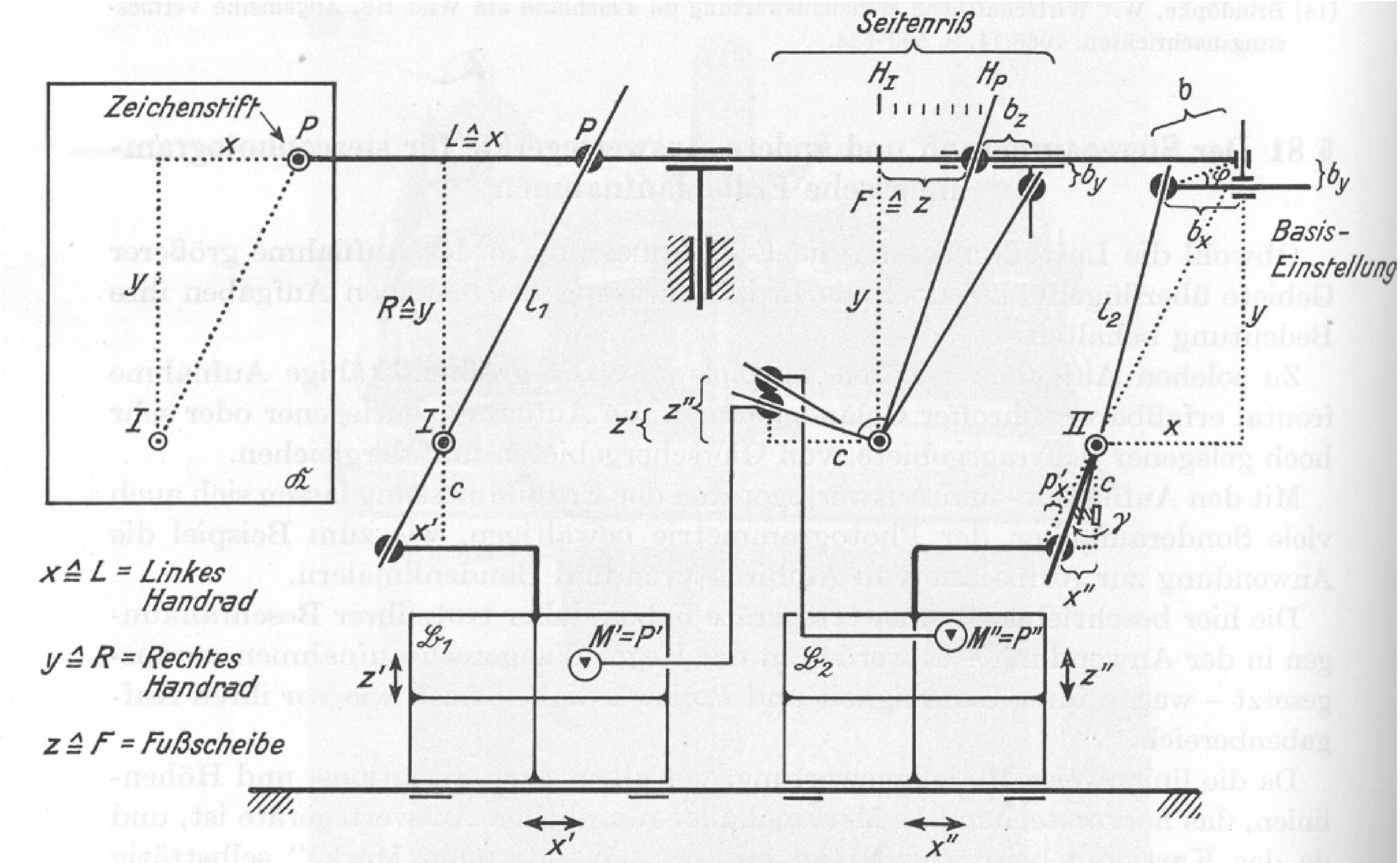
F. Application:Topographic Mapping
1939-1945
on a worldwide scale & 1950 ...

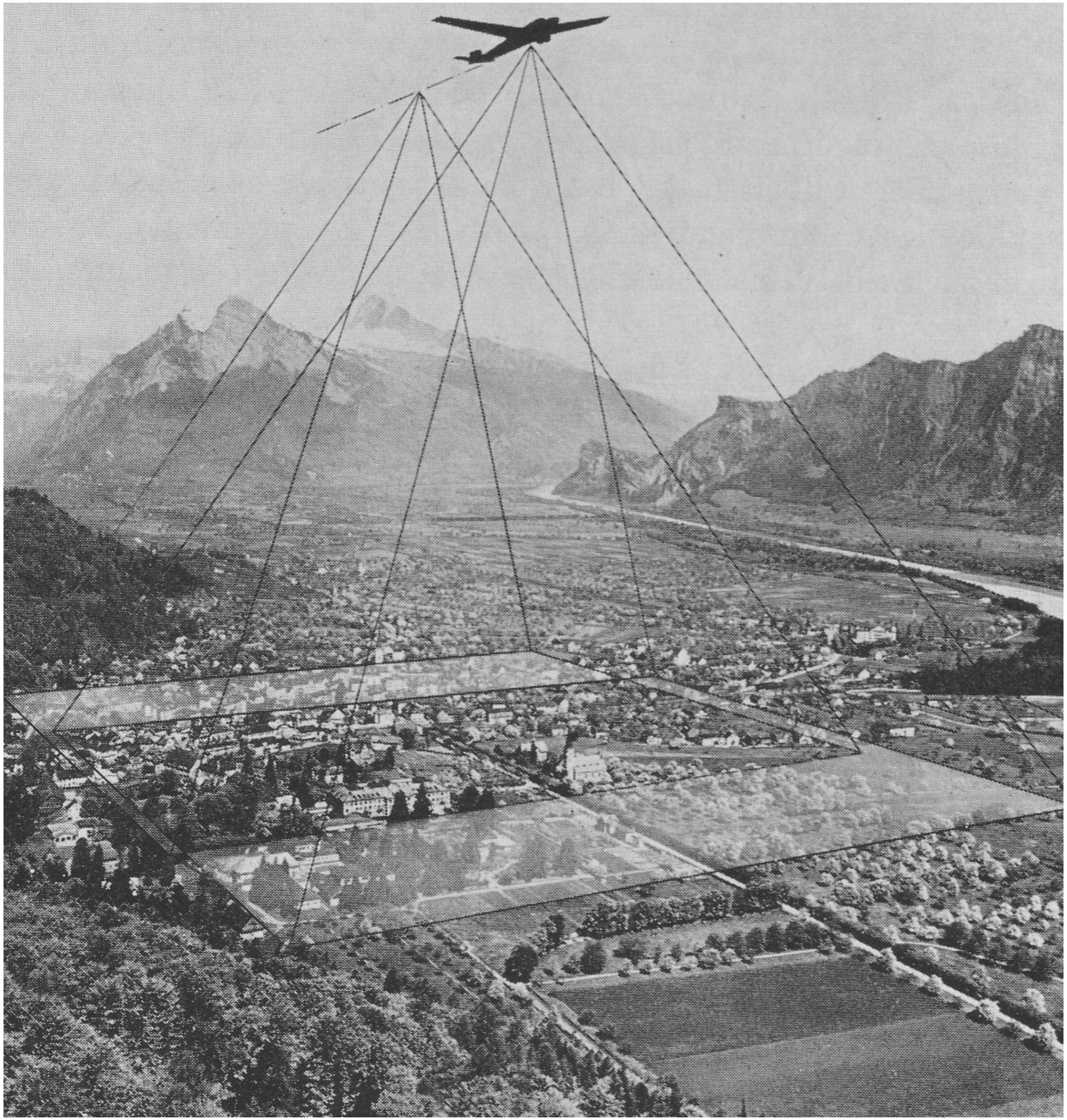
Carl Pulfrich,
Calr Zeiss, Jena

Inventor of
Stereocomparator
1901

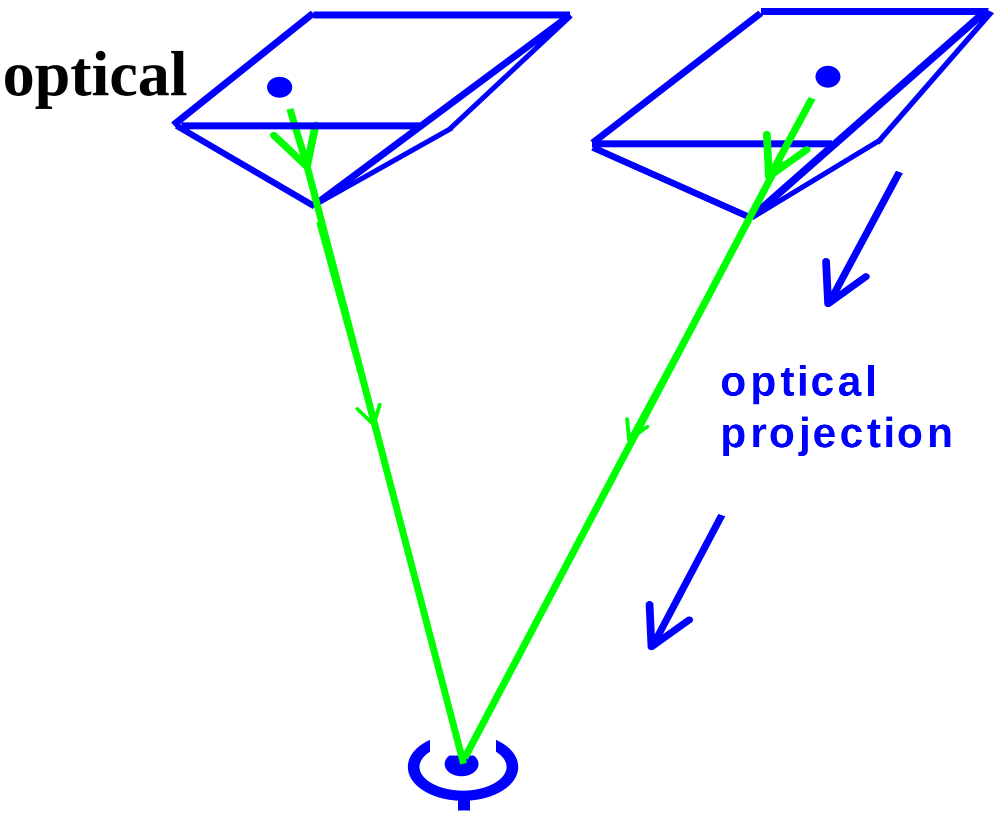
Introduction of
Photogrammetry
Summer Courses

Design of the Stereoatograph Zeiss-Orell for terrestrial photogrammetry



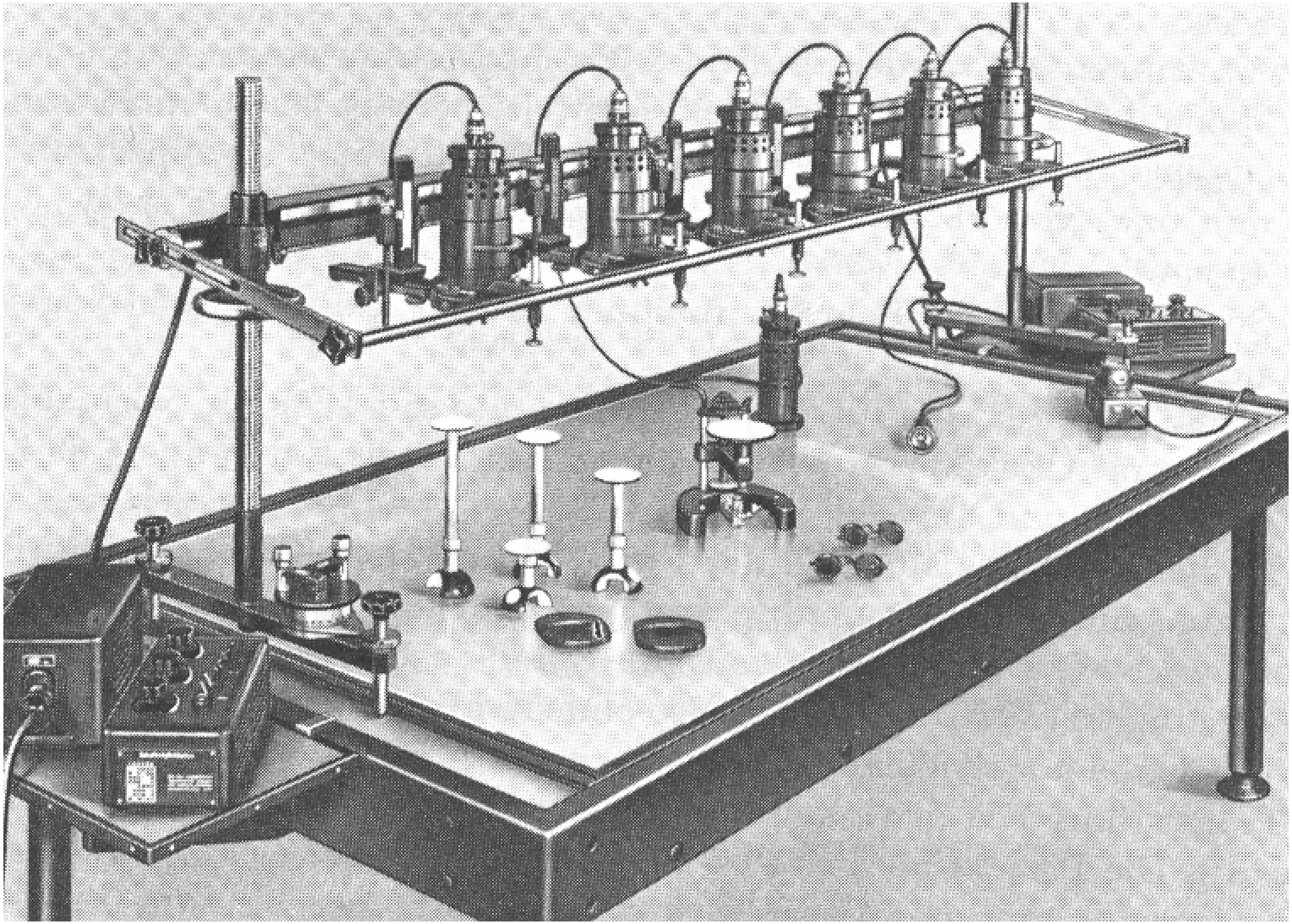


Analog Stereoplotters for Aerial Photos

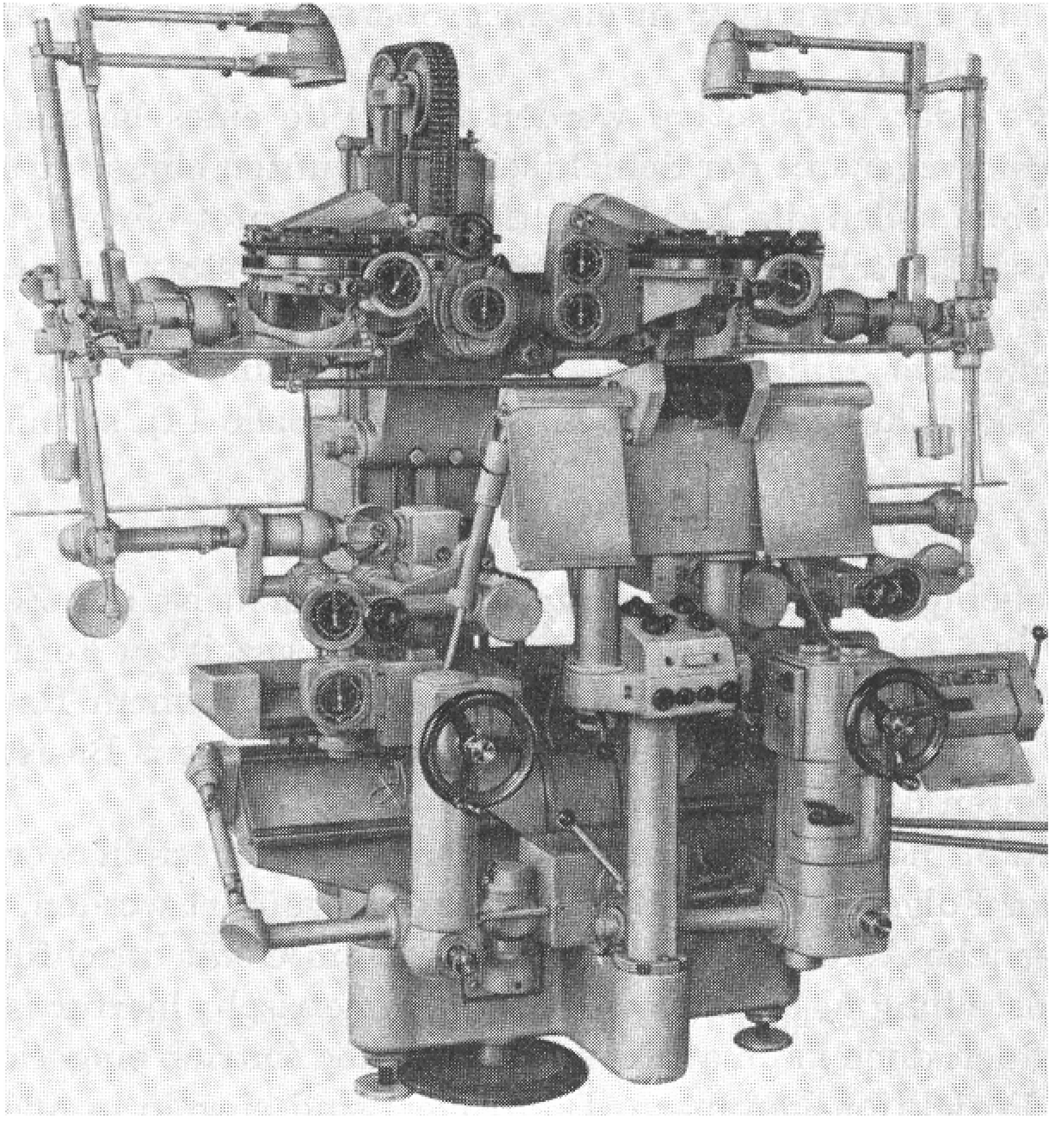


1915Gasser Plotter
1933 Zeiss Multiplex
1921Zeiss Stereoplanigraph (Bauersfeld)
1952Zeiss C8

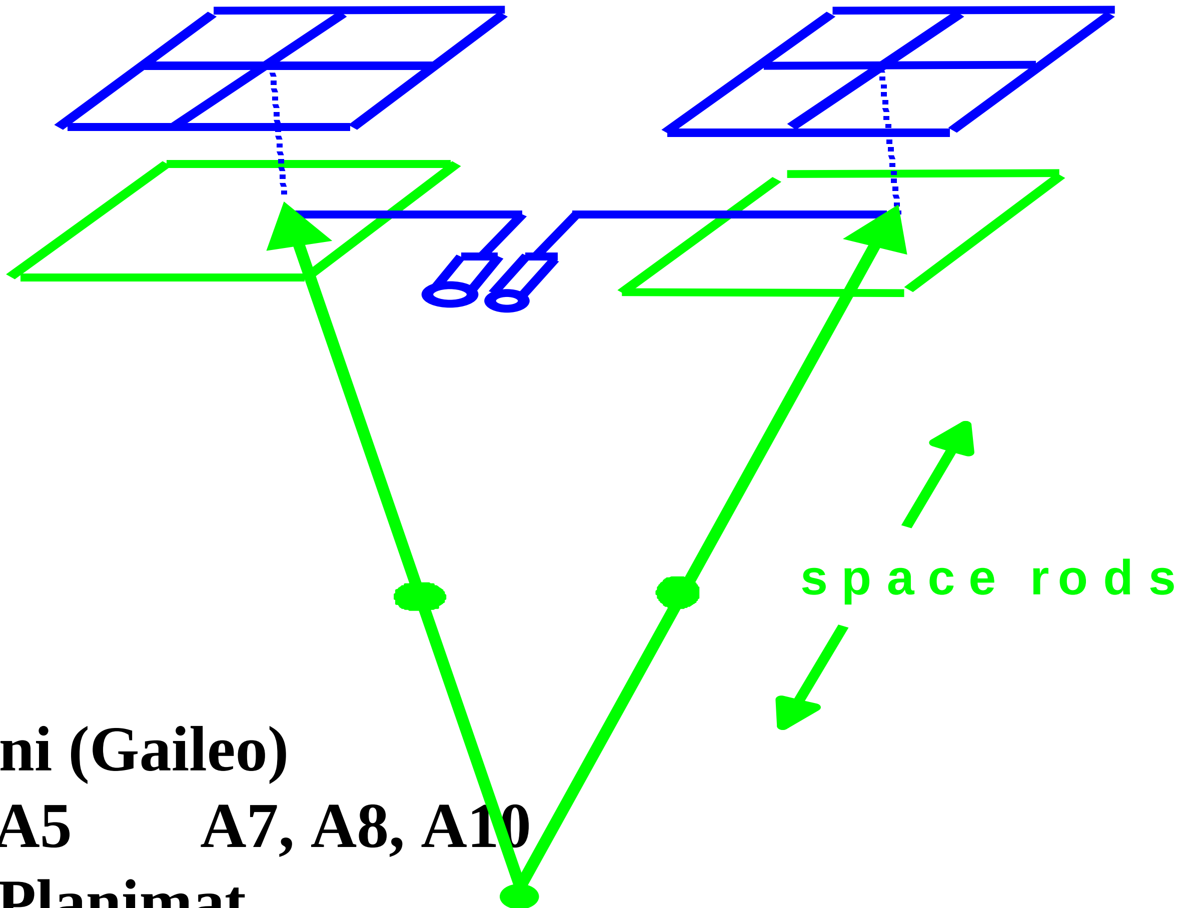
Zeiss Multiplex 1933 Projector Assembly for Aerial Triangulation



Zeiss Stereoplanigraph C8 rebuilt in 1953



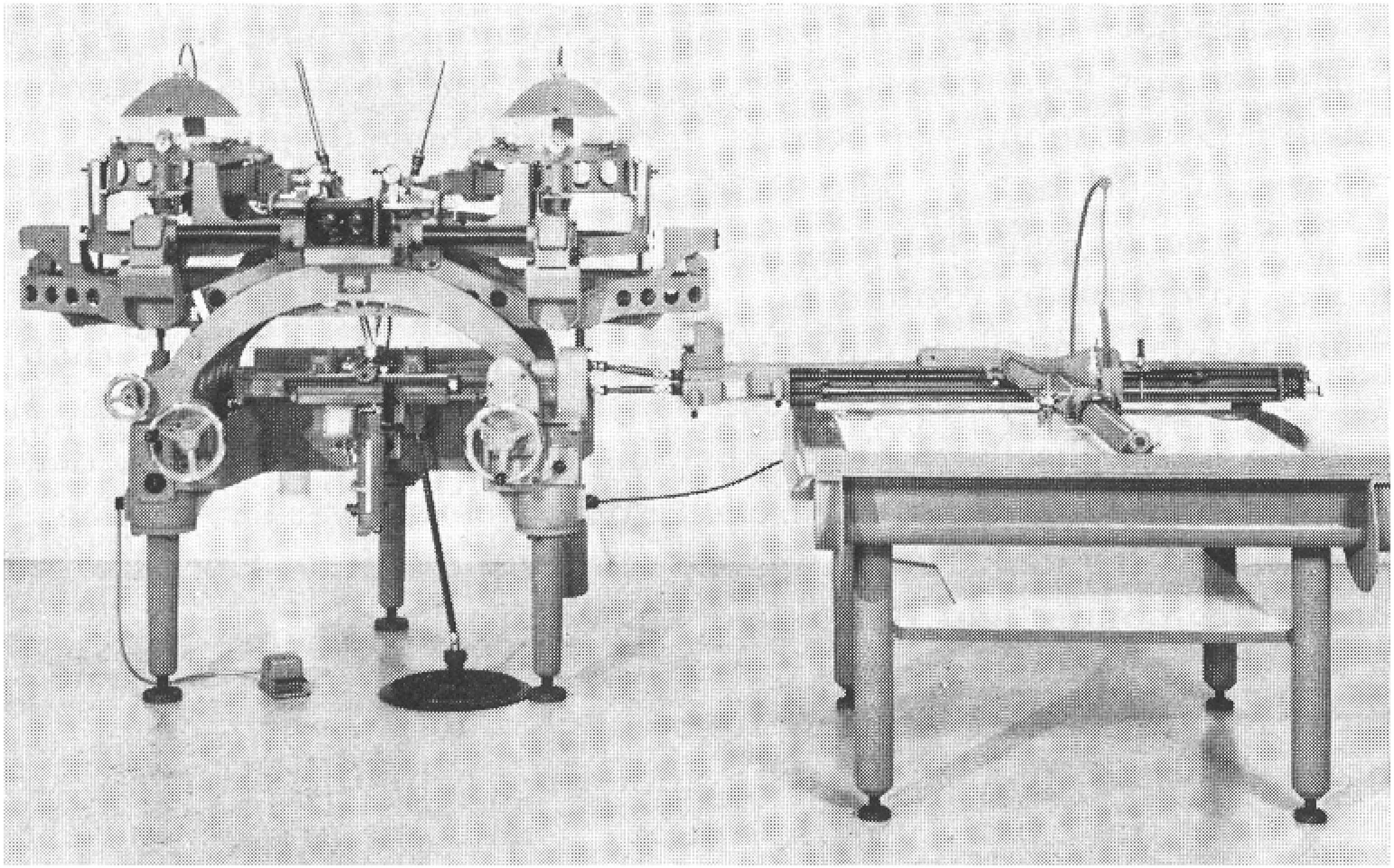
mechanical



1921Santoni (Gaileo)
1936Wild A5 A7, A8, A10
1967Zeiss Planimat

1955Russia (Romanovski)
affine plotters

Stereoautograph Wild A8 („the Volkswagen of Analog Photogrammetry“)



1.3 Analytical Photogrammetry

A. Methodology:Integration of computers in stereo restitution

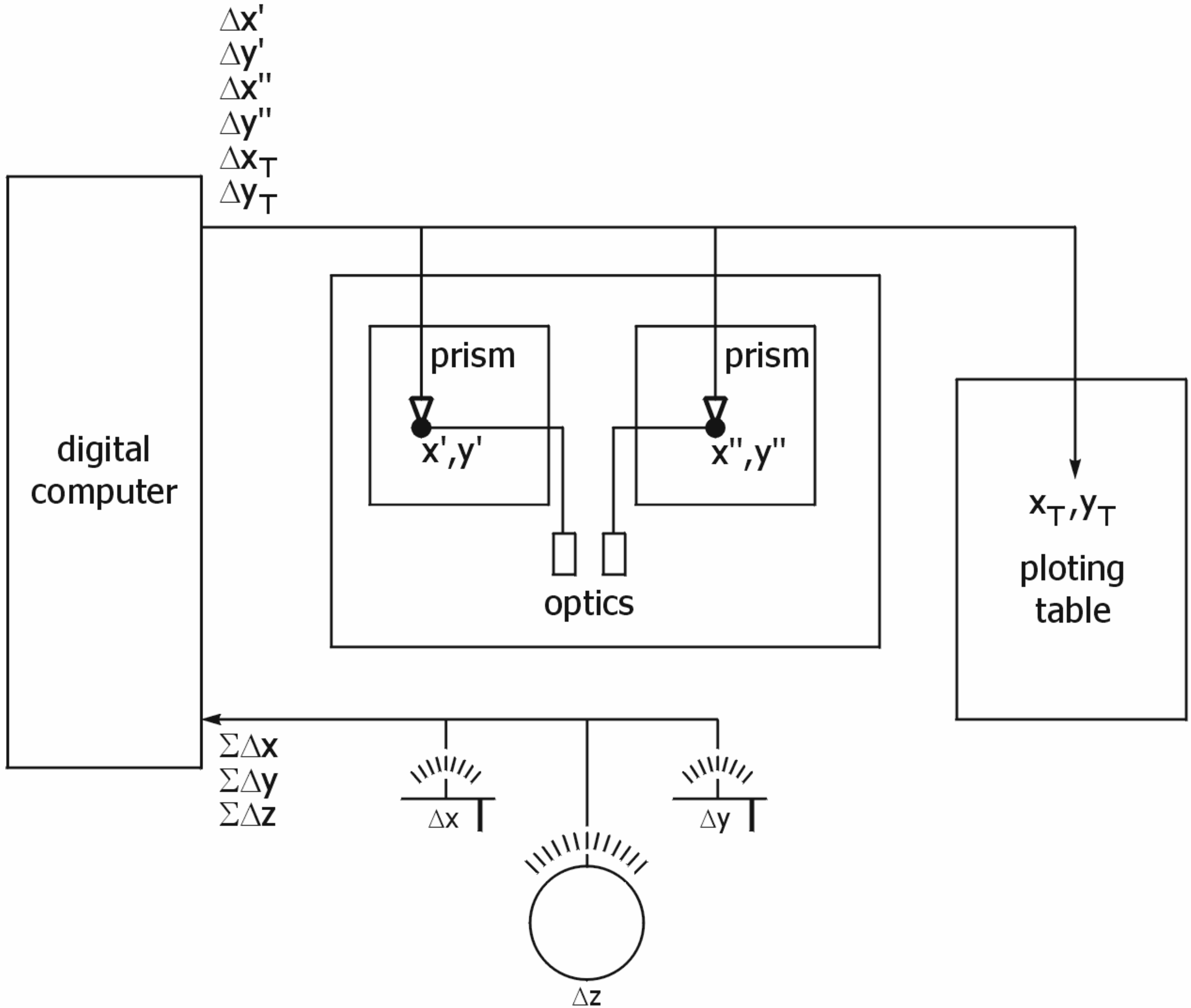
B. Users:Photogrammetrists

C. Auxiliary Disciplines: Analytical Geometry, Matrix Algebra
Least Squares Adjustment

D. Origins:Collinearity Equations (Gast 1930)
Bundle Block Adjustment (H. Schmid 1953)
Analytical Plotter (U. Helava 1957)
Orthocomp by Zeiss (1980)

E. Practical Uses:Semiautomatic Orientation, D.E.M.,
Analytical Aerial Triangulation, Vector Plotting

F. Application:Improved Accuracy and Reliability in Map Restitution


Δx'
Δy'
Δx''
Δy''
Δx_T
Δy_T
digital computer
prism
x',y'
prism
x'',y''
optics
x_T,y_T
ploting table
ΣΔx
ΣΔy
ΣΔz
Δx
Δy
Δz


ZEISS
PLANICOMP P3

1.4 Digital Photogrammetry

A. Methodology: Use of digitized or digital images in pixels

B. Users: Geoinformatics specialists

C. Auxiliary Disciplines: Computer Science, Digital Image Processing

D. Origins: Optronics 1970
Stereo Workstation 1988
Digital Image Matching (Sharp 1965)

E. Practical Uses: Digital Orthophotos,
Space Imagery Restitution

F. Application: Integration into G.I.S.

ISPRS and Surveying and Mapping

1910	Creation of ISP	photogrammetry as new mapping tool used in America and WW II
1950	ITC	introduction of new mapping technology to developing countries
1972	Landsat	introduction of remote sensing to the world
1980	ISPRS	integration of remote sensing and photogrammetry
1990	GPS	new positioning tool
	and GIS	new spatial analysis tool

Eduard Dolezal,
Professor,
Technical
University of Vienna

Founder of the
Austian Society
for Photogrammetry
1907

Founder of the
International
Society for
Photogrammetry
1910

Willem Schermerhorn

1930´s friend of Otto von Gruber

1938 designated ISP Congress Director

1945 – 1946 Prime Minister of the Netherlands

1948 ISP Congress In th Hague, Netherlands

1950 Founder of the ITC

The phases of photogrammetric mapping technology

1. Experimental tool with scientific, military and governmental uses in special cases (Laussedat 1851, terrestrial survey of Paris from rooftops; Meydenbauer 1858 architecture; S. Finsterwalder 1887 glaciers; Deville 1890 Rocky Mountains; Von Orel, Alps)

2. Aerial photogrammetry as competitor to ground surveys (World War I, in 1920´s problem in Europe: exaggerated accuracy requirements, in 1930´s American Society for Photogrammetry, in 1940´s World War II, 1951 ITC: photogrammetry becomes mapping tool for developing world), governmental activities

3. Analytical photogrammetry with computers solves accuracy problem (Duane Brown, Friedrich Ackermann)

4. Digital photogrammetric workstations

5. Outsourcing of mapping to industry, automation of photogrammetric processes (aerial triangulation, image matching, orthophotos versus line mapping)

6. Further automation of feature extraction

Current Photogrammetric Mapping Processes

1) aerial photography

2) digital scanning of aerial photos
(as digital stereo workstations are now considered state of the art)

3) aerial triangulation to determine position and orientation of the aerial photos

4) digital elevation model generation
(digital image matching of overlapping images
is now considered state of the art)

5) digital ortho rectification based on aerial triangulation
and digital elevation model

6) radiometric matching of adjacent orthophotos from map file to map file
or better within a seamless geodatabase

7) vector digitization of topographic map features in 2D
(on screen from the orthophotos) or in 2.5 to 3D (in stereo workstations).

Accuracy Model for Aerial Photogrammetry

$$x = \frac{z}{f} x' \qquad \sigma_x = \pm \frac{z}{f} \sigma_x '$$

$$y = \frac{z}{f} y' \qquad \sigma_y = \pm \frac{z}{f} \sigma_y '$$

$$z = \frac{b \cdot f}{x' - x''} \qquad \sigma_z = \pm \frac{b \cdot f}{(x' - x'')^2} \sigma_{(x' - x'')x} = \pm \frac{z^2}{bf} \sigma_{(x' - x'')}$$

$$b = (23cm - 0,6x23cm) \cdot \frac{z}{f}$$

σx’, σy’ = +/- 5μm for signalzed ponts and +/- 10μm for natural points and σ(x’-x”) = +/- 7 μm **for parallaxes, being the standard deviations of image coordinates,**

σx, σy, σz the resultant accuracies on the ground.

f is the focal length.
For a camera of the image size 23 x 23 cm
a wide angle camera has an f of 15 cm.
A normal angle camera has an f of 30 cm.

The images overlap along the flight line by about 60 % to assure stereo coverage of the terrain

Table 1: Accuracy for different types of cameras and image scales

Wide angle camera f = 15 cm, format 23 x 23 cm			
flying height z	image scale f : z	$\sigma_x = \sigma_y$	σ_y
500 m 1000 m 5000 m 10 000 m	1:3333 1:6666 1:33 333 1:66 666	± 3,3 cm ± 6,6 cm ± 33 cm ± 66 cm	± 3,8 cm ± 7,6 cm ± 38 cm ± 76 cm
normal angle camera f = 30 cm, format 23 x 23 cm			
flying height z	image scale f : z	$\sigma_x = \sigma_y$	σ_y
500 m 1000 m 5000 m 10 000 m	1:6666 1:3333 1:16 666 1:33 333	± 1,6 cm ± 3,3 cm ± 16 cm ± 33 cm	± 3,6 cm ± 7,1 cm ± 36 cm ± 71 cm

Resolution

$$GSD = 15\mu m \cdot \frac{z}{f}$$

aerial photography scale	mapping scale
1: 6000	1: 1000
1: 45 000	1: 10 000

Cost Model for Aerial Photogrammetry:

1) aerial photography: mobilization	5000 € plus 10 € per image
2) scanning of film	15 € per image
3) aerial triangulation	25 € per image
4) digital elevation model depending on the need to include manually observed break lines	10 to 100 € per image
5) digital orthophoto production	15 € per image
6) radiometric adaptation of orthophotos	10 € per image
7) vector digitization of features. this is the highest cost factor:	10 to 100 hrs per image times 20 to 40 € per hr

As steps 1) to 6) are mostly automatic operations the processing of DEM's and orthophotos has a raster homogeneous cost factor over the globe.

Table 2: Cost of orthophotos and line maps from aerial photography; area covered 250 km²

image scale photo dimension air base strip width neat area covered number of photos for area	1:6000 1380 m 552 m 966 m 0,533 km^2 469	1:45 000 10 350 m 4 140 m 7 245 m 29,99 km^2 8,34
cost of orthophotos with automatic DEM	44 865 €	5 709 €
cost of orthophotos with semi-automatic DEM	87 075 €	6 460 €
additional cost of line maps (European prices)	rural 375 200 € urban 1 876 000 €	6 672 € 33 360 €
additional cost of line maps (Asian prices)	rural 187 600 € urban 938 000 €	3 336 € 16 680 €

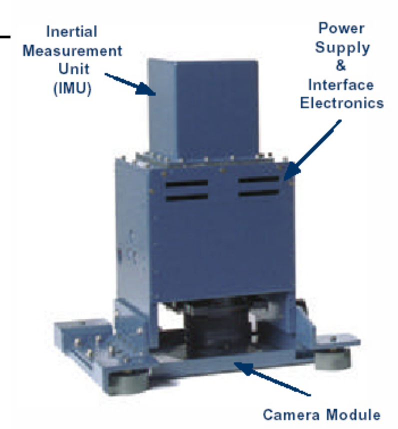
Digital aerial cameras - frame cameras

Very clear trend to digital cameras

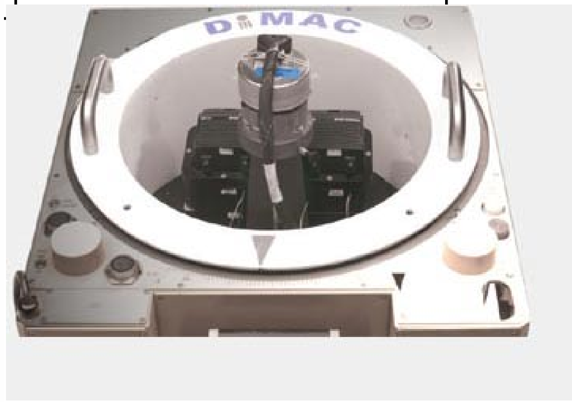
array camera	pixels	pixel size	focal length
Intergraph DMC	8000 x 14000 pan	12 µm	120mm
Vexcel UltraCam$_D$	7500 x 11500 pan	9µm	100mm
Applanix DSS	4092 x 4077	9µm	55mm or 35mm
DIMAC	up to 4 times 4080 x 5440	9µm	60mm – 150mm

DMC

UltraCam$_D$



DSS



DIMAC

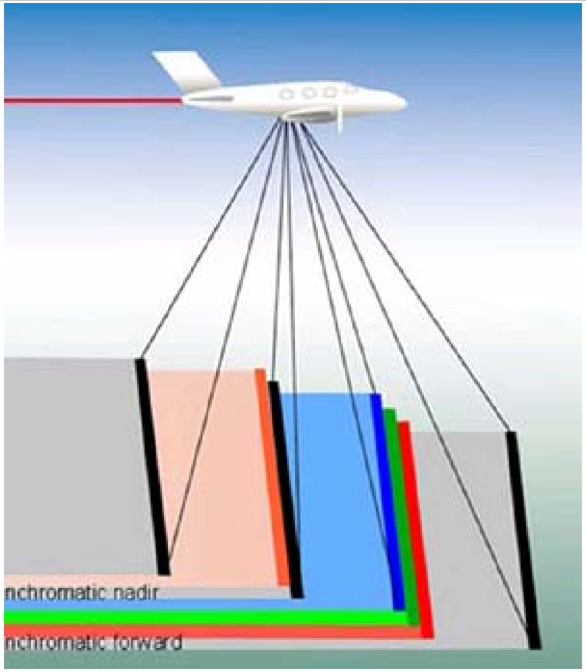
small format in flight direction

connection with GPS + IMU

up to 4 independent cameras

Digital line scan cameras

line camera	pixels	pixel size	view direction in flight direction	field of view across
Leica ADS40	2 x 12000 staggered	6.5µm	-16°, nadir, 26°	62°
Starlabo StarImager	14400	5µm	-23°, nadir, 17°	62°
JAS 150	12000	6.5µm	nadir, +/-12°, +/-20.5°	29°



Leica ADS40 f=62.5mm

4 colour bands with 12000 pixels

3 view directions panchromatic

has to be connected to direct sensor orientation (GPS + IMU)

from h=2km swath=2.4km

GSD=20cm

max: 800 lines/sec

no TDI

Alternatives for Digital Elevation Models

1. Digitization of existing contour maps	2 € / km^2	+/- 5 m
2. Shuttle Radar Topogr. Mission SRTM	free for 90m posting	+/- 15m
3. Airborne Radar Interferometry (NextMap)	4 – 40 € / km^2	+/- 1 m
4. Stereo Satellite Mapping (Spot, Alos)	2 – 4 € / km^2	+/- 5 m
5. Laser Scanning	100 € / km^2	+/- 0.15 m

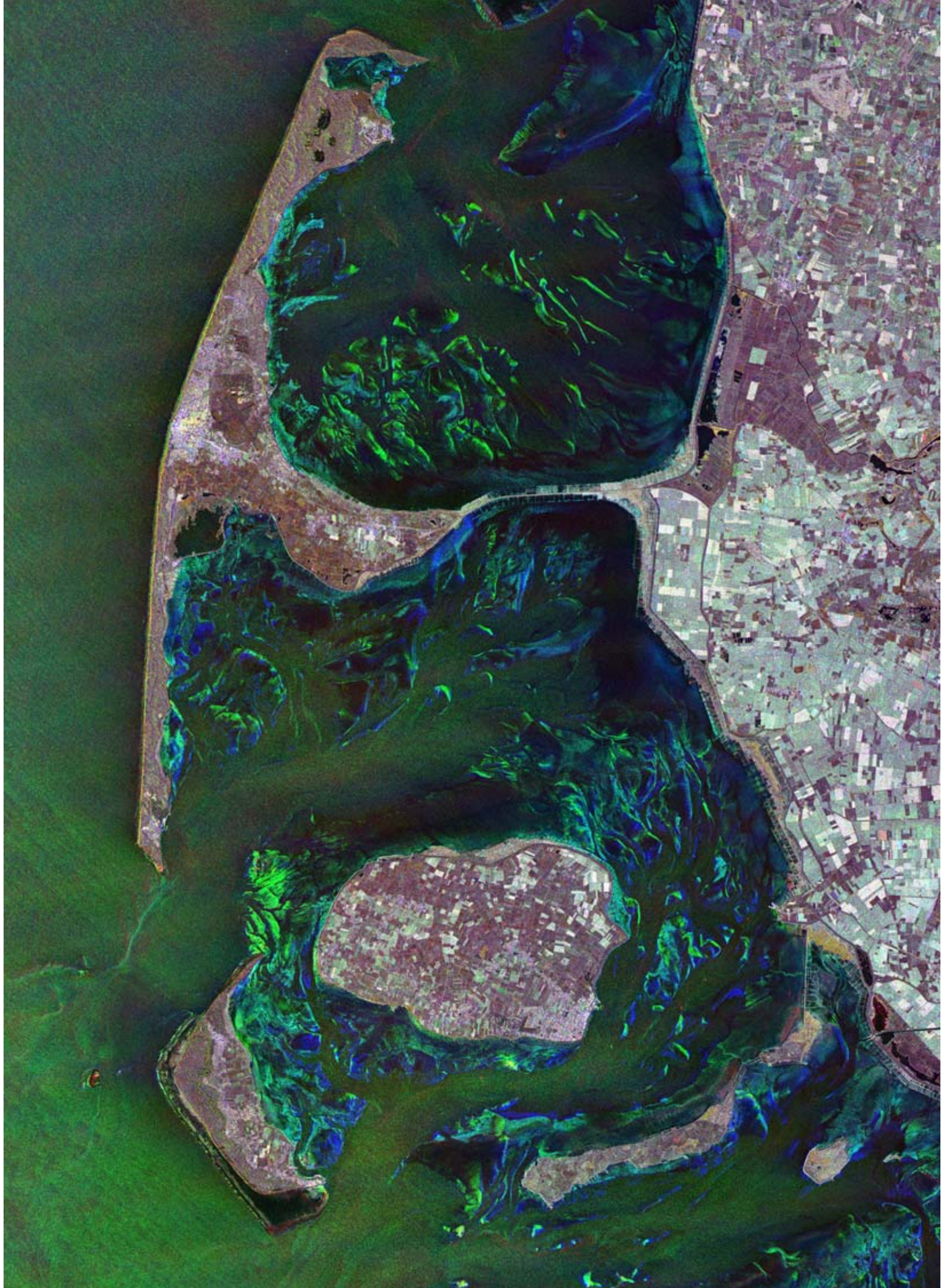
Table 3: Satellite Imagery

Program	Country	GSD	year	use
NOAA satellites	USA	1 km		meteorology, global
Landsat MSS	USA	80 m	1972	vegetation studies
Landsat	USA	30 m	1982	general remote
Spot 1-4	France	10 m	1986	sensing
Spot 5	France	2,5 m	2002	land use studies
Alos	Japan	2,5 m	2006	
Ikonos 2	USA	1 m	1999	stereo option
Quickbird 2	USA	0,6 m	2001	
Orbview 3	USA	1 m	2003	
Topsat	UK	2,5 m	2005	
IRS-P5 Cartosat 1	India	2,9 m	2005	
Formosat 2	Taiwan	2,5 m	2004	
Eros A 1	Israel	2 m	2000	
Eros B	Israel	1,9 m	2006	
Resurs DK 1	Russia	1 m	2006	
World View 1	USA	0,5 m	2007	
GeoEye	USA	0.4 m	2008	

TerraSar X
launched June 15, 2007

Multitemporal Image of the German island Sylt

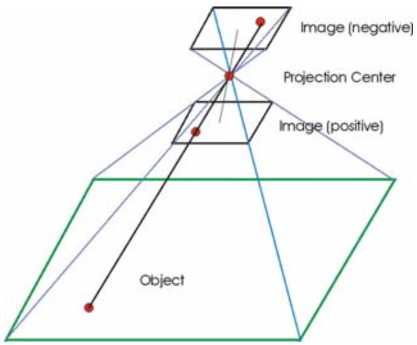
1m GSD



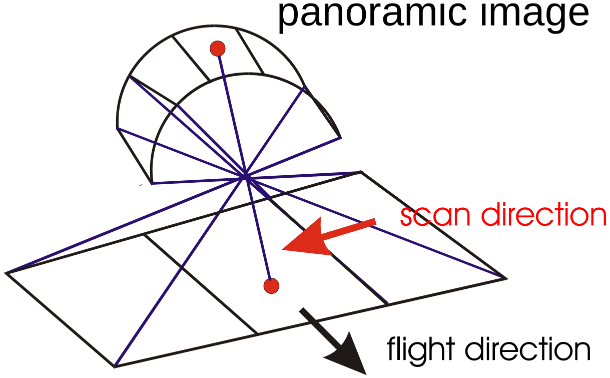
Launch of GeoEye, September 6, 2008, 40cm GSD

Sensor Types

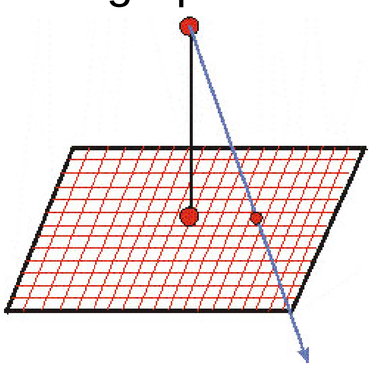
perspective photo



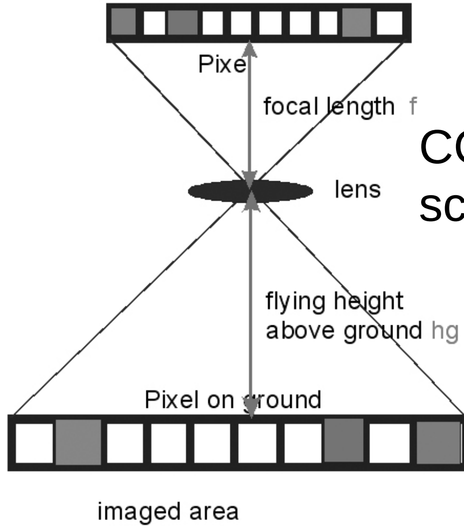
panoramic image



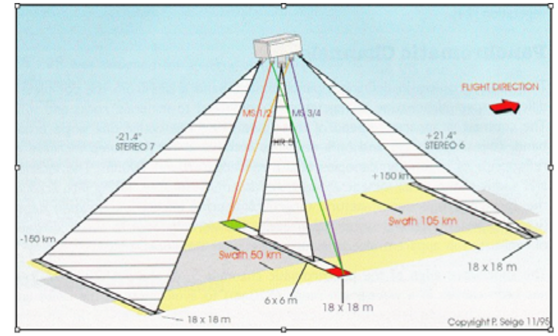
photographic material



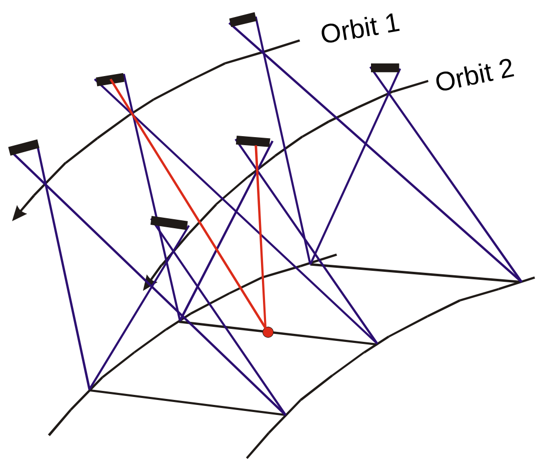
perspective digital image



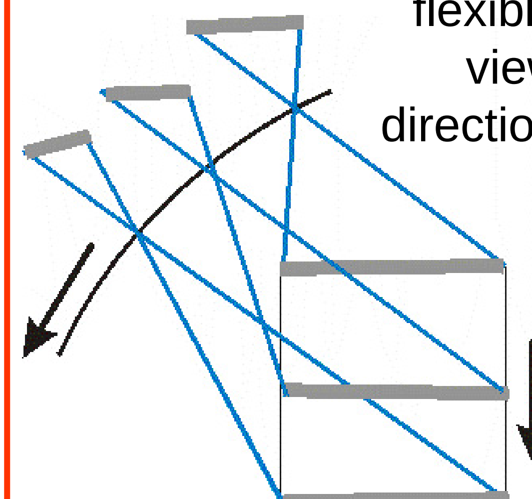
CCD-line scanner



CCD-line scanner with different view directions in orbit

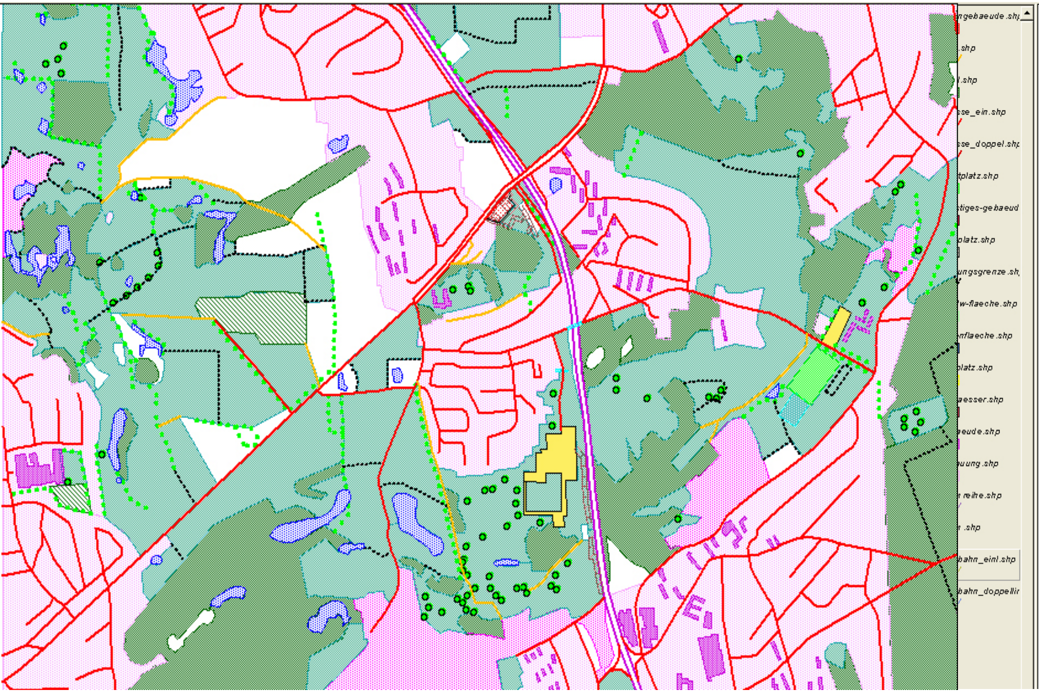


classical view to side



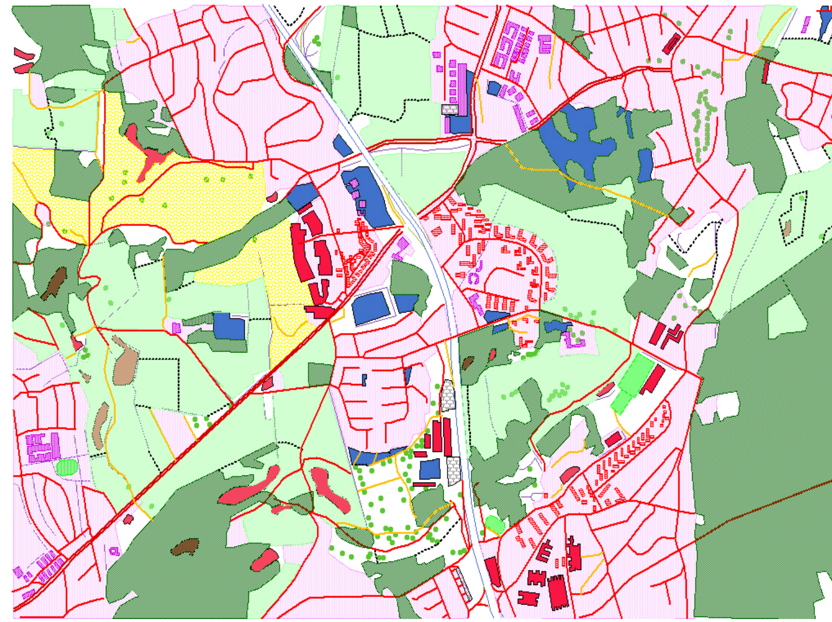
flexible view direction

Mapping SAR-image   C-band, 4 m pixel – aerial photo



map based on Radar-image, C-band,

4m pixel size



map based on aerial photo,

4m pixel size

EuroSDR test data Copenhagen

Optical image - SAR-image

Ground pixel size 1.5m

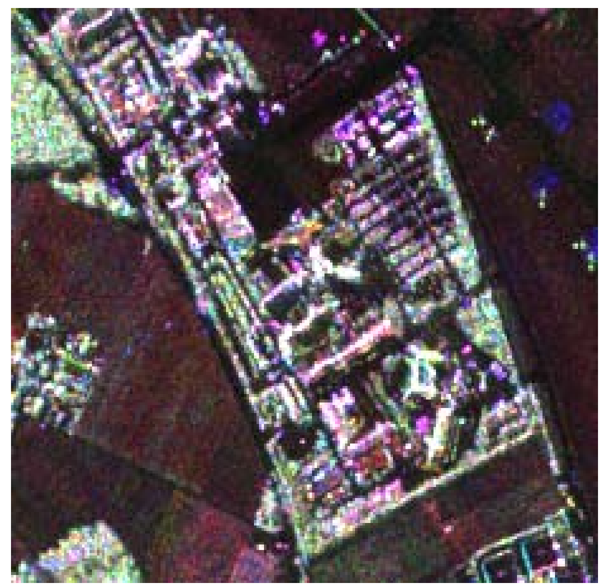
←photo

SAR X-band →

Ground pixel size 3 m

←photo

SAR L-band →



Examples shown for what can be done are from a World Bank Project for the Municipality of Tirana, Albania

Project execution: 6 months in 2005

acquired were:
1 Quickbird satellite image (273 km^2) –orthoready product
1 server with ArcSDE linked to Oracle
2 ArcExplorer
10 ArcView

field survey:
ITRF connection for GPS/DGPS contracted for 4 primary points, densification via RTK to 60 control points for geocoding of satellite image,
detail survey with GPS linked field computer

cost: 200 000$ for 60 km^2

raphics Window Help

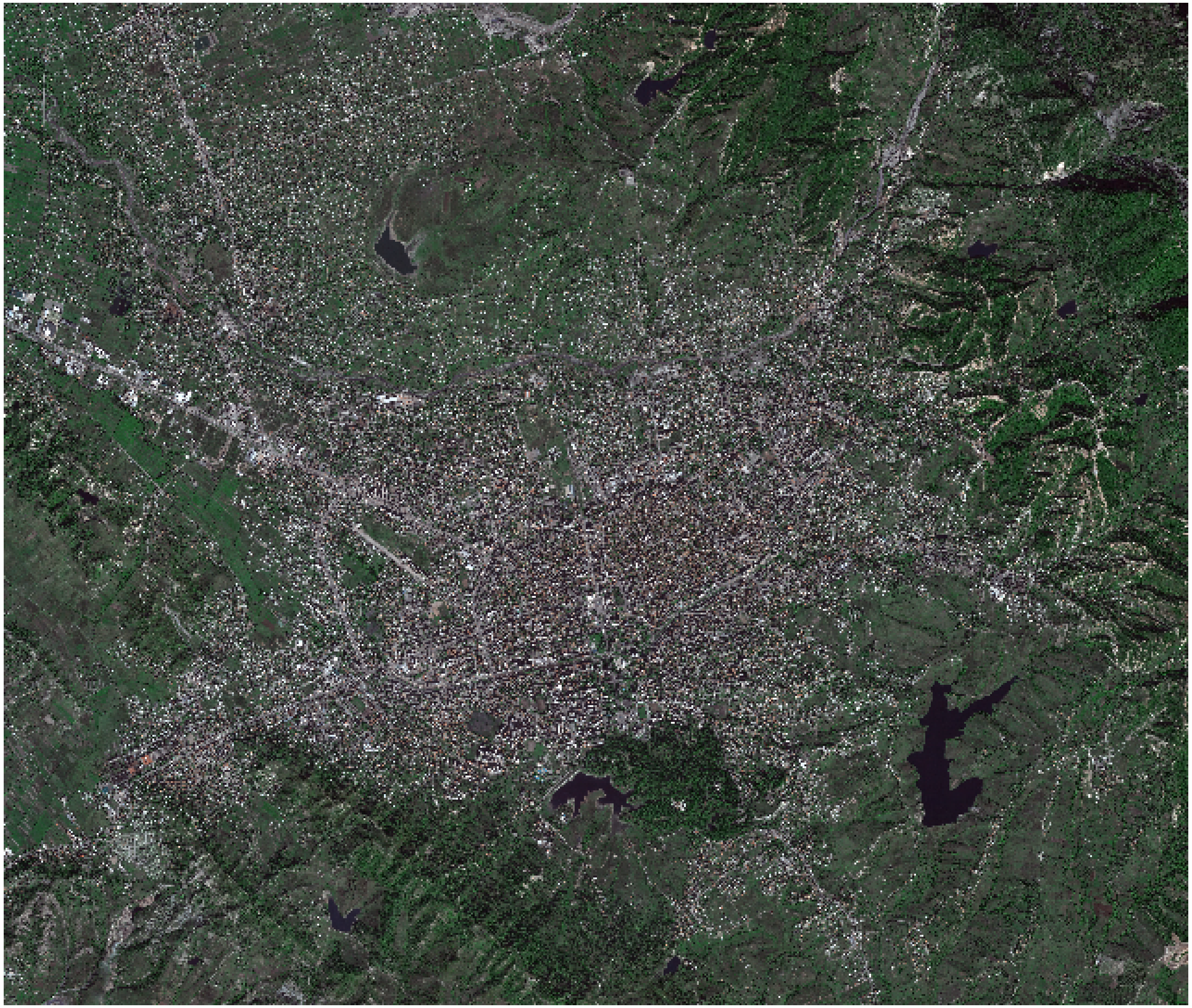
Scale 1:

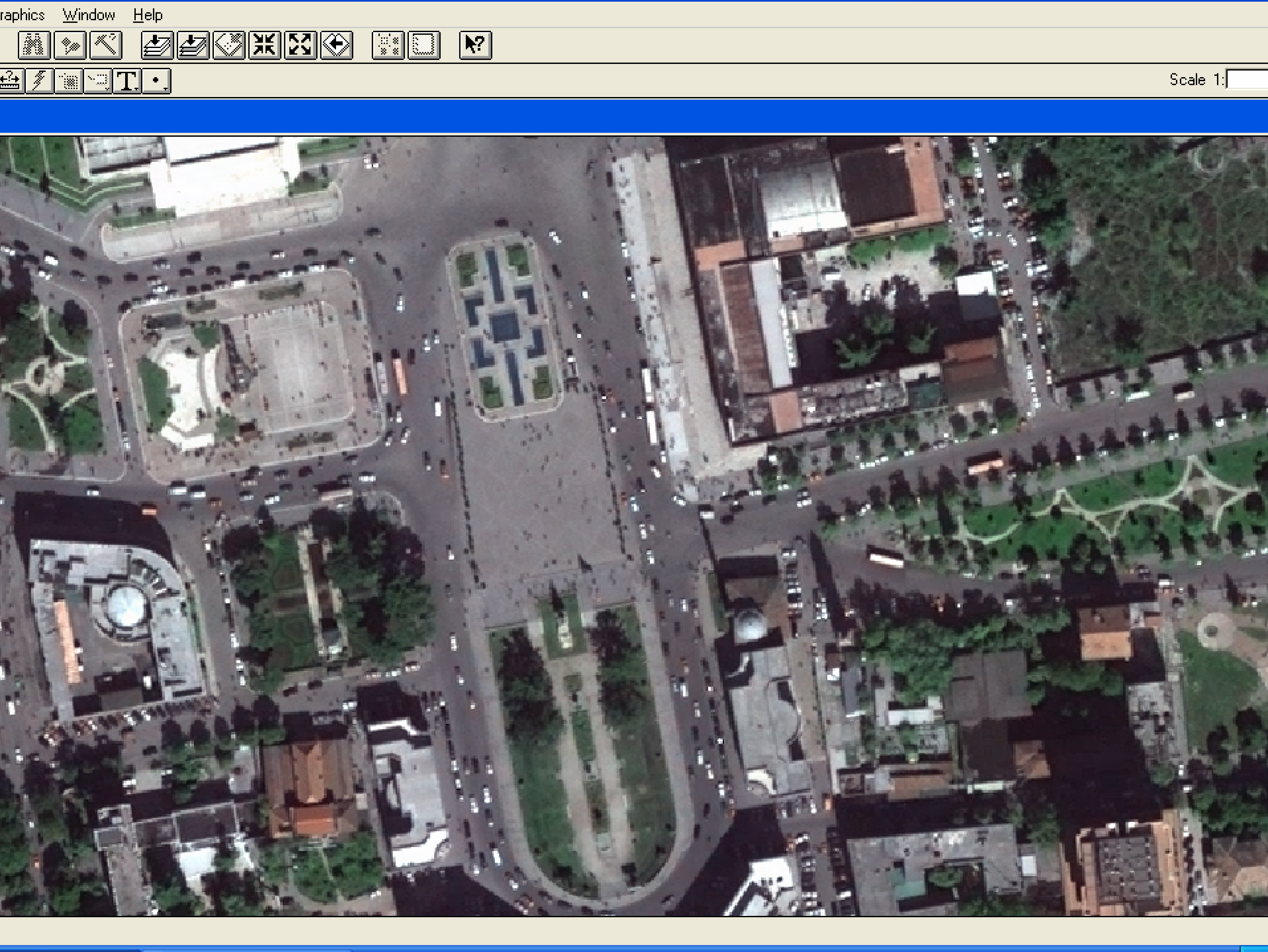
Quickbird Image,

Tirana

60 cm Pixel

273 km^2

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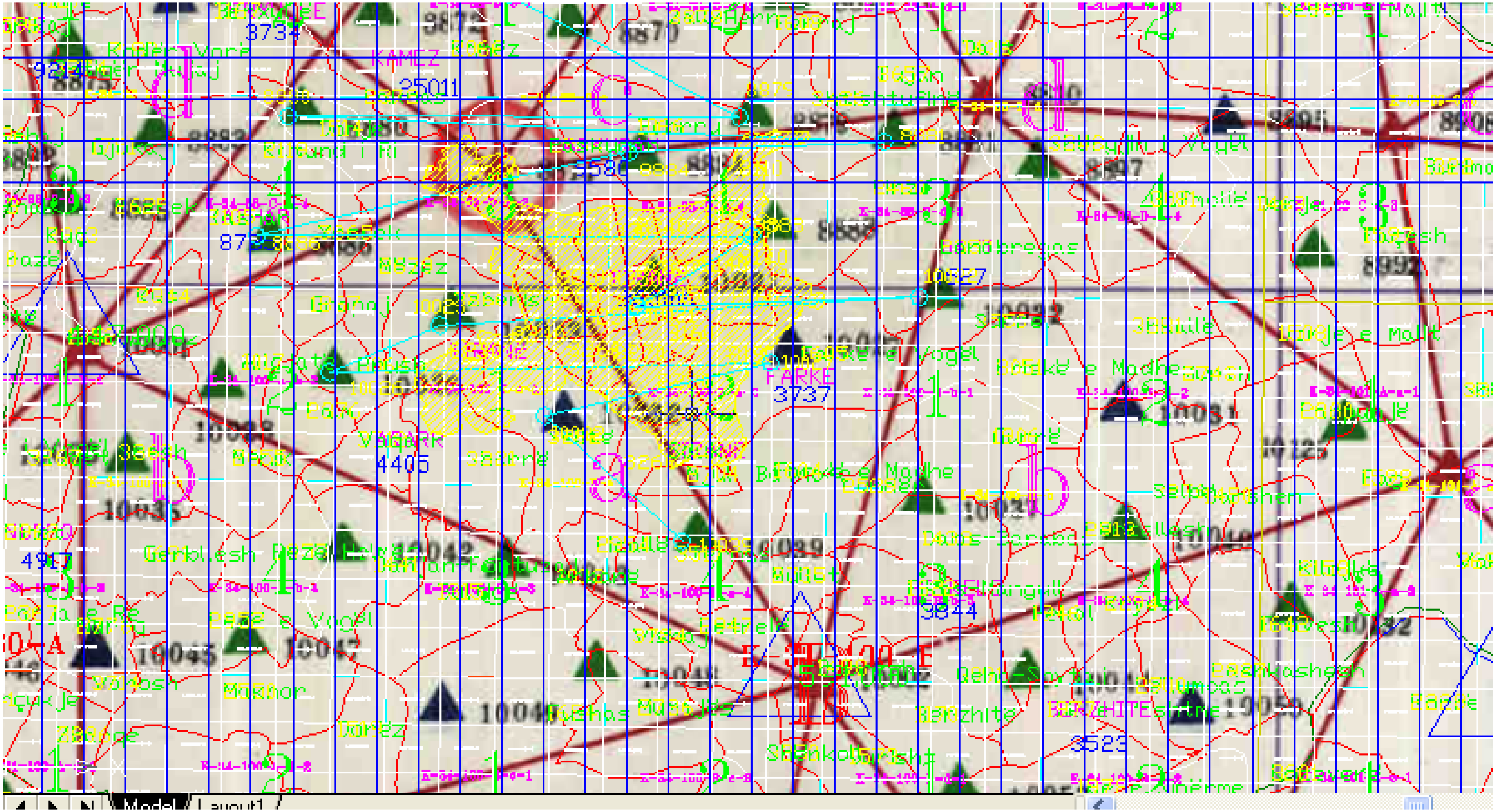
Scale 1:

Geodetic Netwwork referenced to ITRF



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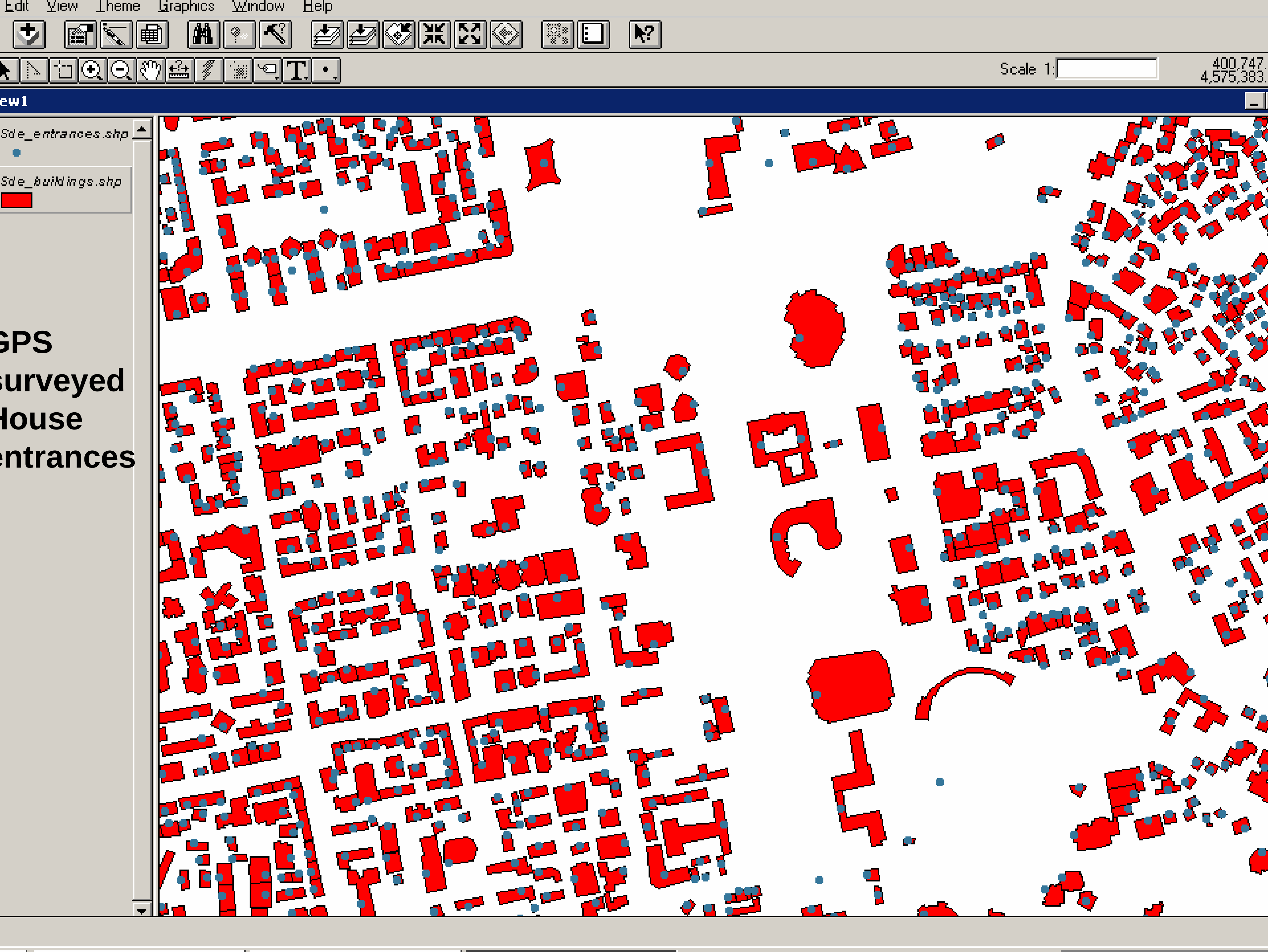
Digitization of New Buildings

Scale 1:

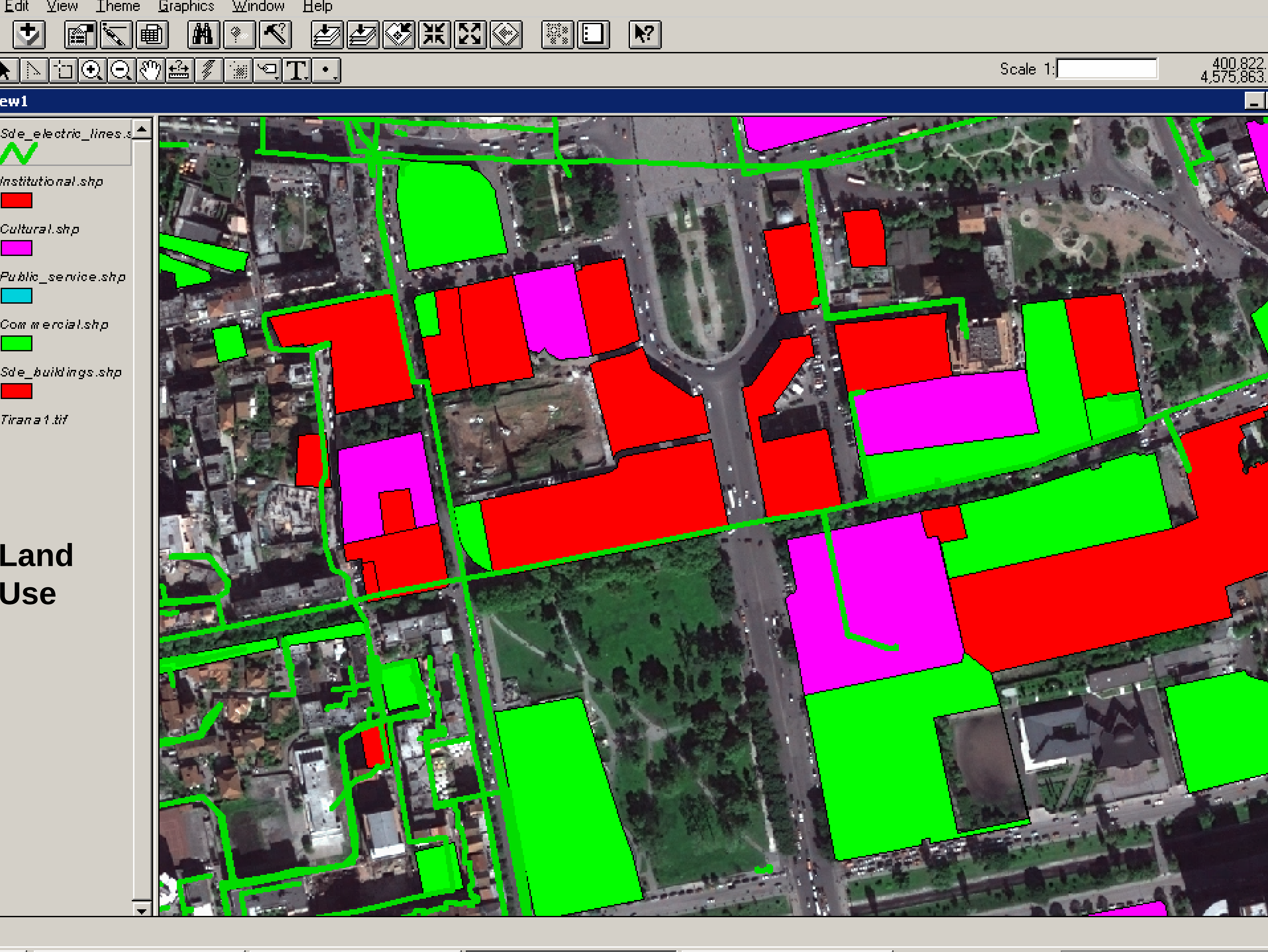
raphics Window Help

Scale 1:

Digitized New Buildings



Edit View Theme Graphics Window Help
Scale 1:
400,747.
4,575,383.
ew1
Sde_entrances.shp
Sde_buildings.shp
GPS
surveyed
House
entrances


Edit View Theme Graphics Window Help
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ew1
Sde_electric_lines.s
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Cultural.shp
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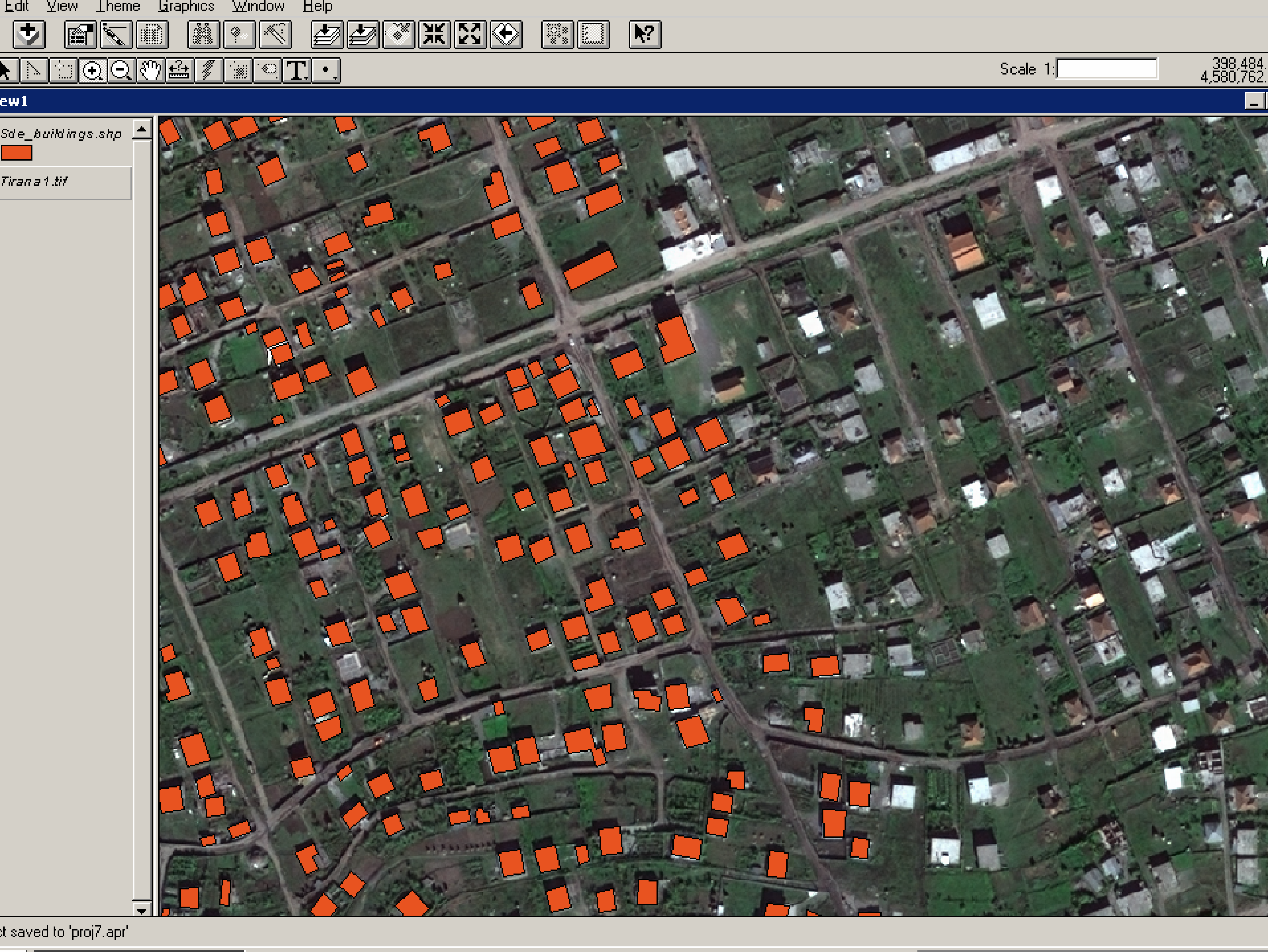
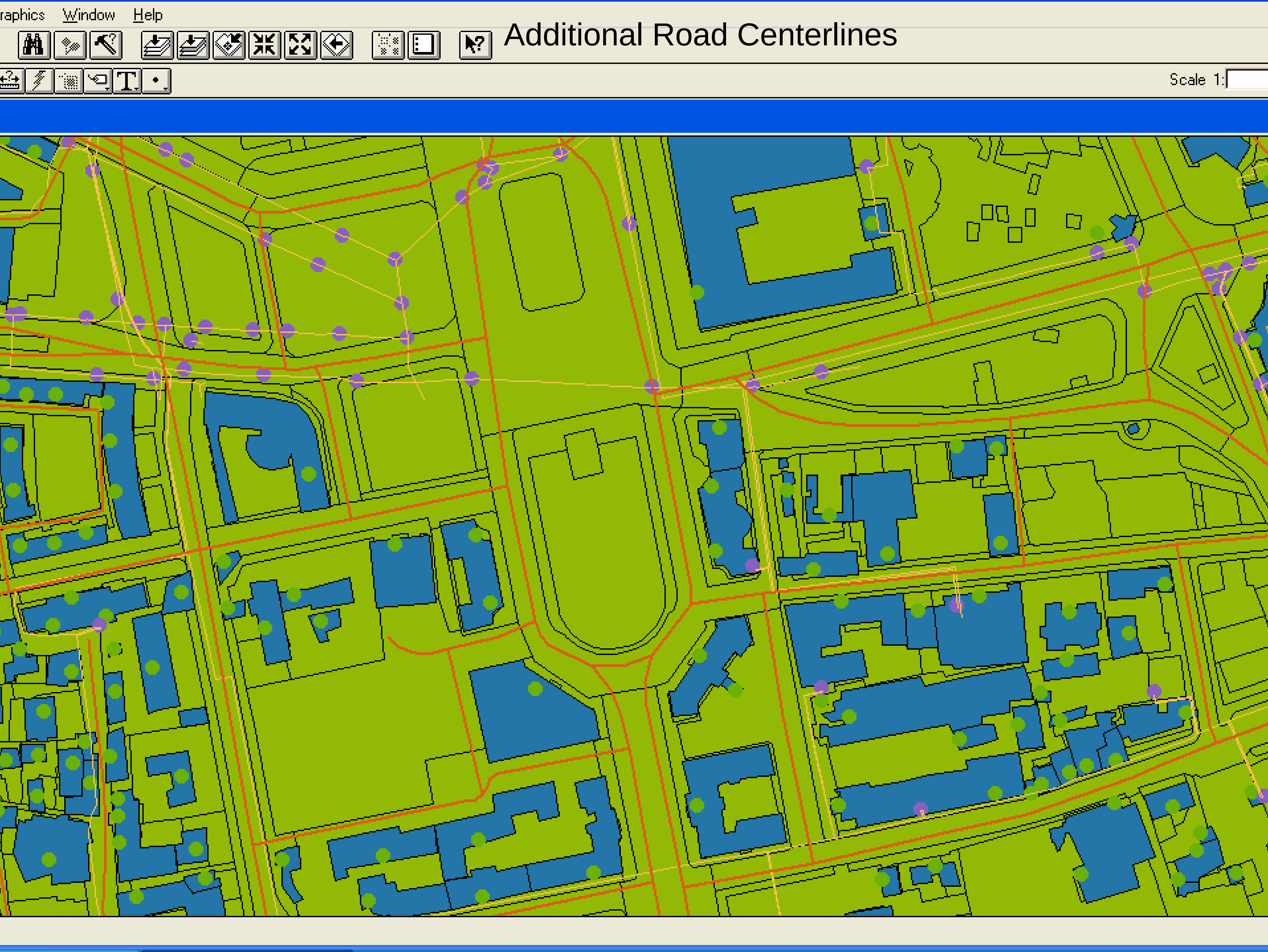
Commercial.shp
Sde_buildings.shp
Tirana1.tif
Land Use


Edit View Theme Graphics Window Help
Scale 1:
398,484.
4,580,762.
ew1
Sde_buildings.shp
Tirana1.tif
t saved to 'proj7.apr'

Additional Road Centerlines



Result of Project:

The Municipality of Tirana now has data to monitor and to plan urban development

- **quickly (6 months)**
- **inexpensively (2000 to 3000$ per square km)**
- **updatable every year (by newly ordered satellite image at cost of 5000$ and by local maintenance contract)**

Threats to Photogrammetric Mapping

1. The USGS Topo Mapping at 1:24 000 with 1m GSD orthophotos can be updates every 5 to 10 years

2. The German Topo ATKIS System at 1:10 000 with 0.4m GSD orthophotos can be updated every 5 years

3. The British Ordnance Survey commits itself to 6 month updates with DGPS and Field PC ground surveys using CORS for the 1:1250 or 1:2500 topo map and Google Earth images

4. The German ALKIS System is a „real time" transaction based cadastral data system for parcels and buildings using CORS DGPS surveys

Present Problems:

1. National Photogrammetric Industry is being bought up by global consortia (Bloom, Fugro)

2. National Photogrammetric Industry outsources to partners in low cost labour countries

3. The old European hardware/software manufacturing industry is no more; development is controlled in the USA (Intergraph Erdas, Trimble, Microsoft; it was sold, because „a 100 M$ market is too small to keep“

4. Haphazard patents have been issued on small technical modifications; protection by patent rights is too lengthy and too costly (orthophotos for cadastral applications, oblique imagery, airborne stereo scanners)

What to do next ?

1. ISPRS has contributed to phenomenal achievements
   - landing on the moon
   - exploration of planets
   - monitoring of the earth

2. Global monitoring is an ISPRS mandate

3. We must find new structures, how to do the task more efficiently with the new tools
   - satellte platforms
   - new sensors (radar, laser)
   - GNSS uses

4. Use of International Earth Observation Programs

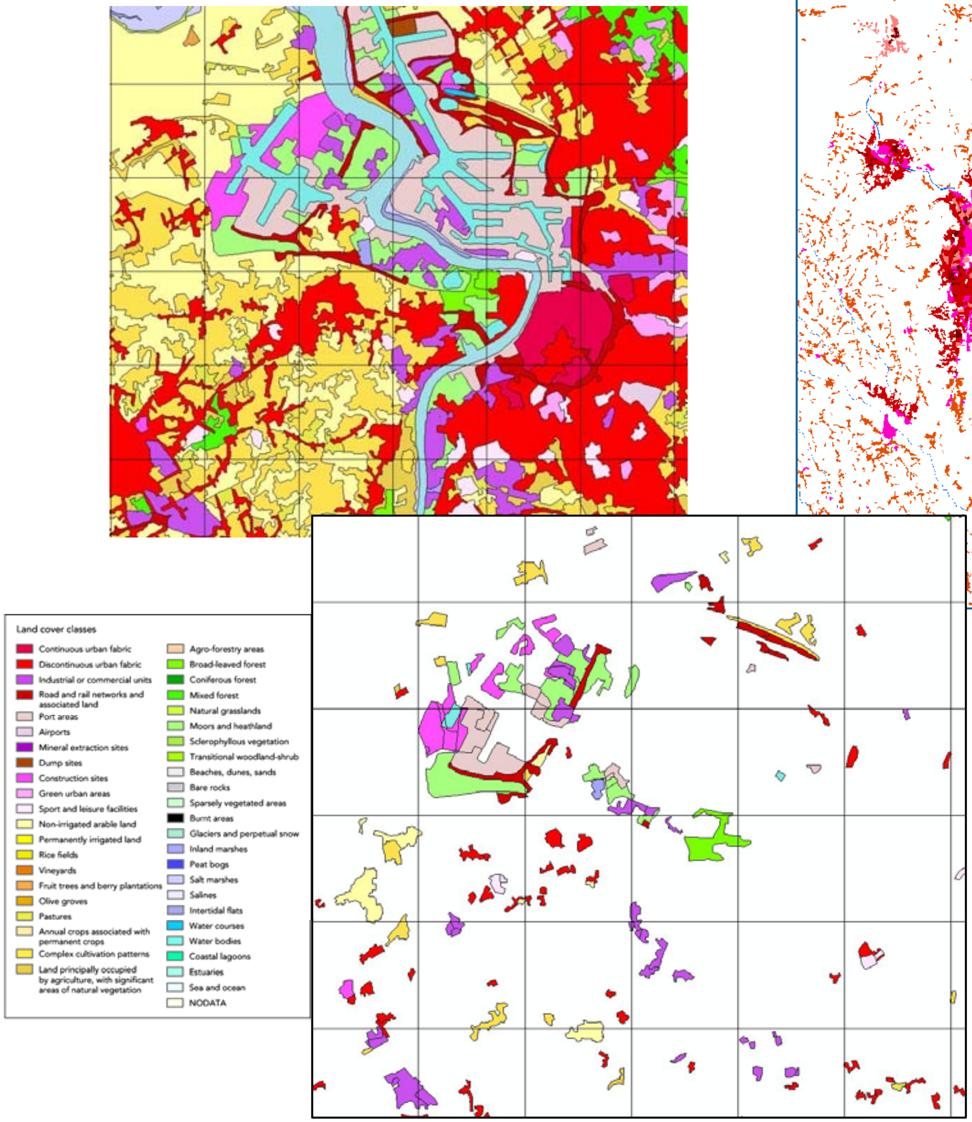
1. **Earth Observation Programs**

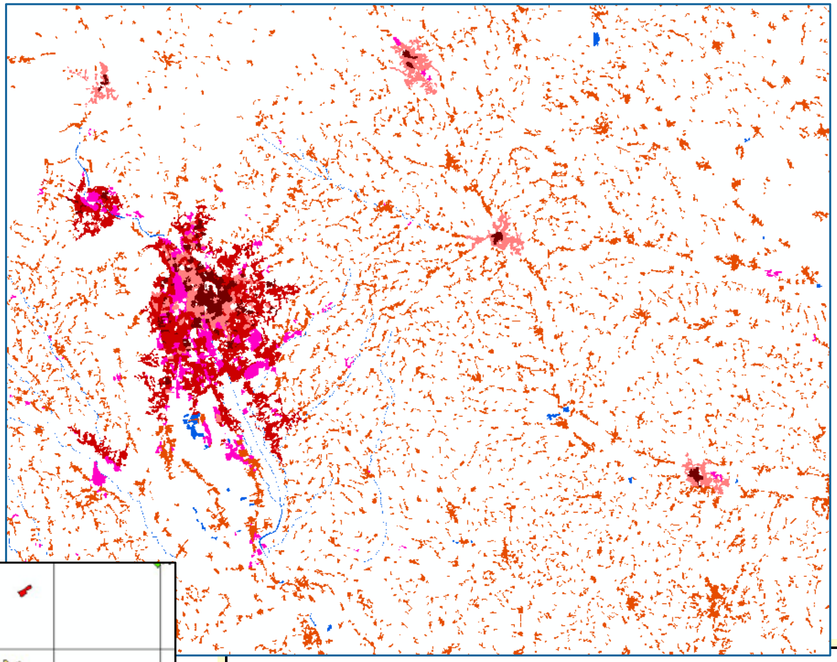
    - **GEOSS (int.)**
    - **GMES (EU)**

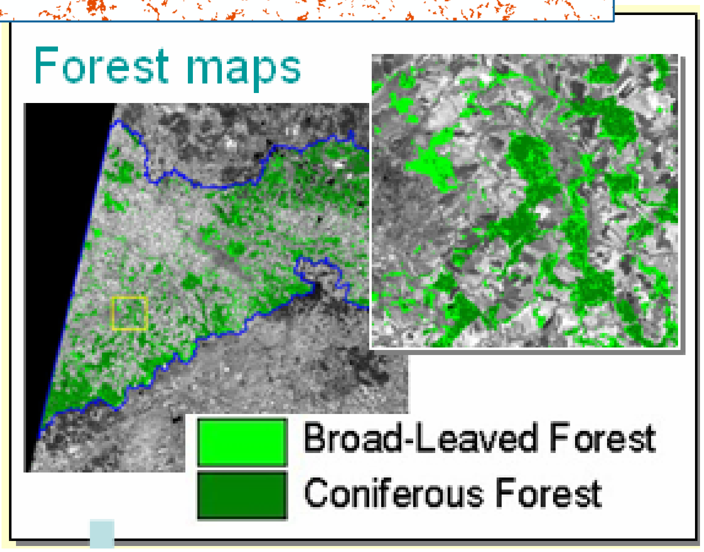
2. **Contributions to Global Monitoring**

    - **New Earth Observation Systems**
        - **high resolution, multispectral, radar**
        - **constellations**
    - **Knowledge-based Image Analysis**
        - **segmentation, spectral information and texture**
        - **multistation point cloud matchIng**

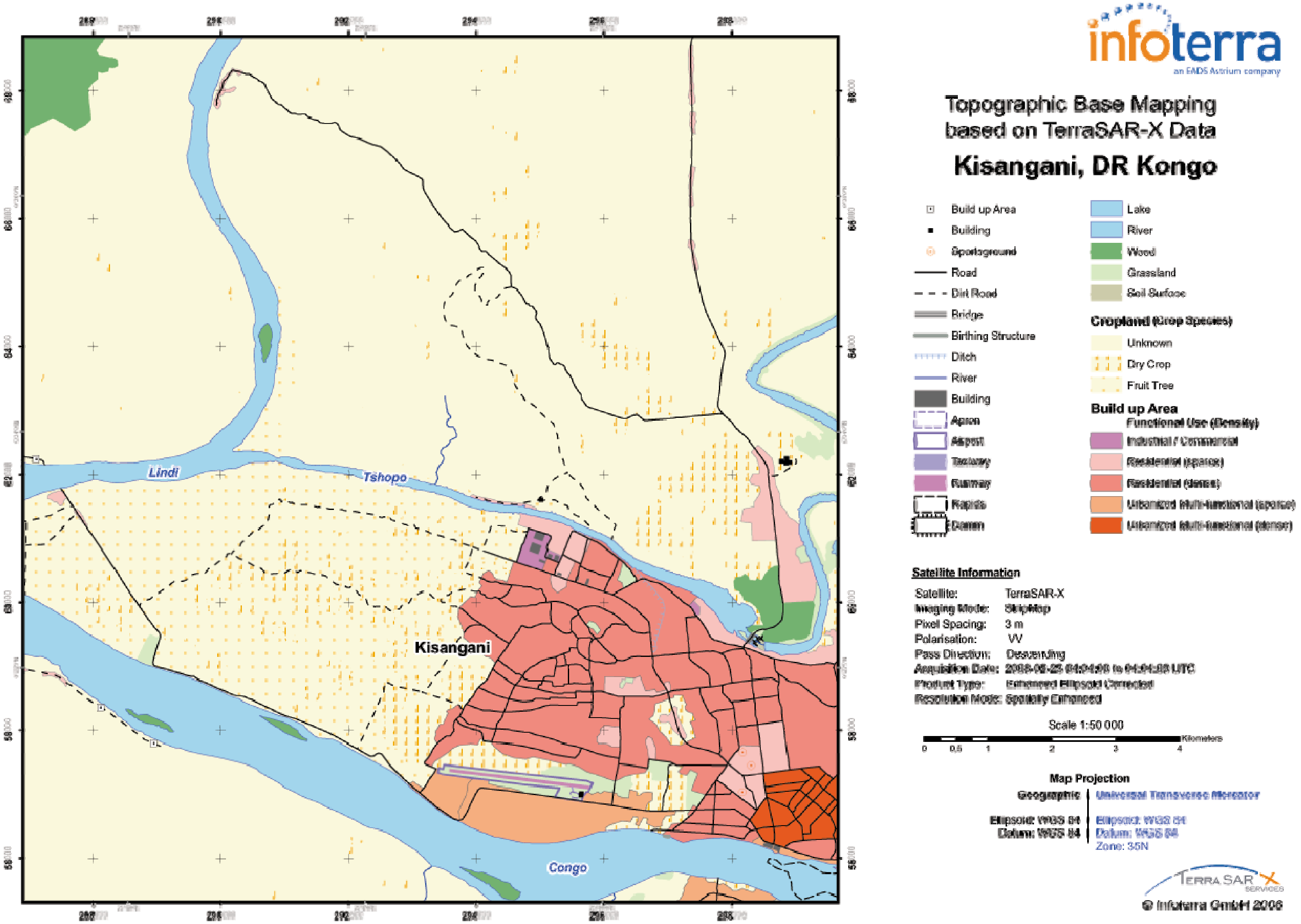
Land Monitoring







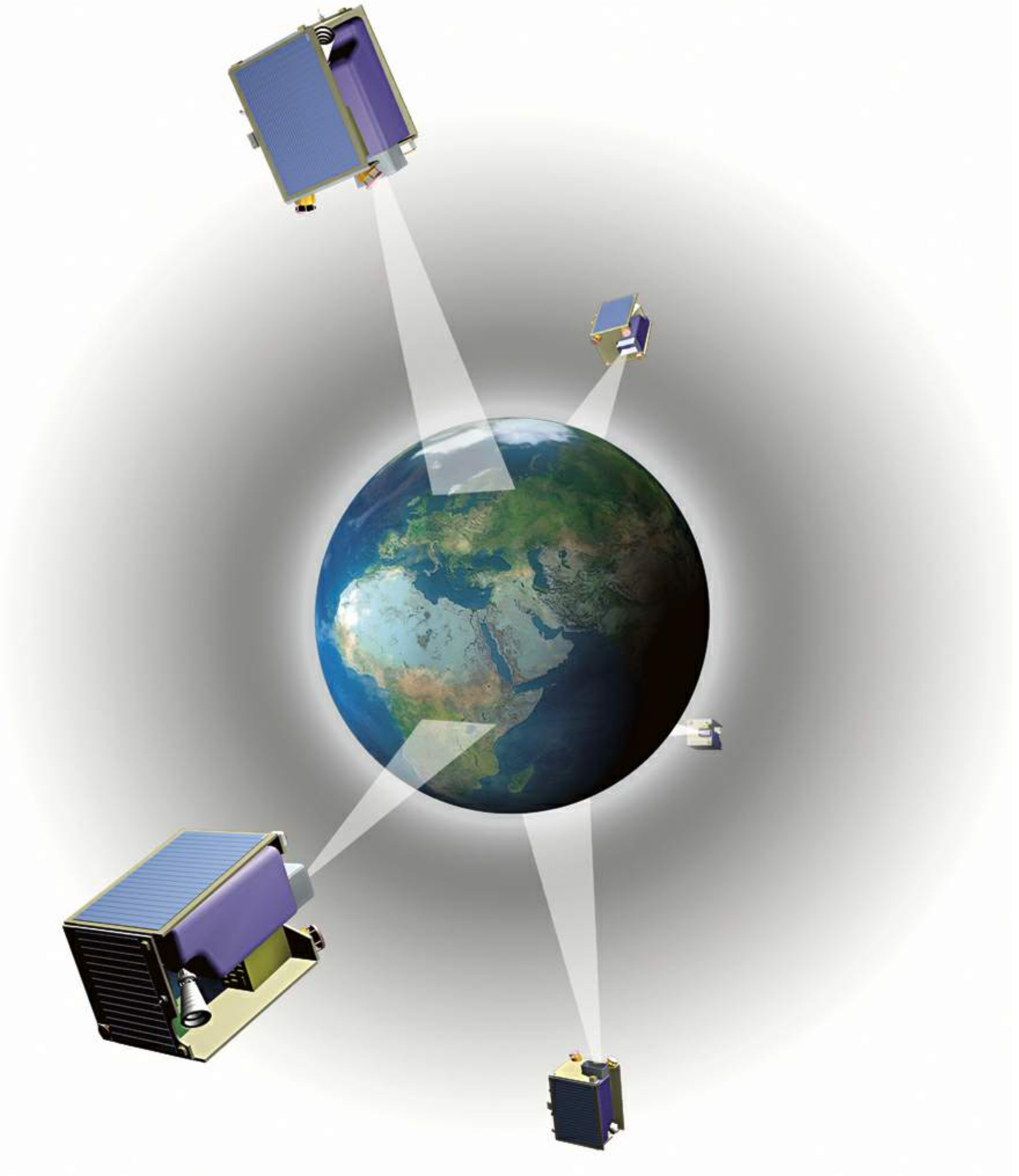
Topographic Mapping with TSX



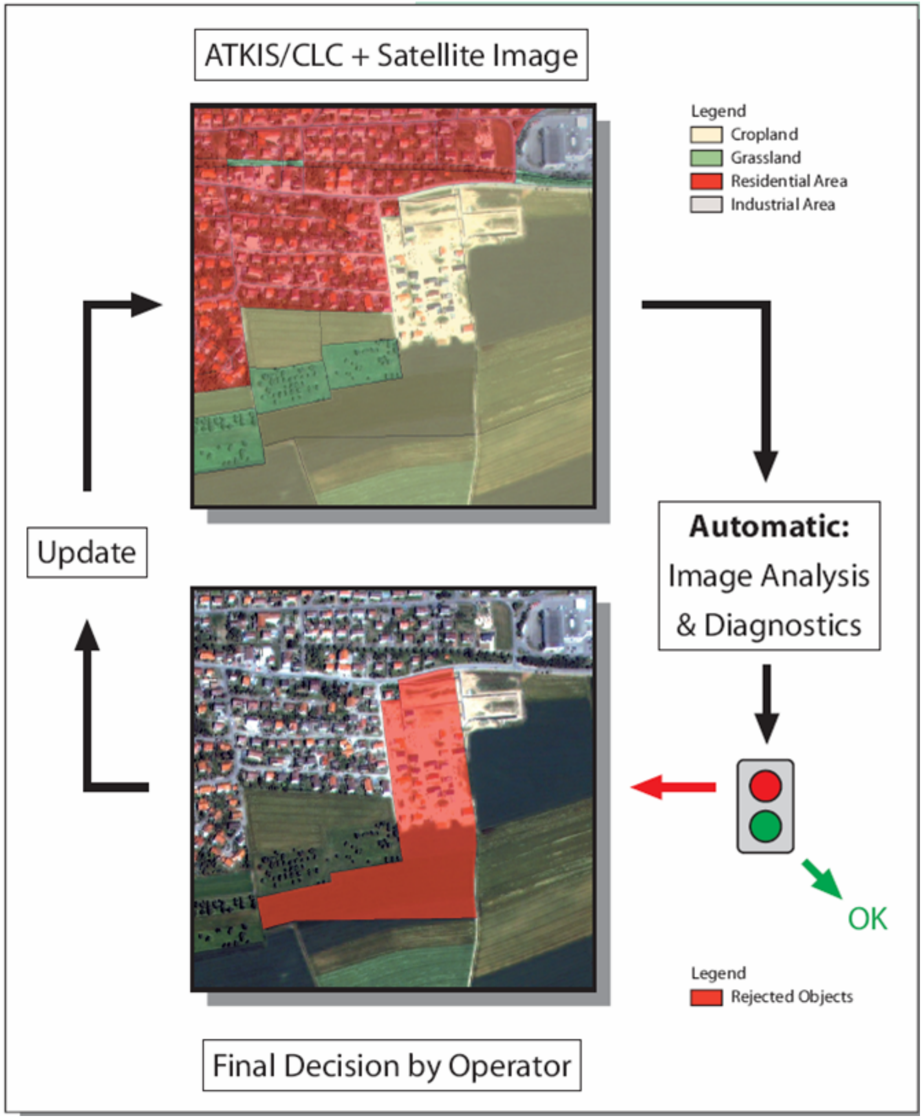
RapidEye Constellation

launched
August 29, 2008

4m GSD

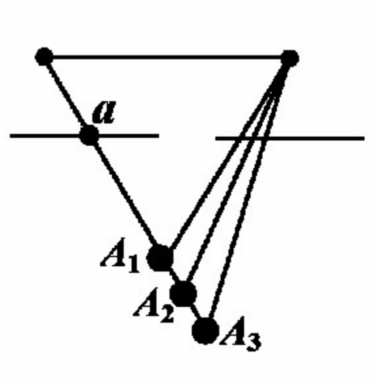


Workflow of WiPKA-QS



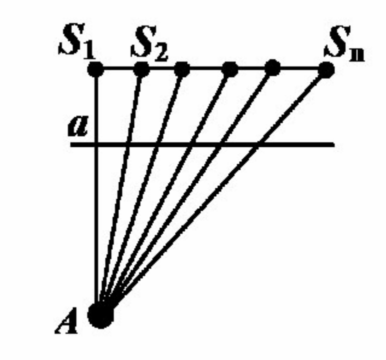
Problems of single base stereo:

1. From a stereo pair to model it is an **ill-posed problem**；
2. From the point of view of surveying there is **no redundant in observations**



Advantages of multi base stereo：

1. Improve the **reliability of image matching**；
2. Smaller intersection angle，easier for matching
3. Have **redundant observations**, improve height precision



Multi base photogrammetry has been used in **close range**

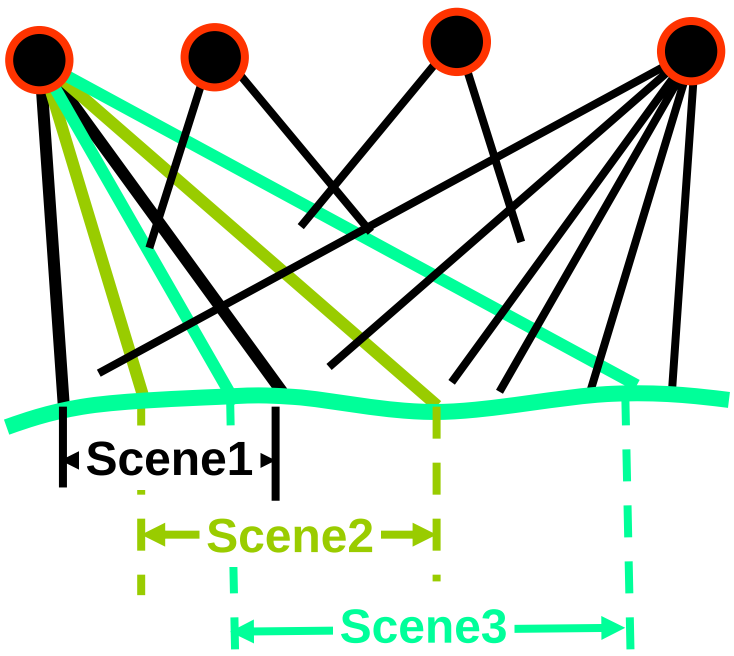
Multi base rotating convergent photography

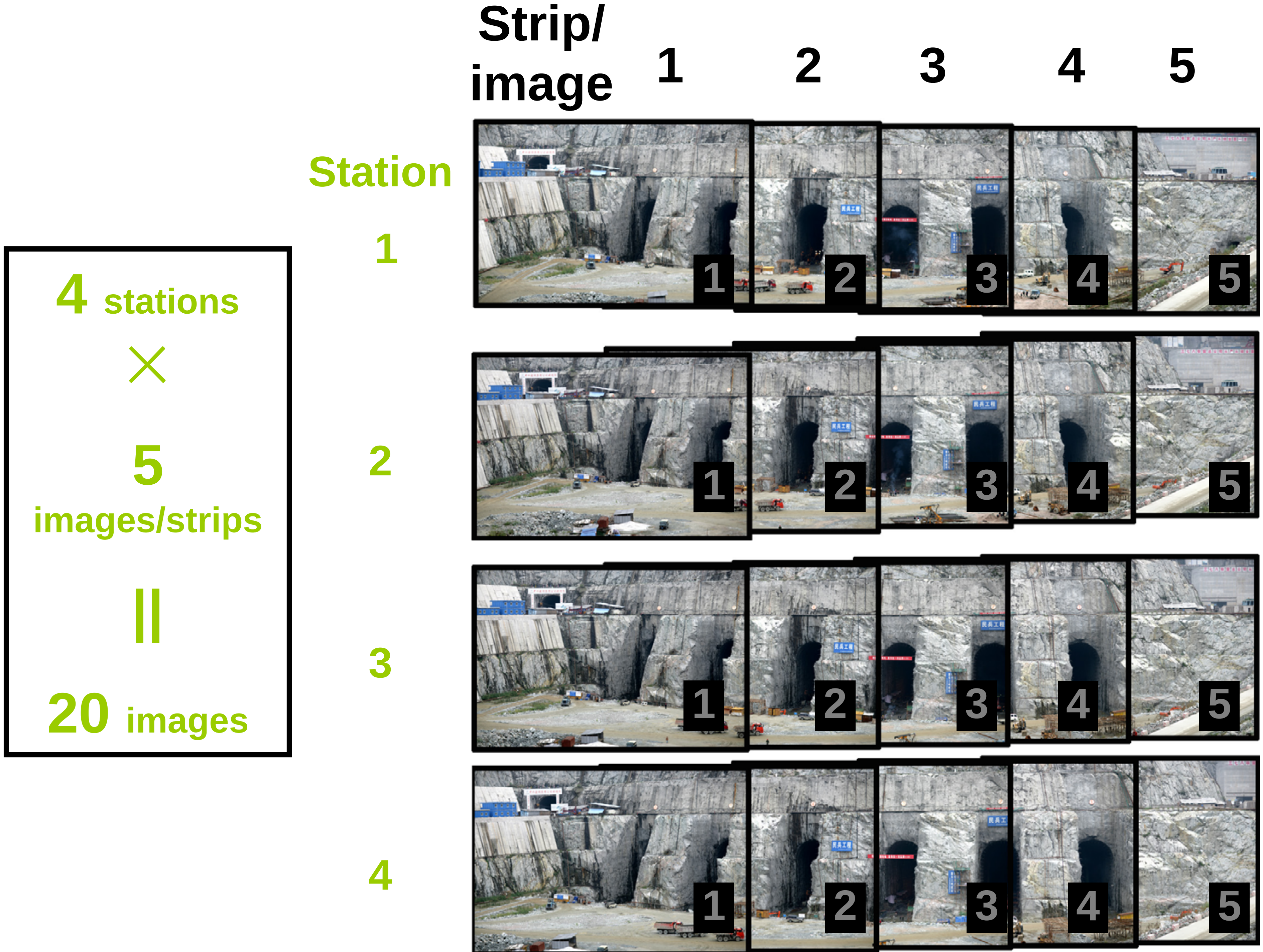
By using the camera with long focal length to photograph a wide scene

More than two stations (in conventional way) are needed;

At the same station rotating the camera **(non- metric),**

several photos (overlapped images) are taken ,





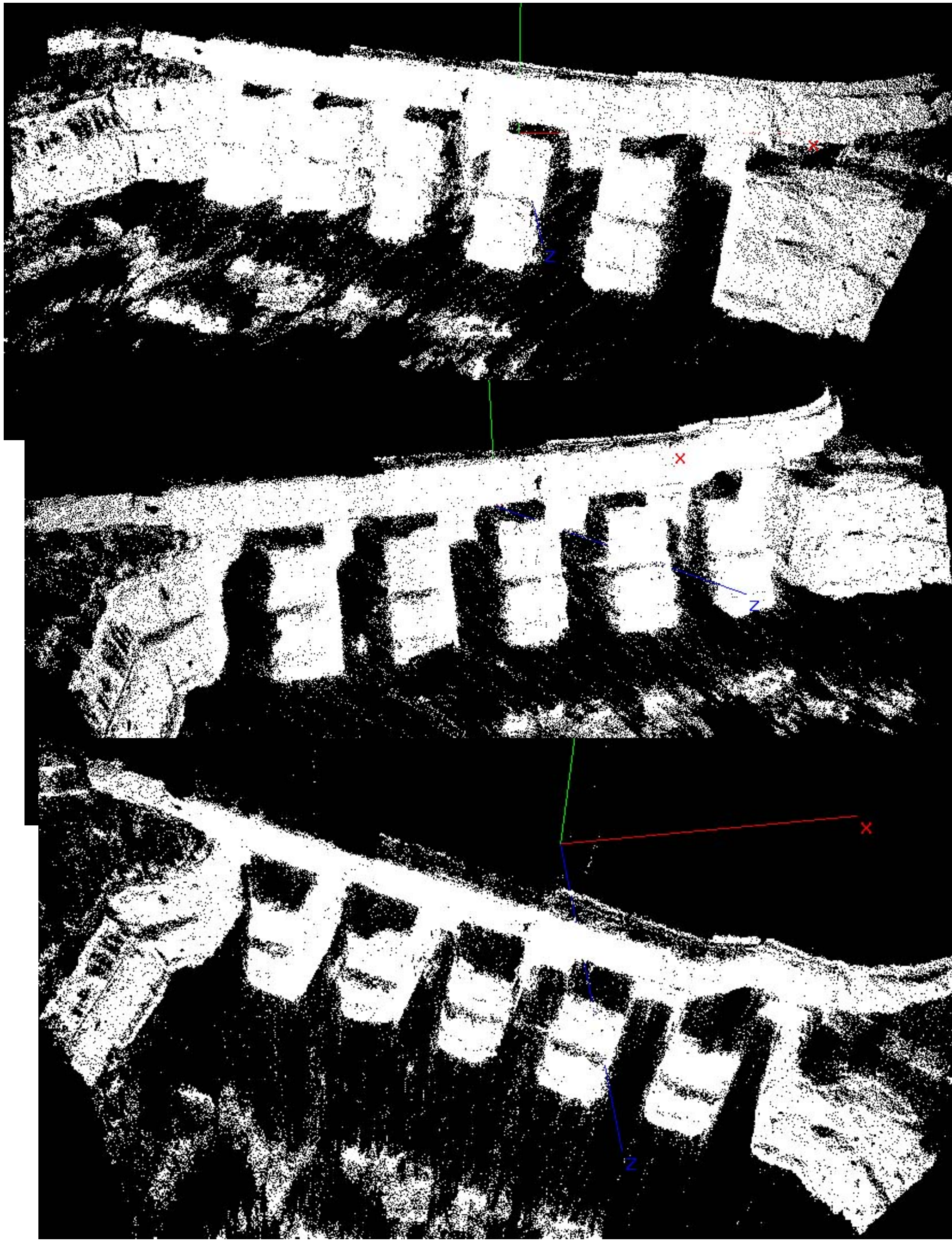
Strip/image
1
2
3
4
5
Station
1
2
3
4
4 stations
×
5 images/strips
||
20 images

Aerial triangulation

Block adjustment

⋮

Point cloud generation



<u>**Point cloud**</u>